University of Southern Queensland

School of Engineering

Feasibility of a Partial Replacement of Cement with Millmerran Pond Ash

A dissertation submitted by

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in fulfilment of the requirements of

ENG4111/ENG4112 Research Project

towards the degree of

Bachelor of Civil Engineering Honours (Civil)

Submitted: October 2023

ABSTRACT

Pond ash is a byproduct of coal fired power plants that is currently unsustainably managed being stored in open ponds that are polluting the surrounding areas. This pond ash could be collected, cleaned, and potentially utilised in concrete as a Supplementary Cementitious Material [SCM]. This would improve the management of waste disposal, and reuse of future waste.

This research project aims to investigate the feasibility of pond ash as an SCM as partial replacement of cement. The main objective of this research project is to comprehensively assess the compressive and flexural properties, along with its workability, of concrete mixes containing varying proportions of pond ash utilising ordinary Portland cement. As higher strength concrete testing utilising pond ash and an SCM was in low quantity, the concrete mix is 40MPa with the mix design being provided by industry for realistic results. Four batches of concrete were planned with a control and a range of replacement percentages of 10%, 20% and 30% by mass.

The results of the slump testing indicated a decrease in workability with the increase in pond ash with a significant decrease at the 20% and above replacements. While largely aesthetic, these samples included voids which introduced some variability in sample density, particularly notable in the 30% pond ash mix. The compressive strengths at 7, 14, 28 and 56 days have been recorded. The mix design yielded higher-than-anticipated strength due to unanticipated shifts in the water-cement ratio. The results indicate that the compressive strength reduced as the percentage of pond ash increased with a major reduction at the 30% pond ash replacement. The reduction in compressive strength of the 10% and 20% batches was only 90% and 86.6% of the control strength respectively and both passed the 28 day testing in this mix design. Flexural strength also exhibits a parallel trend of diminishing strength as pond ash replacement percentages rise, with the 30% replacement samples deviating the most from the projected trend due to inadequate aggregate bonding. The 56 day results shows strength growth beyond the typical 28 day testing with the 20% and the 10% replacement achieving the equivalent strength at 56 days.

The results gathered suggest Millmerran Pond Ash as an SCM in concrete is feasible and that a replacement percentage of less than 20% is promising, possibly requiring the use of additives to enhance workability.

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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.

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Date 11/10/2023

ACKNOWLEDGEMENTS

I extend my sincere appreciation to Dr. Weena Lokuge for her valued guidance in conducting my research and testing.

I would like to extend my profound thanks to Northern Consulting Engineers for their support and encouragement over the years. Their belief in my potential and dedication to my professional development as an Engineer have been key in my growth. Additionally, I am immensely grateful for facilitating the delivery of the pond ash that was critical to the completion of the testing.

Thank you to Construction Sciences Townsville for generously providing access to their testing equipment alongside their industry expertise in conducting testing. I would also like to express my appreciation to Holcim for donating the aggregate materials for the purpose of testing along with providing the mix design itself, which were essential for the testing phase of my project.

To my wife, your unwavering support during this journey has been nothing short of extraordinary. I am deeply grateful for your patience and understanding for enduring long periods of time with me away or busy working on my university studies.

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NOMENCLATURE

AS	Australian Standard
$f'c$	Characteristic Compressive Strength
f_{cf}	Modulus of Rupture or Flexural Strength
f'_{ct}	Uniaxial Tensile Strength
$f_{ct.f}$	Flexural Tensile Strength
GP	General Purpose Portland Cement
LOI	Loss of Ignition
PA	Ponded ash
SCM	Supplementary Cementitious Material
SSD	Saturated Surface Dry
w/c	Water Cement Ratio

CHAPTER 1. INTRODUCTION

1.1 Project Background

One of the largest issues facing engineers and the construction industry in the years to come is that of sustainability. Engineers are at the forefront of development to ensure the technologies of the future consider the global and local environmental health risks. The global concern surrounding the rapidly changing climate includes ever-growing scarcity of natural resources, increasingly extreme weather events and biodiversity losses.

This climate crisis is becoming the focus of research worldwide in many different industries. Australia has seen and felt the effects of climate change, especially in the last decade, with numerous extreme drought, flood, storm, and fire events occurring throughout the more recent years. According to the Australian Museum records, the number of days that break heat records has doubled in the last 50 years (Australian Museum 2021). This has caused heatwaves, fires, drought, and devastating damage to the Great Barrier Reef.

When investigating new ways to ensure sustainability, the protection of Australia's biodiversity and habitats is one of the key discussion points. Australia is home to a diverse range of species that have relatively small native habitats which are especially prone to changes to their ecosystem (Australian Museum 2021). This means that substantial changes to an ecosystem could have widespread effects across a diverse range of species to the severe detriment of the function of that ecosystem.

Globally, 3.7 billion tonnes of coal ash each year is produced by coal fired power plants that destroy large areas of ecosystems directly or indirectly (Environmental Justice Australia 2019). The Australian combustion power industry produces large amounts of by-product in the form of ash from coal fuelled power stations. Australian coal power stations produce 10-12 million tonnes of ash every year, with in excess of 400 million tonnes currently in storage in ash ponds spread across the nation (Environmental Justice Australia 2019).

Coal ash is produced when solid coal is burnt as part of the power generation process. This coal ash is made up of different types of ash; fly ash and bottom ash. Fly ash is a fine powdered ash that is light enough to be captured by electrostatic precipitators as it rises up the broiler chimney stack. Fly ash is a known pozzolanic material with similar properties to Portland cement, that has been proven effective through research and within the construction industry. It is for this reason that it is commonly used as an accepted supplement for cement in concrete and has been used significantly since the mid 1900's (Thomas 2007).

It has been found in research that the toxic nature of fly ash can be somewhat stabilised during the reaction with cement in the concrete. The stabilised fly ash in the concrete heavily reduces the leaching of heavy metals and other toxic chemicals into the environment than just raw fly ash (Kurda et al. 2018). The replacement of cement with fly ash is usually within the range of 10-20%, but can be as high as 50% in large structures such as dams (Thomas 2007).

Bottom ash is a mixture of heavier and larger ash and slag that is collected from the bottom of the broiler unit. This mixture is normally disposed of by washing out the broiler and mixing with water in order to pump to nearby settlement ponds along with any remaining waste fly ash. There are many issues with this current storage method as the often toxic sludge leaches into the soil and nearby waterways as the ponds are usually not properly lined (Environmental Justice Australia 2019).

These ponds are usually not originally built with the preservation of ground water and maintenance of the ecosystem in mind and are more for the benefit of the production plant to keep costs low. They are usually built in close proximity to communities that include residences and primary schools as close as 120m away (Environmental Justice Australia 2019). A map showing the locations of Australian Coal ash dumps can be seen in shown in Figure 1.1. These communities are also susceptible to the ash dust that can become air borne.

Figure 1.1– Map of Coal Ash Dumps in Australia (Environmental Justice Australia 2019).

This pond ash is a toxic waste and can be extremely damaging to the environment if not safely contained and is able to spread into surrounding water systems. The coal ash can contain heavy metals and other dangerous chemicals that can be harmful to humans if inhaled or ingested. On top of the human impacts of these ash ponds, the immediate ecosystem that the pond is constructed within are usually utterly devastated with wider impacts on nearby domestic and agricultural water supplies.

The rehabilitation of these pond sites such as the one shown in shown in Figure 1.2 requires the removal of the pond ash and cleaning of the soils and surrounding area. This is troubling as a large amount of Australia's active coal ash dumps do not have a current ash management plan for the environments that are being polluted (Environmental Justice Australia 2019).

Figure 1.2 – Stored Pond Ash (Bagwan & Kulkarni 2015)

Cement has seen in increase in cost due to the construction materials shortages that have been experienced worldwide over the last couple of years as supply has not been increasing enough to match demand. Pond ash as an alternate replacement of cement or supplementary cementitious material, hereby referred to as SCM, may also prove to be beneficial to the supply of concrete to the industry. Current construction material supply shortages in Australia such as that of timber and steel, has meant alternate materials such as concrete have faced an increase in use. Concrete construction has seen an increase in use due to this effect and has since suffered from reduced supply compared to demand (Domaine Homes 2022). The benefit of the use of pond ash can alleviate the pressure on cement production if found to be an effective supplementary cementitious material.

1.2 The Problem

This paper plans to look at the feasibility of recycling this pond ash as a partial replacement to cement in concrete. It is the hope that this environmentally positive proposal for the use of pond ash as an SCM for Portland cement, is able to be utilised in future concrete mix design in practice.

The existing literature indicates promising results for pond ash as an SCM due to its pozzolanic behaviour. Most of the literature focuses on the chemical composition in comparison to cement and fly ash with some narrow ranges of replacement with compressive test results. The literature is lacking a wide range of tensile and flexural test data along with consistent testing across a range of concrete design strengths.

This research will conduct testing on concrete samples with a known percentage replacement of cement with pond ash by mass and compare the results to control samples that have been developed using traditional mix design methods. This will be undertaken with the use of a constant concrete. It is the hope that this research will aid in filling the knowledge gap for pond ash as a partial replacement of cement in concrete.

1.3 Project Aims and Objectives

This research project aims to investigate the feasibility of pond ash as an SCM as partial replacement of cement by mass by testing the mechanical properties of different replacement percentages.

1. Conduct Literature review of ground harvested pond ash and its general properties relating to its potential pozzolanic properties. Determine an appropriate range of replacement percentages of pond ash.

2. Review concrete testing techniques and prepare a methodology of testing.

3. Prepare and cast testing samples for testing the mechanical properties of pond ash modified concrete. Conduct experimental program based on the methodology.

4. Analyse the test data to determine an appropriate compressive strength value for each replacement percentage and evaluate the results to identify any trends or relationships. Evaluate the most successful percentage of replacement and compare its properties to that of ordinary concrete. Evaluate the test results and the feasibility of partially replacing cement with ground harvested ash.

5. Complete and submit finalized dissertation on the feasibility of the partial replacement of cement with ground harvested ash.

If time and resource permit:

6. Compare costings of ordinary concrete and pond ash modified concrete.

The main objective of this research project is to investigate how the pond ash performs as an SCM utilising ordinary Portland cement across a range of replacement percentages. The divergences between the pond ash modified samples and control samples should provide a relationship from which, a comparison can be developed and expanded.

1.4 Expected Outcomes and Benefits

It is expected the research undertaken in this project will further understanding on how pond ash behaves as an SCM. This will be explored by investigating the effect of a range of pond ash percentages for consistent concrete design strength.

The potential benefits of the project could include an improved ecological and economical solution to the disposal of pond ash. This can provide a solution for existing waste disposal areas and for future waste that will be generated. This potential solution could be a major benefit for coal fired power production plants as this initiative can form part of their pond rehabilitation plan. The environmental effects of coal ash pond rehabilitation for large coal ash pond deposits, can be invaluable for the surrounding ecosystems and communities that inhabit nearby.

The results from this research may also demonstrate the economic benefit of the use of pond ash as an alternative product to fly ash to encourage resource conservation. Investigating pond ash as an alternate SCM will improve the construction materials community understanding of its behaviour and interaction and serve as a basis for further research to develop improved practices for industrial use.

This paper will investigate the use of Pond ash sourced from the Millmerran Power Station as an SCM. This will be conducted by testing the compressive and flexural strengths of test specimen with a range of pond ash percentages. The workability aspects will also be discussed, and the mechanical failure modes investigated.

CHAPTER 2. LITERATURE REVIEW

2.1 Background

Fly ash has been researched extensively as an effective additive for cement in concrete and is a tested and proven SCM in concrete. This is due to its proven pozzolanic behaviour when mixed with cement as an additive to concrete. This pozzolanic behaviour of fly ash shows promise to the utilisation of ground harvested pond ash in concrete due to similar properties. The pond ash includes a portion of waste fly ash and other ashes in the slurry mix when pumped from the coal power plant.

This literature review will focus on the use of pond ash as an SCM, in particular, pond ash partially replacing cement in concrete. It will also provide some necessary background into the proposed project and offer an acceptable range of pond ash replacement of cement for testing, based off previous research results. In addition to the background of the performance of pond ash modified concrete, the literature covers many well developed methods of testing.

The methods for testing and data gathering to develop a sound opinion on the effectiveness of pond ash can provide some inspiration for this project's methodology. This projects methodology can take inspiration from the literature however will be undertaken in accordance with the Australian standards for concrete testing (Standards Australia 2014a, 2014b, 2014d).

The literature includes a range of studies that have investigated pond ash as an additive or replacement in concrete and mortar, including aggregate replacement and mixing the pond ash with fly ash or other additives such as steel fibres. The research involving pond ash as aggregate has also been considered as the findings are still relevant for the use of pond ash in concrete as findings on workability and water absorption are valuable (More & Autade 2015; Hamada et al. 2022).

2.2 Pond Ash Properties

2.2.1 Physical

It is known through previous research that the slow pozzolanic reaction of fly ash can lead to lower than expected early strength. This low strength at early stages can be increased as the fly ash particles increase in fineness (Rathod & Sharma 2015). This behaviour of increased strength due to particle fineness is believed to be shared with pond ash when processed though grinding, sifting and other methods (Giada et al. 2021).

The literature shows that when bottom ash is ground to match the fineness of fly ash, it can achieve good pozzolanic material properties (Arun et al. 2020). As pond ash is more reactive than bottom ash, recent research has started testing powdered pond ash for increased pozzolanic reactivity with the results of the lime reactivity testing confirming the hypothesis of increased strength characteristics (Vidyadhara et al. 2020). This testing and that which was undertaken by Arun et al. (2020) and Vidyadhara et al. (2020), was investigating lime reactivity strength testing and not its direct use in concrete as a partial replacement for cement but gives promising theory.

As seen by the sieve analysis in Tables 2.1 and 2.2 below, fly ash has a much lower average particle size that that of pond ash. In order to reduce the particle size a study used a Los angles abrasion apparatus to reduce the particle size to the required dimensions (Arun et al. 2020). Other processes may be utilised such as vibration or attrition mills using steel balls with attrition mill showing the better results (Yong-Sik et al. 2019).

Table 2.1– Sieve Analysis Result of Fly Ash (Bohara et al. 2017)

Sieve size (mm)	Percentage passing
0.3	100%
0.15	97%
0.075	83%

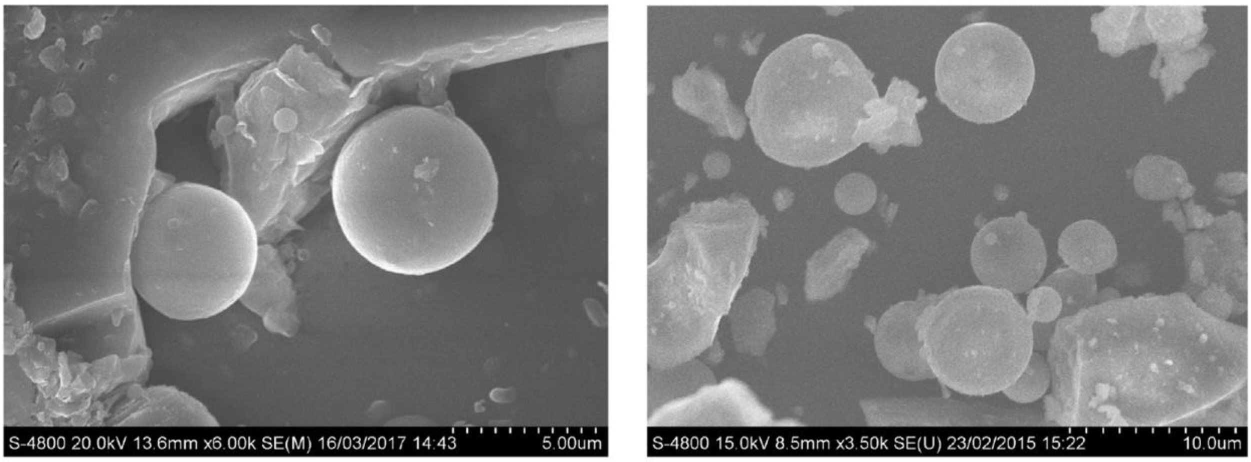
Table 2.2– Sieve Analysis Result of Pond Ash (Harle 2019)

IS Sieve size	Weight retained (gm)	Percentage Weight retained (gm)	Cumulative percentage weight retained	Percentage passing
4.75 mm	6	1.20	1.20	98.8
2.36 mm	35	7.00	8.2	91.8
1.18 mm	124	24.80	33	67
600 mic	239	47.80	80.8	19.2
425 mic	88	17.60	98.4	1.6
300 mic	0	0	98.4	1.6
150 mic	6	1.20	99.60	0.4
75 mic	1	0.2	99.80	0.2
Pan	1	0.2	100	0
Total	500	-	-	-

The effect of the fineness of the ash particles used has a key impact on the performance of the finalised concrete. Testing with pond ash that is within the range of 300-150 microns achieved lower 28 day compressive strength compared to testing that utilised finer pond ash. This only courser ash had a strength reduction of 84% at a replacement of 10% pond ash (Haldive & Kambekar 2013). Research that used pond ash at 50-65% passing at 45µm could see the same reduction in strength at a replacement of 25-35% (Bapat et al. 2006; Bagwan & Kulkarni 2015). The research that utilised pond ash that is only below 45µm achieved results that are consistent with those with 50-65% passing at 45µm seeing no further significant reduction.

The research using only pond ash below 45µm did show to have a slight increase in strength at replacement ranges between 2.5-15% up to 111% the control strengths (Romeekadevi & Tamilmullai 2015; Yuvaraj & Ramesh 2021). This research suggests that a fineness of 50-65% passing at 45µm would be effective for a replacement value of 25-35% with any further processing becoming inefficient for the same replacement values. It could be an option for 15% replacement with all 45µm passing pond ash if the strength is needed to be maintained without altering the mix design. Interestingly, specification of the fineness of fly ash additives are to have a minimum of 75% passing at 45μm (Cement Australia 2016). This value could be adopted for pond ash to ensure the consistent fineness.

The amorphous content plays a major role in the reactivity of the cement as a higher amorphous content allows for a higher surface area for reactions to occur. Pond ash can have a clustered irregular and spherical rough structure which in characterised as amorphous (Dhirajkumar et al. 2019). Figure 2.1 below is a scanning electron microscope [SEM] image that shows the resemblance of cement powder and pond ash showing the irregular and rough surface.



(a) (b)

Figure 2.1– Scanning Electron Microscope, [a] Pond Ash, [b] Cement. (Dhirajkumar et al. 2019)

Crystalline content can be present in pond ash thus lowering the overall opportunity for pozzolanic reaction due to a lower surface area, with quartz content being a main cause as found through XRD analysis (Yuvaraj & Ramesh 2021). It has been found that an improvement of up to 70% in amorphous content can be achieved with wet milling that helps achieve the finer particle sizes required (Giada et al. 2021).

2.2.2 Chemical Composition

The main type of cement used in construction worldwide today is Portland cement. Portland cement cures via a chemical reaction called hydration, which occurs when water is added to the cement powder as part of the concrete mix. The hydration reaction creates a series of chemical compounds that form a crystalline matrix, binding together the particles of sand and gravel to create a solid, durable material. The main chemical components that are responsible for this reaction are the calcium silicates and calcium aluminates. When the cement powder is mixed with water the calcium silicate particles react to form calcium silicate hydrate [C-S-H] and calcium hydroxide [C-H] (Lea & Mason 2022).

Fly ash is commonly used as an SCM in combination with Portland cement to reduce the overall amount of Portland cement in the mix. Chemically speaking, fly ash differs from Portland cement in percentage and purity. Fly ash has a much lower percentage of calcium, and a much higher percentage of silicon as can be seen from the energy dispersive X-ray spectroscopy [EDAX] results below in Figure 2.2.

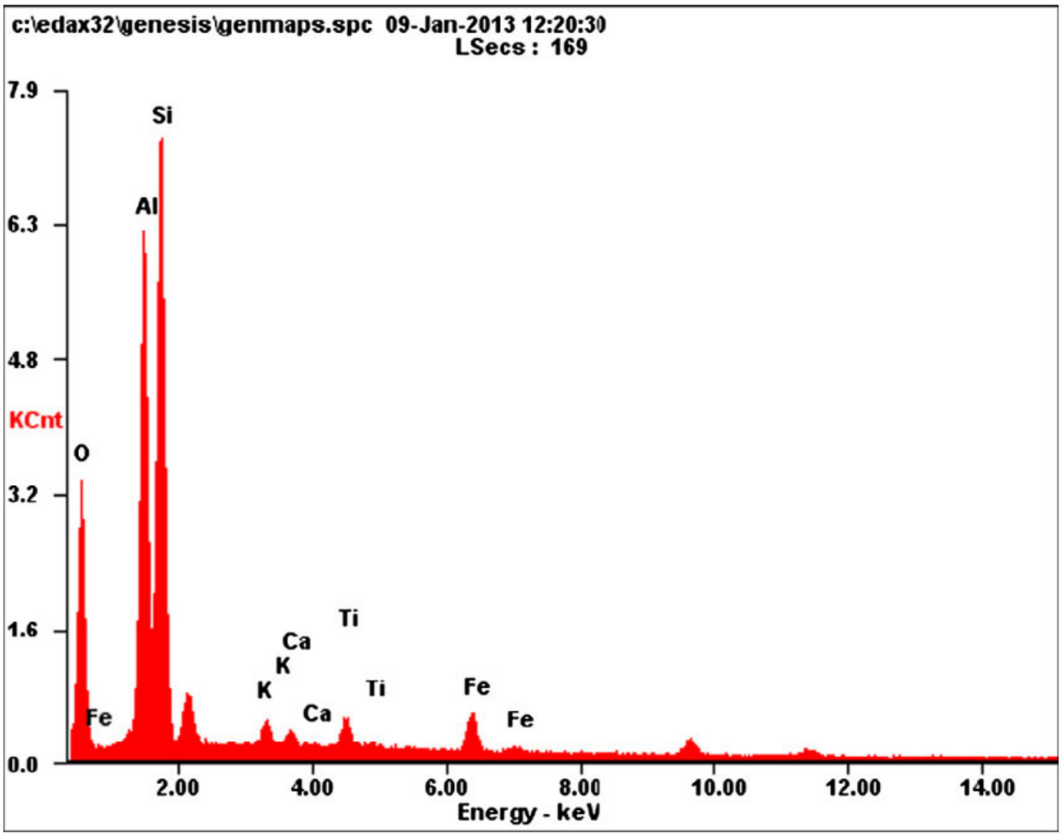


Figure 2.2– EDAX Image Of Pond Ash (Sofi & Phanikumar 2015).

This very low percentage of calcium does not allow for a hydration reaction by itself, however with a high volume of silica, the fly ash can start a pozzolanic reaction with the excess calcium hydroxide to form additional calcium silicate hydrate which acts as the adhesive between the particles of sand and gravel to create a solid, durable material (United States Department of Transportation 2017). Pozzolanic materials are substances that react with calcium hydroxide and water to form additional calcium silicate hydrate [C-S-H], which is the primary binding compound in cement. Pond ash shows promising results as a Pozzolanic material so far (Phanikumar & Sofi 2016).

Effective Utilization of Fly Ash and Pond Ash in High Strength Concrete (Romeekadevi & Tamilmullai 2015) reviewed the chemical compositions of ordinary Portland cement, fly ash and pond ash sourced from India. This investigation shows that the chemical composition of pond ash is very similar to that of fly ash as shown below in Table 2.3.

Table 2.3 – Chemical % by Weight of Pond Ash & Fly Ash, (Romeekadevi & Tamilmullai 2015)

Chemical	Fly ash	Pond ash
Silicon dioxide [Sio_2]	50.32%	51.32%
Aluminium oxide [Al_2O_3]	28.6%	23.6%
Iron oxide [Fe_2O_3]	9.61%	9.61%
Calcium oxide [CaO]	2.91%	1.91%
Magnesium oxide [MgO]	4.93%	5.93%

The high silica and alumina content of pond ash make it pozzolanic, which means it reacts with calcium hydroxide in the presence of water to form cementitious compounds. The reaction products of pond ash with calcium hydroxide are similar to those produced by Portland cement with fly ash. The chemical composition of these materials can vary greatly depending on the specific raw materials used, the manufacturing or refining process employed, and the original source. Results between sources of pond ash and where it is collected can differ slightly.

The range of the chemical constituents of pond ash is shown in the literature. Table 2.4 below shows the collated chemical compositions from 25 different samples from varying pieces of literature (Bapat et al. 2006; Haldive & Kambekar 2013; Bagwan & Kulkarni 2015; Romeekadevi & Tamilmullai 2015; Sofi & Phanikumar 2015; Phanikumar & Sofi 2016; Dhirajkumar et al. 2019; Yuvaraj & Ramesh 2021; Kumar et al. 2022).

Table 2.4 – Varied Chemical Composition of Pond Ash, % by weight.

Chemical	Min %	Max %
Silicon dioxide [Sio2]	50.5	67.4
Aluminium oxide [Al2O3]	18.02	33.11
Iron oxide [Fe2O3]	1.26	14.9
Calcium Oxide [CaO]	0	7.97
Magnesium Oxide [MgO]	0.35	5.93
Sulphur Trioxide [SO3]	0	4.28
Potassium oxide [K2O]	0	1.64
Titanium oxide [TiO2]	0	0.715
Sodium oxide [Na2O]	0	2.9
Phosphorous Pentoxide [P2O5]	0	0.137
Manganese [II] oxide [MnO]	0	0.024

It can be seen from the research that the main constituents of pond ash are Silicon dioxide [Sio2] + Aluminium oxide [Al2O3] + Iron oxide [Fe2O3]. The aluminosilicate components are the chemical constituents that react with the calcium hydroxide as part of the pozzolanic reaction. The variability and the average volume percentage by weight are shown below in Table 2.5 collated form the literature (Bapat et al. 2006; Haldive & Kambekar 2013; Jung & Kwon 2014; Bagwan & Kulkarni 2015; Romeekadevi & Tamilmullai 2015; Sofi & Phanikumar 2015; Phanikumar & Sofi 2016; Dhirajkumar et al. 2019; Yuvaraj & Ramesh 2021; Kumar et al. 2022).

Table 2.5 – Silicon dioxide [SiO_2] + Aluminium oxide [Al_2O_3]+ Iron oxide [Fe_2O_3] Distribution in Pond Ash, % by Weight

Chemical	Min %	Max %	Average %
Silicon dioxide [SiO_2] + Aluminium oxide [Al_2O_3]+ Iron oxide [Fe_2O_3]	60.08	95.34	88.74

As per AS3582.1-2016 the acceptable limit of the chemical combination of Silicon dioxide, Aluminium oxide, and Iron oxide for supplementary cementitious material is above 70% in Australia and above 60% in New Zealand.

After this section of the literature review, it is clear the pond ash will not act independently as a cementitious material but shows promising chemical properties to act as an SCM as a pozzolan additive in the concrete mixture.

Another important property of cementitious materials is the Loss on Ignition. This measures the amount of unburnt carbon by weight. Samples with high LOI can be linked to high variations in the quality of the concrete by increasing the water demand of the mix. (United States Department of Transportation 2017). High values of LOI, greater than 6% have shown longer setting times and lesser mechanical properties when compared to fly ash of lower LOI (Chen et al. 2019). The Australian standard for Supplementary cementitious materials, AS3582.1-2016 (Standards Australia 2016), mentions that the acceptable limits of LOI in Fly ash range from 3% to 6%.

The existing literature for LOI values of pond ash have shown a greater decrease in compressive strength at higher LOI values. One paper used pond ash with a value of 13.74 which is well over the suggested limit for fly ash. The decrease in compressive strength at 35% pond ash replacement was 82% when compared to the control sample (Bapat et al. 2006). Alternately, another research paper used pond ash with an LOI of only 2.2 and the results demonstrated a higher retention in mechanical properties. At a replacement of 30%, a reduction in compressive strength of only 93% of the control sample was found (Phanikumar & Sofi 2016).

2.3 Mechanical Properties

2.3.1 Working State

Pond ash has shown through the literature to have high water absorption due to its porous surface which leads to lower workability for the usual design water cement ratios (Kumar & Radhakrishna 2020). This water content can be considered in the mix design process or controlled with the addition of super plasticizer to achieve the required workability. In one study the reduction in the slump value, that is an indication of the workability of the concrete, shows the workability dropped by 80 % with a replacement of 30% cement with pond ash (Yeshi et al. 2021). This study was testing very low slump values that would indicate very low workability as it was working with mortar.

The use of low slumps while creating mortar mix means that any minor change could have a dramatic effect when presented in percentage loss. Phanikumar & Sofi (2016) also used low slump values in their testing however, the water cement ratio was varied to compensate for the loss of workability due to the increasing pond ash replacement. Higher ranges of slump have been utilised up to 75mm which are closer to those used in australian industy for common use, around 80-120mm. These results still indicate that the loss in slump sevearly increases with a replacement value of 40-50% after only 15 minutes (Bapat et al. 2006). The same study shows that after 40 minutes with only 35% replacement, almost 50% of the slump charicteristic is lost. This can be compared with just under 40% loss in slump with the same conditions for fly ash.

As stated above, it is an option for the use of super plasticizer to be added in the mix to ensure the desired workability is maintained. K. M. Bagwan (2015) tested samples of increasing pond ash to cement ratios while keeping the water cement or water binder ratios consistant. A water cement ratio of 0.49 was used and a slump of 100-120mm was achived for 0 to 35 % pond ash replacement. It was only at 45% replacement and above the super plasticizer was utilised in the mix to ensure a consistent sump value was achieved (Bagwan & Kulkarni 2015). The effect of pond ash on the water requirements within the concrete mix is shown regularly in the literature. The higher the replacement of pond ash in concrete either as a replacement of cement or as aggregate, the lower the workability will be. The nature of pond ash modified concrete drives the use of plasticizer in the mix to achieve the workability required without sacrificing the compressive strength when utilising high replacement values (Harle 2019). It has been shown in the research that the use of super plasticizers can achieve a slight benefit with long term strength with the use of high replacement values (Bapat et al. 2006). This is partialy due to the strength of pond ash modified concrete continuously increasing at a faster rate than ordinary cement after the typical 28 day testing (Kumar et al. 2022).

2.3.2 Compressive Strength

The existing literature has undertaken a range of testing on prepared samples that include a large range of pond ash replacement percentages. These papers do have some variance in compressive strength results (Kumar et al. 2022). Lal D. et al., (2019) tested a comprehensive range of samples ranging from zero to one hundred percent replacement of aggregate and cement with Pond ash. This study was undertaken to find an optimum pond ash replacement value for sand and cement in mortar and not for structural concrete with designated aggregate. The results from this research indicate that the replacement of cement with pond ash is promising within the ranges of 10 to 20 % replacement for cement. The testing at 28 days found that the 10% replacement demonstrated an increase of compressive strength of 104.9 % that of the control specimen and the 20 percent replacement experienced a decrease of compressive strength to 81 % of the control sample (Dhirajkumar et al. 2019). It should be noted that anything over a 3030% replacement was found to be highly detrimental to the 28 day compressive strength which is in line with other studies with mortar.

A different study shows differing results from the previous when focused on the using pond ash as partial replacement of cement in concrete (Bagwan & Kulkarni 2015). As this study focuses on concrete and not mortar, the findings carry more weight in this research as the introduction of varied aggregates complicate the relationship. This study also found that values of replacement over 30-35 percent was detrimental to the compressive strength but not as critically as for the mortar. The 35% replacement for pond ash only gaining 73% of the design compressive strength at 28 days compared to 55 % for mortar.

Both of these studies only covered a single compressive strength mix being 32 MPa and 25 MPa for mortar. An investagation into steel fibre-reinforced pond ash-modified concrete included test specimens with no steel fibre reinforcing as controls that can be investigated for this study (Sofi & Phanikumar 2015). The design or target compressive strength of the specimens is not stated within the paper, however, the control specimen achieved a compressive strength of 38 MPa at 28 days. This study did not have as significant decreases in compressive strength as the other research. The 30% replacement reached 92.9 % strength of the control, much higher than the other research leads to be expected. This study also maintains much lower slump values compared to the other studies, 25-32mm compared to the 100-150mm of the study by Sofi & Phanikumar in 2015.

This reduced slump may have a beneficial effect on the concrete giving higher than expected early strength when pond ash is added, and no comment has been made on this topic within the paper. It was also noted that for the strength in the pond ash modified concrete, the strength development was slower than ordinary concrete which is typical in pond and fly ash modified concrete mixes (Bagwan & Kulkarni 2015). This can be demonstrated by results on mortar showing about 5% higher strength at 56 days age with 20% replacement of cement by pond ash (Kumar & Radhakrishna 2020).

Bapat et al. 2006, undertook testing of a range of high percent replacement values with the control sample at 28 days achieving a compressive strength of 48 MPa. For a replacement of 35% Pond ash, also called lagoon ash in this paper, a compressive strength of 37.5 MPa was achieved, a reduction of 78% in strength at 28 days (Bapat et al. 2006). However, when investigating in the longer term, the 35% replacement specimen achieved 47.2MPa, 98% of the 28day strength for the control sample in 56 days. At 180 days the control achieved 60.4MPa and the 35% replacement specimen achieved 55.7MPa. this shows that when considering the long-term curing of the concrete, pond ash modified concrete can achieve faster later strength development than that of ordinary concrete.

Figure 2.3 shows the average compressive strength change compared to 28 day strength for a range of testing from the literature stated above for pond ash as a partial replacement for cement in concrete can be found below (Bapat et al. 2006; Haldive & Kambekar 2013; Bagwan & Kulkarni 2015; Romeekadevi & Tamilmullai 2015; Sofi & Phanikumar 2015; Phanikumar & Sofi 2016; Yuvaraj & Ramesh 2021; Kumar et al. 2022).

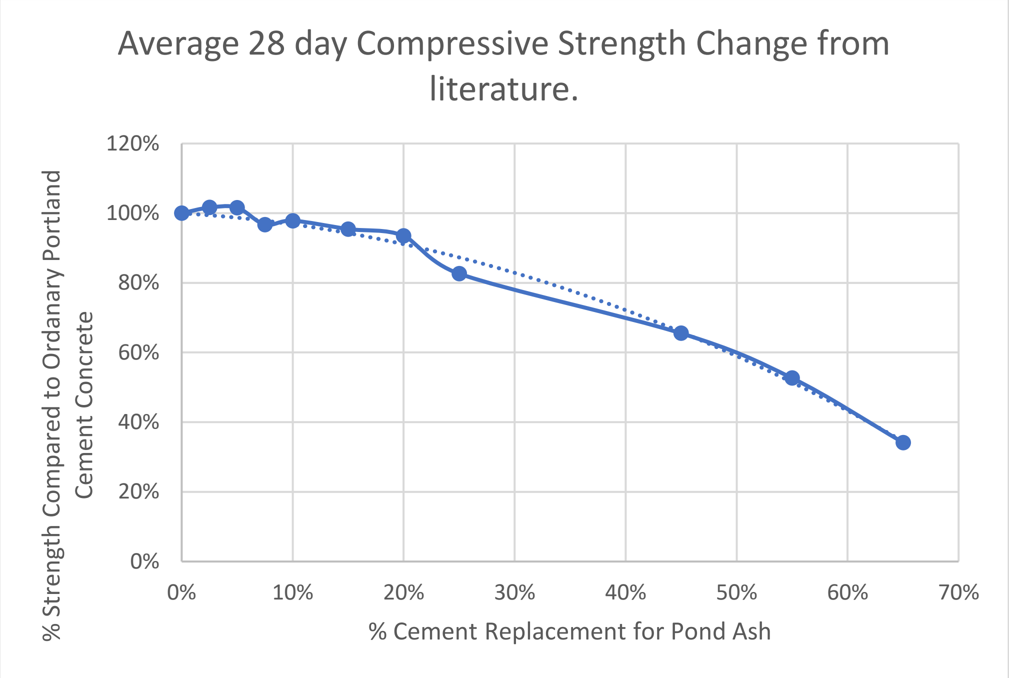


Figure 2.3 – Average 28 day Compressive Strength Change from the Literature. (Bapat et al. 2006; Haldive & Kambekar 2013; Bagwan & Kulkarni 2015; Romeekadevi & Tamilmullai 2015; Sofi & Phanikumar 2015; Phanikumar & Sofi 2016; Yuvaraj & Ramesh 2021; Kumar et al. 2022).

When looking at the range of existing data, each test only uses a single strength of concrete while investigating a range of pond ash percentages. When looking at the range of concrete strengths, a trend starts to show. Table 2.6 demonstrates the upwards trend that the higher the concrete strength, the lower the reduction in strength due to pond ash at 28 days (Dhirajkumar et al. 2019). This increase in compressive strength relative to the control as the design strength increases requires further investigation.

Table 2.6 – % Strength of Control for 20% Replacements Across Varying Concrete Strengths (Dhirajkumar et al. 2019)

Concrete Compressive Strengths (MPa)	% Strength of Control for 20% replacements
25	87%
32	93%
40	96%

2.3.3 Tensile Strength

As Concrete is a brittle construction material, it is vulnerable to tensile cracking under applied loads. The split tensile strength testing results of the pond ash modified concrete in literature so far has been limited and inconsistent in the results. These inconsistent results may be linked to the inconsistent water cement ratios used within the existing literature.

The tensile strength of the concrete is proportionate to the strength of the cement matrix and the bonds between the aggregates (Reinhardt 2013). The water cement ratio directly influences this relationship. The higher the water cement ratio the weaker the bond of the matrix to the aggregate will be, thus reducing the tensile strength (Reinhardt 2013). This relationship is demonstrated in figure 2.4 below.

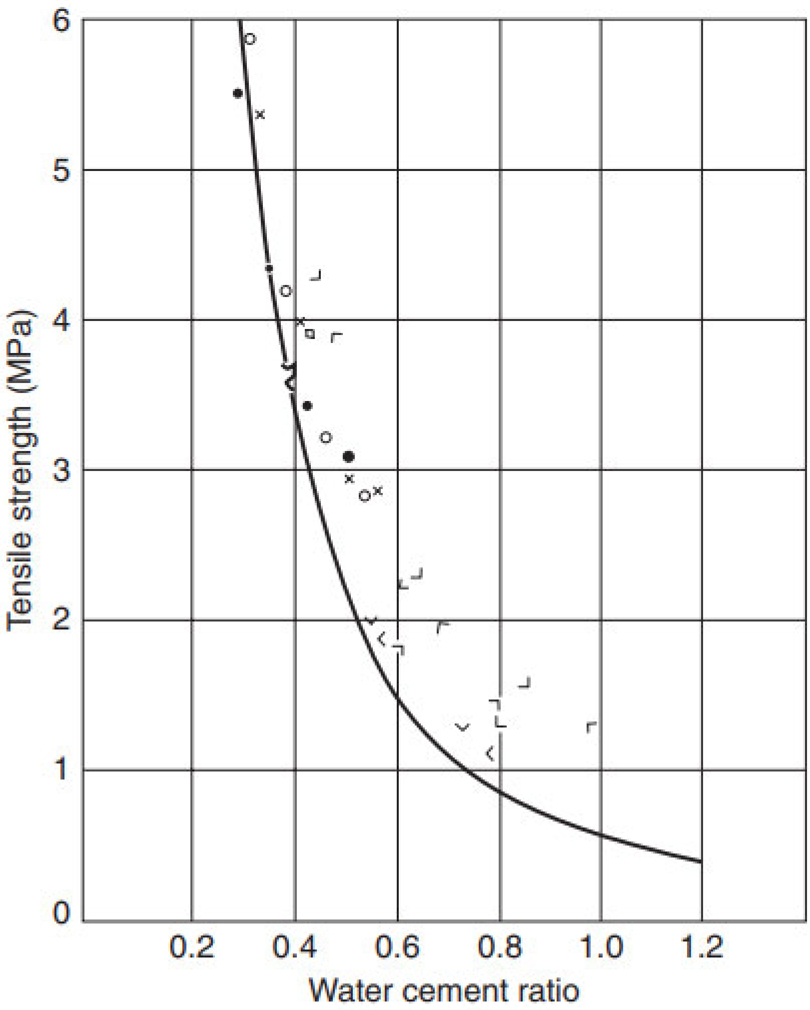


Figure 2.4 – Influence of w/c on Tensile Strength of Mortar. (Reinhardt 2013)

The test specimens in existing literature have a range of water cement ratios that vary from 0.3 up to 0.5 and follow the trends in the graph above. Direct correlations between different research papers is not possible for a consistent pond ash percentage as the target strengths and water cement ratios vary.

Local comparisons within individual studies can be investigated. At a reasonably high target strength of 40MPa a slight increase in splitting tensile strength was observed from 5% up to 15% pond ash percentages with a maximum of 111% of the control test at 10% as shown in Figure 2.5 (Yuvaraj & Ramesh 2021).

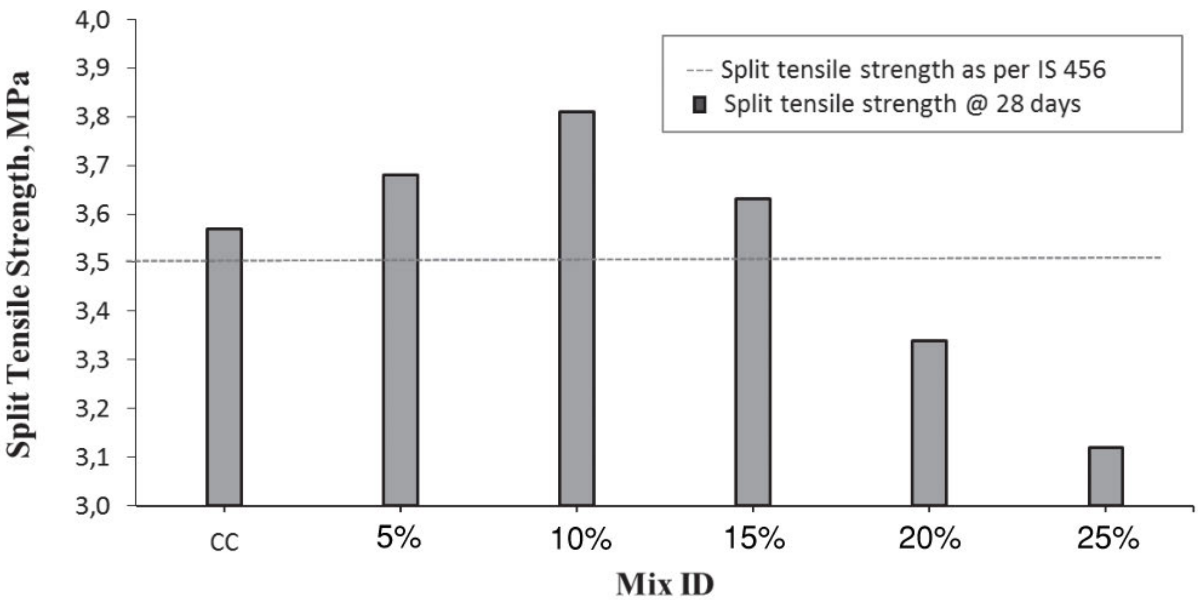


Figure 2.5 – Tensile Strength for Different Percentages of Pond Ash (Yuvaraj & Ramesh 2021)

Other research shows no increase in splitting tensile strength with addition of the pond ash at both high and lower target concrete strengths (Reinhardt 2013). At a target strength of 60MPa, a decrease of 11% of the control tensile strength was found at only 7.5% pond ash (Romeekadevi & Tamilmullai 2015). At a lower target strength of approximately 30-32 MPa, a reduction of 7% of the control tensile strength was found at 30% pond ash (Sofi & Phanikumar 2015).

Further testing is needed in this area to give consistent results between target concrete strengths. The future testing will require consistent water cement ratios and a range of target strengths along with the varied pond ash replacement percentages.

2.3.4 Flexural Strength

Similar to tensile testing, modulus of rupture or flexural testing results are limited in the existing literature. Flexural testing of unreinforced concrete provides a look into its overall performance that compressive testing will not provide by itself.

Flexural testing for mortar containing Pond ash as an SCM has shown that at a replacement of 20%, a slight increase in strength can be seen (Dhirajkumar et al. 2019). This rise in strength may be an anomaly as it does not follow the trends of the rest of the data as shown in figure 2.6 below. The strength is drastically reduced at 50% replacement to only about a third of the strength of the control specimen.

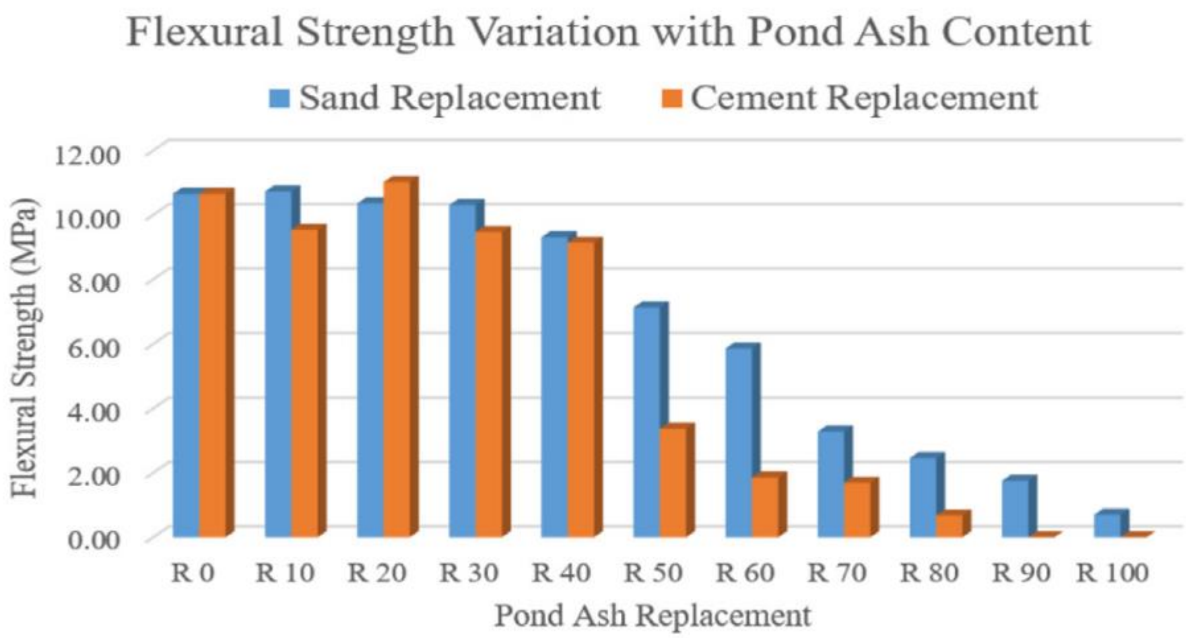


Figure 2.6 – Flexural Strength of Hardened Mortar Incorporating Pond Ash with Sand and Cement [0–100% replacement]. (Dhirajkumar et al. 2019)

The literature shows inconsistent results for flexural testing when investigating the use of pond ash as an SCM with cement. One study has shown an increase in flexural strength with a maximum strength of 107% that of the control sample at 10% replacement (Yuvaraj & Ramesh 2021). Other research doesn’t show that increase in strength with low replacement percentages and instead shows a steady decrease in flexural strength as the ponds ash content is increased (Romeekadevi & Tamilmullai 2015; Sofi & Phanikumar 2015). Even between these studies the decrease in flexural strength differs. Sofi & Phanikumar (2015), show that 92% of the contol samples strength was maintained at a replacement of 20% for the cement with pond ash. However, Romeekadevi. M. (2015), has a more dramatic reduction in flexural strength, reducing down to 95% of the control strength at only a pond ash value of only 7.5% (Romeekadevi & Tamilmullai 2015).

2.4 Replacement Values of Cement for Pond Ash

As indicated by the literature, replacement values for pond ash over 30-35 percent was extremely detrimental to the concrete strength (Bagwan & Kulkarni 2015). Values over this range will not be considered in this research and a maximum of 30% pond ash replacement will be selected. The existing research does have some variance in compressive strength results with differing design strengths. Lal D. et al., (2019) indicated that the replacement of cement with pond ash is promising within the ranges of 10% to 20% replacement for cement and this range will be the focus of this research. Smaller replacement percentages have been considered as some research has indicated an increase of compressive strength at these low replacement rates. However, most studies saw mainly a decreasing trend with the addition of pond ash and 10% was chosen to be a reasonable lower point for testing as set by a majority of other studies.

In summary, replacement percentages up to 20% seem promising for maintaining or potentially enhancing compressive strength, while percentages beyond 30% exhibit significant strength reductions.

2.5 Summary

The use of Pond ash as an SCM for partial replacement of cement is shown to be promising from the current literature. The Chemical composition of pond ash is remarkably close to that of fly ash which is a proven pozzolanic material (Romeekadevi & Tamilmullai 2015). It is also fairly similar in its amorphous content to cement at finer particle sizes (Dhirajkumar et al. 2019).

The use of this pond ash in concrete can have ecological benefits by removing it from the environment and potential economic benefits by addition of an alternate supplementary cementitious material to fly ash. This alternate supply could benefit supply chains of concrete and help reduce the cost of concrete when supply of fly ash drops.

The workability of the concrete mix has been shown to reduce with the addition of pond ash which may be accounted for with the use of a super plasticizer additive. There is also a connection in high LOI and a loss in workability so an LOI between 3-6% is recommended as outlined in the Australian standards.

It should be noted that there is some variance in results across different studies regarding the tested strengths that can be attributed to variations in testing methods, concrete mix designs, and the quality of the pond ash itself. Another factor affecting the varied results is that of concrete vs mortar. Studies that focus on concrete, as opposed to mortar, appear to be more relevant to structural applications and should carry more weight in this review. Concrete studies generally provide more reliable insights into the behaviour of pond ash as an SCM in practical construction scenarios.

Pond ash-modified concrete may exhibit slower strength development compared to ordinary concrete. This phenomenon is typical in concrete mixes containing pond ash or fly ash. Testing at more than the usual 28 days is recommended to investigate this depending on time restraints. The optimum percentage of pond ash replacement for cement appears to be around the 10-20%, with 10% showing little change compared to control samples and 20% showing a drop in strength of about 20%. Values of 10%, 20% and 30% pond ash will be undertaken for this testing.

While existing research provides valuable insights, there is a need for further investigation into various aspects, such as the optimal replacement percentage, the role of superplasticizers with the water absorption of pond ash, and the impact on other concrete properties, including durability and life cycle performance.

CHAPTER 3. METHODOLOGY

3.1 Outline

This section will include the experimental process from the acquisition of materials, through outline the experimental testing and into extraction of data and analysis.

The project methodology plan includes:

1. Material quantity estimation and acquisition for the compressive and flexural testing.
2. Systematically mix the concrete samples for each of the samples required as per the stated mixing methods outlined below.
3. Conduct slump testing and record results to compare against the target slump and gain knowledge on change of workability.
4. Pour sample material into the appropriate sample moulds and set to cure in moist curing.
5. Conduct compressive and flexural testing as per the relevant Australian standards.
6. Analyse results and form a conclusion on the use of pond ash as an SCM.

The aim of this proposed research is to examine the difference in properties of ordinary concrete with concrete that utilises pond ash an SCM for partial replacement of cement over different pond ash replacement percentages.

3.2 Assumptions

The following assumptions have been made for the purpose of this research:

1. Pond ash is available in sufficient quantities to be used as a partial replacement for cement in concrete production for at least the near future.

2. The chemical and physical properties of pond ash are consistent and suitable for use as an SCM. Testing will be undertaken by UniSQ to confirm for this project subject to time constraints.

3. The cost of producing and transporting pond ash is lower than or equal to that of traditional cement with fly ash.

4. The use of pond ash does not pose any health or environmental risks due to its pre-processing prior to addition to the concrete mix.

5. The use of pond ash in concrete production falls into the same standard as Fly as for SCM, AS3582.1: 2016. Grade 1 Ash will be assumed for this purpose.

3.3 Mixing

The mix designs will be produced using an electric cement mixer or pan type mixer in batches. As pond ash is added into the mix, there should be extra care taken to ensure that sample is homogenous and mixed uniformly and the materials are added separately. To aid in this mixing process to ensure that the ash is thoroughly mixed, minimum of 6-8 minutes will be allowed for mixing which is over the recommended 6 minutes as laid out in AS1012.2-2014 and shown in the extract included in figure 3.1 (Standards Australia 2014b).

Once the concrete has been mixed appropriately and passes the slump testing, it will be cast into test cylinders for compressive testing. The preparation of the test cylinders should be completed within 20 minutes as per AS1012.8.1-2014 (Standards Australia 2014a).

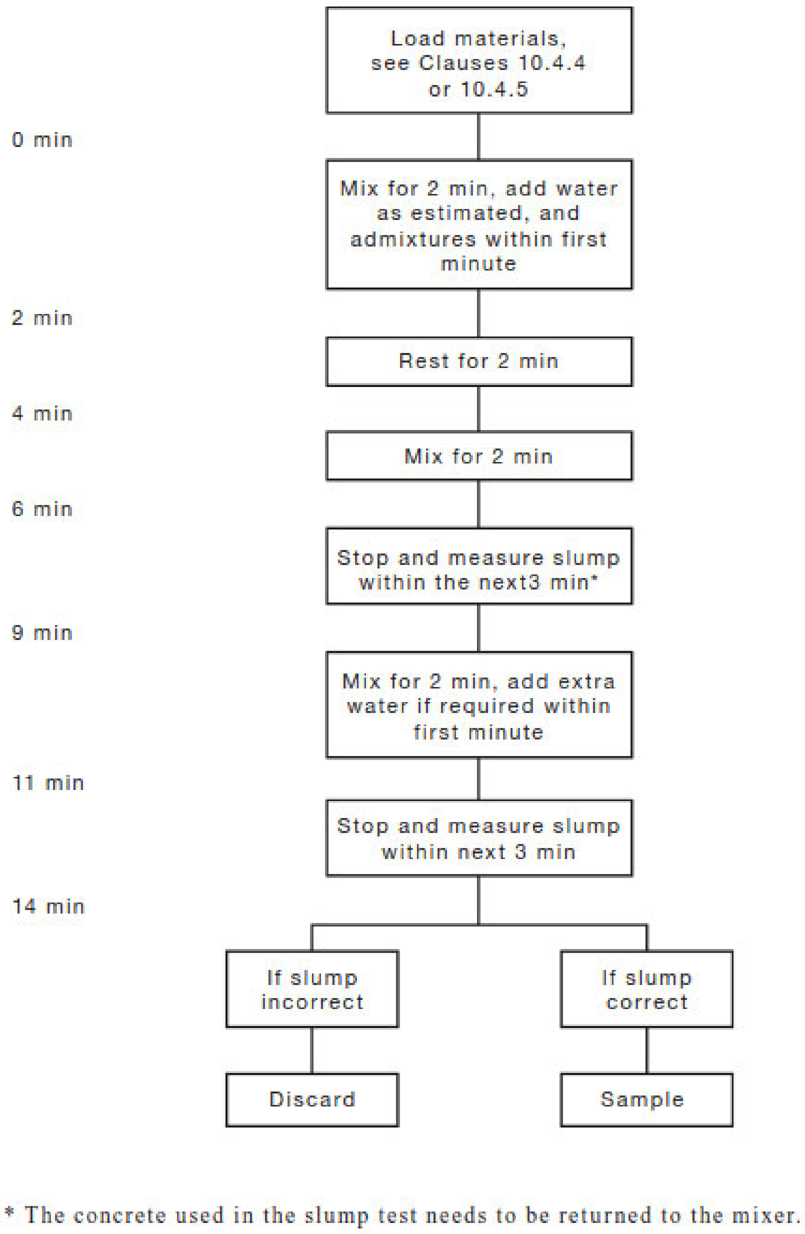


Figure 3.1 – Mixing Procedure (Standards Australia 2014b)

3.4 Casting

AS1012.8.1 - 2014, outlines the shape and diameter of the standard test specimen for compressive testing. For this study a specimen size of 100mm diameter and a height of 200mm will be used for compressive testing. This size is within the parameters set which are between 95-105mm for diameter and 1.95-2.05 times the diameter for the height. Batch sizes must be at least 10% greater than that needed for the moulding of test specimens (Standards Australia). AS1012.8.2 – 2014 outlines the dimensions of the specimens for flexure testing. The size for flexure testing as stated in the standard will be between 95mm-105mm square by 350mm long as the maximum aggregate size will be 20mm (Standards Australia 2014c).

Records will be taken regarding each sample including but not limited to:

- Date of mixing
- Specified strength
- Slump
- w/c ratio
- percent of pond ash
- other record requirements as per AS1012 series such as temperature.

The moulds will be coated in a thin layer of mould release and filled in equal layers symmetrically and each layer will be compacted. To compact the concrete, rodding will be carried out with well distributed strokes in each layer as per AS1012.3.1, AS1012.3.2, and AS1012.3.3. This is to be done with a 16mm diameter rod with a tapered spherical end (Standards Australia 2014e). Once the mould has been filled the top will be levelled off.

After 24 hours, the concrete will be removed from the moulds, marked with identification, and placed in the moist curing tank to ensure standard moist curing of the samples. Standard moist curing ensures a controlled and consistent curing of samples to provide consistent and repeatable results (Cement Concrete Association of Australia 1962). The samples will be cured in moist conditions with a controlled water replacement tank to maintain consistent PH and temperature up to the date of testing. Standard curing as above can be found outlined within AS1012.8.1: 2014 Method for making and curing concrete - Compression and indirect tensile test.

3.5 Testing

Construction Sciences Townsville have agreed to allow the use of their testing facilities. Mechanical testing, i.e., Slump, compressive, and flexural testing will be conducted utilising their equipment and under their professional supervision and guidance. Tensile testing was unable to be undertaken for this research.

3.5.1 Slump Testing

It is important that testing of the workability of the mixture is within acceptable limits. Slump testing will provide a gauge on the workability of the concrete mixture. The slump test is outlined within; AS1012.3.1: 2014 - Methods of testing concrete Determination of properties related to the consistency of concrete - Slump test, and will be followed for this testing.

Slump testing involves filling a cone with the concrete from the main batch in layers and rodding to ensure consolidation in a similar manner as the casting mentioned above. Once the cone has been filled to the top level on top of a steel base plate, the cone is then vertically removed so that the vertical settling of the concrete can be measured. The cone has an opening at each end with dimensions of 200 mm and 100 mm (Standards Australia 2014e). The cones vertical height is to be 300 mm and can be seen below. All measurements of the cone have a tolerance of ± 5mm and an overview of the apparatus can be seen in Figure 3.2.

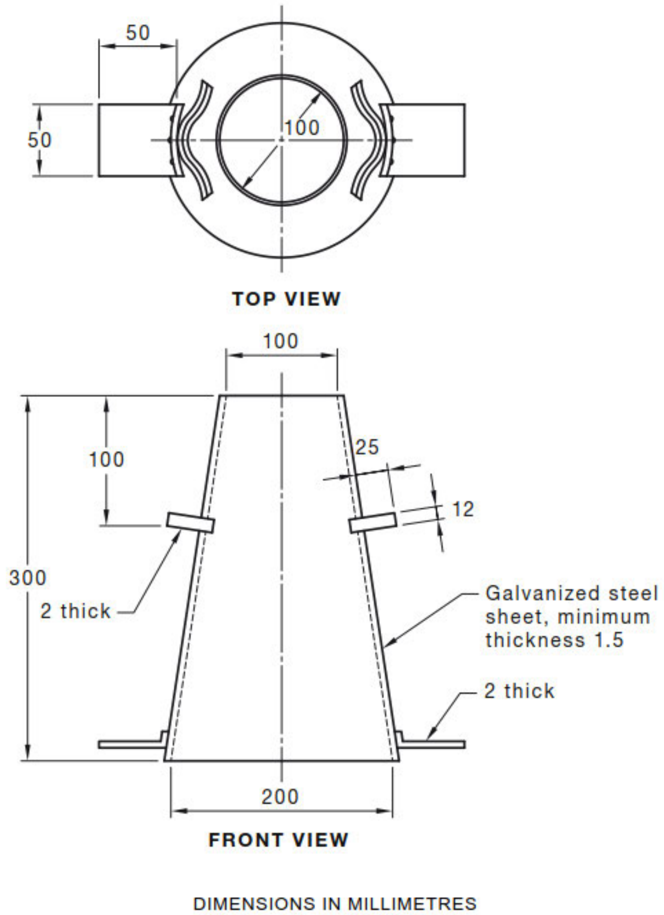


Figure 3.2 – Typical Mould for Slump Test, AS1012.3.1: 2014 (Standards Australia 2014e)

Once the concrete settles, the cone is set to the side and a straight edge is placed on top to allow for a measure to be taken down to the new concrete height (Boral 2017). The shape of the concrete slump will also be considered. If shear failure occurs such as those demonstrated in Figure 3.3, the batch will be discarded, and the mix altered to suit as required. A slump of 80mm will be adopted for the tests in this project.

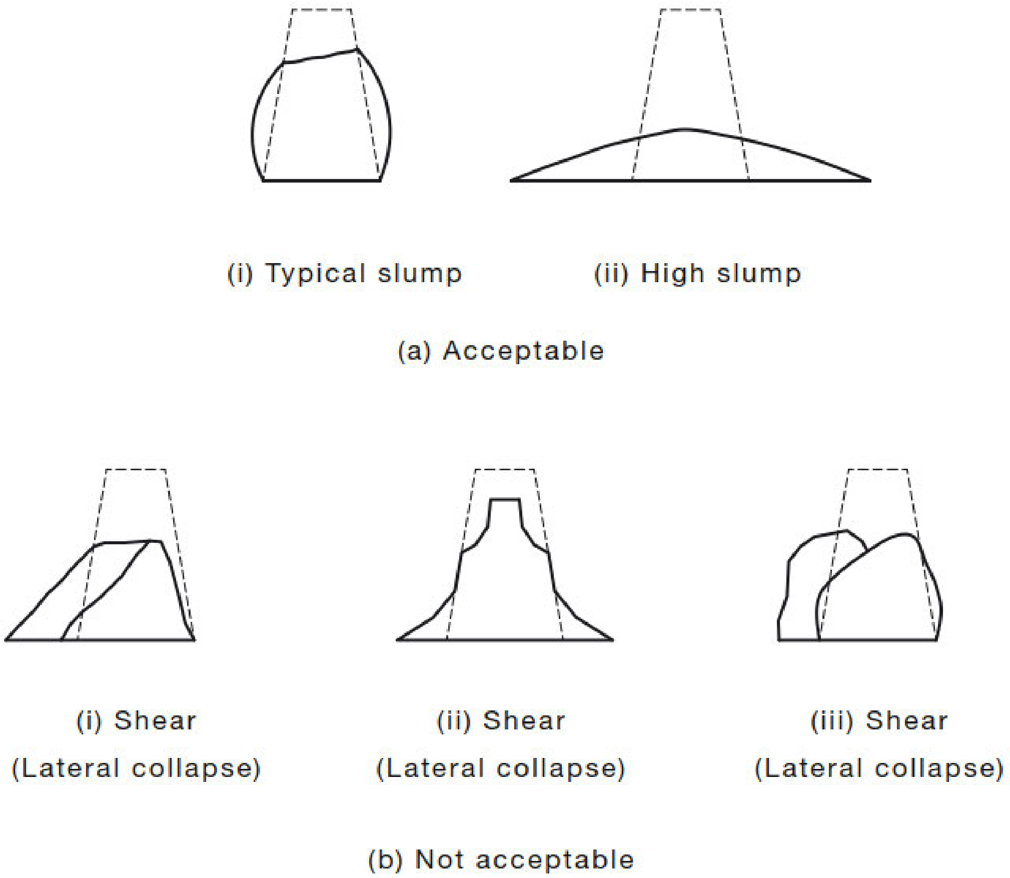


Figure 3.3 – Examples of Slump, AS1012.3.1: 2014 (Standards Australia 2014e)

After the slump test has been conducted and if the test was within the parameters set out, the slump sample will be returned to the mixer and moulds poured and placed aside for initial curing.

3.5.2 Compressive Testing

Compressive testing will be undertaken on the test cylinders with the use of a regulated press capable of reaching the range of forces required. The presses used are rated for up to 2000kN. Concrete compressive testing will be undertaken in accordance with AS1012.9:2014 – Methods of Testing Concrete, Method 9: Compressive Strength Tests - Concrete, Mortar and Grout Specimens (Standards Australia 2014d).

In preparation, the test cylinders will be ground back to create a flush face to correct any abnormalities that appeared in casting. Before testing, the cylinders are to be checked for differences in sizes and weights. The test cylinders are then measured and documented as required and outlined in AS1012.9:2014. The procedure for testing is outlined in AS1012.9 – 2014 Section 8. Each sample will be placed within the concrete compression machine, loaded at a rate of 18-22MPa per minute. The load at failure or until the no increase in force is able to be sustained will be recorded. This load at failure can then be used to find the compressive strength of the concrete using:

$$f'c = \left(\frac{Cr}{\pi * r^2}\right) * 1000 \qquad 3.1$$

where; r is the average radius of the sample [mm]

$f'c$ is Characteristic Strength [MPa]

Cr is the critical or failure load [kN]

The compressive strengths of all the test samples are to be recorded, averaged, tabulated and graphed in order to analyse property comparisons between the samples. Any abnormalities or outliers are to be reviewed and potentially rejected from the data pool as required. The difference in strengths of the pond ash modified concrete and ordinary concrete will be looked into in detail to determine the behaviour the pond ash in the mix design has on the mechanical properties.

3.5.3 Flexural Testing

Flexural testing of concrete is outlined in AS1012.11 -2000 and will be followed for the purposes of this testing. Flexural beam testing will provide a window into its performance in bending and an indication on its tensile properties. Firstly, the specimen will be inspected to check that the dimensions are correct and free from defects for testing. A designated flexural testing machine will be used as it can achieve accuracy in the lower forces required for this testing. The force from the machine will be applied through a frame consisting of an upper and lower die. The dies are made up of 2 fixed rollers on each platen that carry the load equally between the rollers as per in Figure 3.4.

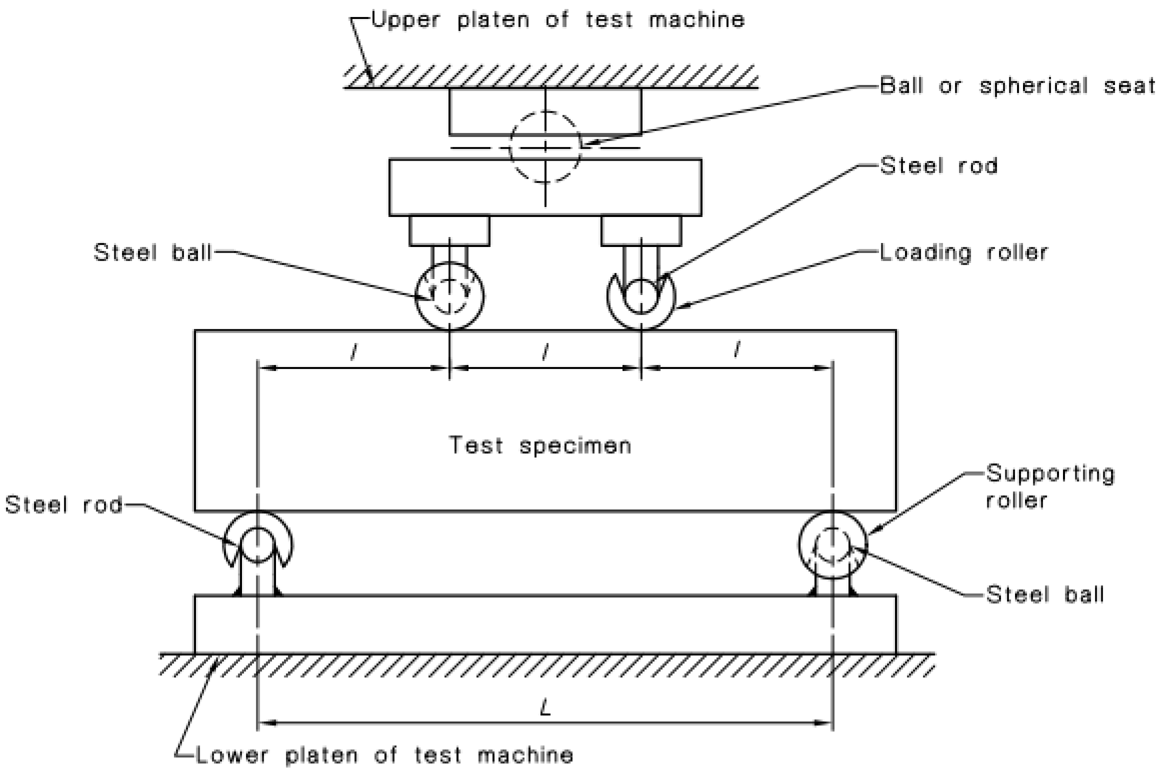


Figure 3.4 – Diagrammatic View of a Suitable Flexure Testing Apparatus AS1012.11: 2000 (Standards Australia 2000)

After the sample has been kept wet for at least 48 hours prior to the testing, it will be wiped and placed centrally into the testing apparatus. A seating load will be applied of no greater than 100N to check for the correct placing then the loading will be increased at a rate of 1 ± 0.1 MPa per minute until no increase in force can be sustained (Standards Australia 2000). The width and depth of the specimen at the failure point along with the load and dimensions can be used to determine the modulus of rupture or flexural strength, in MPa using Equation 3.2 below.

$$f_{cf} = \frac{\mathrm{PL}(1000)}{BD^2} \qquad 3.2$$

where; P is the maximum applied force [kN]

f_{cf} is the modulus of rupture [MPa]

L is the span length, in [mm]

B is the average width of the specimen at the section of failure [mm]

D is the average depth of specimen at the section of failure [mm]

The test will only be valid if the failure point is located within the middle third of the flexural beam. This test will be repeated to a total of 2 times for each type of sample and the average force at failure for the 2 samples will be the result used for analysis.

The compressive testing results can also be used to estimate the flexural tensile strength and provide a guide on which the performance can be scaled and determined. AS3600:2018 Clause 3.1.1.3 *Tensile strength*, states that the Characteristic Compressive Strength values can be used to form an estimate. Below shows this relationship (Standards Australia 2018).

$$f'_{ct.f} = 0.6\sqrt{f'c} \qquad 3.3$$

where; $f'_{ct.f}$ is the Flexural Tensile Strength [MPa]

$f'c$ is Characteristic Strength [MPa]

The flexural testing results cannot be used to calculate the tensile performance as no direct relationship to direct tensile testing has been found as flexural testing generally provides higher results (Cement Concrete & Aggregates Australia 2020b). To find the uniaxial tensile strength of concrete, AS3600:2018 Clause 3.1.1.3 *Tensile strength*, states that the Characteristic Compressive Strength values can be used to form an estimate. The equation 3.4 below shows this relationship (Standards Australia 2018).

$$f'_{ct} = 0.36\sqrt{f'c} \qquad 3.4$$

where; f'_{ct} is the Uniaxial Tensile Strength [MPa]

$f'c$ is Characteristic Strength [MPa]

CHAPTER 4. EXPERIMENTAL PROGRAM

4.1 Materials

The following section gives an overview of the materials used and their details.

4.1.1 Pond Ash

The pond ash shown in Figure 4.1 has been acquired from the Millmerran Power Station by the University of Southern Queensland. It is important that the ponded ash that is used in the testing for this project are in line with the Australian standards that are applicable. The Millmerran Pond Ash testing is being carried out by The University of Southern Queensland to determine if the qualities align with the current standards for supplementary cementitious materials.

Figure 4.1 - Millmerran Pond Ash Sourced by The University of Southern Queensland

The applicable Australian standard for the use of SCM is AS3582.1 and those mentioned within the Coal Combustion Products Handbook (Baweja D. et al. 2014). AS3582.1 provides material requirements for ash as an SCM as seen in Figure 4.2.

MATERIAL REQUIREMENTS

Property (see Note 1)	Special grade limits	Grade 1 limits	Grade 2 limits	Reference method
Fineness by mass passing 45 µm sieve, % minimum	85	75	55	AS 3583.1 or AS 2350.9
Moisture content, % maximum	0.5	0.5	0.5	AS 3583.2
Loss on ignition, % maximum	3.0	4.0	6.0	AS 3583.3
Relative density	–	–	–	AS 3583.5
Relative water requirement, %	–	–	–	AS 3583.6
Strength index, % minimum	105 (see Note 2)	75 (see Note 2)	–	AS 3583.6
Sulfate (as SO_3) content, % maximum	3.0	3.0	3.0	AS 3583.8 or AS 2350.2
Total alkali, %	See Note 3	See Note 3	See Note 3	AS 2350.2
Chloride ion (Cl) content, % maximum	0.1	0.1	0.1	AS 3583.13 or AS 2350.2
Chemical composition in Australia ($SiO_2 + Al_2O_3 + Fe_2O_3$)	70% minimum (see Note 4)			AS 2350.2
Chemical composition in New Zealand ($SiO_2 + Al_2O_3 + Fe_2O_3$)	60% minimum			AS 2350.2

Figure 4.2 – Material Requirements from Table 1, AS3582.1: 2016, (Standards Australia 2016)

Table 4.1 – Millmerran Pond Ash Material Properties, Conducted by UniSQ

Material Property	Millmerran Pond Ash
Fineness by mass passing 45 um sieve, % minimum	55.17
Moisture content, % Average	0.023
Relative density	1.85
Approximate Bulk Density, kg/m^3	1055

The fineness results indicate that the pond ash may be within grade 2 limits however futher testing on the material will need to be conducted to ensure other factors such as the LOI and chemical composition are within the required limits. Due to time and funding constraints, XRD analysis was unable to be conducted by UQ on behalf of UniSQ for the purpose of this paper.

4.1.2 Cement

The cement used for testing as part of this project was Baston brand GP cement as seen in Figure 4.3. This cement conforms to AS3972 with greater than 92% Portland cement with the remainder content containing mostly Lime and Gypsum. As this does not contain any other SCM such as fly ash by default, it was chosen as an undiluted option. The specific gravity of the cement is 3.15 with a density of 1440kg/m^3.

Figure 4.3 – Cement used in Concrete Mix

4.1.3 Aggregates

A wide range of aggregates was used within the mix design for this project as specified by the professional mix design provided by Holcim Townsville. A fine sand sourced from Cleveland near Townsville shown in Figure 4.4 was used alongside the coarse sand sourced from the Burdekin area shown in Figure 4.5. In combination, this formed the sand portion of the mix design.

Figure 4.4 - Fine Sand Sourced from Cleveland

Figure 4.5 - Coarse Sand Sourced from the Burdekin

For the coarse aggregate portion, a mix of 10mm and 20mm was used which was sourced from the Bohle quarry in Townsville shown in Figure 4.6 and Figure 4.7 respectively.

Figure 4.6 - 20mm Aggregate Sourced from the Bohle Quarry

Figure 4.7 - 10mm Aggregate Sourced from the Bohle Quarry

All aggregates were provided by Holcim Townsville from local quarries in and around the Townsville area. These aggregates are as per Holcim mixes used in their industrial plant mixes.

4.2 Material Quantity Estimation

The compressive testing is to be carried out on 7, 14, 28, and 56 day intervals with 3 specimens per test per batch. This gives 12 cylinders required per batch. The Flexural beams required for each batch is only 2 per batch as testing is only taking place at 28 days. It was calculated that an estimated value of about 31 litres of fresh concrete is needed for each batch with an allowance of 20% included for loss. Using the estimated volume calculated above, the mass of each component of the concrete mix can be calculated using the chosen mix design.

4.2.1 Mix Design

To obtain comparable data as part of this research, concrete will need to be produced that contains pond ash as a partial replacement of cement in a consistent manner. This is accomplished by designing mixes of concrete of consistent compressive strength based on existing techniques to be confirmed by industry experts. For the purpose of preliminary material obtainment, the preliminary mix design will be based around the method in Control and Characteristics of Concrete by Cement and Concrete Association of Australia, where it uses Equation 4.1 to determine the target strength (Cement Concrete & Aggregates Australia 2020a).

$$T = C + 1.65 * S \quad (4.1)$$

where; S is an assumed Standard Deviation as per Figure 4.8

C or $f'c$ is Characteristic Strength

T is Target Strength

Table III.2 – Approximate Standard Deviation for Mix Design

Standard Deviations for concrete where no data is available	
Characteristic Strength (MPa)	**Approximate Standard Deviation (MPa)**
20	3.0
25	3.3
32	3.6
40	3.9
50	4.2

Figure 4.8 - Standard Deviation (Cement Concrete & Aggregates Australia 2020a)

This target strength is used for the mix design along with design tables for aggregate sizes and degree of workability, slump in mm, to calculate the mix quantities by weight. When the weights have been calculated, the values will be altered based around the moisture content of the aggregates and quantity of free water in the mix.

The mix design was altered to incorporate ground pond ash by replacing a portion of the cement from the mix by weight. A range of percentage replacements of cement with ground harvested pond ash will be tested with a high strength concrete mix. Values of 10%, 20% and 30% pond ash have been chosen as previously discussed in the literature review chapter.

As part of this mix design a maximum aggregate size of 20 mm will be used to align with AS1012.2: 2014 (Standards Australia 2014b). The chosen slump for this project will be 80mm with a tolerance of $\pm$ 10mm to align with AS1012.8.1: 2014 (Standards Australia 2014a). Variations outside of this tolerance, if found, will be recorded and water ratios kept continuous throughout the testing to ensure comparable results with the same w/c. The initial mix design was used for initial estimation and determination of scope.

After communications with industry representatives, a standard 40 MPa mix design was confirmed by Holcim, an external concrete supplier. This was decided to better match industry processes for a 40 MPa mix. It is the hope that this mix design will give realistic and professionally aligned results that match the concrete that is delivered to construction sites every day within industry. These industrial mixes often reach strengths greater than that of their design target strength at 28 days. This is to ensure that the concrete passes in strength to avoid costly rectifications on site after pour and potential other works completed. Using the estimated batch volume calculated above, the provided mix design for the 40 MPa mix can be seen in Table 4.1 below with the adjusted mixes for the replacements for the pond ash.

Table 4.2 – Mix design for 30L batches, All Values are in kg

Trial		Mix 1	Mix 2	Mix 3	Mix 4
Mix ID		Control	10% Pond Ash	20% Pond Ash	30% Pond Ash
Compressive Strength [MPa]		40	40	40	40
Water [kg/m^3]		190	190	190	190
W/C		0.46	0.46	0.46	0.46
Nominated Spread [mm]		80	80	80	80
Total Binder [kg/m^3]		410	410	410	410
20mm Agg	Bohle	22.7	22.7	22.7	22.7
10mm Agg	Bohle	7.7	7.7	7.7	7.7
FS	Cleveland	9.0	9.0	9.0	9.0
FS	Burdekin	13.5	13.5	13.5	13.5
Cem	Townsville - GP	12.3	11.1	12.3	8.6
SCM	Pond Ash	0.0	1.2	2.5	3.7

4.3 Mixing, Casting & Slump Testing

The creation of the test batches was undertaken over a period of three days starting from the 25th of July through to the 27th of July at Construction Sciences Townsville. Each batch was measured out by hand with the use of a field balance scale system. The batches were mixed using a portable electric mixer, shown in Figure 4.9, as per that laid out in Chapter 3 section 3.3.

Figure 4.9 – Mixing of the Pond Ash Modified Concrete

Slump testing was conducted on each of the four test batches in order to gauge the workability of each mix shown in Figure 4.10. It was found that the slump for the control was only at half that of the initial design.

Figure 4.10 –Slump Testing

On the first day, the time of the first and second pour, it was decided that the casting would continue unchanged due to strict time restraints and access to lab equipment and personnel. This decision was also made as to not change the mix design provided and keep consistency throughout the testing. It was discovered the next day that the aggregates were oven dried by the lab technicians prior to batching. This oven drying had altered the w/c ratio compared to that allowed for in the original mix design. As the aggregates have been oven dried, the control of the water ratio can more strictly controlled. This control will ensure consistent material properties quantities across all tests to produce consistent and comparable results.

Casting was carried out in the designated timeframe with care being taken to ensure that proper compaction was carried out through the rodding technique. The concrete mix was then finished off flush and even with the tops of the moulds and set for initial curing as shown in Figure 4.11.

Figure 4.11 – Prepared Samples, Green (Left) and after Approximately 24 Hours (Right)

4.4 Curing

Once the samples were left to cure in a protected environment for approximately the first 24 hours, the sample moulds were stripped and marked with identifiers as shown in Figure 4.12. The Identifiers included the purchase order number, mould number, number of days testing and the date of testing. The samples were then placed into the water bath for moist-curing in preparation for testing as shown in Figure 4.13.

Figure 4.12 – Prepared Demoulded Samples

Figure 4.13 – Samples in the Curing Bath

4.5 Mechanical Testing

All testing was carried out with assistance from Construction Sciences Townsville Laboratory technicians. All Australian standards requirements were closely observed by industry professionals who carry out daily Quality assurance to ensure the results are consistent and accurate. The following covers the mechanical testing carried out as part of this research project.

4.5.1 Compressive Testing

As stated in Chapter 3, Section 3.5.2 for compressive strength testing, the testing timeline of the samples is 7, 14, 28, and 56 days. Prior to testing, the cylinder samples are ground back flat with a concrete surface grinder which can be seen in Figure 4.14. This is to achieve an even distribution of force through the cylinder.

Figure 4.14 – Concrete Surface Grinder

Once the samples have been ground flat and to the final length, the dimensions are confirmed within tolerance and recorded along with its weight and condition. Once the initial data has been recorded the compressive samples are placed into the compressive testing machine shown in Figure 4.15.

Figure 4.15 – Concrete Compresive Machines

4.5.2 Flexural Testing

The flexural testing was carried out at 28 days after casting. The flexural specimens were measured and weighed and details recorded for calculations. The third points between loading were marked on each specimen shown in Figure 4.16 prior to being set into the flexural bending machine for testing shown in Figure 4.17.

As initial loading was slowly applied, the top roller dye were centered to loading points marked on the samples to ensure evenly distrubuted loading to avoid uneven failure. When failure occurred, the critical load at failure was recorded and the location of failure measured in regard to the centre third of the beam.

Figure 4.16 – Flexural Samples with Third Points Marked for Testing

Figure 4.17 – Four-Point Flexural Bending Test Machine

CHAPTER 5. RESULTS AND DISCUSSION

5.1 Introduction

The following chapter will cover the results of the testing carried out in the experimental program. It will also cover any discrepancies or unexpected values that have come from the testing. As mentioned in section 4.3, the aggregates used during batching were oven dried to remove all moisture. This oven drying was not able to be taken into consideration during batching due to time and accessibility restraints. If the batching and casting was delayed further than that caused by the late arrival of the pond ash, the testing may not have been able to be completed prior to the set deadline. It was decided that the batching would continue as the results would still be comparable. It was advised by the lab technicians that compaction would still be achieved even with the lower workability.

5.2 Workability

The slump test results and conditions for each mix can be found below in Table 5.1. Detailed concrete sampling report can be found in Appendix C.

Table 5.1 – Slump Testing Results

	Control	10% Pond Ash	20% Pond Ash	30% Pond Ash
Slump	40mm	35mm	15mm	10mm
Air/Concrete Temperature (°c)	24/24	24/24	25/25	26/23

The slump results were significantly lower than the expected 80mm designated in the mix design. At the time of casting, it was unsure if this was due to a mix up in aggregate size/amount or the water cement ratio. It was later discovered this low slump was due to the aggregates being oven dried prior to use by the laboratory technicians without the information being passed on. The mix design was designed to have a slump of 80mm, however, it considered saturated surface dry for the aggregates in its calculations. As the aggregates were much dryer than expected on the day, the water was absorbed by the aggregates more than expected, lowering the workability. Due to time and access restraints, the water amount was not altered, and no super plasticiser was on hand to compensate for this change.

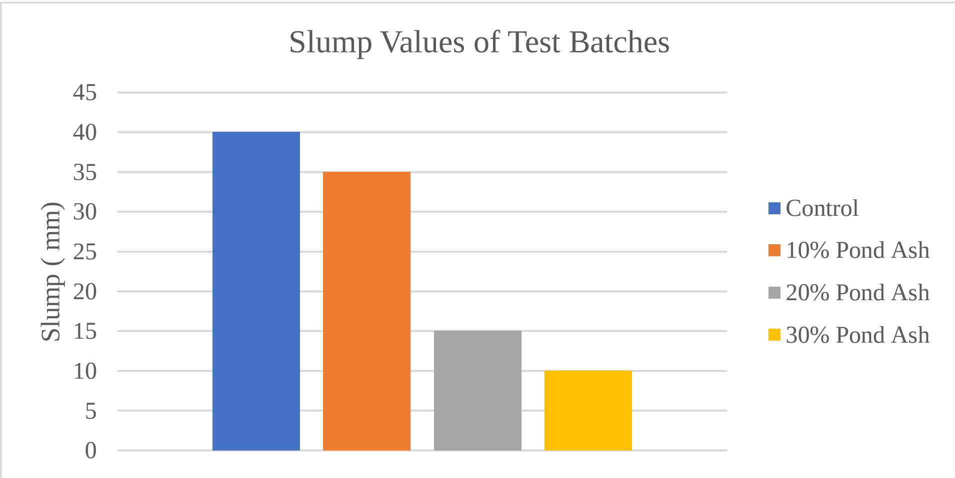


Figure 5.1 – Slump Values of Test Batches

The effect of pond ash on workability can be seen graphically from the results in Figure 5.1. A slight change in slump can be seen with the addition of 10% pond ash, a reduction of 13%. However, a drastic reduction in workability can be seen from 20% and the 30% replacement values with a reduction of 63% and 75% respectively. These significantly reduced slump values indicate a substantial loss of workability, making the concrete highly stiff and challenging to handle during placement. A slump value as low as 10mm is only practical for very niche construction such as continuously extruded barricade fencing for motorway construction or road pavements (Nassima & Fattoum 2022). It may lead to difficulties in achieving proper compaction and finishing in most cases.

With the result of the reduction in workability, the appearance of air voids in the concrete surface becomes evident. These air voids can affect the strength of the concrete during loading and should be considered. Figures 5.2 & 5.3 show the surface finish for the control sample and the 30% pond ash sample respectively. A considerably higher amount of surface imperfections can be found on the 30% replacement samples but can also be found to a lesser extent on the 20% and 10% replacement samples.

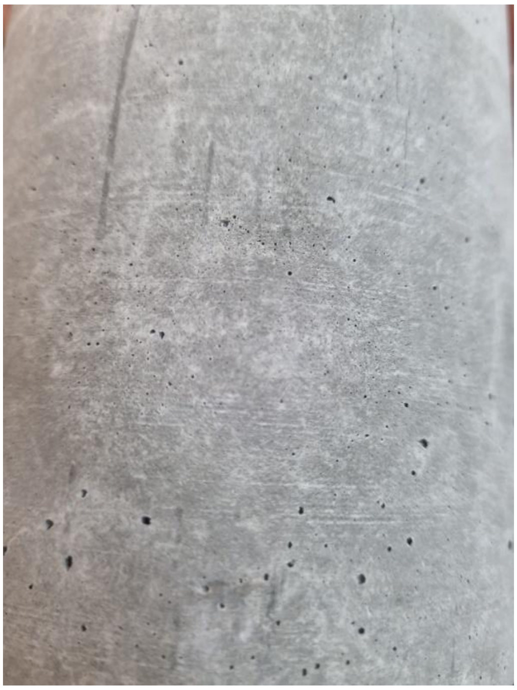


Figure 5.2 – Surface Finish of Typical Control Cylinder, After 7 Day Testing

Figure 5.3 – Surface Finish of Typical Cylinder with 30% Pond ash, After 7 Day Testing

The air voids can be estimated using the densities calculated during testing. The theoretical densities can be calculated using the mix design and the densities of the materials. The density of the cement is 1440 kg/m^3 and pond ash was measured to be 1055 kg/m^3. Using the 30 Liter batch design values mentioned in section 4.2.1, the control has 8.54 Liters of cement in the batch, this is 28.67% by Volume. Continuing this for the replacement pond ash samples increases the overall batch volume and provides the following values.

- 10% pond ash – Cement is 25.53% & Pond ash is 3.87% by Volume.
- 20% pond ash – Cement is 22.46% & Pond ash is 7.67% by Volume.
- 30% pond ash – Cement is 19.46% & Pond ash is 11.38% by Volume.

This change in batch volume through the change in density of the pond ash reflects a decrease in the theoretical mass per sample by 113.6 grams for the 30% replacement samples. From this reduction in mass per sample, the expected density can be estimated. Using 2376 kg/m^3 for the average control density, it can be expected that the density can be reduced to 2304 kg/m^3, a reduction of only 75 kg/m^3. The estimated theoretical densities found in Table 5.2 below can be seen to decrease as the percentage of pond ash increases. This decrease in density has been seen in other studies in the same area (Verma et al. 2016).

Table 5.2 – Approximate Theoretical Density Calculation Table

	Volumes (Liters)			
Materials	Control	10% PA	20% PA	30% PA
20mm Agg	7.81	7.81	7.81	7.81
10mm Agg	2.64	2.64	2.64	2.64
Fine Sand	4.32	4.32	4.32	4.32
Coarse Sand	6.48	6.48	6.48	6.48
Cement	8.54	7.69	6.83	5.98
Pond Ash	0.00	1.17	2.33	3.50
Total Batch Volumes (Liters)	29.80	30.11	30.42	30.73
Estimate Cylinder weights (kg)	3.73	3.69	3.66	3.62
Estimate Cylinder Densities (kg/m3)	2376	2351	2327	2304

The theoretical estimated density for each of the samples are remarkably close to the actual average densities recorded. The actual density of the samples can be found in Figure 5.4.

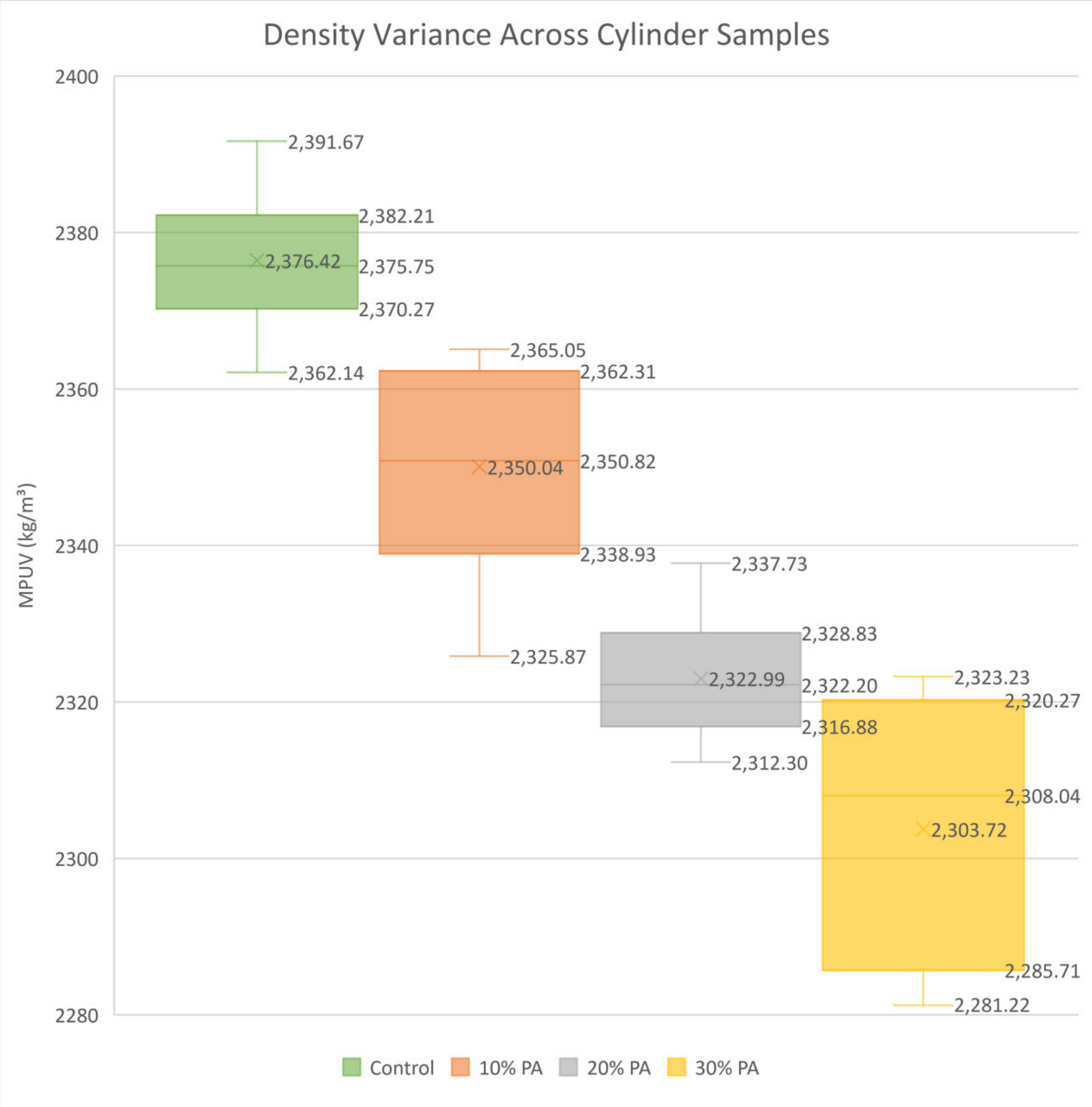


Figure 5.4 – Density Variance Across Cylinder Samples

Figure 5.4. shows the recorded density of the samples with upper and lower limits along with the upper and lower quartile and median shown. As mentioned above, the average densities marked with a cross, match with what is expected from the theoretical estimated densities. However, when looking at the range of the values, the control has a tight gap between its upper

and lower quartiles while the 30% replacement has a range just over 3 times that size. The higher recorded densities can be due to entrapped water from the moist curing bath after initial drainage has occurred. Although the average of 30% replacement samples are within expectations, the variance in the densities recorded are over a larger range. It can also be seen that the lower densities in the 30% replacement samples bring the average value further below the median than that of the other samples. It should also be noted that a similar trend can be seen in the 10% replacement samples indicating that compaction may not have been as consistent for this batch. This wide range of variance for the 30% replacement could represent voids in the concrete samples. This should be taken into consideration when investigating the mechanical strengths however not a large percentage of the sample mass has been lost due to voids.

5.3 Compressive Testing

During the Compressive testing the load at failure was recorded and input into Construction Sciences program to work the strength values from the accurate measurement data previously recorded. These results in Construction Sciences Townsville report format can be seen in Appendix C. In addition to Construction Sciences reporting, the loads and measurements were also input into a spreadsheet created using Equation 3.1 for verification. The spreadsheet information can be seen in Appendix D.

The failure pattens of the cylinders can be investigated to provide an insight into the failure modes and find any anomalies or irregularities. The typical types of failure pattens for compressive testing can be found in Figure 5.5 (ASTM International 2005). The most common failure pattens are Type 1 through to Type 3 with Types 5 & 6 indicating failure prior to the ultimate loading scenario (ASTM International 2005).

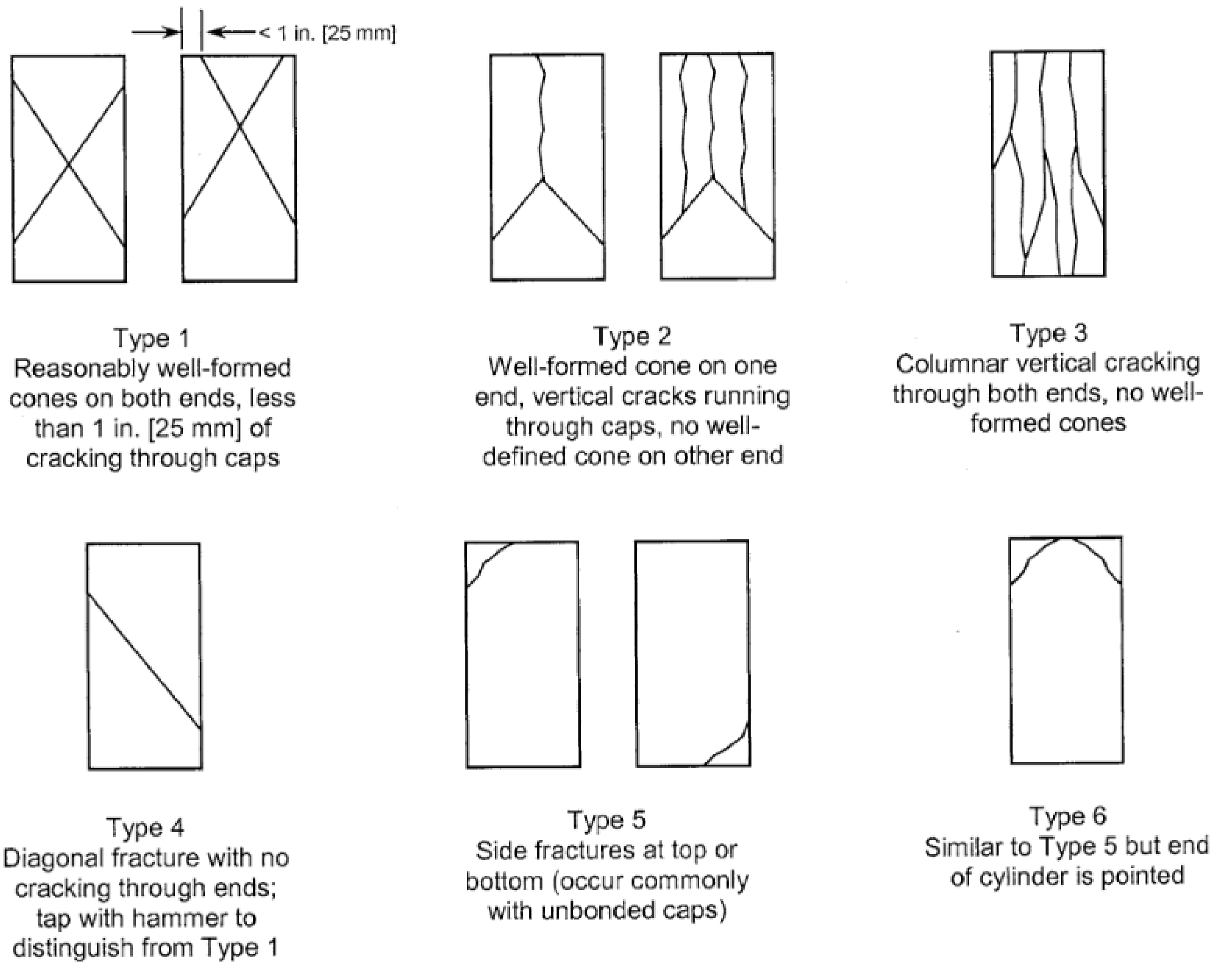


Figure 5.5 – Schematic of Typical Fracture Patterns (ASTM International 2005)

The control samples included mainly Type 2 failure with a cone on one end with vertical cracks. The 28 day sample shown in Figure 5.6 Shows a Type 3 failure with no well-defined cone. The Type 3 failure was common throughout the testing showing up consistently in the 10%, 20% & 30% pond ash samples shown in Figures 5.7 to 5.9. The 14 day samples from the 20% batch did show a Type 4 failure with a single diagonal fracture line indicating shear failure but no determinable change in strength was noted.

One of the 7 day samples from the 30% pond ash batch achieved only 16.5 MPa, well under the other two samples at 25.5 MPa and 26 MPa. This cylinder was inspected closer and was found to have failed through a series of voids and was rejected from the sample for determining the average strength. It was also found to have a Type 5 failure due to uneven loading.

Figure 5.6 – Control Sample Fracture Patterns, Left - 7 Days, Middle - 14 Days, Right - 28 Days

Figure 5.7 – 10% Sample Fracture Patterns, Left - 7 Days, Middle - 14 Days, Right - 28 Days

Figure 5.8 – 20% Sample Fracture Patterns, Left - 7 Days, Middle - 14 Days, Right - 28 Days

Figure 5.9 – 30% Sample Fracture Patterns, Left - 7 Days, Middle - 14 Days, Right - 28 Days

Table 5.3 – Compressive Strengths Over Time

	Compressive Strength (MPa)				
	7	14	28	56	Pass/Fail
Control	39.67	44.17	52.17	55.5	Pass
10% Pond Ash	37.83	41.5	47.17	52.33	Pass
20% Pond Ash	32.5	39.83	45.17	52.17	Pass
30% Pond Ash	22.67	31.17	34.33	43.33	Fail

From Table 5.3 and Figure 5.10 compressive strength results can be seen to reduce with the substitution of pond ash for cement. The target compressive strength for all batches was 40 MPa at 28 days. The 30% pond ash replacement batch is the only batch that failed at 28 day testing falling short by over 5 MPa. A severe strength reduction can be seen with the 30% replacement of cement with pond ash which is consistent with the literature.

The 30% pond ash samples only achieved 85.8% of the target strength at 28 days and was separated by a large gap between the results for 20% pond ash samples.

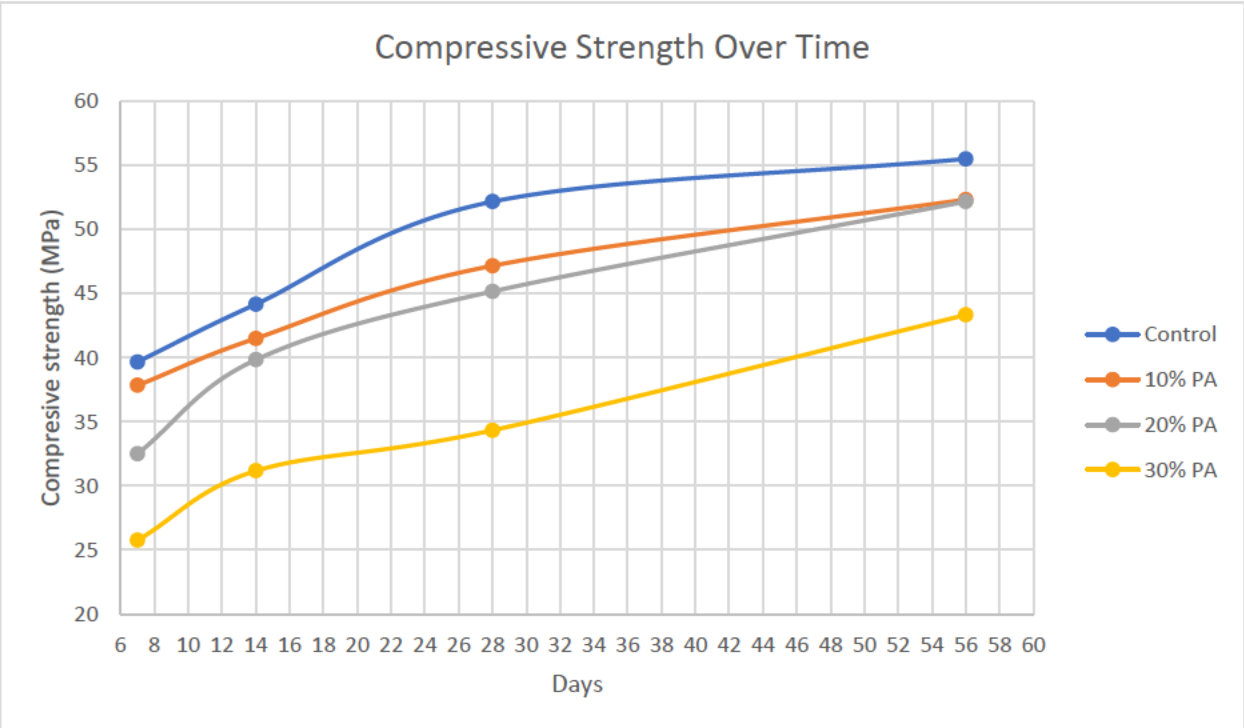


Figure 5.10 – Compressive Strength Over Time

A low initial strength can be seen in the 20% and 30% samples which mirrors the slow pozzolanic reaction of fly ash leading to lower than expected early strength as mentioned in Section 2.21.

It should be noted that the control samples achieved a compressive strength much greater than that of the target strength due to unintended water cement ratio changes. Looking at the difference in control strength to that of the 30% replacement samples provides a more comparable picture. The 30% replacements only achieved 65.8% of the 28 day compressive strength of the control. The compressive strengths as a ratio of the control can be used to investigate the behaviour of pond ash as an SCM relative to an adjusted benchmark. This comparison with an adjusted benchmark can be seen in Table 5.4 below where the values are changed to reflect if the control achieved 40 MPa at 28 days.

Table 5.4 – Adjusted Compressive Strengths for Comparison.

	Ratio to control at 28 days	Adjusted Compressive Strength (MPa)
Control	1.000	40
10% Pond Ash	0.904	36.17
20% Pond Ash	0.866	34.63
30% Pond Ash	0.658	26.33

The mix design used during casting was designed slightly over strength as a precaution to avoid costly rectifications on site if the cylinders fail the 28 day strength. This permits for some deviation which allowed the 10 and 20 percent replacement samples to pass the 28 day testing. The results for the 56 day testing will demonstrate the strength gain past this time which will demonstrate if the test samples will reach that of the control at 28 days.

The 10% replacement results are closer to the 20% replacement results than that of the control. This difference between the testing results and those discussed in the literature may be due to the varied range of densities in the 10% samples compared to those in the control and the 20% replacement samples as discussed in Section 5.2.

When looking at the 56 day results, it can be see that there is strength growth beyond the typical 28 day testing. This pozzolanic behaviour enables the 20% replacement to achieve the same strength as the 10% replacement at 56 days. This delayed strength may not be desired if structures are required to be loaded quickly after pour.

Given the compressive results above, the addition of Millmerran Pond Ash as an SCM in concrete appears feasible up to 10% without major loss in workability and up to 20% with some addition of a plasticizer or similar additive required to aid in workability. The cost benefit of the addition of plasticizer to the increased use of the pond ash will need to be investigated further. Further testing needs to be conducted to confirm the required mix designs to use pond ash effectively as an SCM and to narrow into the most efficient replacement percentage.

5.4 Flexural Testing

At failure of the flexural testing specimens, the crack location was recorded in reference to the middle of the beam and to the closest third point. Similar to the compressive testing the load at failure was recorded and input into Construction Sciences program to calculate the accurate strength values. These results in report format can be seen in Appendix C. In addition to Construction Sciences reporting, the loads and measurements were also input into a spreadsheet created using Equation 3.2 for verification. The spreadsheet calculations can be found in Appendix D.

Using the compressive results from the previous section, the flexural tensile strength can be estimated to provide a guide for the flexural strength of the samples. The estimated flexural tensile strengths calculated using Equation 3.3 can be found in Table 5.5 below. The modulus of rupture is typically higher than flexural tensile strength for the same concrete mix and so the below values should be used as a guide for change in percent Strength that can be expected (Cement Concrete & Aggregates Australia 2020b).

Table 5.5 – Estimated Flexural Tensile Strength.

	Estimated Flexural Tensile Strengths (MPa)	% Strength of Control
Control	4.33	100%
10% Pond Ash	4.12	95.1%
20% Pond Ash	4.03	93.0%
30% Pond Ash	3.52	81.1%

Table 5.6 – Modulus of Rupture Test Results.

	Modulus of Rupture (MPa)	% Strength of Control
Control	7.55	100.0%
10% Pond Ash	7.05	93.4%
20% Pond Ash	7.0245	93.0%
30% Pond Ash	5.7	75.5%

The results from the flexural strength testing are used to find the Modulus of rupture values utilizing Equation 3.2. A summary of the results can be found in Table 5.6 along with the percentage change compared to that of the control.

The modulus of rupture results decreases with the addition of the pond ash as expected and discussed in the literature review section. When comparing the results for the pond ash modified samples to the control, a minor decrease can be found for the 10 and 20 percent replacement samples with a larger gap for the 30% replacement. This behaviour is reflective of the compressive testing results. However, when compared to the theoretical change from Table 5.5, the difference in flexural strength between the control and 30% sample is lower than expected. It was estimated the flexural strength be 81.1% of the control but, only achieved 75.5% through testing. Another small dip was noted at 10% replacement but was not below that of the 20% and may be attributed to varied range of densities for the 10% replacement batch discussed above. The results can be seen with the estimated trend plotted alongside in Figure 5.11.

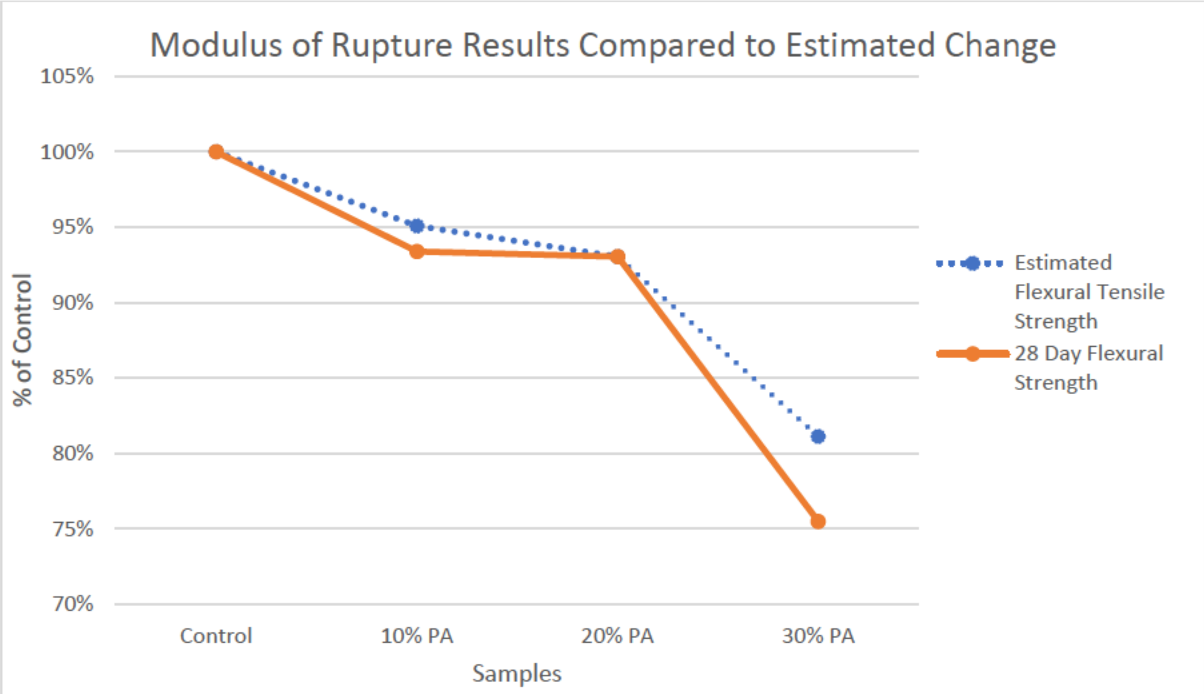


Figure 5.11 – Modulus of Rupture Results Compared to Estimated Change from Control

The samples across all batches fractured within the middle third as required by the testing criteria. Both control and 30% samples fractured within 5mm the centre line yet showed different fracture behaviour. Upon review of the fractures samples, the aggregate adhesion rate differed from the control sample as the higher percentage of pond ash was added with the largest jump from the 20% to the 30% replacement samples.

The cross-section of the control and 30% pond ash samples are shown in Figures 5.12 and 5.13 respectively. The cross-section images are marked where the aggregate has been fractured in green and where the aggregate bond has failed in red.

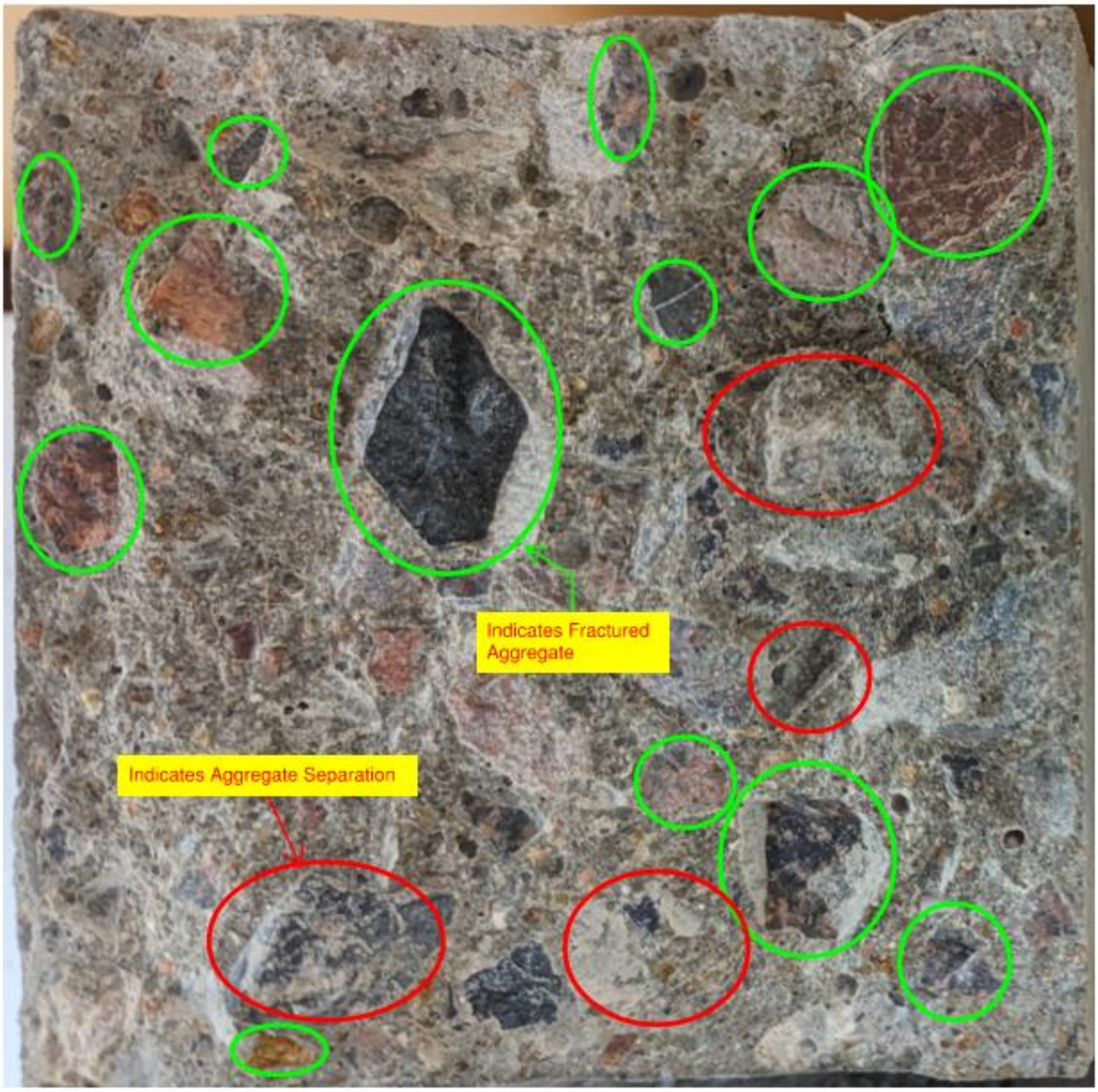


Figure 5.12 – Cross Section of Fractured Control Sample

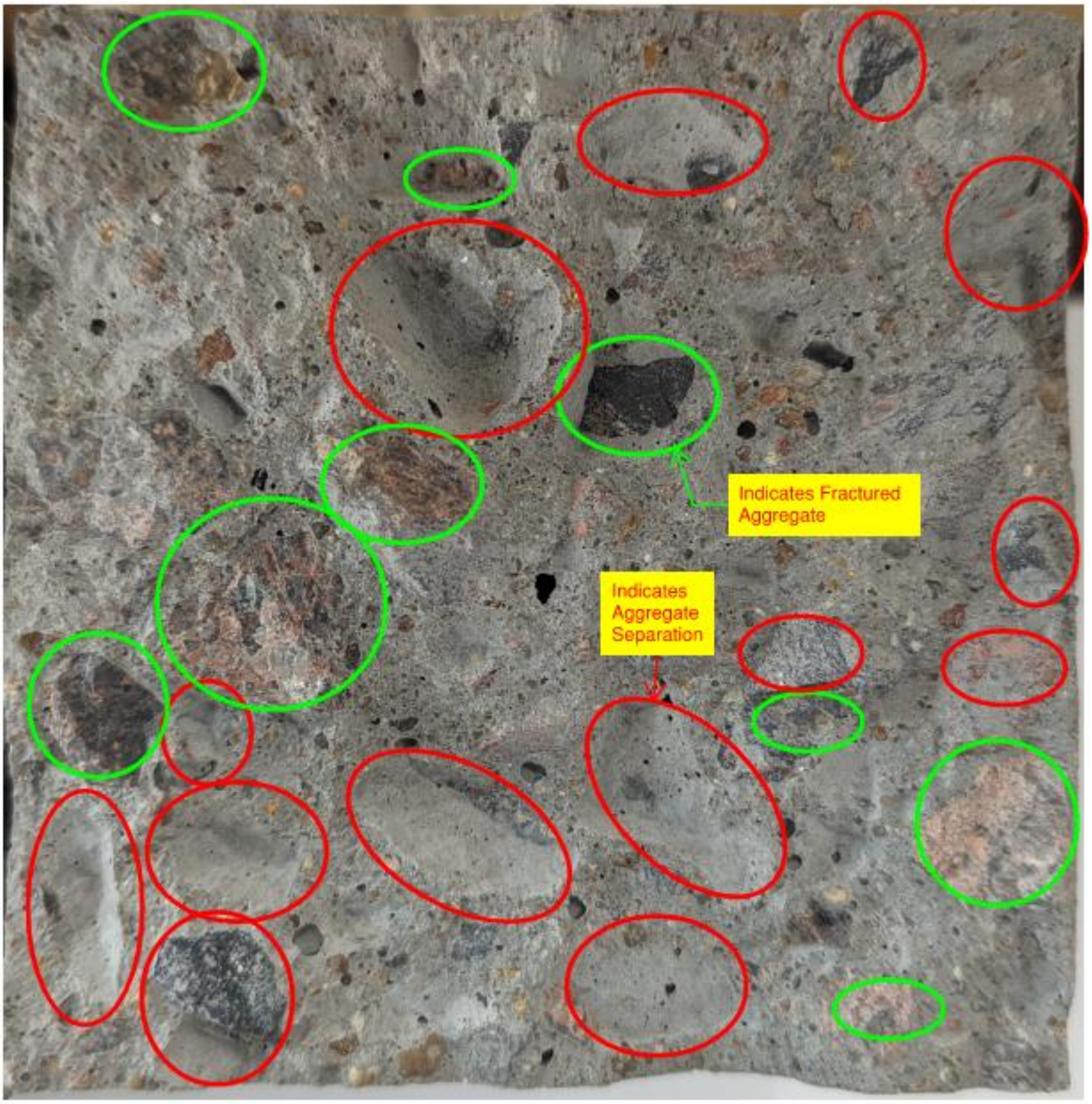


Figure 5.13 – Cross Section of Fractured 30% Replacment Sample

Whether the aggregate has de-bonded, or the crack has propagated through the aggregate indicates the apparent strength and effectiveness of the bond between the cement matrix and the aggregate (Kozul & Darwin 1997). Where the aggregate bond is strong, the cracks will travel through the aggregate particle aiding in strength, predictable load transfer and load distribution.

From the figures above, the rate of aggregate fracture in the control sample is much greater that that shown for the 30% pond ash replacement sample. The high presence of aggregate bonding in the control sample suggests that the bond between the cement matrix and the aggregate particles is strong, which is reflected through the testing results. The 30% pond ash sample has a much higher rate of aggregate separation at the matrix/aggregate interface compared to the other samples including the 20% replacement samples which has a similar workability. It should also be noted that Figure 5.13 shows the internal voids within the test specimen. Similar voids can be found within the 20% test specimen also, indicating the voids are not playing as larger a role compared to the aggregate bonding behaviour.

The feasibility of using Millmerran Pond Ash as an SCM in concrete based on the flexural testing shows promise up to 20% matching the predicted change in the estimated flexural tensile strength as expected calculated from the Australian standard. The results indicate a weakening of the bond of the binder matrix to the aggregate which may be caused by unreacted pond ash at the interface as can be found with fly ash (Hosseini & Bagheri 2021). This weakened bond could cause significant issues in use in infrastructure.

If cracks were to occur, they will be more likely to propagate through the concrete using the weaker bonds as a passing point. This will decrease the concrete strength and could permit moisture ingress, allowing reinforcement to corrode, or allowing efflorescence to occur prematurely. This weakened bonding behaviour could also infer that the development lengths for reinforcement currently used in the construction industry may not be adequate. Further research would be required to investigate the behaviour of these aggregate bonds at the higher replacement percentages to ensure consistent results and failure mechanisms.

CHAPTER 6. CONCLUSIONS

6.1. Conclusions and Project Outcomes

The research and testing conducted has investigated the use of Millmerran Pond Ash as an SCM in concrete in terms of evaluating the feasibility of its use. The practical experimentation aspect of this research focused on the compressive and flexural mechanical properties of pond ash modified concrete as well as considering its workability and practical use. The following conclusions summarize the key outcomes of the research:

- The addition of pond ash decreases the workability of the concrete mix. This is extremely evident with replacement percentages of 20% and over. With a replacement on only 10% pond ash only a minor decrease in workability was found which may be acceptable in some construction applications. The cost benefit of the addition of plasticizer to the increased use of the pond ash will need to be investigated further.

- The 56 day testing shows that there is significant strength growth after the traditional 28 day testing. This late strength development may be able to be considered in future use with considerable research and conditions around the loading after pour. This delayed strength may not be desired if structures are required to be loaded quickly after pour as this would delay project timelines.

- The decrease in workability came with the addition of voids within the cured concrete. This was found to be largely aesthetic but did bring some variability into the resultant densities in the 30% pond ash mix. This variability in density may have affected the flexural testing results with both the 10% replacement (which showed some variance in density recordings) and the 30% replacement showing lower than expected flexural strengths. These results were consistent with the magnitude the densities varied. Further research is required to confirm this behaviour.

- Compressive testing results indicated that the compressive strength reduced as the percentage of pond ash increased with a major reduction at the 30% pond ash replacement.

- The mix design used was over strength due to the change in water cement ratio from unforeseen circumstances. This high strength control base design aided in the 10 and 20 percent pond ash replacement mixes to pass the 28 day testing requirements.

- The reduction in compressive strength of the 10% and 20% batches was only 90% and 86.6% of the control strength respectively. This reduction will need to be considered if the mix design is altered to bring the compressive strength closer to the target strength.

- Similar to the compressive strength results, flexural strength exhibited a decreasing trend with a higher pond ash replacement percentage once again seeing the biggest change in the 30% replacement samples.

- The flexural strength of the 10% and 20% pond ash batches closely reflected the estimated values calculated from the compressive test results as per AS3600:2018. However, the 30% replacement dipped significantly below the estimated trend. The difference in failure mode of the 30% replacement beams was due to insufficient aggregate bonding.

- The cost difference could not be determined due to time restraints and lack of clear information on the future price of pond ash once commercialised.

The key outcomes from this project have shown that the use of Millmerran Pond Ash as an SCM in concrete is feasible. The research would suggest that a replacement percentage of less than 20% would be possible and may need some workability additives such as super plasticizer to achieve the required workability.

The work undertaken in this project has been able to enrich the body of knowledge around the use of coal combustion products in construction, specifically pond ash as an SCM in concrete and its potential failure mechanisms. It is hoped that this will aid in sustainability advancements and resource conservation as an alternate solution which may act to provide cost savings in the future as demand continues to increase.

6.2. Recommendations and Further Research

- Analysis will need to be undertaken to determine if the ecological and financial benefits outweigh the cost of processing the ash for use in concrete.

- Further analysis of the Millmerran Pond Ash properties is being carried out by The University of Southern Queensland to determine if the qualities align with the current standards such as AS/NZS 35823.1:2016 for supplementary cementitious materials and what grade it may fall into. LOI testing should also be carried out to rule out if this is what is causing the high loss in workability.

- The use of super plasticiser should be investigated to improve the workability while maintaining the water cement ratio of the mix. The water absorption rate of the pond ash is to be investigated to determine a correction factor for the mix design.

- Further testing should be conducted with high slump mix designs to determine the overall effect of pond ash to the wet properties of concrete regarding its workability and potential voids.

- Testing will need to be undertaken to narrow down the optimal replacement percentage for differing pond ash types. This includes testing a range of concrete strengths to determine if the behaviour is consistent in both ordinary and high strength concrete applications. It is strongly encouraged that further testing with a large sample size is conducted to expand the data pool.

- Further flexural testing needs to be undertaken to expand the sample size to ensure the results are repeatable. The testing carried out within this research was limited by time and resources so only two flexural beams were tested for each replacement ratio.

- Investigation is required to determine the cause of the aggregate bonding failure difference found from the flexural testing. This would include detailed imagery of the interface of the cementitious matrix and the aggregate to determine if unreacted ash is present.

- Further dedicated tensile testing is required to be undertaken to provide an accurate picture on the tensile properties and failure mechanisms.

- Investigations will need to be conducted to determine the best economic process to prepare the pond ash on a large scale to prepare for use in the industry.

- The toxicology of the pash in the concrete will need to be looked into to determine safe levels and if any of the toxins will leak out of the concrete.

- Durability and life cycle testing should be conducted to ensure adverse consequences are avoided. Especially if voids within the concrete remain present.

As indicated in the literature review, the properties of pond ash vary greatly depending on the source. Continued study across possible pond ash sources will be required to form a full picture on the requirements for detailed future design and use. These recommendations were derived from the research undertaken as part of this project. It should not be seen as a complete list of future aspects of research.

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APPENDIX A – PROJECT SPECIFICATION

ENG4111/4112 Research Project

Project Specification

For: Jack Knight

Title: Feasibility of partial replacement of cement with ground harvested ash

Major: Civil Engineering

Supervisors: Weena Lokuge

Enrolment: ENG4111 – EXT S1, 2023

ENG4112 – EXT S2, 2023

Project Aim: To investigate the feasibility of pond ash as a partial replacement of cement by testing the mechanical properties of different replacement percentages.

Time permitting, this research also aims to compare the cost of ordinary concrete and pond ash modified concrete if the data is available for the pond ash.

Programme: Version 1, 14th March 2023

1. Conduct Literature review of ground harvested pond ash and its general properties relating to its potential pozzolanic properties. Determine an appropriate range of replacement percentages of pond ash.
2. Review concrete testing techniques and prepare a methodology of testing.
3. Prepare and cast testing samples for testing the mechanical properties of pond ash modified concrete. Conduct experimental program.
4. Analyse the test data to determine an appropriate compressive strength value for each replacement percentage and evaluate the results to identify any trends or relationships. Evaluate the most successful percentage of replacement and compare its properties to that of ordinary concrete. Evaluate the test results and the feasibility of partially replacing cement with ground harvested ash.
5. Complete and submit finalized dissertation on the feasibility of the partial replacement of cement with ground harvested ash.

If time and resource permit:

1. Compare costings of ordinary concrete and pond ash modified concrete.

APPENDIX B – RISK ASSESSMENT AND SAFTEY DATA SHEETS

Safety Risk Management Plan			
Assessment Title:	Research Project Risk Assessment	Assessment Date:	19/04/2023
Workplace [Division/Faculty/Section]:	ENG4111/2 - Faculty of Health, Engineering and Sciences	Review Date:[5 Years Max]	24/05/2023
Context			
Description:			
What is the task/event/purchase/project/procedure?	Mixing, pouring samples, and mechanical testing of concrete samples		
Why is it being conducted?	To record data about characteristics of concrete samples		
Where is it being conducted?	Construction Sciences Townsville, Carmel Street, Garbutt QLD		
Course code [if applicable]	ENG4111 – EXT S1, 2023 & ENG4112 – EXT S2, 2023	Chemical name [if applicable]	Not applicable
What other nominal conditions?			
Personnel involved	Jack Knight		
Equipment	Concrete mixer, Cone for slump testing, cylinder forms, Mixing materials, Shovel, compressive testing machine		
Environment	Concrete testing lab		
Briefly explain the procedure/process	Mix concrete samples then let set for 28 days. Return for compressive testing and record results		
Assessment Team - who is conducting the assessment?			
Assessor[s]	Jack Knight		
Others consulted:	Weena Lokuge		

Eg 1. Enter Consequence

Eg 2. Enter Probability

Eg 3. Find Action

	Consequence				
Probability	**Insignificant** No Injury 0-$5K	**Minor** First Aid $5K-$50K	**Moderate** Med Treatment $50K-$100K	**Major** Serious Injuries $100K-$250K	**Catastrophic** Death More than $250K
Almost Certain 1 in 2	M	H	E	E	E
Likely 1 in 100	M	H	H	E	E
Possible 1 in 1000	L	M	H	H	H
Unlikely 1 in 10 000	L	L	M	M	M
Rare 1 in 1 000 000	L	L	L	L	L

Recommended Action Guide
E=Extreme Risk – Task ***MUST NOT*** proceed
H=High Risk – Special Procedures Required (See USQSafe)
M=Moderate Risk – Risk Management Plan/Work Method Statement Required
L=Low Risk – Use Routine Procedures

UniSQ Project risk assessment graph

Step 1 [cont]	Step 2	Step 2a	Step 2b	Step 3			Step 4				
Hazards: From step 1 or more if identified	*The Risk:* What can happen if exposed to the hazard without existing controls in place?	*Consequence:* What is the harm that can be caused by the hazard without existing controls in place?	*Existing Controls:* What are the existing controls that are already in place?	*Risk Assessment:* Consequence x Probability = Risk Level			*Additional controls:* Enter additional controls if required to reduce the risk level	*Risk assessment with additional controls:*			
				Probability	**Risk Level**	**ALARP? Yes/no**		**Consequence**	**Probability**	**Risk Level**	**ALARP? Yes/no**
Example											
Working in temperatures over 35^0 C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	catastrophic	Regular breaks, chilled water available, loose clothing, fatigue management policy.	possible	high	No	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
Concrete dust	Inhalation of dust causing damage to lungs	Minor	Face mask and safety glasses	Unlikely	Low	Yes		Select a consequence	Select a probability	Select a Risk Level	Yes or No
Dropping Heavy Items	Crush damage to fingers and feet	Minor	Saftey boots, gloves	Unlikely	Low	Yes		Select a consequence	Select a probability	Select a Risk Level	Yes or No
Concrete mixer	Getting limbs caught in the mixer	Moderate	No loose clothing, emergency shut off button	Unlikely	Moderate	No	more than one person able to turn off mixer	Moderate	Rare	Low	Yes
Electrical chords	Electrocution from faulty wires	Catastrophic	Regular industry checks of electrical equipment	Unlikely	Moderate	No	Check of all electrical chords quality prior to start	Catastrophic	Rare	Low	Yes
Concrete splash	Concrete splash into eye leading to injury	Moderate	Protective eyeware and clothing	Rare	Low	Yes		Select a consequence	Select a probability	Select a Risk Level	Yes or No
shatering and flying concrete shards	concrete debris hits eye or other sensitive area	Moderate	Debris Proof Cover engaged while in use	Rare	Low	Yes		Select a consequence	Select a probability	Select a Risk Level	Yes or No
Compressive testing machine	Crushed body part in compresive testing machine	Minor	Debris Proof Cover engaged while in use so not able to place body parts into machine while running	Rare	Low	Yes		Select a consequence	Select a probability	Select a Risk Level	Yes or No
Sharp edges	Cut or lacerate on concrete sample	Moderate	Wear safety gloves when handling concrete samples	Unlikely	Moderate	Yes		Select a consequence	Select a probability	Select a Risk Level	Yes or No
Loud Noise	Damage to hearing	Moderate	Wear hearing protection	Rare	Low	Yes		Select a consequence	Select a probability	Select a Risk Level	Yes or No

Step 1 [cont]	Step 2	Step 2a	Step 2b	Step 3			Step 4				
Hazards: From step 1 or more if identified	*The Risk:* What can happen if exposed to the hazard without existing controls in place?	*Consequence:* What is the harm that can be caused by the hazard without existing controls in place?	*Existing Controls:* What are the existing controls that are already in place?	*Risk Assessment:* Consequence x Probability = Risk Level			*Additional controls:* Enter additional controls if required to reduce the risk level	*Risk assessment with additional controls:*			
				Probability	**Risk Level**	**ALARP? Yes/no**		**Consequence**	**Probability**	**Risk Level**	**ALARP? Yes/no**
Example											
Working in temperatures over 35^0 C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	catastrophic	Regular breaks, chilled water available, loose clothing, fatigue management policy.	possible	high	No	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
Technician practices	Poor practises by unerxpirieces Technician	Moderate	Technician has been trained in correct operation of compression machines by senior staff or has suitable level of supervision. Technicians must be 'fit for work' before beginning the task.	Possible	High	Yes		Select a consequence	Select a probability	Select a Risk Level	Yes or No
Debris on the floor	Tripping or slipping creating a fall hazzard	Moderate	Continually sweep throughout the day and Clean concrete work station thoroughly at the end of every day	Unlikely	Moderate	Yes		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Insignificant		Rare	Low	Yes		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Insignificant		Rare	Low	Yes		Select a consequence	Select a probability	Select a Risk Level	Yes or No

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Job Safety Analysis (JSA)

Use this template to record your JSA after analysing a particular task in your workplace. For details see our *Process for developing Job Safety Analysis.*

Task: Compressive Concrete Testing

Safety risks: Slip/trip/fall, Noise, Manual Handling, Crush, Projectile Hazards

You must wear this personal protective equipment when doing this task:

							
☒ Safety Shoes	☒Protective Eyewear	☒Protective Gloves	☒Hearing Protection	☐Respirator	☐ Face shield	☐ Hair tidied back	

Pre-Operational Safety Checks

- ✓ Technician has been trained in correct operation of compression machines by senior staff or has suitable level of supervision.
- ✓ Visually inspect machines for damage before operating daily, is 'equipment fit for use'
- ✓ Ensure the plastic protective flap located at the rear of the compression machines are in place.
- ✓ Technicians must be 'fit for work' before beginning the task.

Operational Requirements

- ✓ Start machines. Check settings and complete pace rate checks on first tests to ensure machines are operating correctly.

DO

- ✓ Ensure concrete cylinders are stacked on trolleys in a way that doesn't create a crush hazard or they can be knocked off.
- ✓ Test all high MPA concrete cylinders in machine located furthest away from computer and balance.
- ✓ Wear hearing protection (when crushing high MPA concrete)
- ✓ Ensure front access door is closed/locked during every test.
- ✓ Ensure concrete waste segregated and disposed of into correct industrial waste bins.

DON'T

- ✓ Do not use faulty equipment. Immediately report suspect machinery.
- ✓ Do not throw concrete cylinders (place crushed cylinders carefully in bins)
- ✓ Do not over fill the lab bin. Empty once filled to ¾ mark. (Two man push if necessary)

Housekeeping

- ✓ Monitor debris from crushed samples do not create a slip, trip or fall hazard (continually sweep throughout the day).
- ✓ Clean out concrete machines between each test.
- ✓ Monitor location of trolleys and bins so they do not block walkways and emergency exits at any stage.
- ✓ Clean concrete work station thoroughly at the end of every day.

Safe work procedure approved by:

Wesley Barrie	[redacted]	09/02/2023
Manager's name	Manager's signature	Date

This Job Safe Analysis does not necessarily cover all possible hazards associated with the machine and should be used in conjunction with other references it is designed to be used as an adjunct to safety documentation and to act as a reminder to users prior to machine use.

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EVERY JOB. EVERY DAY

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Safe Operating Procedure (SOP)

SOP No.: SOP-Concrete Crush

Use this template to record a SOP after conducting a risk assessment of equipment or task in your workplace.

Task: Compressive Concrete Testing

Safety Risks: Slip/trip/fall, Noise, Manual Handling, Crush, Projectile Hazards

You must wear this personal protective equipment when doing this task:

☒ Safety Shoes	☒ Protective Eyewear	☒ Protective Gloves	☒ Hearing Protection	☐ Respirator	☐ Face shield	☐ Hair tidied back

PRE-OPERATIONAL SAFETY CHECKS

✓ Technician has been trained in correct operation of compression machines by senior staff or has suitable level of supervision.

✓ Visually inspect machines for damage before operating daily, is 'equipment fit for use'

✓ Ensure the plastic protective flap located at the rear of the compression machines are in place.

✓ Technicians must be 'fit for work' before beginning the task.

OPERATIONAL REQUIREMENTS

✓ Start machines. Check settings and complete pace rate checks on first tests to ensure machines are operating correctly.

DO

✓ Ensure concrete cylinders are stacked on trolleys in a way that doesn't create a crush hazard or they can be knocked off.

✓ Test all high MPA concrete cylinders in machine CF1 and stand clear.

✓ Wear hearing protection (when crushing high MPA concrete)

✓ Ensure front access door is closed/locked during every test.

✓ Ensure concrete waste segregated and disposed of into correct industrial waste bins.

DON'T

✓ Do not use faulty equipment. Immediately report suspect machinery.

✓ Do not throw concrete cylinders (place crushed cylinders carefully in bins)

✓ Do not over fill the lab bin. Empty once filled to ¾ mark. (Two man push if necessary)

HOUSEKEEPING

✓ Monitor debris from crushed samples do not create a slip, trip or fall hazard (continually sweep throughout the day).

✓ Clean out concrete machines between each test.

✓ Monitor location of trolleys and bins so they do not block walkways and emergency exits at any stage.

✓ Clean concrete work station thoroughly at the end of every day.

SOP approved by:

Manager's name	Manager's signature	Date
Mitchell Simpson	[redacted]	15/04/2021

APPENDIX C – TESTING REPORTS

Construction Sciences

Construction Sciences Pty Ltd
ABN: 74 128 806 735

Address:
37 Carmel Street,
Garbutt QLD 4814

Laboratory: **Townsville Laboratory**
Phone: 07 4426 8100
Fax: 07 4728 8024
Email: Townsville@constructionsciences.net

CONCRETE SAMPLING REPORT

Client:	Construction Sciences - Townsville	Report Number:	10599/R/173364-1
Client Address:	[redacted]	Project Number:	10606/P/158
Project:	QAA, Proficiency & Infrequent Tests	Lot Number:	
Location:	Townsville	Internal Test Request:	10599/T/75001
Supplied To:	n/a	Client Reference/s:	Thesis Trail Pours
Area Description:	Townsville Lab	Report Date / Page:	3/08/2023 Page 1 of 1

Supplied To:	n/a	Concrete Plant Code:		Concrete Mix Code:	
Concrete Supplier:	Not Supplied	Nom. Slump / Tol (mm)	80 / +/-15	Date Sampled / Cast:	25/07/2023
Concrete Class:	40/20/80	Agg. Corr. Factor (%):	-	Sampled By:	Wesley Barrie
Specified Strength (MPa)	40.0	Air Cont. Comp Method:	-	Weather:	Fine
Structure:	Trail 1 & 2			Construction Element:	-

Test Procedures:	AS1012.1, AS1012.1 (Sect 6a), AS1012.3.1, AS1012.8.1 (7.3), AS1012.8.2 (7.3)	Sampling Method / Location:	AS1012.1 (7.2.1) / Central Mixer

Batch Sample Code / Batch Number	Load (m³) / Prog. Tot. (m³)	Batch Time / Samp. Time	Air Temp (°C) / Con Temp (°C)	Air Content (%)	Slump (mm)	Comp. Index	Density (kg/m³)	Comp. Index	Cylinder Sample Numbers (Test Age) / Flex Beam Sample Numbers (Test Age)
10599/C/420500	-	14:30	24		35	-			C/420501(7 days), C/420502(7 days), C/420503(7 days), C/420504(14 days), C/420505(14 days), C/420506(14 days), C/420507(28 days), C/420508(28 days), C/420509(28 days), C/420510(56 days), C/420511(56 days), C/420512(56 days)
Trail 1	-	14:40	24			-			C/420526(28 days), C/420527(28 days)
10599/C/420513	-	15:15	24		40	-			C/420514(7 days), C/420515(7 days), C/420516(7 days), C/420517(14 days), C/420518(14 days), C/420519(14 days), C/420520(28 days), C/420521(28 days), C/420522(28 days), C/420523(56 days), C/420524(56 days), C/420525(56 days)
Trail 2	-	15:25	24			-			C/420528(28 days), C/420529(28 days)

Remarks

NATA

Accredited for compliance with ISO/IEC 17025 – Testing

Accreditation Number: 1986
Corporate Site Number: 10599

[redacted]

Approved Signatory: Wesley Barrie
Form ID: W1Rep Rev 1

Construction Sciences

Construction Sciences Pty Ltd
ABN: 74 128 806 735

Address:
37 Carmel Street,
Garbutt QLD 4814

Laboratory: Townsville Laboratory
Phone: 07 4426 8100
Fax: 07 4728 8024
Email: Townsville@constructionsciences.net

CONCRETE SAMPLING REPORT

Client:	Construction Sciences - Townsville	Report Number:	10599/R/173366-1
Client Address:	[redacted]	Project Number:	10606/P/158
Project:	QAA, Proficiency & Infrequent Tests	Lot Number:	
Location:	Townsville	Internal Test Request:	10599/T/75029
Supplied To:	n/a	Client Reference/s:	Thesis Trial pour- day 2
Area Description:	Townsville Lab	Report Date / Page:	3/08/2023 Page 1 of 1

Supplied To:	n/a	Concrete Plant Code:	N/A	Concrete Mix Code:	N20
Concrete Supplier:	Not Supplied	Nom. Slump / Tol (mm)	90 / +/-20	Date Sampled / Cast:	26/07/2023
Concrete Class:	40/20/90	Agg. Corr. Factor (%):	-	Sampled By:	Luke Kingston
Specified Strength (MPa)	-	Air Cont. Comp Method:	-	Weather:	Fine
Structure:	Trial			Construction Element:	-

Test Procedures:	AS1012.1, AS1012.1 (Sect 6a), AS1012.3.1, AS1012.8.1 (7.3), AS1012.8.2 (7.3)	Sampling Method / Location:	AS1012.1 (7.2.1) / Central Mixer

Batch Sample Code	Load (m³)	Batch Time	Air Temp (°C)	Air Content	Slump	Comp.	Density	Comp.	Cylinder Sample Numbers (Test Age)
Batch Number	Prog. Tot. (m³)	Samp. Time	Con Temp (°C)	(%)	(mm)	Index	(kg/m³)	Index	Flex Beam Sample Numbers (Test Age)
10599/C/420690	-	14:20	25		15	-			C/420691(7 days), C/420692(7 days), C/420693(7 days), C/420694(14 days), C/420695(14 days), C/420696(14 days), C/420697(28 days), C/420698(28 days), C/420699(28 days), C/420700(56 days), C/420701(56 days), C/420702(56 days)
Trial 3	-	14:30	25			-			C/420723(28 days), C/420724(28 days)

Remarks

Accredited for compliance with ISO/IEC 17025 – Testing

NATA

Accreditation Number: 1986
Corporate Site Number: 10599

[redacted]

Approved Signatory: Wesley Barrie
Form ID: W1Rep Rev 1

Construction Sciences

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Email: Townsville@constructionsciences.net

CONCRETE SAMPLING REPORT

Client:	Construction Sciences - Townsville	Report Number:	10599/R/173368-1
Client Address:	[redacted]	Project Number:	10606/P/158
Project:	QAA, Proficiency & Infrequent Tests	Lot Number:	
Location:	Townsville	Internal Test Request:	10599/T/75105
Supplied To:	n/a	Client Reference/s:	Thesis Trial pour- day 3
Area Description:	Townsville LAB	Report Date / Page:	3/08/2023 Page 1 of 1

Supplied To:	n/a	Concrete Plant Code:		Concrete Mix Code:	N20
Concrete Supplier:	Not Supplied	Nom. Slump / Tol (mm)	90 / +/-20	Date Sampled / Cast:	27/07/2023
Concrete Class:	40/20/90	Agg. Corr. Factor (%):	-	Sampled By:	Teao Kelemete
Specified Strength (MPa)	40.0	Air Cont. Comp Method:	-	Weather:	Fine
Structure:	Trial pour			Construction Element:	-

Test Procedures:	AS1012.1, AS1012.1 (Sect 6a), AS1012.3.1, AS1012.8.1 (7.3), AS1012.8.2 (7.3)	Sampling Method / Location:	AS1012.1 (7.2.1) / Central Mixer

Batch Sample Code / Batch Number	Load (m³) / Prog. Tot. (m³)	Batch Time / Samp. Time	Air Temp (°C) / Con Temp (°C)	Air Content (%)	Slump (mm)	Comp. Index	Density (kg/m³)	Comp. Index	Cylinder Sample Numbers (Test Age) / Flex Beam Sample Numbers (Test Age)
10599/C/421098	-	10:55	26		10	-			C/421099(7 days), C/421100(7 days), C/421101(7 days), C/421102(14 days), C/421103(14 days), C/421104(14 days), C/421105(28 days), C/421106(28 days), C/421107(28 days), C/421108(56 days), C/421109(56 days), C/421110(56 days)
Trial 4	-	11:23	23			-			C/421111(28 days), C/421112(28 days)

Remarks

Accredited for compliance with ISO/IEC 17025 – Testing

NATA

Accreditation Number: 1986
Corporate Site Number: 10599

[redacted]

Approved Signatory: Wesley Barrie
Form ID: W1Rep Rev 1

Construction Sciences

Construction Sciences Pty Ltd
ABN: 74 128 806 735

Address:
37 Carmel Street,
Garbutt QLD 4814

Laboratory: Townsville Laboratory
Phone: 07 4426 8100 **Fax:** 07 4728 8024

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

CONCRETE COMPRESSIVE STRENGTH REPORT

Client:	Construction Sciences - Townsville	Concrete Class:	40/20/80	Date Sampled / Cast:	25/07/2023	Report Number:	10599/R/175917-1
Client Address:	[redacted]	Specified Strength (MPa):	40.0	Nom. Slump / Tol (mm):	80 / +/-15	Project Number:	10606/P/158
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	4/10/2023
Project:	QAA, Proficiency & Infrequent Tests	Sampled By:	Wesley Barrie	Air Cont. Comp Method:		Test Request No:	10599/T/75001
Supplier:	Not Supplied	Sampling Location:	Central Mixer	Sampling Method:	AS1012.1 (7.2.1)	Constr. Element:	-
Client Reference/s:	Thesis Trail Pours	Weather:	Fine	Structure/s:	Trail 1 & 2		

Test Procedures: AS1012.1, AS1012.1 (Sect 6a), AS1012.8.1 (7.3), AS1012.3.1, AS1012.9, AS1012.12.1

Component:

Sample No	Batch No	Truck No	Load Size (m³)	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	MPUV (kg/m³)	Comp Strength (MPa)	Test Remarks
10599/C/420501	Trail 1	-	-	14:45	24	35	19	1/08/2023	7 days	6 days - STD	100.4	196	2360	**38.5**	
10599/C/420502	Trail 1	-	-	14:45	24	35	19	1/08/2023	7 days	6 days - STD	99.9	197	2380	**40.5**	
10599/C/420503	Trail 1	-	-	14:45	24	35	19	1/08/2023	7 days	6 days - STD	99.9	197	2380	**40.0**	
10599/C/420504	Trail 1	-	-	14:45	24	35	19	8/08/2023	14 days	13 days - STD	100.6	196	2360	**44.0**	
10599/C/420505	Trail 1	-	-	14:45	24	35	19	8/08/2023	14 days	13 days - STD	100.4	196	2380	**42.0**	
10599/C/420506	Trail 1	-	-	14:45	24	35	19	8/08/2023	14 days	13 days - STD	100.5	196	2380	**46.5**	
10599/C/420507	Trail 1	-	-	14:45	24	35	19	22/08/2023	28 days	27 days - STD	100.6	195	2400	**52.5**	
10599/C/420508	Trail 1	-	-	14:45	24	35	19	22/08/2023	28 days	27 days - STD	100.4	196	2380	**53.0**	
10599/C/420509	Trail 1	-	-	14:45	24	35	19	22/08/2023	28 days	27 days - STD	100.5	195	2380	**50.5**	
10599/C/420510	Trail 1	-	-	14:45	24	35	19	19/09/2023	56 days	55 days - STD	100.3	195	2360	**55.5**	
10599/C/420511	Trail 1	-	-	14:45	24	35	19	19/09/2023	56 days	55 days - STD	100.2	195	2380	**56.5**	
10599/C/420512	Trail 1	-	-	14:45	24	35	19	19/09/2023	56 days	55 days - STD	100.6	196	2380	**54.5**	
10599/C/420514	Trail 2	-	-	15:30	24	40	18	1/08/2023	7 days	6 days - STD	99.9	197	2360	**38.5**	
10599/C/420515	Trail 2	-	-	15:30	24	40	18	1/08/2023	7 days	6 days - STD	99.9	195	2360	**37.5**	
10599/C/420516	Trail 2	-	-	15:30	24	40	18	1/08/2023	7 days	6 days - STD	100.1	196	2360	**37.5**	

Remarks:

Accredited for compliance with ISO/IEC 17025 – Testing

NATA

Accreditation Number: 1986
Corporate Site Number: 10599

[redacted]

Approved Signatory: Wesley Barrie
Form ID: W84TDRep Rev 1

Notes

1: Temperature Zone - Standard Tropical Zone
2: Curing Conditions: STD = Standard Moist Curing, MST = Moist, DRY = Dry
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Website: www.constructionsciences.net

CONCRETE COMPRESSIVE STRENGTH REPORT

Client:	Construction Sciences - Townsville	Concrete Class:	40/20/80	Date Sampled / Cast:	25/07/2023	Report Number:	10599/R/175917-1
Client Address:	[redacted]	Specified Strength (MPa):	40.0	Nom. Slump / Tol (mm):	80 / +/-15	Project Number:	10606/P/158
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	4/10/2023
Project:	QAA, Proficiency & Infrequent Tests	Sampled By:	Wesley Barrie	Air Cont. Comp Method:		Test Request No:	10599/T/75001
Supplier:	Not Supplied	Sampling Location:	Central Mixer	Sampling Method:	AS1012.1 (7.2.1)	Constr. Element:	-
Client Reference/s:	Thesis Trail Pours	Weather:	Fine	Structure/s:	Trail 1 & 2		

10599/C/420517	Trail 2	-	-	15:30	24	40	18	8/08/2023	14 days	13 days - STD	100.6	195	2320	**39.5**	
10599/C/420518	Trail 2	-	-	15:30	24	40	18	8/08/2023	14 days	13 days - STD	100.5	195	2360	**42.5**	
10599/C/420519	Trail 2	-	-	15:30	24	40	18	8/08/2023	14 days	13 days - STD	100.6	196	2340	**42.5**	
10599/C/420520	Trail 2	-	-	15:30	24	40	18	22/08/2023	28 days	27 days - STD	100.7	196	2360	**47.5**	
10599/C/420521	Trail 2	-	-	15:30	24	40	18	22/08/2023	28 days	27 days - STD	100.2	196	2360	**46.0**	
10599/C/420522	Trail 2	-	-	15:30	24	40	18	22/08/2023	28 days	27 days - STD	100.0	196	2360	**48.0**	
10599/C/420523	Trail 2	-	-	15:30	24	40	18	19/09/2023	56 days	55 days - STD	100.4	195	2340	**51.5**	
10599/C/420524	Trail 2	-	-	15:30	24	40	18	19/09/2023	56 days	55 days - STD	100.4	197	2340	**55.0**	
10599/C/420525	Trail 2	-	-	15:30	24	40	18	19/09/2023	56 days	55 days - STD	100.6	195	2360	**50.5**	

Remarks:

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Form ID: W84TDRep Rev 1

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CONCRETE COMPRESSIVE STRENGTH REPORT

Client:	Construction Sciences - Townsville	Concrete Class:	40/20/90	Date Sampled / Cast:	26/07/2023	Report Number:	10599/R/175918-1
Client Address:	[redacted]	Specified Strength (MPa):	-	Nom. Slump / Tol (mm):	90 / +/-20	Project Number:	10606/P/158
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	4/10/2023
Project:	QAA, Proficiency & Infrequent Tests	Sampled By:	Luke Kingston	Air Cont. Comp Method:		Test Request No:	10599/T/75029
Supplier:	Not Supplied	Sampling Location:	Central Mixer	Sampling Method:	AS1012.1 (7.2.1)	Constr. Element:	-
Client Reference/s:	Thesis Trial pour- day 2	Weather:	Fine	Structure/s:	Trial		

Test Procedures: AS1012.1, AS1012.1 (Sect 6a), AS1012.8.1 (7.3), AS1012.3.1, AS1012.9, AS1012.12.1 — Plant Code / Mix Code: N/A / N20

Sample No	Batch No	Truck No	Load Size (m³)	Time Cast	Concrete Temp (°C)	Slump (mm)	Initial Curing (hrs)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Avg Diameter	Height	MPUV (kg/m³)	Comp Strength (MPa)	Test Remarks
10599/C/420691	Trial 3	N/A	-	14:30	25	15	18	2/08/2023	7 days	6 days	100.3	196	2320	**33.5**	
10599/C/420692	Trial 3	N/A	-	14:30	25	15	18	2/08/2023	7 days	6 days	100.2	197	2320	**35.5**	
10599/C/420693	Trial 3	N/A	-	14:30	25	15	18	2/08/2023	7 days	6 days	100.5	197	2320	**30.5**	
10599/C/420694	Trial 3	N/A	-	14:30	25	15	18	9/08/2023	14 days	13 days	100.3	197	2320	**40.0**	
10599/C/420695	Trial 3	N/A	-	14:30	25	15	18	9/08/2023	14 days	13 days	100.4	195	2340	**40.0**	
10599/C/420696	Trial 3	N/A	-	14:30	25	15	18	9/08/2023	14 days	13 days	100.6	196	2320	**39.5**	
10599/C/420697	Trial 3	N/A	-	14:30	25	15	18	23/08/2023	28 days	27 days	100.3	197	2320	**46.0**	
10599/C/420698	Trial 3	N/A	-	14:30	25	15	18	23/08/2023	28 days	27 days	100.5	196	2320	**43.0**	
10599/C/420699	Trial 3	N/A	-	14:30	25	15	18	23/08/2023	28 days	27 days	100.6	196	2320	**46.5**	
10599/C/420700	Trial 3	N/A	-	14:30	25	15	18	20/09/2023	56 days	55 days	100.6	195	2340	**51.5**	
10599/C/420701	Trial 3	N/A	-	14:30	25	15	18	20/09/2023	56 days	55 days	100.3	197	2340	**55.5**	
10599/C/420702	Trial 3	N/A	-	14:30	25	15	18	20/09/2023	56 days	55 days	100.4	197	2320	**49.5**	

Remarks:

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NATA

Accreditation Number: 1986
Corporate Site Number: 10599

[redacted]

Approved Signatory: Wesley Barrie
Form ID: W84TDRep Rev 1

Notes
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Website: www.constructionsciences.net

CONCRETE COMPRESSIVE STRENGTH REPORT

Client:	Construction Sciences - Townsville	Concrete Class:	40/20/90	Date Sampled / Cast:	27/07/2023	Report Number:	10599/R/175919-1
Client Address:	[redacted]	Specified Strength (MPa):	40.0	Nom. Slump / Tol (mm):	90 / +/-20	Project Number:	10606/P/158
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	4/10/2023
Project:	QAA, Proficiency & Infrequent Tests	Sampled By:	Teao Kelemete	Air Cont. Comp Method:		Test Request No:	10599/T/75105
Supplier:	Not Supplied	Sampling Location:	Central Mixer	Sampling Method:	AS1012.1 (7.2.1)	Constr. Element:	-
Client Reference/s:	Thesis Trial pour- day 3	Weather:	Fine	Structure/s:	Trial pour		

Test Procedures: AS1012.1, AS1012.1 (Sect 6a), AS1012.8.1 (7.3), AS1012.3.1, AS1012.9, AS1012.12.1 — Plant Code / Mix Code: - / N20

Sample No	Batch No	Truck No	Load Size (m³)	Time Cast	Concrete Temp (°C)	Slump (mm)	Initial Curing (hrs)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm) Avg Diameter	Height	MPUV (kg/m³)	Comp Strength (MPa)	Test Remarks
10599/C/421099	Trial 4	-	-	11:25	23	10	21	3/08/2023	7 days	6 days - STD	100.4	197	2300	**16.5**	
10599/C/421100	Trial 4	-	-	11:25	23	10	21	3/08/2023	7 days	6 days - STD	100.7	196	2280	**25.5**	
10599/C/421101	Trial 4	-	-	11:25	23	10	21	3/08/2023	7 days	6 days - STD	100.7	196	2280	**26.0**	
10599/C/421102	Trial 4	-	-	11:25	23	10	21	10/08/2023	14 days	13 days - STD	100.5	196	2300	**30.0**	
10599/C/421103	Trial 4	-	-	11:25	23	10	21	10/08/2023	14 days	13 days - STD	100.2	196	2300	**32.0**	
10599/C/421104	Trial 4	-	-	11:25	23	10	21	10/08/2023	14 days	13 days - STD	100.4	196	2320	**31.5**	
10599/C/421105	Trial 4	-	-	11:25	23	10	21	24/08/2023	28 days	27 days - STD	100.5	195	2320	**34.5**	
10599/C/421106	Trial 4	-	-	11:25	23	10	21	24/08/2023	28 days	27 days - STD	100.4	196	2320	**36.0**	
10599/C/421107	Trial 4	-	-	11:25	23	10	21	24/08/2023	28 days	27 days - STD	100.6	196	2300	**32.5**	Shear Failure
10599/C/421108	Trial 4	-	-	11:25	23	10	21	21/09/2023	56 days	55 days - STD	100.6	197	2280	**44.5**	
10599/C/421109	Trial 4	-	-	11:25	23	10	21	21/09/2023	56 days	55 days - STD	100.3	196	2320	**46.5**	
10599/C/421110	Trial 4	-	-	11:25	23	10	21	21/09/2023	56 days	55 days - STD	100.6	196	2320	**39.0**	

Remarks:

Accredited for compliance with ISO/IEC 17025 – Testing

NATA

Accreditation Number: 1986
Corporate Site Number: 10599

[redacted]

Approved Signatory: Wesley Barrie
Form ID: W84TDRep Rev 1

Notes
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Website: www.constructionsciences.net

MODULUS OF RUPTURE REPORT

Client:	Construction Sciences - Townsville	Concrete Class:	40/20/80	Date Sampled / Cast:	25/07/2023	Report Number:	10599/R/174213-1
Client Address:	[redacted]	Specified Strength (MPa):	40.0	Nom. Slump / Tol (mm):	80 / +/-15	Project Number:	10606/P/158
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	22/08/2023
Project:	QAA, Proficiency & Infrequent Tests	Sampled By:	Wesley Barrie	Air Cont. Comp Method:		Test Request No:	10599/T/75001
Supplier:	Not Supplied	Sampling Location:	Central Mixer	Sampling Method:	AS1012.1 (7.2.1)	Constr. Element:	-
Client Reference/s:	Thesis Trail Pours	Weather:	Fine	Structure/s:	Trail 1 & 2		
Test Procedures:	AS1012.1, AS1012.1 (Sect 6a), AS1012.8.2 (7.3), AS1012.3.1, AS1012.11, AS1012.12.1			Component:			

Sample No	Batch No	Time Cast	Slump (mm)	Inital Curing (hours)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm)			Mass per Unit Volume (kg/m³)	Modulus of Rupture (MPa)	Test Remarks
								Width	Depth	Span			
10599/C/420526	Trail 1	14:45	35	19	22/08/2023	28 days	27 days - STD	101.7	100.2	300	2380	**7.0**	
10599/C/420527	Trail 1	14:45	35	19	22/08/2023	28 days	27 days - STD	100.5	100.0	300	2380	**8.1**	
10599/C/420528	Trail 2	15:30	40	18	22/08/2023	28 days	27 days - STD	100.0	100.1	300	2360	**6.7**	
10599/C/420529	Trail 2	15:30	40	18	22/08/2023	28 days	27 days - STD	99.6	100.5	300	2360	**7.4**	

Remarks:

NATA

Accredited for compliance with ISO/IEC 17025 – Testing

Accreditation Number: 1986
Corporate Site Number: 10599

[redacted]

Approved Signatory: Blake Lowis
Form ID: W86Rep Rev 1

Notes
1: Temperature Zone - Standard Tropical Zone
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MODULUS OF RUPTURE REPORT

Client:	Construction Sciences - Townsville	Concrete Class:	40/20/90	Date Sampled / Cast:	26/07/2023	Report Number:	10599/R/174308-1
Client Address:	[redacted]	Specified Strength (MPa):	-	Nom. Slump / Tol (mm):	90 / +/-20	Project Number:	10606/P/158
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	24/08/2023
Project:	QAA, Proficiency & Infrequent Tests	Sampled By:	Luke Kingston	Air Cont. Comp Method:		Test Request No:	10599/T/75029
Supplier:	Not Supplied	Sampling Location:	Central Mixer	Sampling Method:	AS1012.1 (7.2.1)	Constr. Element:	-
Client Reference/s:	Thesis Trial pour- day 2	Weather:	Fine	Structure/s:	Trial		
Test Procedures:	AS1012.1, AS1012.1 (Sect 6a), AS1012.8.2 (7.3), AS1012.3.1, AS1012.11, AS1012.12.1			Plant Code / Mix Code:	N/A / N20		

Sample No	Batch No	Time Cast	Slump (mm)	Inital Curing (hours)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm)			Mass per Unit Volume (kg/m³)	Modulus of Rupture (MPa)	Test Remarks
								Width	Depth	Span			
10599/C/420723	Trial 3	14:30	15	20	23/08/2023	28 days	27 days - STD	100.2	100.0	300	2340	**7.2**	
10599/C/420724	Trial 3	14:30	15	18	23/08/2023	28 days	27 days - STD	99.6	100.1	300	2340	**6.9**	

Remarks:

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Approved Signatory: Blake Lowis
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Notes
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MODULUS OF RUPTURE REPORT

Client:	Construction Sciences - Townsville	Concrete Class:	40/20/90	Date Sampled / Cast:	27/07/2023	Report Number:	10599/R/174307-1
Client Address:	[redacted]	Specified Strength (MPa):	40.0	Nom. Slump / Tol (mm):	90 / +/-20	Project Number:	10606/P/158
Supplied To:	n/a	Lot Number:		Agg. Corr. Factor (%):		Report Date:	24/08/2023
Project:	QAA, Proficiency & Infrequent Tests	Sampled By:	Teao Kelemete	Air Cont. Comp Method:		Test Request No:	10599/T/75105
Supplier:	Not Supplied	Sampling Location:	Central Mixer	Sampling Method:	AS1012.1 (7.2.1)	Constr. Element:	-
Client Reference/s:	Thesis Trial pour- day 3	Weather:	Fine	Structure/s:	Trial pour		
Test Procedures:	AS1012.1, AS1012.1 (Sect 6a), AS1012.8.2 (7.3), AS1012.3.1, AS1012.11, AS1012.12.2			Plant Code / Mix Code:	- / N20		

Sample No	Batch No	Time Cast	Slump (mm)	Inital Curing (hours)	Date of Test	Test Age	Curing Conditions	Specimen Dimensions (mm)			Mass per Unit Volume (kg/m³)	Modulus of Rupture (MPa)	Test Remarks
								Width	Depth	Span			
10599/C/421111	Trial 4	11:25	10	21	24/08/2023	28 days	27 days - STD	100.2	100.1	300	2330	**5.8**	
10599/C/421112	Trial 4	11:25	10	21	24/08/2023	28 days	27 days - STD	100.0	100.2	300	2320	**5.6**	

Remarks:

Accredited for compliance with ISO/IEC 17025 – Testing

NATA

Accreditation Number: 1986
Corporate Site Number: 10599

[redacted]

Approved Signatory: Blake Lowis
Form ID: W86Rep Rev 1

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APPENDIX D – CONSEQUENCES AND ETHICS

The investigation of the feasibility of pond ash as an SCM is an important task that requires consideration of both the consequences and the related ethics. This project looks to improve pollution in the coal combustion industry by removing pond ash from the environment, where is causes detrimental effects to natural habitats and nearby human populations.

As an engineer, it is essential to adhere to the Engineers Australia code of ethics (Engineers Australia 2019), which requires a high level of professionalism, ethical conduct, and responsibility. The code outlines four fundamental principles: honesty, integrity, respect, and accountability.

The use of pond ash as an SCM has numerous potential ecological and economic benefits for sustainability. For instance, it reduces the demand for traditional cement, which reduces the amount of carbon dioxide emissions from cement production and provides an alternate to the ever-increasing demand for fly ash. This reduction in greenhouse gas emissions and cleaning of natural environments helps to combat climate change and environmental degradation.

Using pond ash as a partial replacement for cement can be potentially cost-effective. Additionally, the use of pond ash can result in the creation of new markets for power plant by-products, thereby providing a new revenue stream for power plants. As pond ash may contain heavy metals and other contaminants that could adversely affect human health and the environment, it must be carefully treated and processed ready for use. This processing needs to be undertaken with appropriate quality control testing prior to use in concrete.

The use of pond ash may provide an alternate SCM over fly ash which is experiencing industry shortages in some countries. This alternate SCM could aid in production allowing concrete costs to stay low and availability to remain constant (Infrastructure Australia 2022).