University of Southern Queensland

School of Engineering

Ductility and Cracking Behaviours of Engineered Cementitious Composites

A dissertation submitted by

Blake Neumann

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Abstract

The production of cement contributes approximately 8% of global CO_2 emissions and it is essential that alternative methods of producing construction materials are explored to assist with reducing emissions. An alternative material to conventional concrete is engineered cementitious composites (ECC). ECC are a specific cement mixture which consists of a unique blend of fibres and composites.

ECC currently contains a waste product from coal power plants known as fly ash. Another waste product from coal power plants is bottom ash and if the fly ash and bottom ash are not used, the ash is pumped into large dams/ponds and creates pond ash. This is an environmental hazard as the dams can overflow during excess rainfall and cause the toxic substance to seep into the soil and pollute the surrounding area. This research project investigated if pond ash could be a successful replacement of fly ash in ECC.

The main objective of this research project was to determine if fly ash could be replaced with pond ash in ECC. This was determined by analysing the ductility and cracking behaviours of ECC. This was performed by casting beams with 0%, 25%, 50% and 100% replacement of fly ash with pond ash.

Flexural testing was conducted to investigate the ductility of the samples. It was found that the 0%, 25% and 100% samples all behaved in the same manner after initial cracking and the 25% sample had the greatest ductility index. Crack-mouth opening displacement (CMOD) testing with the use of digital imaging correlation (DIC) technology was conducted to investigate the cracking behaviours of the samples. The results obtained showed that the 25% sample had the optimal post-cracking performance and the residual strength of all the samples, except for the 100% sample were predicted to be the same. Scanning electron microscopy (SEM) imaging was conducted to observe the samples at a microstructural level. The images produced showed that the 25% sample had the optimal microstructural properties.

From the testing conducting, it was confirmed that pond ash is a successful replacement that can be used in ECC; however further research should be conducted to validate the results.

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Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses, and conclusions set out in this dissertation are entirely my own effort, expect 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.

Blake Neumann

Student Number: [redacted]

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Nomenclature

CMOD – Crack Mouth Opening Displacement

DIC – Digital Imagining Correlation

ECC – Engineered Cementitious Composites

PVA – Polyvinyl Alcohol

SEM – Scanning Electron Microscopy

Chapter 1: Introduction

1.1 Background

Concrete is one of the most used engineering materials in today's world. Concrete was invented approximately 200 years ago and since then it has evolved; however it still has the stereotype of being a very brittle material. Conventional concrete is becoming a source of many disasters and faults in our infrastructure and also for the environment from the emissions polluted during the making of concrete (Li 2019, p.7). ECC is believed to be the solution to overcome these challenges as it has enhanced properties and is environmentally sustainable.

ECC are an innovative approach to conventional concrete which have the potential to have many positive affects in the world due to its enhanced mechanical properties and is also environmentally sustainable. By conducting a project on an innovative alternative to conventional concrete, it has potential to have several benefits. Further research into ECC will gather more data and research which will support its use in real world applications. ECC have a huge potential to change the civil infrastructure industry as it offers an alternative solution to conventional concrete which has been used for over 200 years. Further research will only increase the supportiveness of ECC, which is the purpose of this research project.

ECC were developed in the early 1990s by Dr Victor Li, who is a professor of Structural and Materials at the University of Michigan. Dr Li's main purpose of developing ECC was to produce a different form of concrete that was not brittle like conventional concrete and also retained its strength during cracking. ECC application in the real world is growing and still remains unknown to many engineers and designers. However, it is attractive to research due to its ductile performance and enhanced characteristics compared to normal concrete.

ECC are a specific cement mixture which consists of a unique blend of fibres and composites which improve the ductility and tensile strength of concrete and also have the ability to repair concrete (Li 2019, p.102). Standard concrete mixture has a brittle nature and tends to crack easily when a significant load is applied. ECC are a class of fibre reinforced concrete as it contains fibre in a cementitious matrix. As seen in figure 1.1, the microstructural components of ECC are systematically tuned to enable the fibre, matrix, and interface features to interact with one another in a specific manner when the composite is under a load (Li 2019, p.14).

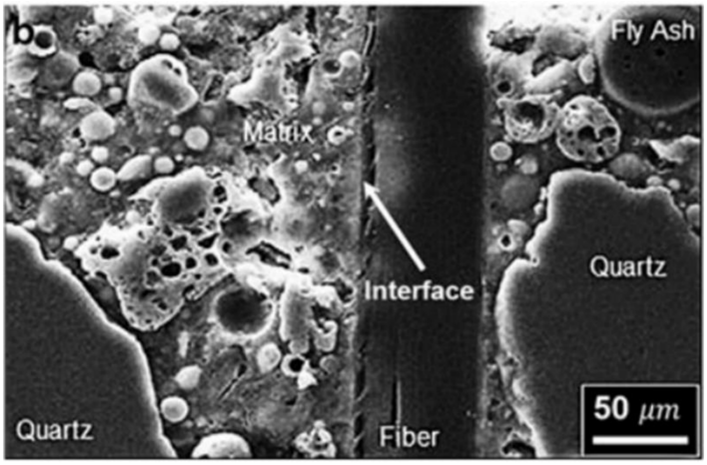

Figure 1.1 ECC Microstructure. Source: (Li 2019, p.15)

Under an applied load, ECC experience a tension-softening behaviour after the presence of cracking, which can be noticed in figure 1.2. When cracking occurs, the crack does not widen as it is autogenously controlled by the composite, compared to conventional concrete which relies on steel reinforcement. ECC have a strain capacity of approximately 3-7% which is significantly greater than ordinary concrete which has a strain capacity of 0.1% (Yuva Engineers 2011). The bending of the concrete is a resemblance of the increased structural durability that ECC enable.

Figure 1.2 ECC Under an Applied Load. Source: (Yuva Engineers 2011)

A large amount of research has already been conducted in regard to ECC and has found that it does have enhanced ductility and cracking behaviours when compared to conventional concrete. The research has also confirmed that the use of ECC has a positive impact on the environment and climate change. However, most of the research conducted involves the use of fly ash in the ECC mixture. Fly ash is a waste product from coal plants and typically occupies a large amount of open land as it is wasted. The previous research has identified that fly ash can successfully be used in ECC, which is positive for the environment and human health.

1.2 The Problem

The production of cement is known to contribute as much as 8% of the global CO_2 emissions. This is an extensive amount of emissions and over the past few decades, extensive research has been conducted to investigate incorporating waste products into concrete mixtures to have a positive impact on the environment and reduce the amount of emissions. However, there are still large amounts of construction related emissions that are present in today's world, and it is important that further research is conducted to investigate how waste products can be incorporated into construction materials to positively impact climate change.

Coal is one of Australia's and the world's largest waste products with approximately 12 million tonnes of coal ash produced each year in Australia. Coal ash consists of fly ash and bottom ash, and if this ash is not used, the ash is pumped into large dams/ponds and creates pond ash.

ECC studies have successfully used fly ash to create a specific concrete mixture to create an alternative to conventional concrete. Fly ash has already been well studied around the world and it is essential that the use of pond ash in ECC is also investigated to reduce the amount of pond ash present at coal power plants.

This research project will focus on replacing fly ash with pond ash and investigate the ductility and cracking behaviours of the ECC to effectively confirm if pond ash is a successful replacement for fly ash.

1.3 Research Objectives

The main objective of this research project is to investigate the ductility and cracking behaviour of ECC when the fly ash is replaced with pond ash. By conducting this research it will hopefully provide information regarding if pond ash can be used in ECC.

The goal of this project is to provide research and data in regard to combatting climate change by using waste products in construction materials. If the objectives of this research project are positive, it could lead to an innovative approach to the construction industry and reduce the negative impacts that construction materials have on the environment and human health.

1.4 Thesis Outline

This dissertation consists of six chapters, as outlined below:

Chapter 1 Introduces the project and provides background knowledge regarding the topic and also identifies the problem and the main objectives of the project.

Chapter 2 Reviews the past research conducted regarding ECC and the research involving other alternatives used in ECC.

Chapter 3 Details the methodology used for this research, explains the outline, assumptions, how the specimens were produced, and the testing involved.

Chapter 4 Explains the tasks undertaken during the experimental investigation, including the mix design, materials, mixing and casting, and the testing.

Chapter 5 Discussing the results obtain from the testing. This involves discussing the fresh concrete properties, ductility, cracking behaviours, and the microstructural properties.

Chapter 6 Concludes the dissertation by summarising the key findings and explains the future research opportunities.

Chapter 2: Literature Review

A literature review has been conducted to investigate and evaluate the current knowledge available regarding ECC. The current available knowledge regarding using pond ash in concrete mixtures will also be investigated. From this, it will be able to identify the knowledge gap and identify the purpose of conducting this research project.

2.1 ECC studies including fly ash

There are several studies that have been conducted regarding using fly ash in ECC. These studies have analysed the ductility and cracking behaviours of ECC. The mechanical properties have also been investigated regarding the matrix bonding. Several studies have also focused on seismic resistance and performance as the use of ECC are becoming desirable in earthquake prone locations. Studies have also been conducted which specifically focus on using high-volume fly ash. These studies are explored further below.

2.1.1 Durability and cracking behaviour of slabs, beams, and columns

Kang et al. (2015) conducted a study that investigated the progressive collapse resistance of a precast beam column which consisted of ECC. The authors main aim of this study was to identify if ECC affected the collapse resistance of a beam. The specimens used in this experiment consisted of a control specimen made from conventional concrete and another five specimens which consisted of ECC. Each beam consisted of different reinforcement. The results showed that the beam which had enhanced properties was one which consisted of ECC. The study proved that ECC had better resistance against collapse properties than conventional concrete.

A study conducted by Nguyen and Lee (2021) analysed the flexural behaviours of ECC. The specimens used for this study consisted of three beams which consisted of ECC. The size of the beams used were fabricated using identical high strength steel I-sections with a thickness of either 140mm or 170mm. The results obtained from the testing showed that the ECC had a slight improvement in flexural capacity. The beam also failed gradually with softening behaviours, whereas the normal concrete beam failed quickly and had a significant drop in bending resistance after the maximum load was applied, which can be noticed in figure 2.1.

Figure 2.1 Comparison of Failure Modes. Source: (Nguyen & Lee 2021)

Another study conducted by Ye et al. (2021) investigated reinforced ECC and reinforced concrete slab column under a vertical monotonic load. The ECC mix design used for this experiment can be seen in table 2.1 below. The main purpose of conducting this study was due to the fact that regular concrete slabs collapse easily because of their brittle nature due to the low tensile strength and high tensile brittleness (Ye et al. 2021). The main factors examined in this research were strain and displacement under an applied load for both the reinforced ECC and reinforced concrete slabs. The results obtained from the study showed that the reinforced ECC specimens had load capacities that were approximately three times greater than the reinforced concrete. This study successfully analysed the strain and displacement characteristics of engineered cementitious composites and confirmed that they could perform better under an applied load than reinforced concrete.

Mixture proportion of high-strength ECC (mass ratio).

No.	Cement	SF	Cenosphere	Sand	Water	W/B	HRWR	Fiber/Vol%
ECC	0.7	0.1	0.2	0.6	0.2	0.2	0.015	2.0

Table 2.1 ECC Mix Design. Source (Ye et al. 2021)

2.1.2 Seismic resistance and performance

Qudah and Maalej (2014) investigated the feasibility of using ECC to enhance the performance of connections between beams and columns. The ECC mix design used can be seen below in table 2.2. The experiment was conducted by using a hydraulic actuator which simulated lateral displacements similar to an earthquake, which can be seen in figure 2.2 below. From the results obtained, it was confirmed that the specimens containing ECC had more ability to resists the reverse-cyclic loading. It was also found that the ultimate load was greatly enhanced with the beams containing ECC and they also demonstrated enhanced structural integrity. The study successfully confirmed that the use of ECC as a replacement of concrete can significantly enhance several factors such as cracking response, shear resistance and energy absorption.

Mix proportions for ECC material.

Component	Cement	Silica Fume	Sand	Water	Super-plasticizer	Fiber (volume%)
Proportion	1.0	0.1	0	0.35	0.02	2

Table 2.2 ECC Mix Design. Source: (Qudah & Maalej 2014)

Figure 2.2 Test Set Up with Hydraulic Actuator. Source: (Qudah & Maalej 2014)

Another study conducted by Said and Razak (2016) was very similar to the study by Qudah and Maalej (2014) as they investigated the structural behaviour of ECC beam-column joints under reversed cyclic loading. The main parameters investigated in this study were load-deflection, crack propagation and energy absorption capacity. The mix designs of the normal concrete and ECC can be seen below in table 2.3. As seen in figure 2.3 below, the results obtained showed that the load-deflection relationship for the sample with ECC gradually decreased compared to the normal concrete curve, which indicates that the ECC specimen had improved load and shear capacity, energy absorption ability and damage tolerance. The study successfully found that the ECC joint had enhanced ultimate shear and moment capacities, deformation failure and damage tolerance.

Mix proportion used in NC and ECC.

Type of mix	Cement C/C	Sand S/C	Gravel G/C	Fly ash FA/C	Water W/B	(SP/B)%
Normal concrete NC	1 (360)	2 (720)	3 (1080)	0.125 (90)	0.47 (171)	0.2 (0.81)
Engineered cementitious composite ECC	1 (820)	0.8 (656)	–	0.25 (205)	0.37 (379.25)	0.3–0.35 (3.075–3.588)

Table 2.3 Normal Concrete and ECC Mix Designs. Source: (Said & Maalej 2016)

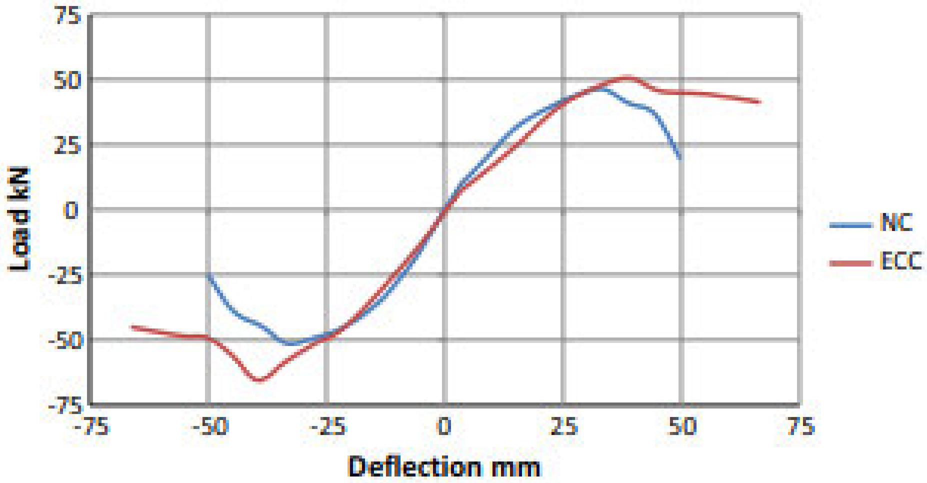

Figure 2.3 Load-Deflection Relationship of Normal Concrete and ECC. Source (Said & Maalej 2016)

2.1.3 High-Volume Fly Ash

A study conducted by Wang and Li (2007) investigated the mechanical performance of ECC with high-volume fly ash. This research focused on the influence of fly ash content in ECC. The mix designs used in this experiment can be seen below in table 2.4.

The results obtained from the study showed that the tensile strength increased, however as the fly ash content increased, it led to a decrease in the interface frictional stress and chemical bond. It was also found that the increase in fly ash reduced the matrix toughness of the ECC. Overall, the study identified an ideal mix design which showed an increase in strain and capacity.

Material	Cement, kg/m (lb/yd^3)	Aggregates, kg/m^3 (lb/yd^3)	Water, kg/m^3 (lb/yd^3)	HPMC,* kg/m^3 (lb/yd^3)	HRWRA, kg/m^3 (lb/yd^3)	Fiber, kg/m^3 (lb/yd^3)
Concrete	390 (657)	1717 (2894)	166 (280)	—	—	—
PE-ECC	1205 (2031)	603 (1016)	314 (529)	0.60 (1.0)	12 (20)	17 (29)
PVA-ECC R0	832 (1402)	832 (1402)	366 (617)	1.26 (2.1)	17 (29)	26 (44)

Table 2.4 Specimen Mix Designs. Source: (Wang and Li 2007)

Sahmaran and Li (2009) conducted a study which investigated the durability properties of micro-cracked ECC containing high-volume fly ash. The main aim of this study was to analyse the effect fly ash has on the durability of ECC. The study involved performed direct tensile tests to evaluate the deterioration of tensile strain and strength and the crack width of ECC. The mix designs used for the experiment can be seen below in Table 2.5. The results obtained showed that samples with high volumes of fly ash had greater durability and an increased tensile strain, however as the fly ash content increased, it reduced the strength of the ECC.

Mixture properties of ECC and mortar.

Ingredients	ECC-1 (M45)	ECC-2
Water (W), kg/m^3	331	327
Cement (PC), kg/m^3	570	386
Fly ash (FA), kg/m^3	684	847
Sand (S), kg/m^3	455	448
Fiber (PVA), kg/m^3	26	26
HRWR, kg/m^3	4.9	3.7
FA/PC	1.2	2.2
W/CM[a]	0.27	0.27
7-day compressive strength, MPa	38.1	21.6
28-day compressive strength, MPa	50.2	36.3
90-day compressive strength, MPa	55.4	41.9

Table 2.5 Specimen Mix Designs. Source: (Sahmaran and Li 2009)

Another study conducted by Yang et al. (2007) investigated the mechanical properties of ECC by using high volumes of fly ash. This study involved analysing the effect fly ash has on the micro-structure and mechanical properties of ECC. The mix designs of all the specimens can be seen below in table 2.6. The results obtained from the study showed that the fly ash had an increased tensile ductility, and the crack width was reduced to the increase of the frictional bond of the fibre/matrix interface.

Mixture	FA/C	Cement, kg/m³ (lb/yd³)	Fly ash, kg/m³ (lb/yd³)	Sand, kg/m³ (lb/yd³)	Water, kg/m³ (lb/yd³)	High-range water-reducing admixture, kg/m³ (lb/yd³)	PVA fiber, kg/m³ (lb/yd³)	Total, kg/m³ (lb/yd³)
1	1.2	571 (962)	685 (1154)	456 (768)	332 (559)	6.80 (11.46)	26 (43.8)	2077 (3500)
2	1.6	477 (804)	763 (1286)	456 (768)	330 (556)	6.05 (10.19)	26 (43.8)	2060 (3471)
3	2.0	412 (694)	824 (1388)	456 (768)	326 (549)	5.52 (9.30)	26 (43.8)	2051 (3456)
4	2.4	362 (610)	870 (1466)	456 (768)	323 (544)	5.10 (8.59)	26 (43.8)	2042 (3441)
5	2.8	324 (546)	906 (1527)	456 (768)	320 (539)	5.29 (8.91)	26 (43.8)	2037 (3432)
6	3.2	292 (492)	935 (1575)	456 (768)	312 (526)	5.52 (9.30)	26 (43.8)	2027 (3415)
7	3.6	266 (448)	959 (1616)	456 (768)	309 (521)	5.80 (9.77)	26 (43.8)	2022 (3407)
8	5.6	190 (320)	1063 (1791)	456 (768)	300 (506)	6.45 (10.87)	26 (43.8)	2032 (3424)

Table 2.6 Specimen Mix Designs. Source: (Yang et al. 2007)

A study conducted by Lu et al. (2023) investigated incorporating polyvinyl alcohol fibres into ECC to assist the fly ash. The research wanted to confirm if the addition of polyvinyl alcohol fibres would result in an increase in strength gain of the ECC over the long term. The research involved curing ECC with high levels of fly ash and polyvinyl alcohol fibres for 28, 90, 180 and 365 days. The results obtained showed that there were increased in the fibre/matrix interfacial bonding which led to increases in compressive strength and toughness over time. However, the tensile strain decreased over time.

2.2 ECC studies using alternatives to fly ash

There are minimal studies which replace fly ash with an alternative material. However, this literature review discovered that crumb rubber, rice husk ash, red mud and slag has been researched.

2.2.1 Recycled crumb rubber

Hou et al. (2022) investigated using recycled crumb rubber and silica fume in the ECC mixture instead of fly ash. The main parameters investigated in this study were the crack control width and the mechanical properties. The results showed that the crumb rubber increased the strain and hardening performance of the ECC, however increasing the amount of crumb rubber reduced the compressive strength.

2.2.2 Rice husk ash

Zhang et al. (2021) replaced fly ash in ECC with an agricultural waste-rice husk ash. The study focused on analysing the tensile strength, strain capacity and cracking behaviours of the ECC. The samples involved using rice husk ash to partially replace cement up to 40%. The results gathered from the study showed that the compressive strength of the desired ECC mixture increased from 80 MPa to 111 MPa. It was also found that the tensile strain increased due to an increase in micro-cracks, which can be seen below in figure 2.4. However, the tensile strength decreased.

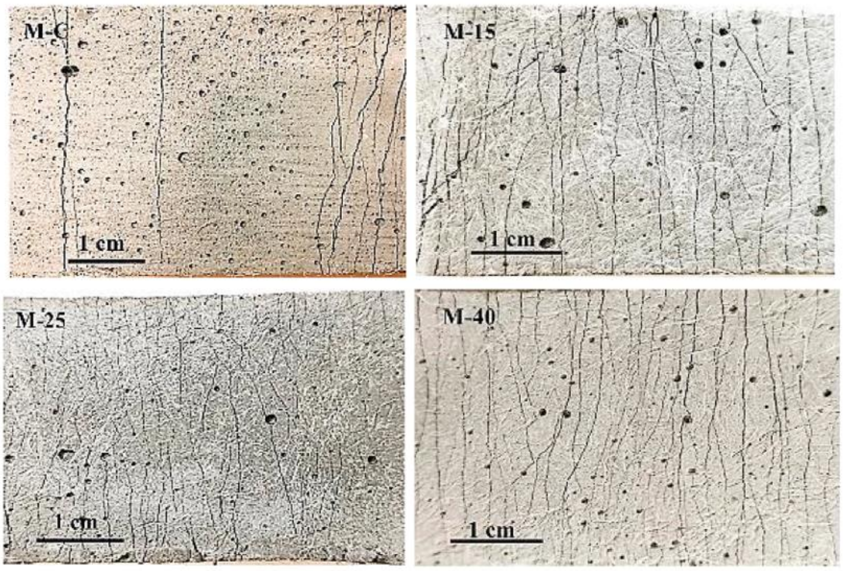

Figure 2.4 Crack Patterns of Samples. Source: (Zhang et al. 2021)

2.2.3 Red mud

A study conducted by Kan et al. (2022) investigated using red mud waste as a replacement for fly ash in ECC. The authors wanted to use red mud as it is generally stockpiled and occupies large open areas and has several safety risks to the soil and groundwater. The mix design used can be seen below in table 2.7. By replacing the fly ash with red mud, the results obtained showed that all the mixtures containing red mud had high tensile strain capacities and for mixtures with less than 10% amounts of red mud, the tensile strength and compressive strength was increased.

Mix proportions of the RM-ECCs.

Mix	Components (wt. %)							
	RM	FA	OPC	Sand	Water	HRWRA[a]	VM[b]	PVA[c]
0%RM-ECC	0	42.91	18.39	18.39	18.39	0.54	0.10	1.7
5%RM-ECC	2.15	40.76	18.39	18.39	18.39	0.54	0.10	1.7
10%RM-ECC	4.29	38.62	18.39	18.39	18.39	0.54	0.10	1.7
30%RM-ECC	12.87	30.04	18.39	18.39	18.39	0.54	0.10	1.7
40%RM-ECC	17.16	25.75	18.39	18.39	18.39	0.54	0.10	1.7
50%RM-ECC	21.45	21.45	18.39	18.39	18.39	0.54	0.10	1.7

Table 2.7 Specimen Mix Designs. Source: (Kan et al. 2022)

2.2.4 Slag

Booya et al. (2020) investigated using slag as a replacement for fly ash in ECC. The main reasoning for investigating the use of slag was due to need for sustainable power generation, which as a result would reduce the amount of fly ash that is available. The results obtained from the study confirmed that the slag had generally the same characteristics as fly ash. It was also found that the mixture containing slag had higher shrinkage strains compared to the fly ash mixtures.

2.3 Concrete studies incorporating pond ash

There are no studies that have been conducted which replace fly ash with pond ash in ECC, however there are several studies that incorporate pond ash into standard concrete mixtures.

A study conducted by Sofi and Phanikumar (2015) investigated the flexural behaviours of plain and fibre-reinforced pond ash modified concrete. A three-point bending system was used to analyse the concrete beams under a monotonic load. Crack width was also investigated in this study. The mix designs of the specimens can be seen below in table 2.8. The results obtained from the study confirmed that the ultimate load increase as the pond ash content increased. It was also found that the ductility increased as the pond ash content increased. It was confirmed that the use of pond ash had enhance performance compared to conventional concrete.

Table 3 Mix proportions.					
Ingredients	Cement (kg/m^3)	Pond ash (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate	
				12 mm (kg/m^3)	20 mm (kg/m^3)
0% pond ash	413.33	–	671.84	410	762
10% pond ash	372.00	41.33	667.88	407	758
20% pond ash	330.67	82.66	652.08	397	740
30% pond ash	289.34	124.00	653.06	398	738

Table 2.8 Specimen Mix Designs. Source: (Sofi and Phanikumar 2015)

Yuvaraj and Ramesh (2022) investigated the strength, morphological and durability of coal pond ash concrete. The aim of their study was to find a use of pond ash in concrete as it is a major waste material from industries and power plants. The study was conducted by replacing 10% of cement with coal pond ash. The strength was tested by using modulus of elasticity testing. The morphological characteristics were tested by using scanning electron microscopy and energy dispersive x-ray analysis. Durability was tested by using the weathering resistance, acid resistance, chloride resistance tests. The results obtained from the testing found that the coal pond ash concrete had significant resistance against weathering action, chloride penetration, chloride and acid attack and also had increased strength.

Lal at al. (2019) conducted a study that investigated the properties of cement mortar which included pond ash. The study focused on using pond ash from a thermal power plant in India. In the testing, pond ash replaced cement from 0% to 100%. Several factors were examined such as, flexural strength, compressive strength, and workability. The study also used x-ray imagine and scanning electron microscope to study the microstructure. The results obtained from the testing found that the presence of pond ash has enhanced properties up until 40%.

Kumar and Radhakrishna (2018) conducted a study which focused on replacing sand as the fine aggregate in cement mortar with pond ash. The aim of this study was to find a replacement for sand as there is an increased demand for sand. In this study, river sand was replaced by pond ash from 0% to 100% at 20% intervals. During the testing, the flow characteristics were analysed by conducting a flow test. The study found that the compressive strength of the pond ash increased. However, there was a reduced density and modulus of elasticity of the pond ash compared to river sand.

Similar to Kumar and Radhakrishna, Yimam et al. (2021) also investigate replacing river sand with pond ash. This study particularly focused on the workability, compressive strength and of the concrete. The testing involved replacing river sand with pond ash from 0% to 30% at 5% intervals. The results obtained found that as the pond as percentage increased, the workability and density of the concrete reduced. It was found that that compressive strength of the concrete increased with pond ash of 5% and 10%. It was concluded that the optimal replacement of river sand with pond ash is at 10%.

A study conducted by Harle (2019) investigated the use of pond ash in concrete. The aim of this study was to find an effective way to use pond ash in the construction industry to reduce the environmental impacts pond ash has on the environment and human health. Harle stated that 200 million square meters of land is covered with pond ash in India. The results from this study found that as the percentage of pond ash increased in the concrete mixture, the compressive strength and workability of the concrete decreases. As the results found that the pond ash decreased the compressive strength and workability, plasticizer was used to increase these factors.

Jung and Kwon (2013) conducted a study to investigate the engineering properties of cement mortar with pond ash. The main aim of this study was to determine if pond ash could be used as an alternative to fly ash, as fly ash is the main waste product that is used in concrete mixture. Pond ash percentages of 0%, 30% and 60% were examined and the factors of workability and physical properties were examined. Several tests were conducted such as, compressive strength, setting time and flow. It was found that pond ash was a successful waste product that could be used in concrete.

A study conducted by Haldive and Kambekar (2013) incorporated both fly ash and pond ash into concrete mixtures as a way to reduce the amount of waste produced from thermal power plants. The study aimed at investigating the strength and durability of concrete. Several tests were conducted to analyse these parameters such as, compressive strength, water permeability and chloride penetration test. The results confirmed that concrete which included both fly ash and pond ash had enhanced properties compare to regular concrete.

2.4 Summary/Knowledge gap

From conducting this literature review it is noticeable that there is extensive research regarding ECC and confirm that they have enhanced properties compare to conventional concrete. Several studies which have been performed by using alternatives to fly ash have also been successful in confirming that these materials can be used in ECC. This literature review has confirmed that there has been no research which replaces fly ash with pond ash in ECC. There are multiple studies which use pond ash in standard concrete mixtures, and all have positive results. By replacing fly ash with pond ash in ECC, it will address the evident knowledge gap and lead to further studies in this area.

Chapter 3: Methodology

3.1 Outline

To effectively analyse the ductility and cracking behaviours of ECC with the replacement of fly ash with pond ash, it is essential that that an experimental investigation is conducted. Four samples will be produced which contain different volumes of pond ash. The size of the samples will be as required for the specific testing. To investigate the ductility and crack behaviours, the chosen tests that will be conducted are three-point bending test and crack mouth opening displacement (CMOD) test with the use of digital imaging correlation (DIC). The results obtained from the testing will be able to clearly identify if the replacement of fly ash with pond ash in ECC has improved properties.

The methodology for this experiment has been defined as the following:

1. Create a mix design
2. Source and order materials
3. Prepare one control batch containing no pond ash. Prepare three batches containing replacement of fly ash with pond ash at 25%, 50% and 100%.
4. Investigate the rheological matrix properties of the samples.
5. Prepare required samples for testing.
6. Conduct testing to investigate the ductility and cracking behaviours.
7. Analyse the results.

3.2 Assumptions

For the purposes of this research, the following assumptions have been made:

- The pond ash sourced for the experiment is indicative only and may not be the specific pond ash that can be expected for general use.
- The fly ash sourced for the experiment is indicative only and may not be the specific pond ash that can be expected for general use.
- The properties of the other materials sourced are comparative to the general properties of these materials.

3.3 Producing Specimens

3.3.1 ECC Mixing

Firstly, it is essential that the ECC mixing occurs. This process involved combining all the materials to create an ECC mixture. Previous research that has been identified in the literature review conducted by Wang and Li 2007 and also Yang et al. 2007, used a similar technique in mixing the ECC. The process involved three stages, which involved mixing all the dry materials first, followed by the water and then the fibres. Yang et al. 2007 confirmed that achieving optimal rheological matrix properties prior to adding fibres, allows the fibre distribution to be uniform and have enhanced properties.

The detailed ECC mixing for this experiment is as follows:

1. Add dry materials such as cement, silica sand, fly ash and pond ash to the mixer and mix for 1 minute.
2. Add water and superplasticizer and mix for another 3-4 minutes.
3. Test the rheological matrix properties by performing a slope cone test.
4. Add polyvinyl alcohol (PVA) fibres and mix until the fibres are uniformly distributed.

3.3.2 Specimen Details

For this experiment, three specimens are required for each test. This ensures that sufficient data can be captured, while meeting the budget requirements for the research project. The number of specimens and dimensions are tabulated below in table 3.1. The size of the specimens are in accordance with the relevant Australian Standards.

Number of samples	Test	Shape of sample	Sample size (mm)
12	Flexural	Prism	305 x 76 x 38
12	Ductility	Prism	305 x 76 x 38

Table 3.1 Specimen Details

3.3.3 Specimen Casting

After the mixture is created, the desired samples are required to be moulded. 24 beam moulds are required to be moulded into the dimensions specified in table 3.1 and 12 cubes are also required.

3.3.4 Specimen Curing

In accordance with AS1012-2014, the specimens are required to be covered and left for 18-36 hours. The specimens are then required to be removed from their moulds and stored in the laboratory designated storage cabinets. The specimens are then required to be cured for 28 days in accordance with AS2012-2014.

3.4 Testing

3.4.1 Rheological Properties Testing

Testing the rheological properties is to be conducted after completing the mixing of the ECC. A slump test and marsh cone test can be conducted to investigate the rheological properties. This can determine the yield stress and plastic viscosity of the ECC. The slump test is to be conducted in accordance with AS1012.3.5-2015. The set up is to be in accordance with figure 3.1 below. The procedure is to be conducted in accordance with Clause 7 of AS1012.3.5-2015.

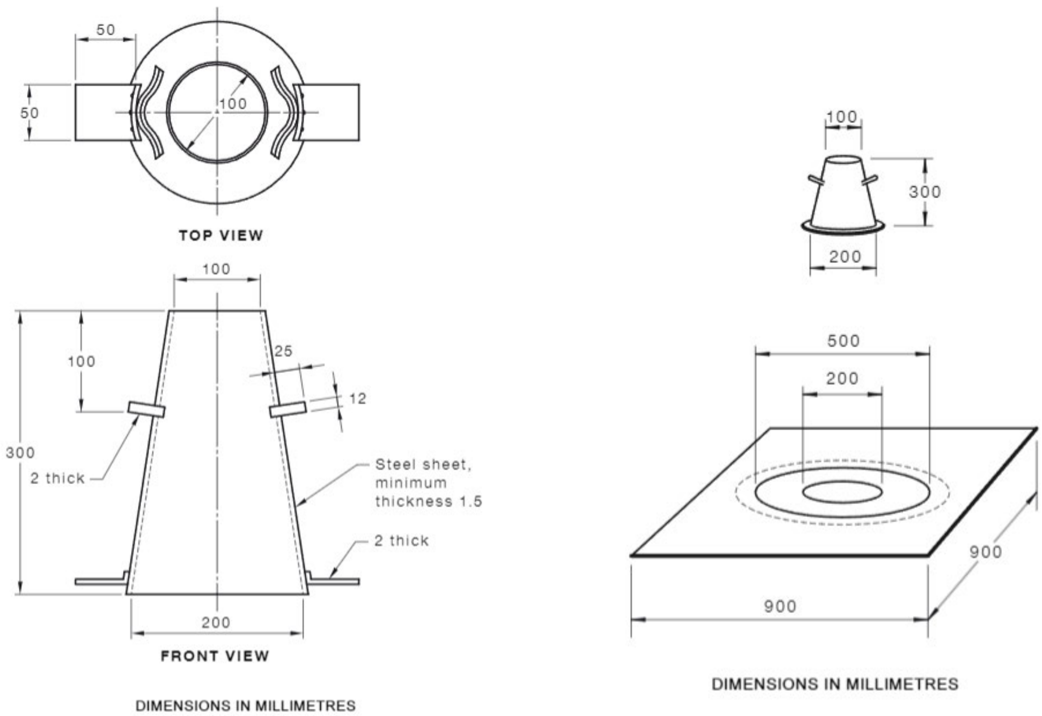

Figure 3.1 Slump Test Set Up in Accordance with AS1012.3.5:2015. Source: (Australian Standards 2015)

3.4.2 Flexural Testing

Flexural testing is required to be conducted to investigate the ductility properties of the specimens. The flexural test is required to be conducted in accordance with AS1012.11-2000. A three-point machine is required to conduct the testing. The set up should be as per figure 3.2 and in accordance with Clause 5 of AS1012.11-2000. The testing procedure is to be in accordance with Clause 6 of AS1012.11-2000.

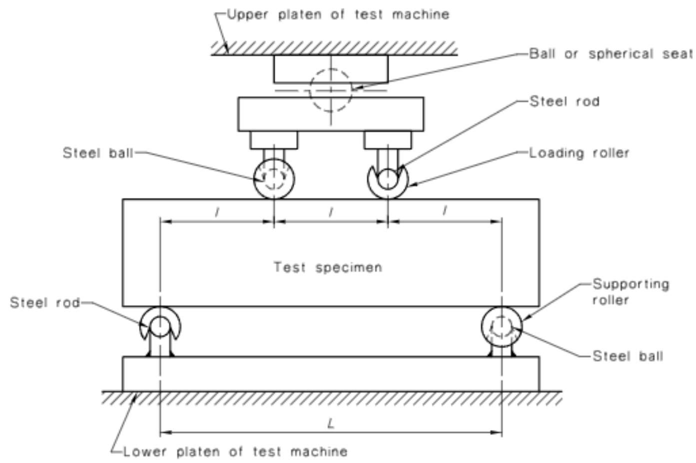

Figure 3.2 Flexural Test Set Up in Accordance with Clause 5. Source: (Australian Standards, 2000)

3.4.3 Crack-Mouth Opening Displacement Test (CMOD)

The CMOD testing will be in accordance with BS-EN 1461-2005. This testing will focus on measuring the displacement along the longitudinal axis of the specimen. To effectively conduct this testing, a small notch is required to be made in the samples in accordance with clause 7.3. As the sample size is not in accordance with BS-EN 1461-2005, a ratio is to be calculated to determine the depth of the notch. DIC will be used to measure the displacement as it is predicted to be relatively small. The test set up will be in accordance with figure 3.3 below, however, the required distance between the supports will be a 265mm with a 20mm overhand on each side.

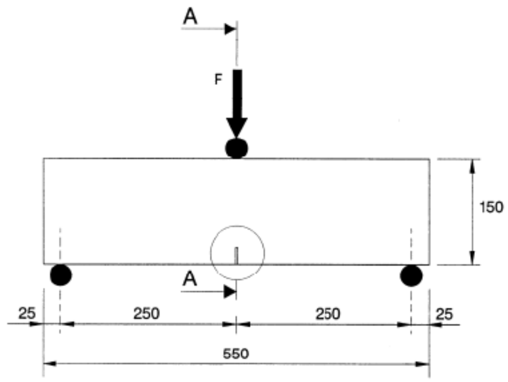

Figure 3.3 CMOD Test Set Up in Accordance with Clause 8. Source: (British Standards, 2005)

3.4.4 Scanning Electron Microscopy (SEM) Testing

To examine the microstructure of the specimens, SEM testing is required. This involves preparing small samples of approximately 2cm x 2cm dimensions and using a SEM testing machine to effectively investigate the microstructure of the specimen. This is to be conducted for each batch, to examine the surface of the batches and identify any key differences between the batches.

Chapter 4: Experimental Investigation

4.1 Mix Design

A mix design was required to be created to effectively investigate the replacement of fly ash and pond ash. Table 4.1 below, represents the ratios of each sample. It can be noticed that the batches consist of a control batch and three batches that replace fly ash with pond ash at intervals of 25%, 50% and 100%.

	Control	25%	50%	100%
Cement	1.0	1.0	1.0	1.0
Water	0.4	0.4	0.4	0.4
Silica Sand	0.6	0.6	0.6	0.6
Fly Ash	0.8	0.6	0.4	0
Pond Ash	0	0.2	0.4	0.8
Superplasticizer	0.04	0.04	0.04	0.04

Table 4.1 Mix Design for Samples

4.2 Materials

The materials required to create the mixture consisted of:

- Cement
- Water
- Silica Sand
- Fly ash
- Pond Ash
- Superplasticizer
- PVA fibres

The quantities required have been calculated using the spreadsheet noticed in figure 4.1 below. These quantities consist of the volume required for this experiment and also another experiment that is being conducted separately by another student.

No. of samples (Per mix)	No. of samples (Total)	Tests	Shape of sample	Sample size (mm)	Volume of each sample (mm3)	Volume per batch (mm3)	Total volume (mm3)	Comments
9	36	Compressive	Cube	50x50x50	125000	1125000	4500000	
3	12	Flexural	Prism	305x76x38	880840	2642520	10570080	
3	12	Tensile	Dogbone	330x60x13	257400	772200	3088800	
6	24	Fibre pullout	Silicone mould cube	25x25x25	15625	93750	375000	
3	12	Ductility	Prism	305x76x38	880840	2642520	10570080	
1	4	Extra cube for SEM, TGA	Cube	50x50x50	125000	125000	500000	
1	4	Flowability (fresh specimen)			351214.2857	351214.2857	1404857.143	
	104					7752204.2857	31008817.1429	

fresh concrete volume including wastage	38450933.2571	39	litres	Control 9.61	25% 9.61	50% 9.61	100% 9.61	Total 38.45
		9.8	litres/batch					

MIX DESIGN	Control	25%	50%	100%
Cement	1.000	1.000	1.000	1.000
Water	0.400	0.400	0.400	0.400
Silica Sand	0.600	0.600	0.600	0.600
FA	0.800	0.6	0.400	0.000
PA	0.000	0.2	0.4	0.8
SP	0.040	0.040	0.040	0.050
	2.840	2.840	2.840	2.850

Total Estimation			Control	25%	50%	100%	Total	
Total Volume of fresh concrete including Wastage	0.0390	m3	0.0096	0.0096	0.0096	0.0096	0.0385	m3
Total Quantity of Fresh concrete including wastage	78	Kg	19	19	19	19	77	kg
Total Quantity of Cement	27	Kg						
Total Quantity of Sand	16	Kg						
Total Quantity of Fly ash	12.2	Kg	5.42	4.06	2.71	0	12.2	kg
Total Quantity of Pond Ash	9.5	Kg	0.00	1.35	2.71	5.396622212	9.5	kg
Total Quantity of SP	1.1	Kg	0.27	0.27	0.27	0.34	1.1	kg

Material	Qty in Kg		Qty in Bags (20 Kg)	Supplier	Contact	Email	Phone
Cement	27		2	Darling Downs Brick Sales	https://www.ddbs.com.au/shop/cement-sand-plasticiser/general-purpose-gp-cement-type-a-20kg-bag-ex-yard-toowoomba/	shop@ddbs.com.au	07 4633 3311
Silica Sand	16		1	Domcrete	https://domcrete.com.au/product/graded-silica-sand-20kg/	info@domcrete.com.au	1300 132 679
PA	9		1	Sourced by Weena			
FA	12		1	Darling Downs Brick Sales	https://www.ddbs.com.au/shop/cement-sand-plasticiser/fly-ash-20kg-bag-ex-yard-toowoomba/		
PVA Fibres	0.00078	Volume	1	Domcrete	https://domcrete.com.au/product/buddy-rhodes-pva-fibre-recs-15-450gm-1lb-bag/		
SP			1	Darling Downs Brick Sales	https://www.ddbs.com.au/shop/cement-sand-plasticiser/brickies-own-mortar-plasticiser-1l-concentrate/		
Grand total	65.58715739						

Figure 4.1 Material Estimation Spreadsheet

The cement used for the mixture was source from Darling Downs Brick Sales in Toowoomba. The cement was a general-purpose cement from Cement Australia. The cement fully complies the Australian Standards requirements for type G cement as per AS3972 (Cement Australia, 2023). The sourced cement used in the mixture can be noticed in figure 4.2.

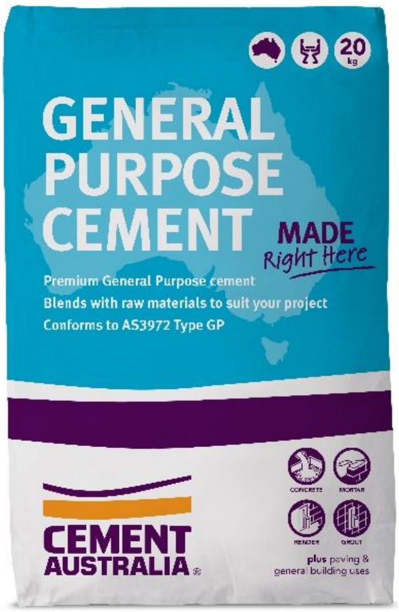

Figure 4.2 General Purpose Cement Used in Mixture. Source: (Cement Australia, 2023)

The fly ash was also sourced, from Darling Downs Brick Sales in Toowoomba. This fly ash was a grade 1 and fully complied with AS3582.1 (Cement Australia, 2023). The fly ash used can be noticed in figure 4.3 below.

Figure 4.3 Fly Ash Used in Mixture

The pond ash used for the samples was sourced from Millmerran Fly Ash. They provide coal combustion products from their Millmerran power station. The pond ash sourced complies with Australian Standard AS3582.1. The pond ash used in the mixture can be noticed in figure 4.4 below.

Figure 4.4 Pond Ash Used in Mixture

The silica sand used was source from Domcrete Australia. This sand was sourced as it is used in ECC mix designs. The silica sand used can be seen in figure 4.5 below.

Figure 4.5 Silica Sand Used in Mixture

The PVA fibres used were also sourced from Domcrete Australia. These fibres were sourced as they are high-performance reinforcement fibres for mortar. These fibres had a length of 12mm. The PVA fibres used in the mixture can be seen in figure 4.6 below.

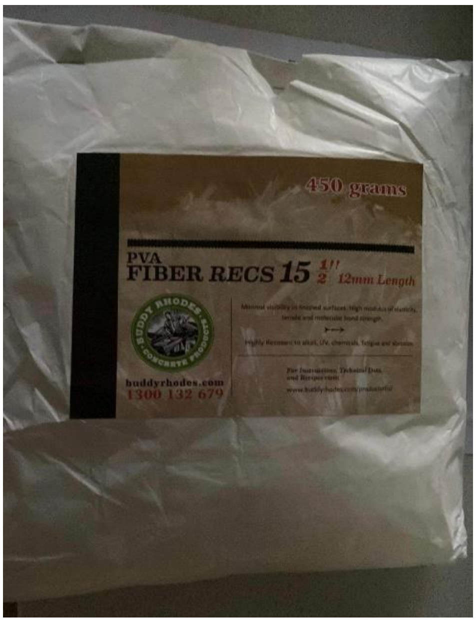

Figure 4.6 PVA Fibres Used in Mixture

The superplasticiser was sourced from Darling Downs Brick Sales in Toowoomba. The superplasticiser was a Cement Australia product. This superplasticiser is for mortar and complies with AS1478 (Cement Australia, 2023). The superplasticiser used in the mixture can be seen below in figure 4.7.

Figure 4.7 Superplasticiser Used in Mixture. Source: (Cement Australia, 2023)

4.3 Material Quantities

The total volume required was calculated, as seen in table 4.2 below, including 20% wastage.

Quantity	Shape	Size (mm)	Volume of each sample (m^3)	Total Volume (m^3)
12	Beam	305 x 76 x 38	0.00088084	0.0105701
12	Beam	305 x 76 x 38	0.00088084	0.0105701
			Fresh mortar volume (m^3)	0.0212
			Fresh mortar volume including wastage (m^3)	0.0254

Table 4.2 Volume Calculations

Each material was weighed to determine the density of each material. The density of each material used can be noticed in table 4.3 below.

Material	Density (kg/m^3)
Cement	1140
Water	1000
Silica Sand	1848
Fly Ash	1000
Pond Ash	624
PVA Fibres	196

Table 4.3 Material Densities

The mixture proportions adopted for the batches are shown in table 4.4 below.

Material	Control	25%	50%	100%
Cement	416.06	416.06	416.06	414.55
Water	131.39	131.39	131.39	130.91
Silica Sand	364.20	364.20	364.20	362.88
Fly Ash	291.97	404.67	269.78	0.00
Pond Ash	0.00	45.55	91.09	181.53
PVA Fibres	3.92	3.92	3.92	3.92
Superplasticiser	0.04	0.04	0.04	0.04

Table 4.4 Mixture Proportions

From this, the total weight of each material required for each batch was calculated. This can be seen in table 4.5 below.

Material	Control	25%	50%	100%
Cement	4.16	4.16	4.16	4.15
Water	1.31	1.31	1.31	1.31
Silica Sand	3.64	3.64	3.64	3.63
Fly Ash	2.92	4.05	2.70	0.00
Pond Ash	0.00	0.46	0.91	1.82
PVA Fibres	0.0392	0.0392	0.0392	0.0392
Superplasticiser	0.04	0.04	0.04	0.04

Table 4.5 Material Quantities

4.4 Mixing and Casting

The mixing and casting was conducted on campus at USQ Toowoomba, in the Z block laboratories. The samples were produced in accordance with section 3.5 of this report. Each material was weighed using the scales in the laboratory as seen in figure 4.8. The materials were mixed by using a Hobart mixing machine, which is identified in figure 4.9. The mixing times were adjusted from the times identified in section 3.5 during the mixing process. The dry materials were added and mixed for 2 minutes, instead of 1 minutes. The water and superplasticiser when then added to the mixture and mixed for 8 minutes, instead of 3-4 minutes. Lastly, the PVA fibres were added to the mixture and mixed until evenly distributed, which was approximately 8 minutes.

Figure 4.8 Materials Being Weight with Scales in Laboratory

Figure 4.9 Hobart Mixer

The rheology properties test was conducted after mixing for each batch, which involved conducting a modified marsh cone test and a slump test in accordance with section 3.6.1. The results obtained from these tests are evaluated in section 5.1.

After the rheology properties had been tested, the mixture was added to the moulds seen in figure 4.10. These moulds were custom made to accommodate the required dimensions for the beams. The samples were then left in the lab for 24 hours to set at room temperature. It was noticed that in the 100% pond ash batch, it was not as hardened as the other samples, therefore it was decided to let this set for an additional 8 hours before taking it out of the moulds. All the samples were inspected, and it was noticed that none of the samples had any noticeable defects.

Figure 4.10 Mixture Added to the Custom Moulds

The specimens were then moved into the curing room in the Z1 laboratory, where they were cured for 28 days. The specimens were placed on the shelves in the fog room as seen in figure 4.11. The curing room was set to a temperature of 27 degrees and humidity of 86%, as seen in figure 4.12.

Figure 4.11 Samples Stored in Curing Room

Figure 4.12 Temperature and Humidity of Curing Room

Once, the samples had been cured for 28 days, they were removed from the fog room and weighed. The samples were then ready to undergo testing.

4.5 Experimental Testing

Testing of the specimens commenced on 28 August 2022, which was 28 days after the control batch had been casted. The ductility testing was conducted over four consecutive days, when each batch had been cured for 28 days. The CMOD test occurred over the course of one day, which was 28 days after the 100% pond ash mix had been casted. This ensured that the standard curing time of each sample was achieved. The SEM test was also carried out after each sample had achieved 28 days of curing time.

All of the testing was conducted with the assistance of USQ technical staff at the Toowoomba Campus. The durability testing and SEM testing was conducted in the Z block laboratories, however the CMOD testing was conducted in the P block laboratory due to the availability of the DIC technology.

4.5.1 Flexural Testing

Flexural testing was conducted in the Z block laboratory as USQ Toowoomba campus. The testing was conducted in accordance with section 3.6.3 of this report and as per AS1012.11-2000. The set up of the testing can be seen in figures 4.13 and 4.14. The equipment included a three-point bending machine and a computer which was equipped with software to record the load and displacement during the test. Before testing commenced, the beams were measured, weighed, and inspected for any defects.

Figure 4.13 Flexural Test Set Up

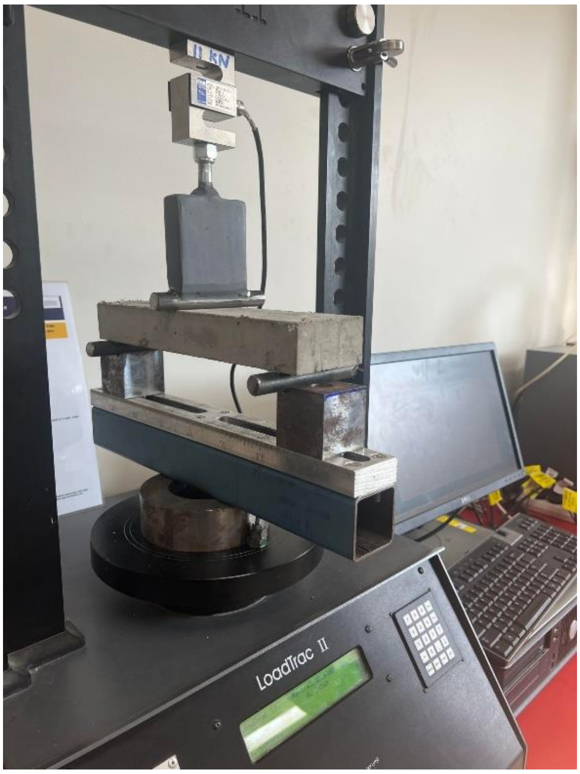

Figure 4.14 Beam Placed in Three-Point Bending Machine

The flexural testing was conducted with the assistance of the technical staff. The beams were positioned in the three-point bending machine, in accordance with AS1012.11-2000. The technical staff began the test by applying the load to the beam and recorded the load and displacement. The recorded data was then captured and transferred to a hard drive for analysing.

The flexural testing was able to generate load and displacement values. From this, the ductility of the samples could be examined by interpreting the load-deflection curve. A ductility index can also be calculated to compare the ductile performance of the samples. The formula can be noticed below.

$$Ductility\ Index = \frac{ultimate\ deflection}{first\ yield\ deflection}$$

The results obtained from the flexural testing are analysed and evaluated in section 5.3 of this report.

4.5.2 Crack Mouth Opening Displacement (CMOD) Testing

The CMOD testing was conducted in the P block laboratory at the USQ Toowoomba Campus. The testing was conducted in accordance with section 3.6.4 of this report and as per BS-EN1461-2005. Before testing could commence, a notch was required to be made in the beams in accordance with BS-EN1461-2005. As the beams were not in accordance with the code, a ratio had to be calculated to determine the depth required of the notch. This was calculated to be 10mm. A 10mm notch was sawn into all of the beams with the use of a wet saw. This can be seen in figures 4.15 and 4.16 below.

Figure 4.15 Wet Saw

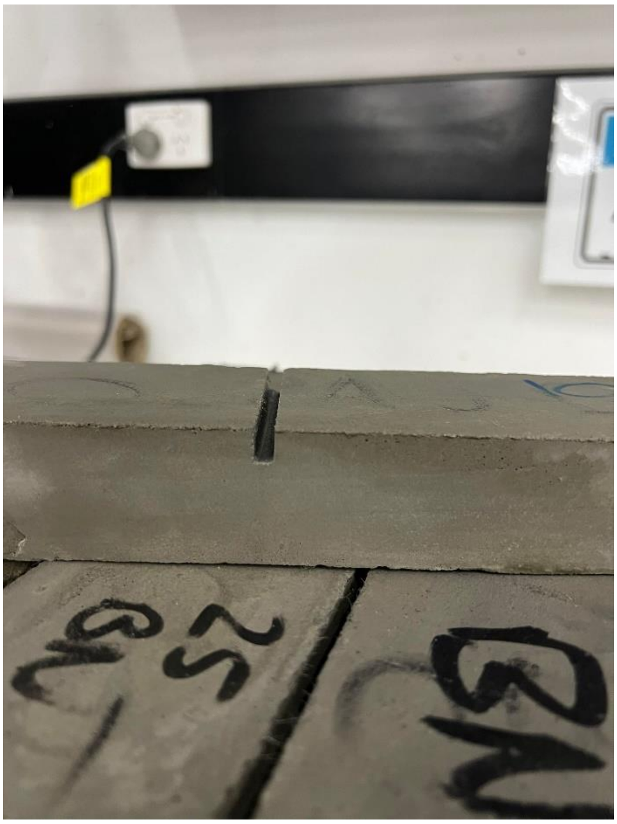

Figure 4.16 10mm Notch in Beams

The beams were then ready to undergo testing. As previously mentioned, the beams were not in accordance with the size specified by the code, therefore the width of the support rollers had to be calculated to be in accordance with the code. The distance between the support rollers was 256mm with a 20mm overhang on each side.

Once the beam had been positioned in the three-point bending machine, the DIC technology was set up by technical staff. DIC was used to measure the linear displacement of the notch as a linear displacement transducer was not available. DIC also has the capabilities to investigate the cracking behaviours by the use of a strain map, however this was unavailable at the time of testing. Five crosses were drawn onto each beam to assist the DIC with focusing on the notch, which can be seen in figure 4.17. This allows for more precise displacement recordings.

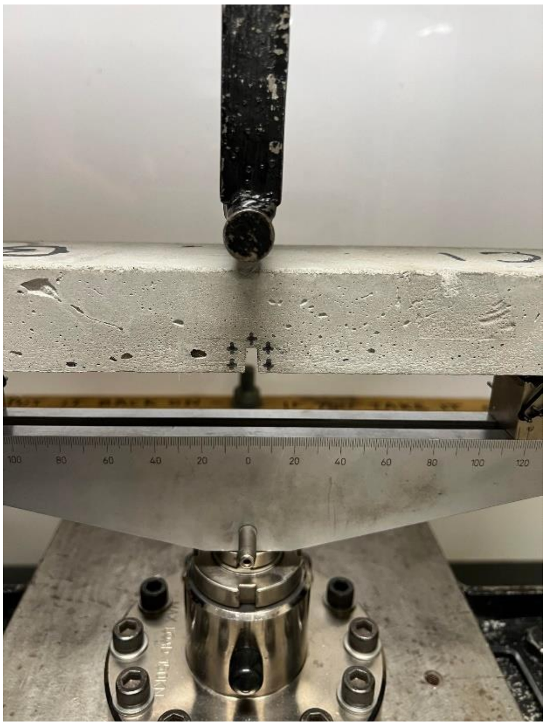

Figure 4.17 Crosses Used to Assist with DIC Focus

The set up of the CMOD testing can be seen in figure 4.18 below. A three-point bending machine was used to perform the testing with the use of the DIC camera.

Figure 4.18 CMOD Testing Set Up

The DIC was able to focus on the nodes and record the displacement of the nodes throughout the duration of the testing. The data recorded from the DIC camera was recorded on a computer which contained specific software that enabled the DIC to function correctly. The set up can be seen below in figure 4.19. The DIC also provided a video of the sample undergo the testing. A screen capture of the video can be seen below in figure 4.20.

Figure 4.19 Computer with DIC Software

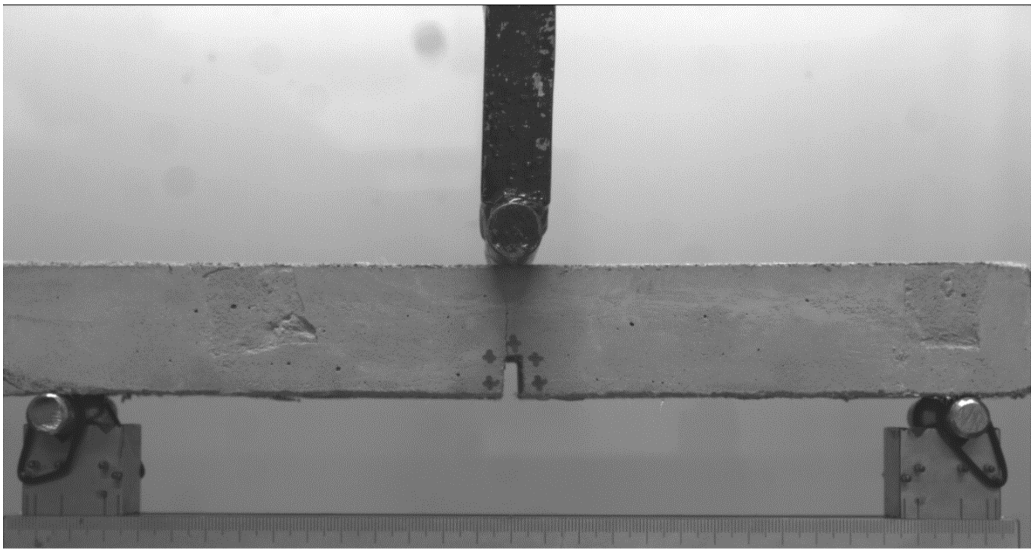

Figure 4.20 Screen Capture from DIC Video

The technical staff then assisted with commencing the testing. During the testing, computer software was able to record the load and displacement about the y-axis and the DIC recorded the displacement of the notch in both the x and y axis. For the purpose of this test, the only parameters that were relevant were the load and the displacement in the x axis. From the data obtained from this testing, the load and CMOD could be investigated for the different samples. The results obtained from the CMOD testing are analysed and evaluated in section 5.4 of this report.

4.5.3 Scanning Electron Microscopy (SEM) Testing

SEM testing was conducted in the Z block laboratories at USQ Toowoomba Campus. SEM testing was conducted to examine the microstructure of the specimens. As very small samples were required, the samples casted had to be broken up into small pieces. The samples were then glued onto holders as seen in figure 4.21. Gloves wear worn during the preparation of the samples as fats from the skin can be seen when using the SEM machine.

Figure 4.21 SEM Sample

Then samples then had to be coated with an ultra-thin layer of gold. The gold sputter coating improves the structural protection of the sample from the electron beam and also improves the conductivity. The gold sputter was applied by using the machine seen in figure 4.22.

Figure 4.22 Machine Used to Apply Gold Sputter Coating

The sample was then placed into the SEM machine and analysed by the use of computer software. The machine and the software were able to examine the specimen accurately up to x500 zoom. The test set up can be seen in figure 4.23 below.

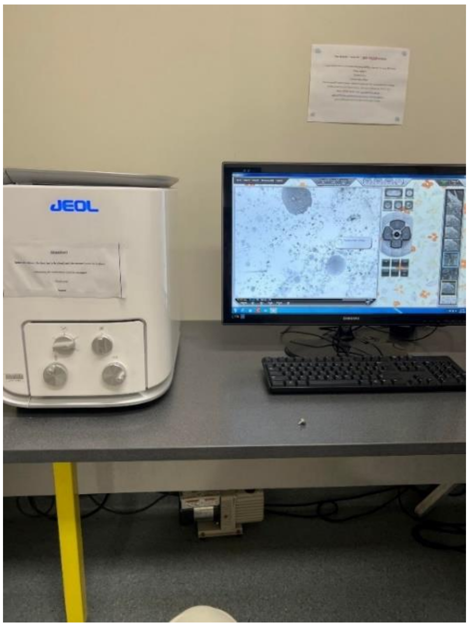

Figure 4.23 SEM Machine and Computer Software

A sample from each batch was examined using SEM to examine the microstructural differences between the batches. The images generated from the SEM testing and the analysis of the samples are described in section 5.5 of this report.

Chapter 5: Results and Discussion

5.1 Fresh concrete properties

The rheological properties of the mortar were determined in accordance with section 3.6.1 of this report. During the mini slump flow test, the dimensions between the edge of the plate and the mortar flow was recorded and from this, the flow diameter was calculated. This can be seen below in figure 5.1.

Figure 5.1 Measuring Length of Flow

For the marsh cone test, a volume of mortar was placed into a cone and the time taken for the mortar to flow through the cone was recorded with the use of a stop watch. This can be seen in figure 5.2 below.

Figure 5.2 Conducting Marsh Cone Flow Test

As defined by Yang et al. (2007), high plastic viscosity and low yield stress of the mortar is optimal to achieve ideal hardened properties and uniform distribution of the fibres in the mixture. High plastic viscosity is represented by an increased marsh cone flow time and a low yield stress is represented by a greater slump flow diameter. Figure 5.3 identifies the relationship between the marsh cone flow time and the pond ash content. Figure 5.4 below shows the relationship between the slump flow diameter and the pond ash content in the mixture

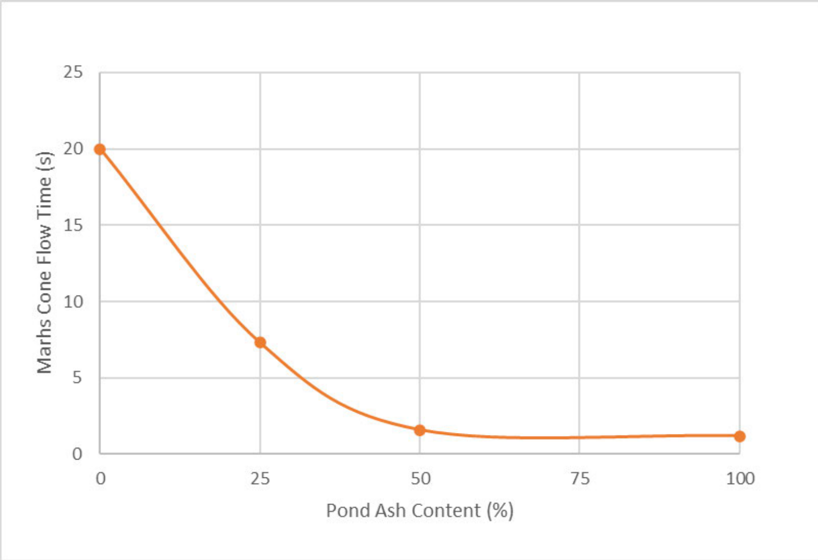

Figure 5.3 Marsh Cone Flow Time of Mortar

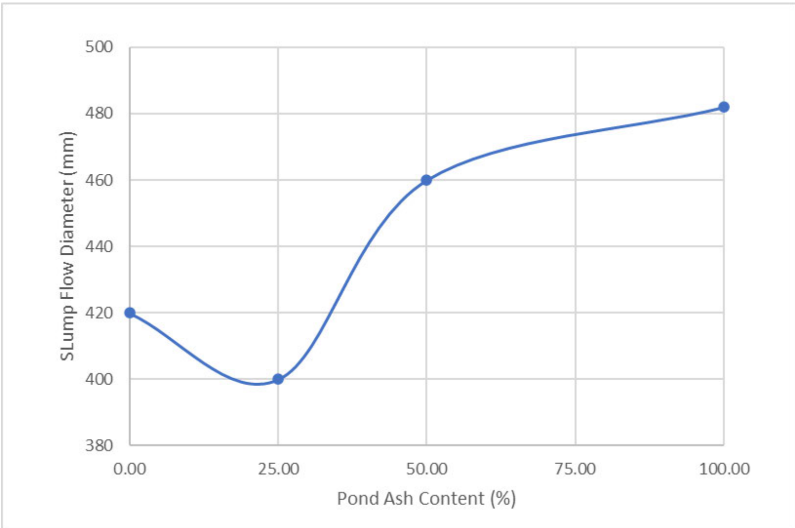

Figure 5.4 Slump Flow Diameter of Mortar

From analysing the graph in figure 5.4, it can be noticed that the slump flow diameter decreases for the 25% pond ash mixture, but then increases for the 50% and 100% mixtures. This indicates that when fly ash is replaced with 25% pond ash, the yield stress of the mortar increases, however at 50% and 100% replacement, the yield stress decreases. It can be noticed that the sample with the lowest yield stress is the 100% pond ash replacement.

The graph shown in figure 5.3 indicates that as the replacement of pond ash increases, the marsh cone flow time decreases. This represents that the as the pond ash replacement percentage is increased, the plastic viscosity decreases.

As previously mentioned, to achieve ideal hardened properties and uniform distribution of the PVA fibres in the mixture, a high plastic viscosity and a low yield stress is optimal. From analysing these results, it was found that the 100% pond ash replacement batch had the lowest yield stress and the 0% pond ash replacement batch had the highest plastic viscosity.

By comparing the plastic viscosity and yield stress in figure 5.5 below, it can be noticed that none of the batches have an ideal high plastic viscosity and a low yield stress. This may indicate that there was not enough mixing energy during the casting process.

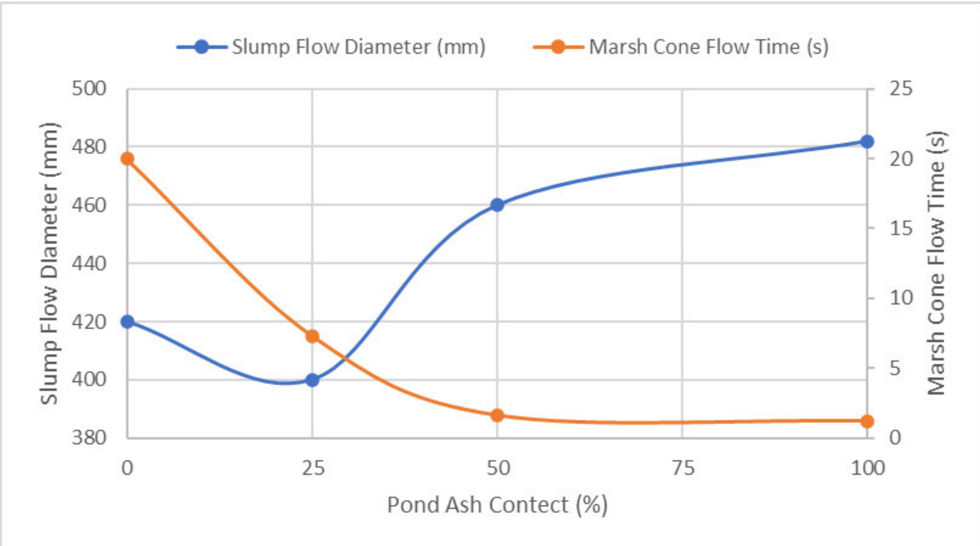

Figure 5.5 Comparing Slump Flow Diameter and Marsh Cone Flow Time of Mortar

5.2 Density

Prior to commencing testing, each of the beams were measured and weighed as seen in figures 5.6 and 5.7 below. It was noticed that majority of the beams had the same dimensions after curing. Some beams were ± 2mm their required dimensions, however this was not considered in the analysis of the results due to the minimal impact it will have on the overall results. The weight of the beams was recorded by using scales provided in the Z block laboratory. All three of the beams from each batch were weighed and the average weight was calculated. It can be noticed in table 5.1 below that the weight increased as the pond ash content increased, and then decreased for the 100% pond ash batch. From determining the volume and weight of the beams, the density of the beams could be calculated, which can be seen in table 5.1 and figure 5.8.

Figure 5.6 Tape Used to Measure Dimensions of Beams

Figure 5.7 Scales Used to Measure Weight of Beams

Sample	Volume (m^3)	Weight (kg)	Density (kg/m^3)
0%	0.00088	1.45	1647.73
25%	0.00088	1.48	1681.82
50%	0.00088	1.57	1784.09
100%	0.00088	1.49	1693.18

Table 5.1 Density calculation of samples

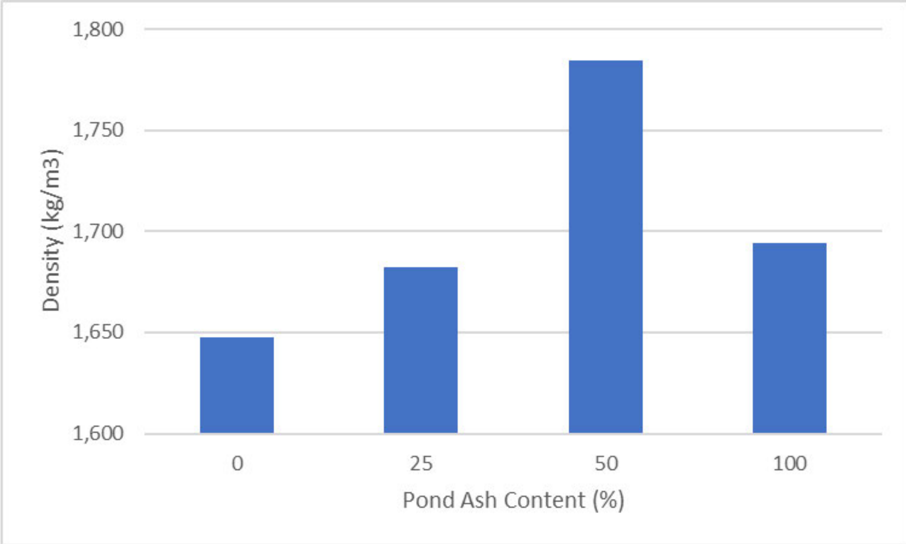

Figure 5.8 Density of Samples

It can be seen in table 5.1 and figure 5.8 that the density of the beams increased as the percentage of pond ash in the batch increased, however for the 100% the density decreased slightly with the removal of fly ash in the mixture. It can be noticed that the sample with the highest density was the 50% batch, and the lowest density was the 0% batch.

5.3 Ductility

The ductility of the beams was analysed by conducting flexural testing in accordance with section 4.4.1 of this report. The testing conducted was successful as all of the beams failed when a load was applied. All of the beams failed in the same manner with similar cracking. This can be seen in figure 5.9 below.

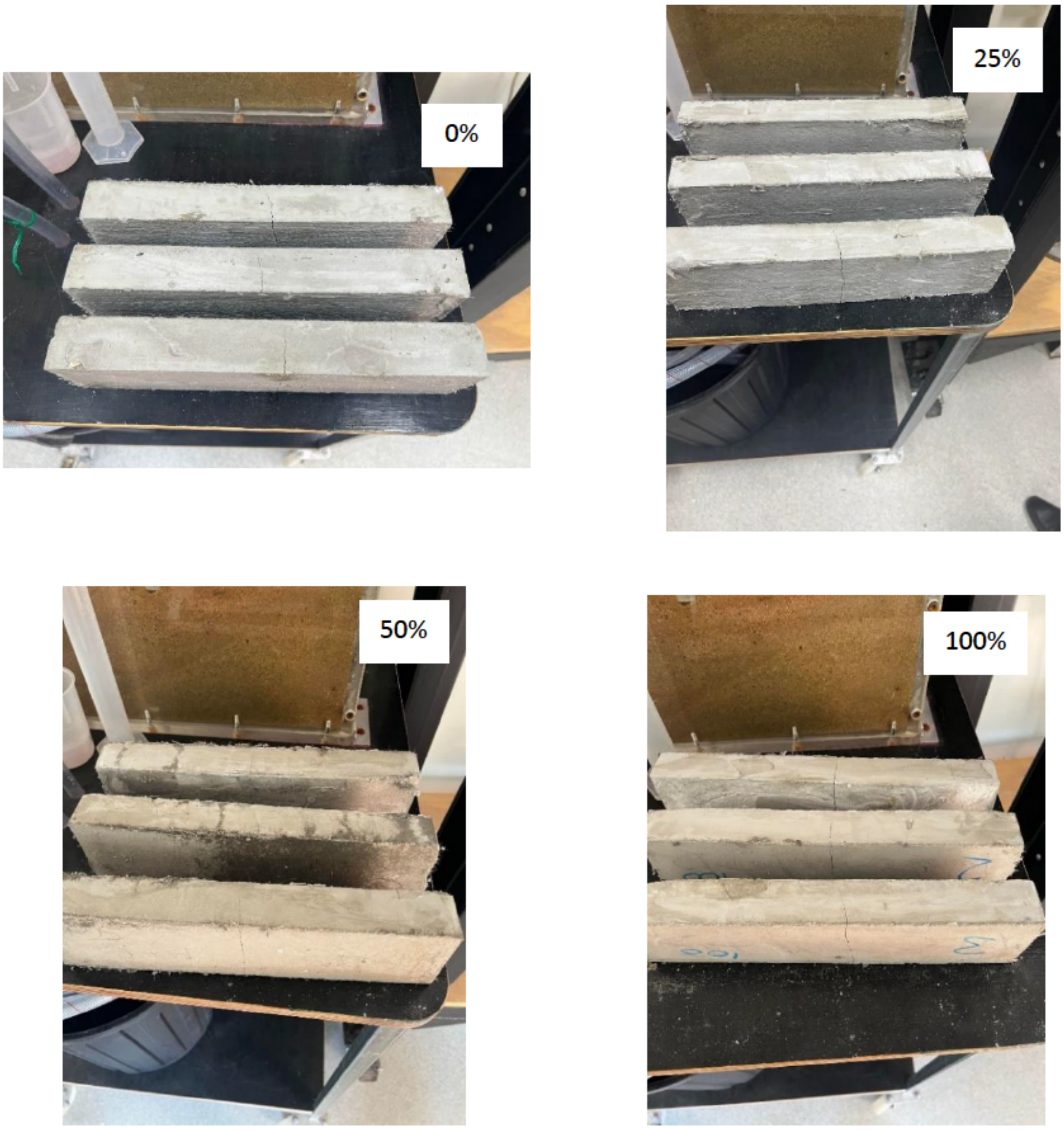

Figure 5.9 Failure of All Beams Undergoing Flexural Testing

From the testing conducted, the load and displacement was able to be recorded. The results obtained were analysed and graphs were produced to be able to compare the results of the different replacement percentages. The load deflection graphs of each sample can be seen below in figures 5.10, 5.11, 5.12 and 5.13 below. It can be noticed that for all of the tests, the three beams from each sample obtained relatively similar results.

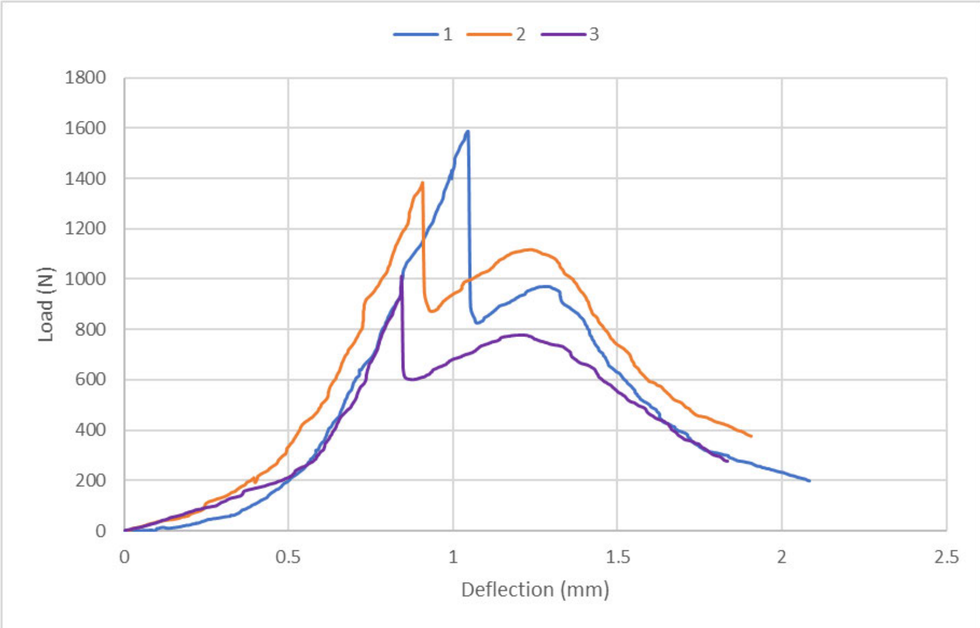

Figure 5.10 Load Deflection Curves of 0% Pond Ash Replacement

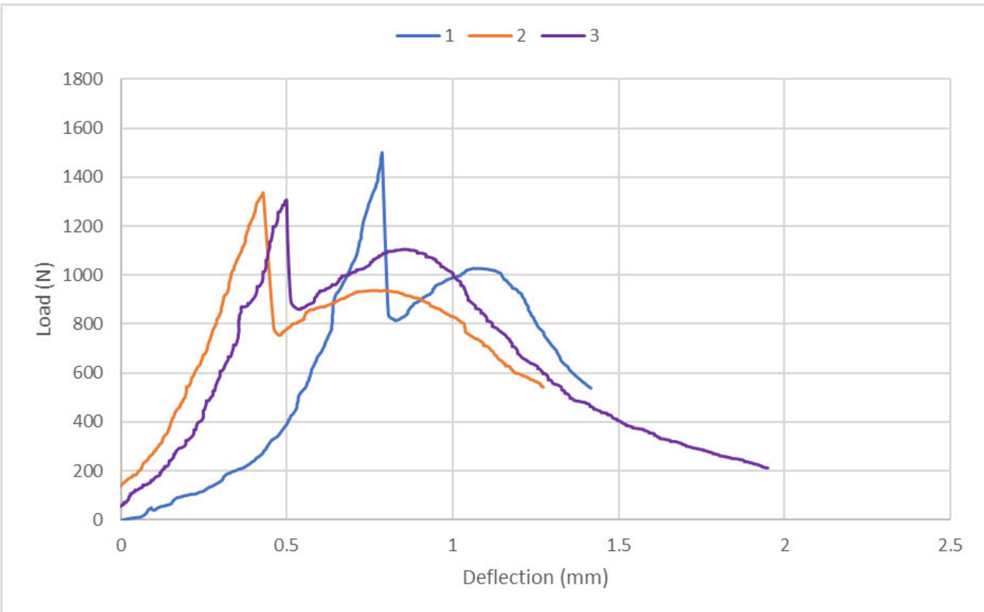

Figure 5.11 Load Deflection Curves of 25% Pond Ash Replacement

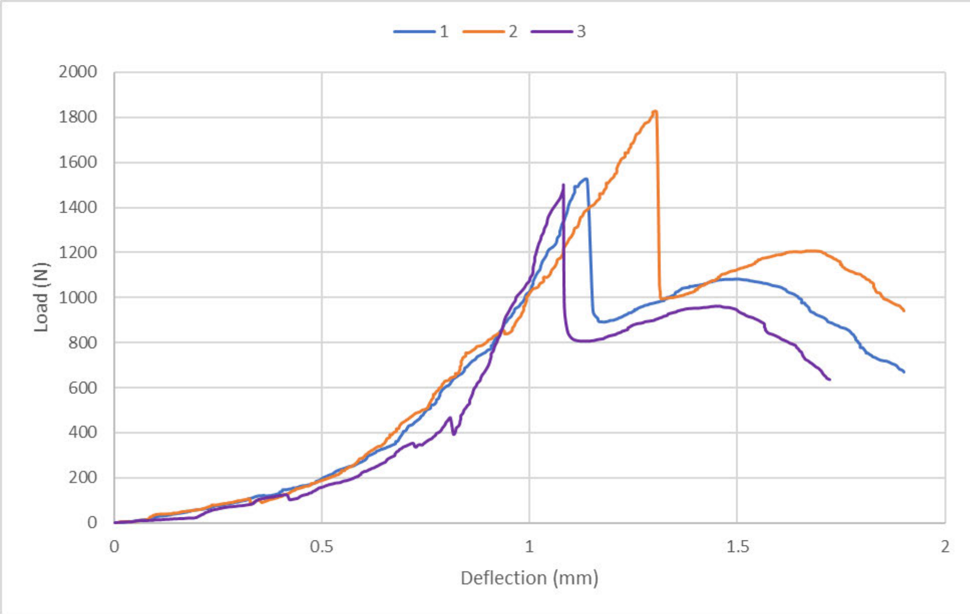

Figure 5.12 Load Deflection Curves of 50% Pond Ash Replacement

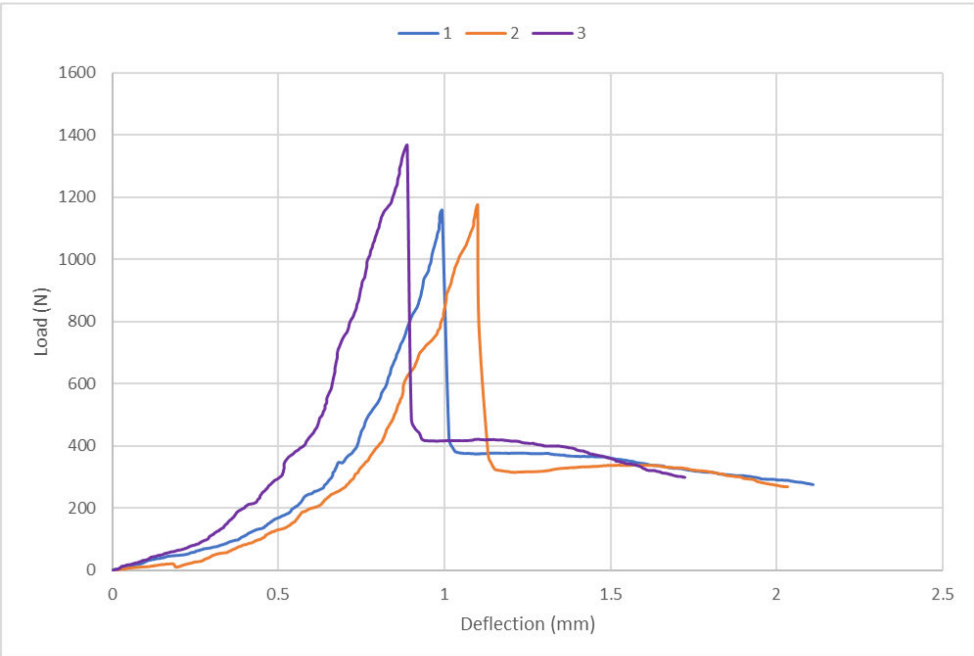

Figure 5.13 Load Deflection Curves of 100% Pond Ash Replacement

The ductility index of each sample was able to be calculated by using the equation identified in section 4.4.1. As each test was not conducted for a long period of time, the ultimate deflection was not recorded. Base of the trends of the load deflection curve, an ultimate deflection of was adopted to for all cases to determine the ductility index. The ductility index for each sample can be noticed in figures 5.14, 5.15, 5.16 and 5.17 below. It can be noticed that the ductility index for each sample in each batch obtained relatively similar ductility indexes.

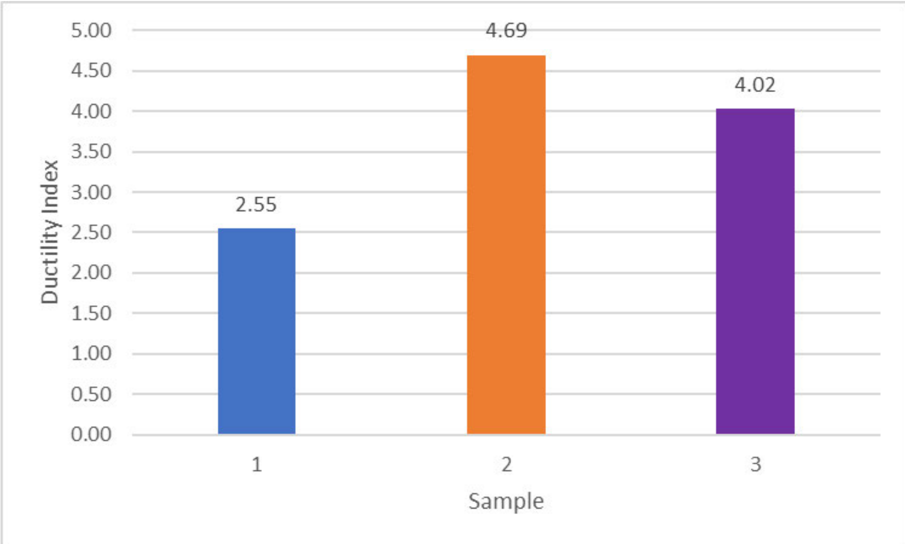

Figure 5.14 Ductility Indexes of 0% Pond Ash Replacement

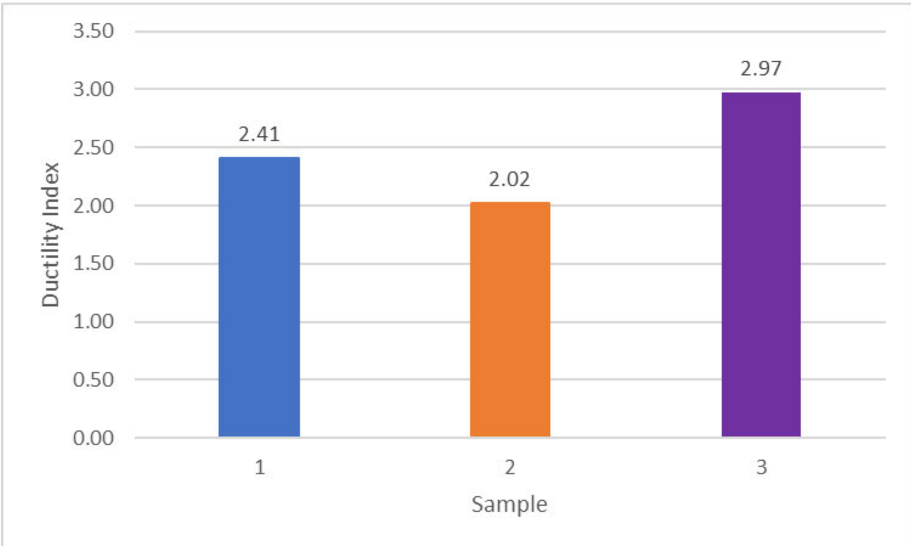

Figure 5.15 Ductility Indexes of 25% Pond Ash Replacement

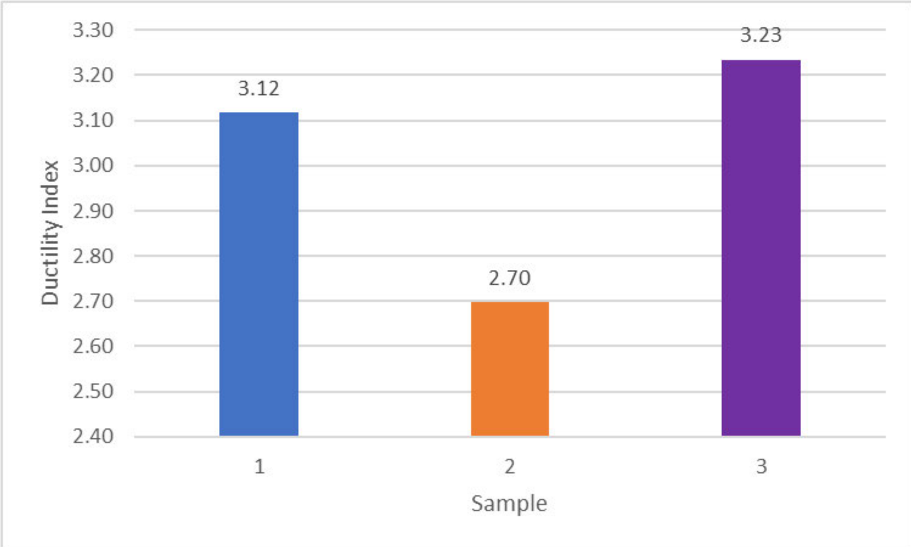

Figure 5.16 Ductility Indexes of 50% Pond Ash Replacement

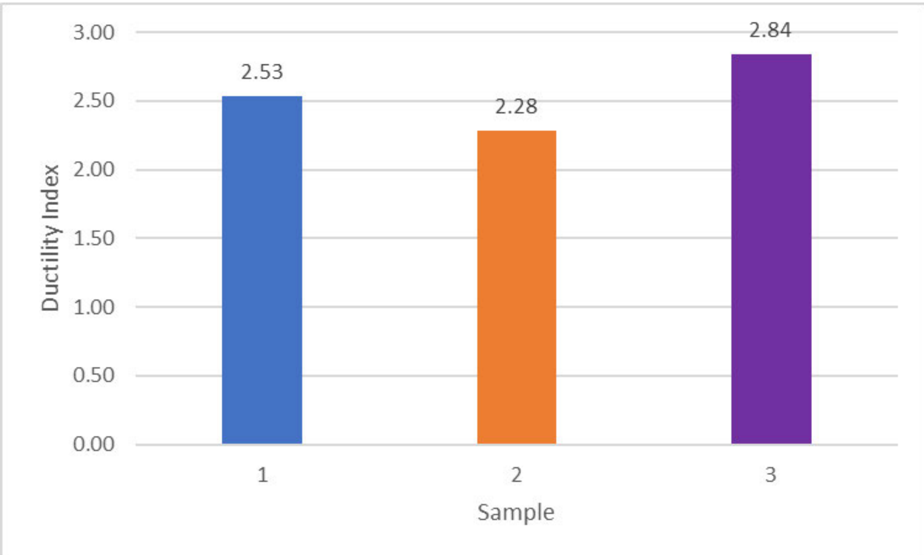

Figure 5.17 Ductility Indexes of 100% Pond Ash Replacement

All of the results analysed were combined to be able to determine which pond ash replacement percentage had the most advance ductility properties. The average line of each load deflection curve was taken from each test and then the average lines were combined to enable an analysis of the different pond ash replacement percentages to be conducted. The combined load deflection curves of each batch can be noticed below in figure 5.18. The ductility indexes of each test was averaged and then the results were combined. The ductility index of each pond ash replacement percentage can be seen in figure 5.19.

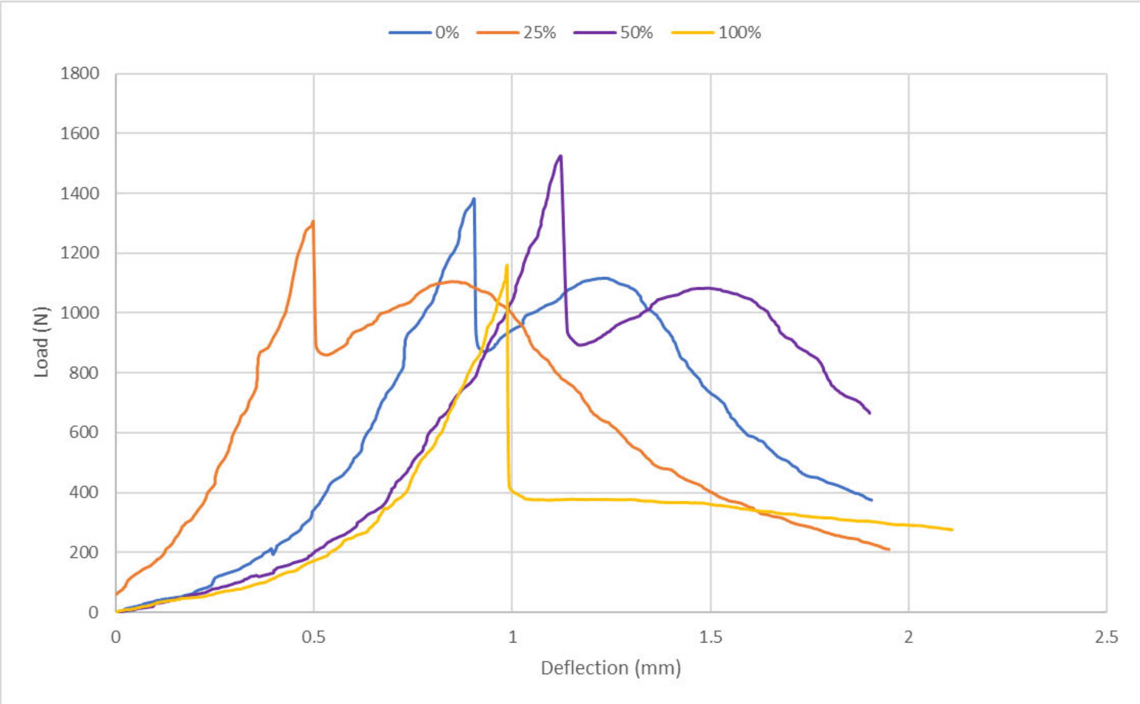

Figure 5.18 Load Deflection Curve Comparison of Pond Ash Replacement Percentages

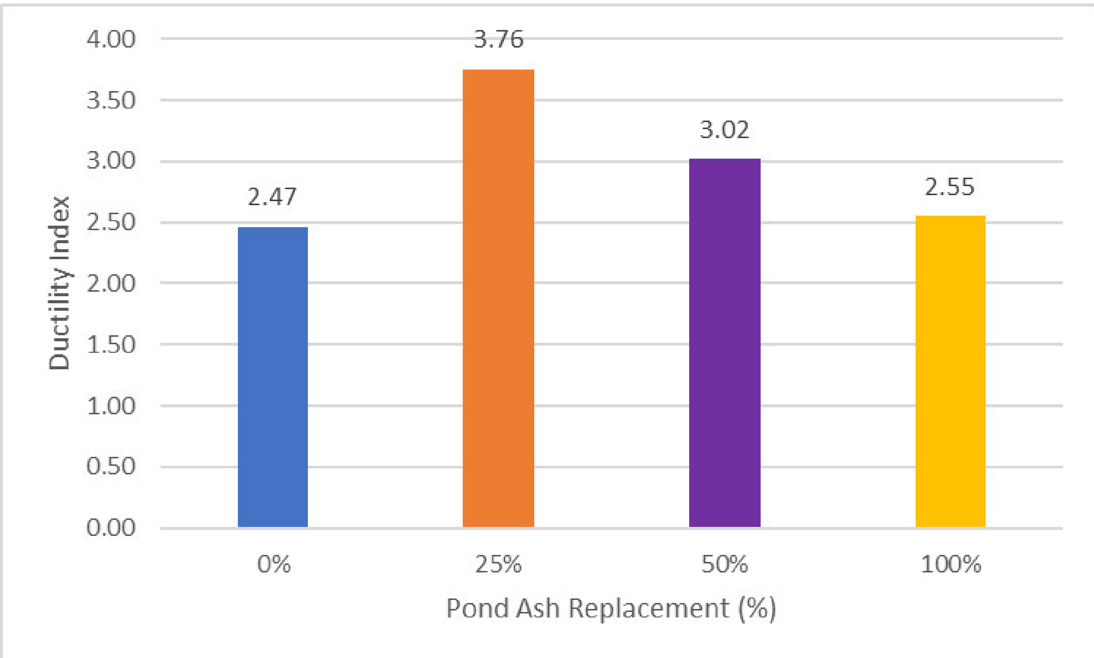

Figure 5.19 Ductility Indexes of Pond Ash Replacement Percentages

By comparing the load deflection curves of the difference pond ash replacement percentages, it can be noticed that each of the percentages experienced the same load deflection relationship, except for the 100% mix. It can be noticed that after the specimen had reached its load capacity, the specimen failed, however, the beam then showed advanced ductile properties as it the load capacity began to increase for a period of time before it slowly started to fail again. For the 100% mix, this relationship was not evident, and the beam did not show any signs of load capacity increase after it had failed, however it did maintain some load bearing capacity. This indicates that the inclusion of pond ash in the mixture has the same ductile properties as fly ash, as it has the ability to sustain plastic deformation after the first point of failure.

The ductility indexes of the different pond ash replacement percentages can be seen in figure 5.19. It is noticeable that the 25% and 50% pond ash replacement had an increased ductility index, compared to the 0% and 100%. In particular, the 25% had the largest ductility index with an index of 3.76. The higher ductility index indicates that the specimen has greater ductility properties and has the ability to sustain plastic deformation. Therefore, the 25% pond ash replacement mixture had the greatest ability to sustain plastic deformation. This confirms that this replacement ratio is the ideal replacement percentage to achieve advanced ductility properties.

5.4 Crack mouth opening displacement (CMOD)

The crack mouth opening displacement was analysed by conducting CMOD testing with the use of a three-point bending machine and DIC technology. The testing was conducted in accordance with section 4.4.2 of this report. The testing was performed successfully as the CMOD was able to be measured accurately with DIC technology. The testing was also successfully performed as all of the specimens failed under an applied load. The cracking of all the test specimens initiated from the notch of the beam. This can be seen in figure 5.20 below.

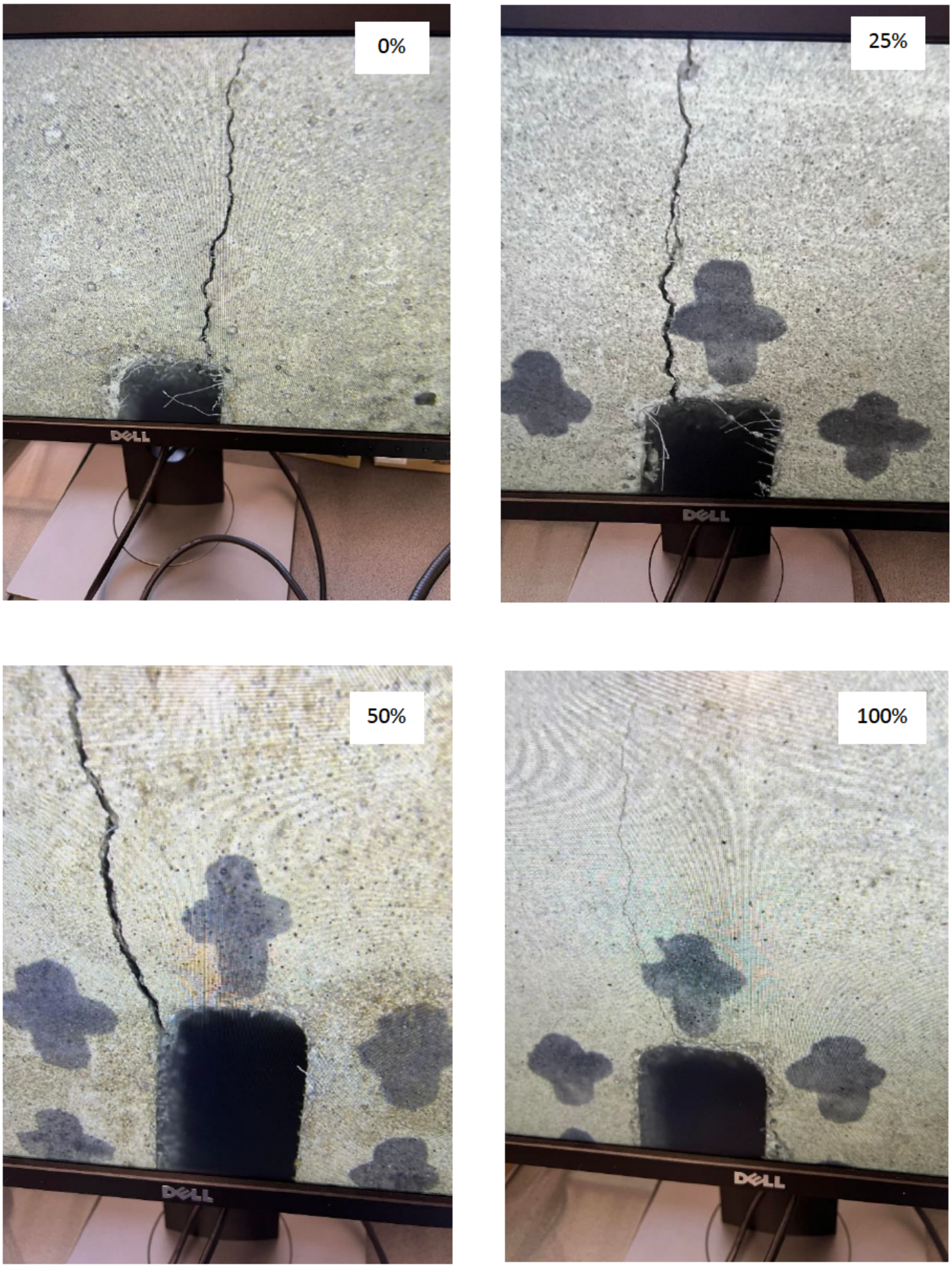

Figure 5.20 Crack Initiation from Top of Notch for Samples

From the testing conducted, the load and x-axis displacement was able to be recorded. The x-axis displacement was recorded by the use of DIC technology. From the x-axis displacement, the CMOD displacement could be calculated. The results were analysed, and graphs were produced to compare the results. The load CMOD graphs for each sample can be seen below in figure 5.21, 5.22, 5.23 and 5.24. It can be noticed that the tests for the control samples are scattered and were not performed long enough due to getting used to the equipment and adjusting the parameters.

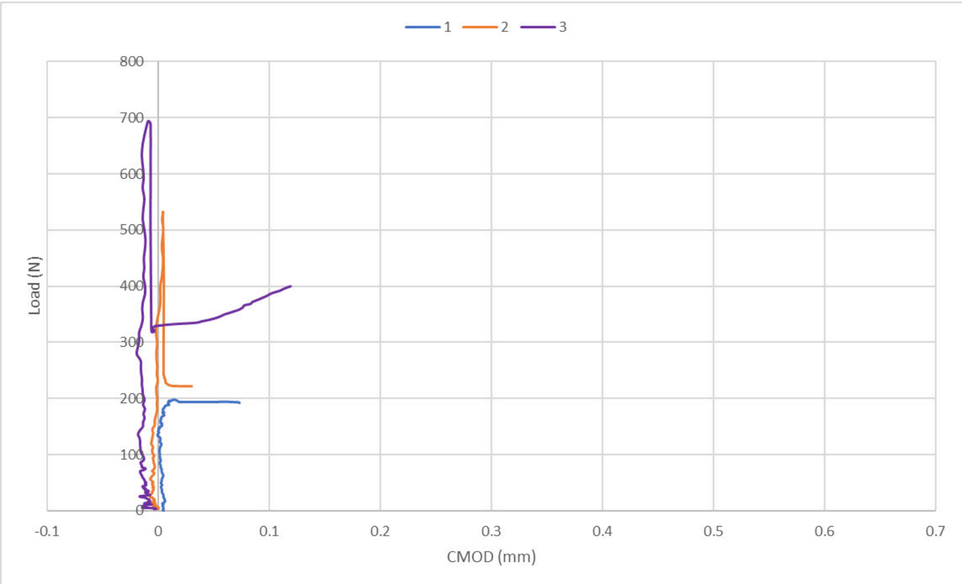

Figure 5.21 Load-CMOD Relationship of 0% Pond Ash Replacement Samples

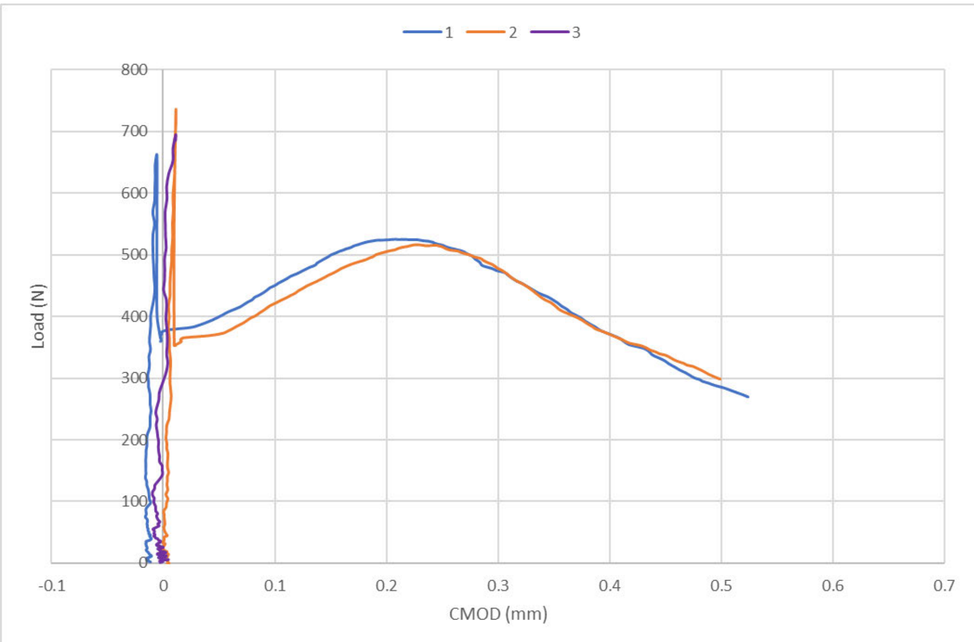

Figure 5.22 Load-CMOD Relationship of 25% Pond Ash Replacement Samples

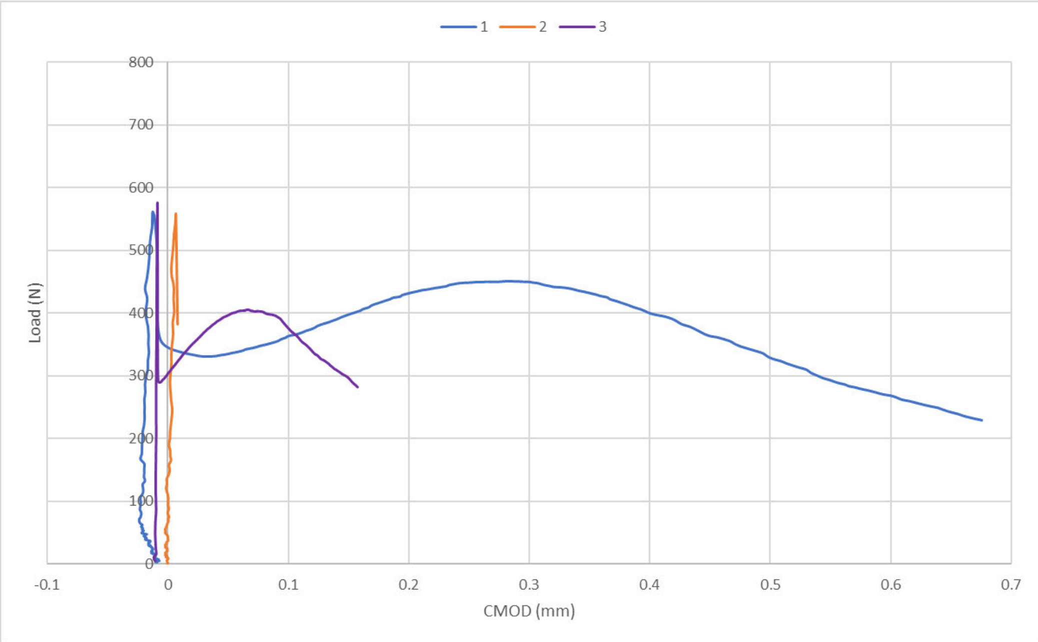

Figure 5.23 Load-CMOD Relationship of 50% Pond Ash Replacement Samples

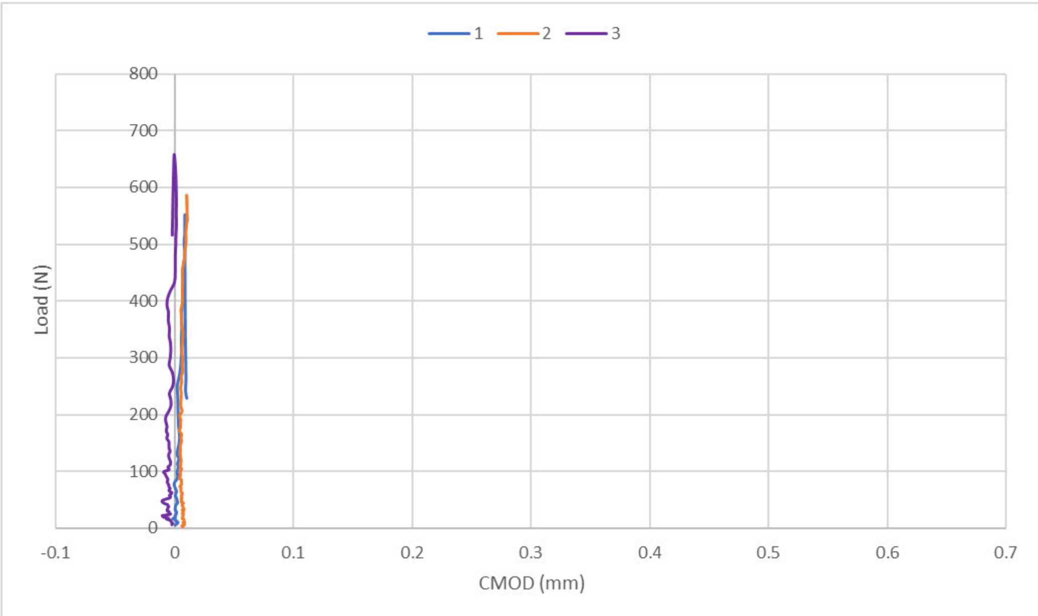

Figure 5.24 Load-CMOD Relationship of 100% Pond Ash Replacement Samples

The analysis of the results were combined to effectively evaluate the load CMOD relationship between the different pond ash replacement percentages. The averages of each test was combined to compare the mixtures. The combined load CMOD graph can be seen below in figure 5.25. From this, the optimal replacement percentage of pond ash could be determined by investigating the load CMOD relationship.

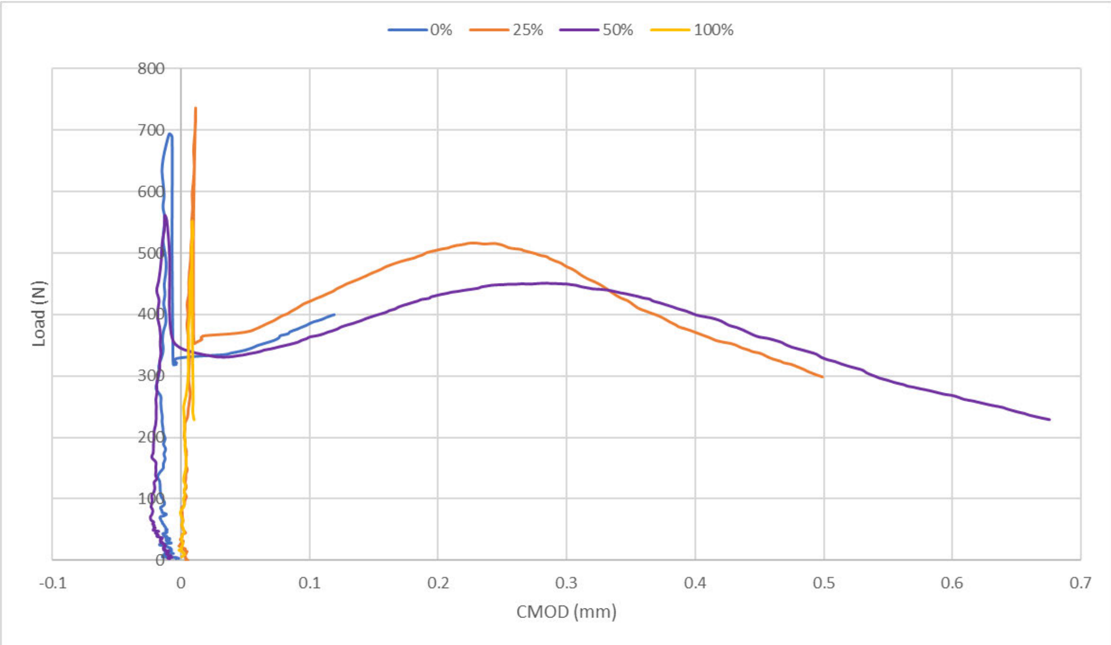

Figure 5.25 Comparison of Load-CMOD Relationships of Different Pond Ash Replacement Percentages Samples

It can be noticed when comparing the results, that the CMOD testing was successful as efficient data was able to be captured. The only evident error from the testing is that the 0% replacement samples testing was not conducted long enough. This was due to getting used to the testing equipment and altering parameters to ensure the testing was conducted effectively. However, the 0% still produced efficient data to interpret the predict trend of the load-CMOD relationship.

The 0% and 25% replacement samples had the greatest initial load bearing capacity. It can be noticed that the 25% replacement sample had the greatest load bearing capacity. By analysing the post cracking performance, it can be noticed that the 0%, 25% and 50% replacement samples all had good performance. Each of these samples were able to generate load bearing capacity again after cracking. Even though the 0% test was stopped too soon, the trend of the data indicates that it would have gained more load bearing capacity, before slowly starting to fail again. For the 100%, it can be noticed that the post cracking performance was non-existent and failed completely. From the graph in 5.22, it is clear that the 25% replacement sample had the greatest post cracking performance as it reached the highest load bearing capacity.

To effectively analyse the residual strength of the samples, the testing would have had to be conducted for a longer period of time. The residual strength is determined by observing the CMOD value when the sample has reached ultimate failure. Based off the trends of the curves in figure 5.25, it can be predicted that 0%, 25% and 50% would all have similar residual strengths. Further testing would have to be conducted to effectively analyse the residual strengths of the samples.

Based on the results obtained, it is evident that the 0%, 25% and 50% replacement samples all had similar post cracking performance and residual strengths. However, the 25% replacement sample had the highest load bearing capacity after initial cracking, which indicates that this replacement ratio had the optimal performance.

5.5 Scanning electron microscopic (SEM) analysis

SEM testing was conducted in accordance with section 4.4.3 of this report to analyse the microstructure of the different mix designs. Below in figures 5.26, 5.27, 5.28 and 5.29 are some images captured from the SEM technology of the microstructure of the different samples that were used in this research project.

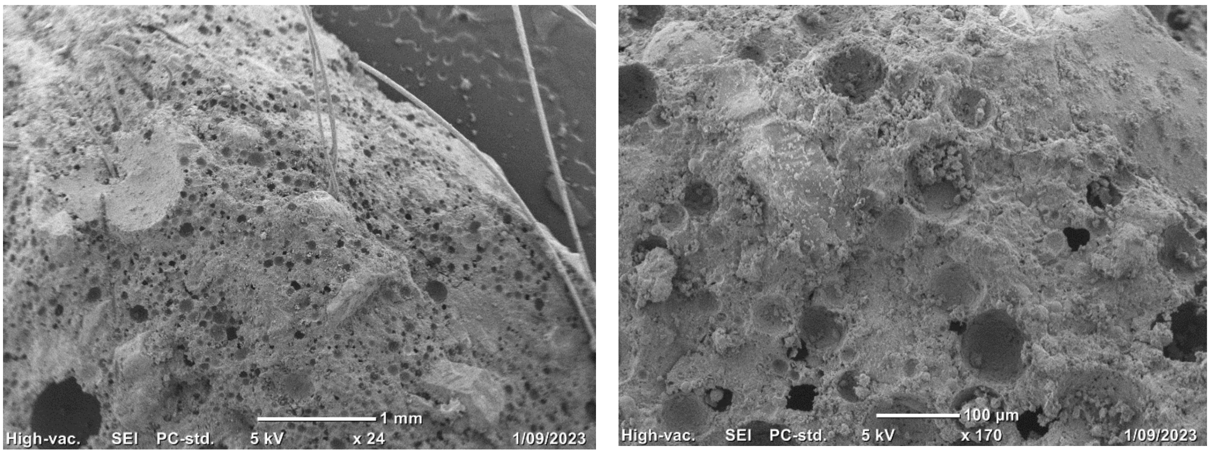

Figure 5.26 SEM Images of 0% Pond Ash Replacement Sample

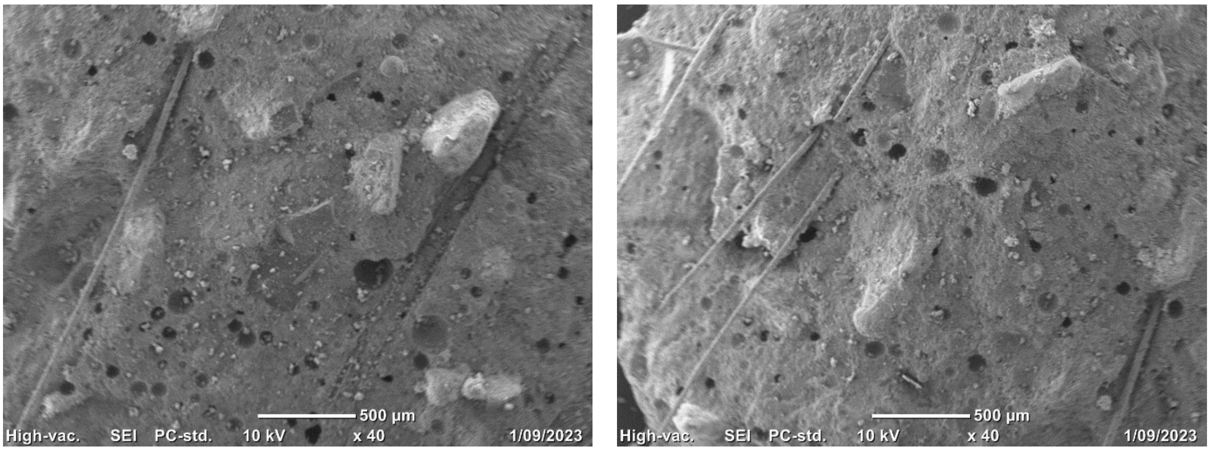

Figure 5.27 SEM Images of 25% Pond Ash Replacement Sample

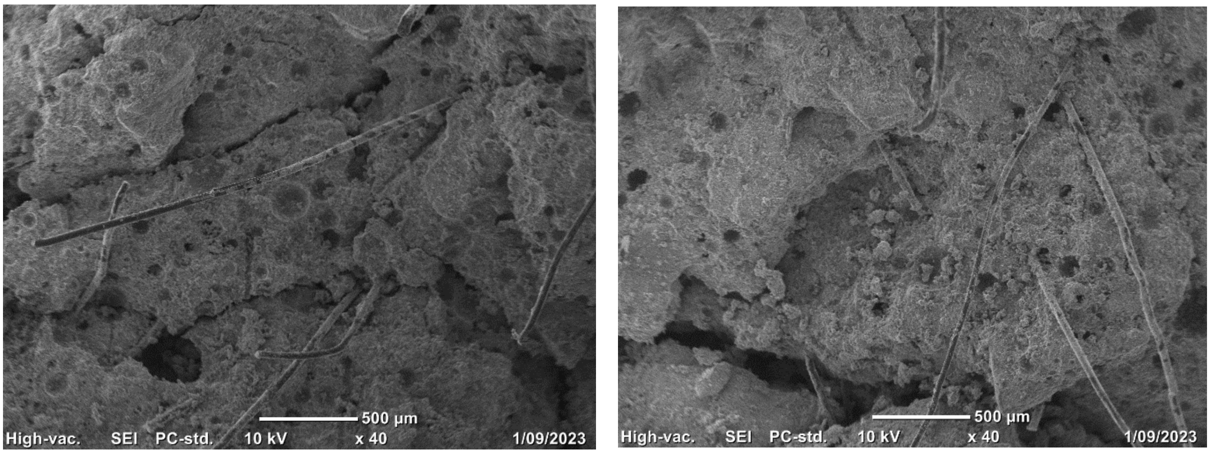

Figure 5.28 SEM Images of 50% Pond Ash Replacement Sample

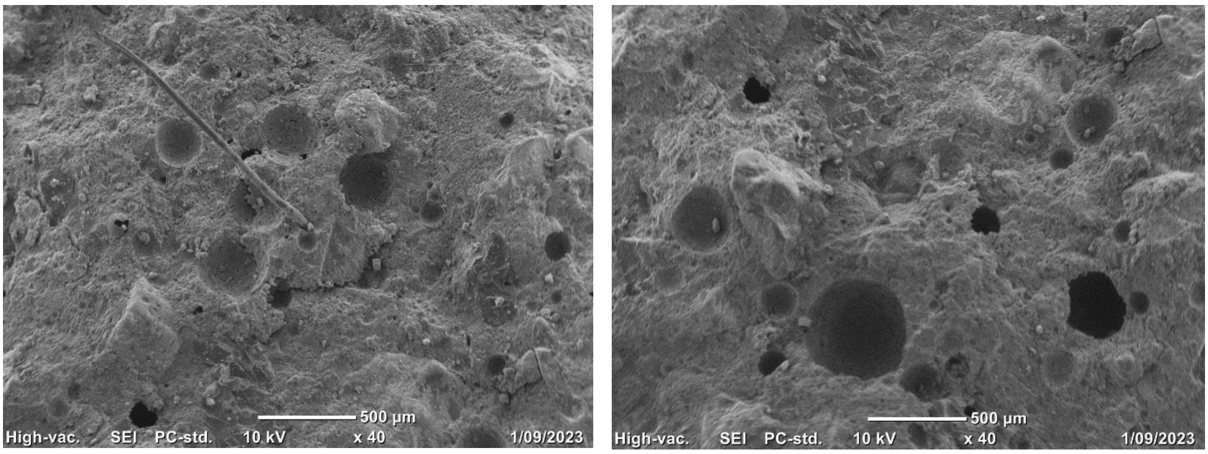

Figure 5.29 SEM Images of 100% Pond Ash Replacement Sample

By comparing the different batches, it can be noticed that the samples are relatively similar at the microstructural level. From observing the images, the 100% pond ash replacement sample has larger pores throughout its structure, which indicates why it does not have the same ductility and ultimate load capacity properties as the other samples. It can also be noticed that the 25% and 50% samples are almost identical, except that the 50% has more cracking present in the structure. The 0% sample has larger pores when compared to the 25% and 50% sample, which indicates why it does not have the same properties as these samples. Overall, it can be noticed from the SEM images that the 25% pond ash replacement sample has the optimal microstructure properties, which is why it has performed the best during the testing phase.

Chapter 6: Conclusion

6.1 Summary

The main aim of this research project was to replace fly ash with pond ash and investigate the ductility and cracking behaviours to confirm if pond ash is a successful replacement. As the production of cement contributes approximately 8% of global CO_2 emissions, the addition of pond ash in ECC would help reduce climate change as it is a waste product.

By analysing the ductility properties of the samples by conducting flexural testing, it was found that the 0%, 25% and 50% replacement samples all showed advanced ductile properties as the load capacity increased after initial cracking. It was found that the 25% replacement sample achieved the greatest load capacity after cracking. In terms of the ductility index, it was found that the 25% and 50% had increased ductility indexes compared to the 0% and 100%, in particular, the 25% had the greatest. This indicates that the 25% replacement sample had the greatest ductility properties.

The analysis of cracking behaviours by the use of CMOD testing found that the 25% replacement sample had the optimal post cracking performance; however, for the 0% replacement sample, the testing was not conducted for a long enough period of time to effectively analyse the post cracking behaviour. The residual strength of the samples was only predicted based off the Load-CMOD curve as the testing needed to be conducted for a longer period of time to determine the CMOD value at the ultimate failure. From the prediction, it was determined that the 0%, 25% and 50% would all have similar residual strengths. The strain mapping capability of the DIC was unavailable during testing, which would have assisted to further analyse the cracking behaviours.

SEM imagining confirmed that all of the samples were relatively similar at the microstructural level. The images align with the results as the 0% and 100% replacement samples had larger pores when compared to the 25% and 50% replacement samples. The 50% replacement sample had noticeable more microstructural cracking than the 25% replacement sample, which confirmed that the 25% replacement sample had the optimal microstructural properties.

Overall it can be concluded that this research has provided evidence that pond ash is a successful replacement in ECC; however future research should be conducted to effectively determine a precise replacement percentage. By using the waste product of pond ash in the construction industry, it will help reduce the negative impact waste materials has on the environment and human health. This is essential for the longevity of our climate and future research in this field will further assist with reducing CO_2 emissions and waste products.

6.2 Future Research

From conducting this research project, it is noticeable that future research is required to accurately determine if pond ash is a successful substitute for fly ash in ECC.

Several parameters within this research were not able to be accurately analysed due to material availability and also performance of the testing conducted. It was mentioned in this report that the residual strength was not able to be analysed due to not performing the testing for a longer period of time. Also, the strain map capability of DIC was unavailable during testing, which would further assist with analysing the cracking behaviours. If future research was conducted, these parameters could be accurately analysed.

Further research regarding this topic could include a variety of parameters to further justify if pond ash is a successful replacement of fly ash. By performing and in-depth analysis of replacement percentages between 25-50, it would be able to determine a more accurate replacement percentage. Further research could also validate if the results obtained from this research project align with other research. Using pond ash from several locations would be an example of a parameter that could confirm these results.

There are multiple areas that could be explored that further extend from this research. By conducting further research, it will assist with exploring the aims and objectives of this research project.

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Appendix A – Project Specification

ENG4111/4112 Research Project

Project Specification

For: Blake Neumann

Title: Ductility and Cracking Behaviours of Engineered Cementitious Composites

Major: Civil Engineering

Supervisor: Weena Lokuge

Enrollment: ENG4111 – EXT S1, 2023

ENG4112 – EXT S2, 2023

Project Aim: To investigate and analyse the ductility and cracking behaviours of engineered cementitious composites. This will involve sample preparation, testing and analysing the results. By conducting the project using several design mixtures, the ductility and cracking behaviours will be able to be analysed over a range of results.

Programme: Version 2, 30th March 2023

1. Conduct research regarding the research topic and gain further knowledge regarding engineered cementitious composites.

2. Plan experiments and source materials for the developed methodology.

3. Conduct testing such as mechanical properties in accordance with the Australian Standards.

4. Gather and analyse the results.

5. Submit dissertation and conduct presentation.

As time and resources permit:

6. If the outcomes of the research are successful, research and investigate the practical uses of the desired engineered cementitious composite mixture.

7. Use a computer model to analyse the results obtained from the project and determine if they are similar.

Appendix B – Risk Assessment

Risk assessment and management was conducted to ensure all risk associated with conducting the project were identified and assessed. The risk assessments were conducted using Table B1. The risk assessment for the experimental works can be shown in Table B2. This is also available on the UniSQ Safe Track System (Ref No: 2544). Further project risks can be seen in Table B3.

Table B1 – Risk Assessment Matrix

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					

Table B2 – Experimental Risk Assessment

NUMBER	RISK DESCRIPTION	TREND	CURRENT	RESIDUAL
2544	Testing ductility and cracking behaviours of engineered cementitious composites		Low	Low

DOCUMENTS REFERENCED

RISK OWNER	RISK IDENTIFIED ON	LAST REVIEWED ON	NEXT SCHEDULED REVIEW
Blake Neumann	02/06/2023	05/07/2023	05/07/2024

RISK FACTOR(S)	EXISTING CONTROL(S)	PROPOSED CONTROL(S)	OWNER	DUE DATE
Working with cement, fly ash, pond ash, PVA fibres and other materials. Potential risk of eye, skin, lung damage and also burns.	**Control:** Clear access to eye wash and shower station. Following the handling procedures in the SDS for the particular material. Working under the supervision of technical staff. **Control:** Ensuring appropriate PPE is worn (glasses, gloves, mask and other essential equipment).	**No Control:**		
Strain injuries from lifting samples and using testing equipment.	**Control:** Use correct lifting methods. Using available assistance equipment to lift heavy samples. Seek assistance for lifting heavy samples.	**No Control:**		
Injury from operating concrete mixer.	**Control:** Ensure machine is working properly before use. Stay clear of machine while it is operating. Ensure machine is off and finished rotating before removing concrete. **Control:** Ensure appropriate PPE is worn (steel cap boots, gloves and glasses).	**No Control:**		
Injury from operating concrete tester.	**Control:** Laboratory induction has been conducted. Technical staff will operate the equipment and supervise the testing. **Control:** Ensure appropriate PPE is worn (steel cap boots, gloves and glasses).	**No Control:**		
Injury from damaged electrical cords.	**Control:** Ensure electrical cords are not damaged. Check tag to see if they have been serviced. Ensure work area is dry.	**No Control:**		
Noise exposure from operating equipment.	**Control:** Ensure hearing protection is worn when operating loud equipment.	**No Control:**		
Injury from objects falling and also tripping/falling.	**Control:** Ensure appropriate PPE is worn (steel cap boots).	**No Control:**		
Injury caused from untidy and unorganised work area.	**Control:** Ensure work area is tidy and clean up any mess immediately. Ensure other people are not working within designated working area.	**No Control:**		

Table B3 – Other Project Risk Assessment

Risk	Risk Level	Control	New Risk Level
Sitting at computer for long hours	M	Ensure regular breaks are taken to rest eyes. Ensure work set up is tidy and set up correct.	L
Computer/internet malfunction	L	Ensure computer is in good working order. Have a back up computer/laptop to complete work if required. Ensure internet connection is adequate.	L
Laboratory not available	M	Book laboratory in well in advance and ensure time can be taken off work for set time.	L
Materials not available	M	Check with supplier to ensure materials are in stock. Source materials from alternative suppliers if not available.	L
Loss of experimental data	M	Ensure there is a back up copy of the data.	L
Loss of report	M	Ensure there is a back up copy of the report.	L
Insufficient time to prepare for presentation	L	Make sure all testing is completed early to allow adequate time to analyse data.	L
Insufficient time to complete report	L	Make sure an adequate timeline is prepared and that leave is taken off work to complete report.	L

Appendix C – Laboratory Inductions

Z1 Laboratory Safety Induction Form

UNIVERSITY of SOUTHERN QUEENSLAND

Laboratory Specific Safety Induction Checklist

Z1 Civil Laboratory

To obtain laboratory and equipment use authorisation, a student must read, understand and sign off this Laboratory Specific Safety Induction Checklist before commencing work in any laboratory.

No	Item	Description	√
1	Introduce relevant staff	Academic and technical staff involved	☑
		USQ Emergency contact Number – 2222 - [illegible] Location of nearest telephone - Z1.101A Location of First aid kit - Next to z1.106 room	☑
		Exists and Assembly areas • In case of fire or other danger Proceed in an orderly manner to the designated assembly point. Emergency Squad Members will be on hand to direct you to this area so, please follow the instructions. • Do not return to buildings until authorised personnel give the ALL CLEAR.	☑
2	**Emergency Procedure**	Evacuation Alarm – (Automatic smoke/heat detector) • The alarms are very sensitive so be careful what work you do near them. • When the alarm sounds, evacuating the building immediately and head off to the assembly area. • If it is safe to do so you can take your personal belongings with you but under no circumstances re-enter the building to get your possessions. • If you are aware of a false alarm, or that an emergency does not exist, inform the Building Warden in person after the evacuation. • Keep all roadways clear. • Inform an Emergency Squad member if there are any persons with a disability or an injury who require assistance. Fire Extinguisher • Staff only to use. Before using a fire extinguisher, read the instructions to ensure it is appropriate for that type of fire.	☑
		If you require first aid, please see the Academic or Technical. Please report any injuries or accidents /incidents	

SAFETY INDUCTION CHECKLIST 1/5

3	**First Aid**	to Academic or Technical staff and ensure an incident report form is complete. Safety Blanket, Safety Shower and Eye wash • Student must familiarise themselves with the nearest accessible location of these. Please see Academic or Technical staff before using to ensure suitability	
4	**Behaviour**	• Reckless behaviour, practical jokes or unauthorised experiments in the laboratories are strictly prohibited. • Eating and drinking are strictly prohibited inside laboratories.	☑
5	**Housekeeping**	• Good housekeeping practices should always be followed to maintain work areas in neat and tidy manner. • Small spills shall be cleaned up immediately from work areas and floors. (Contact Technical Officer for large spills.) • All tools and equipment shall be returned to their proper storage location after use. • Access to exits, hallways, emergency equipment, and utility controls shall remain accessible at all times. • Disposal of waste should be in the appropriate containers. Eg: Please make sure not to exceed the weight capacity written for the metal bins (mainly for concrete waste). Disposing of either chemicals, contaminated liquid or any solid matters in to laboratory drains is strictly prohibited.	☑
6	**Personal Protective Equipment**	• You will not be allowed in to the laboratories without enclosed footwear. All other personal protective equipment (safety glasses, gloves, lab coats, ear protection, dust masks, etc.) must be worn as appropriate(eg: asphalt area needs steel capped safety shoes, heat protective gloves, lab coats, eye protection and ear muffs) • Please see Technical Staff or feel free to access PPE (Eye protection, gloves, ear protection and dust masks only) and their storage locations.	☑

7	**Use of equipment**	• It is the responsibility of students to ensure they have been fully instructed in, and understand the use of equipment before operating it. • Check, read and understand the SWP/SOP documents attached to the equipment before use (eg: Concrete mixer, CBR machine, Marshal test frame, ovens etc.) • No equipment of any type may be operated unless the person is authorised to do so(eg: Compression Testing machine) • Report for any damage or faulty equipment found. • Do not attempt to operate/use any item which has been tagged unusable for safety reasons. • Make sure to turn off power once the task is complete.	☑
8	**Risk assessments**	• Risk assessment forms(online version) must be completed by the student incorporating with his/her academic supervisor and USQ SAFE representative as required, and should be assessed by an authorised person before any experiment or project is undertaken independently (***These are not applicable for practice course sessions***). • Each and every step of the experiment must be included in the Risk assessment and the developed risk assessment should be revised if any alterations occurred with the on-going experiment. • No laboratory work will be permitted without a completed Risk Assessment document.	☑
9	**Manual Handling**	• Employ correct methods while lifting and shifting. • Apply correct postures appropriately in lifting and shifting goods (lifting and shifting of concrete moulds, concrete samples, materials, drop hammers etc.) • Do not over –reach and ensure stable footing at all times. Please refer to the laboratory specific safety guidelines for more details. • Use available lifting aids; trolleys, scissor or electric lifter as appropriate and be conscious about their carrying capacities. If heavy lifting, or pushing and pulling is involved, seek help from staff.	☑
10	**Storage**	• Samples to be tested should be labelled and kept only in designated areas for storage(eg: in fog room) • All the unlabelled samples would be discarded by the laboratory tech staff without further notice.	☑

		• Limited storage space is available. Samples or experimental setups must be discarded or removed from the lab once the work finished.	
11	**For Post-grad and Project students only**	After Hours Access policy • Normal working hours in this laboratory are weekdays 8.00 am to 5.00 pm. • Laboratory staff should be consulted if work in the laboratory after hours is required. • No undergrad students are allowed for after hour access. • Staff and post grad students must have an approved after hour access form authorised by the academic supervisor and Head of School if necessary. The form of approval must be forwarded to the relevant tech staff to act accordingly. • It is a general rule that No duplicate keys for laboratory doors will be issued for student's name. Students must borrow keys from tech staff or ask help from USQ security. A copy of signed authority form and University ID card must be carried with you when working after hours. Rules of access – • Ensure that doors to buildings and internal areas are securely closed and locked after entering and leaving the building • Ensure that you are familiar with USQ safety rules and emergency contact numbers • You will not lend keys to another person • You must not provide access to unauthorized persons in to the building • Operation of equipment – No equipment may be operated unless two persons are present	☐ NA

Name (print) Blake Neumann

Student No [redacted]

Signature [redacted]

Date 17 / 5 / 23

Technical Staff Piumika Angela.

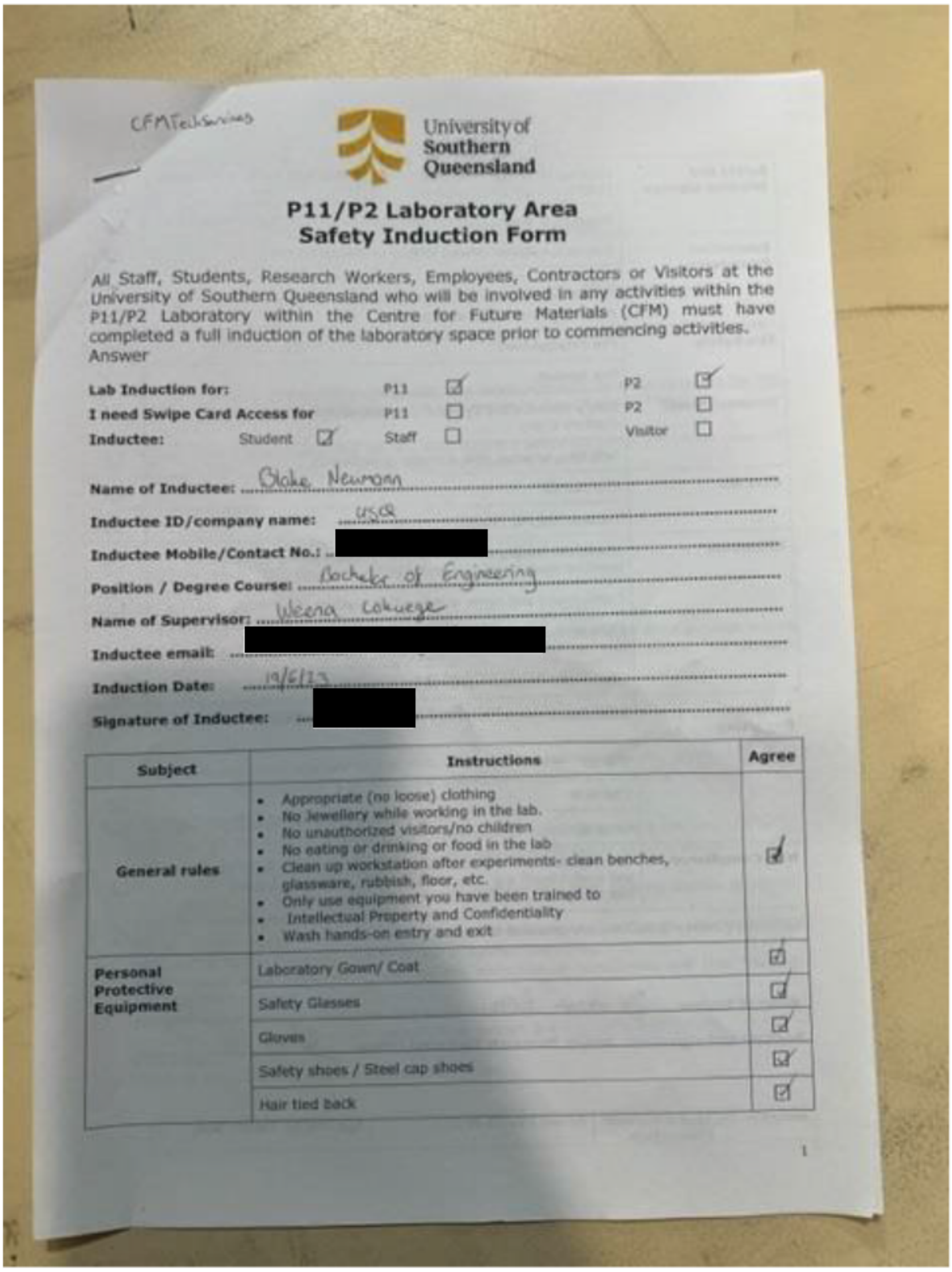
Signature [redacted]

Supervisor

Signature

SAFETY INDUCTION CHECKLIST 4/5

P11/P2 Laboratory Safety Induction Form



CFMTechServices

University of Southern Queensland

P11/P2 Laboratory Area Safety Induction Form

All Staff, Students, Research Workers, Employees, Contractors or Visitors at the University of Southern Queensland who will be involved in any activities within the P11/P2 Laboratory within the Centre for Future Materials (CFM) must have completed a full induction of the laboratory space prior to commencing activities.
Answer

Lab Induction for: P11 ☑ P2 ☑

I need Swipe Card Access for P11 ☐ P2 ☐

Inductee: Student ☑ Staff ☐ Visitor ☐

Name of Inductee: Blake Newman

Inductee ID/company name: USQ

Inductee Mobile/Contact No.: [redacted]

Position / Degree Course: Bachelor of Engineering

Name of Supervisor: Weena Lokuge

Inductee email: [redacted]

Induction Date: 19/6/23

Signature of Inductee: [redacted]

Subject	Instructions	Agree
General rules	• Appropriate (no loose) clothing • No Jewellery while working in the lab. • No unauthorized visitors/no children • No eating or drinking or food in the lab • Clean up workstation after experiments- clean benches, glassware, rubbish, floor, etc. • Only use equipment you have been trained to • Intellectual Property and Confidentiality • Wash hands-on entry and exit	☑
Personal Protective Equipment	Laboratory Gown/ Coat	☑
	Safety Glasses	☑
	Gloves	☑
	Safety shoes / Steel cap shoes	☑
	Hair tied back	☑

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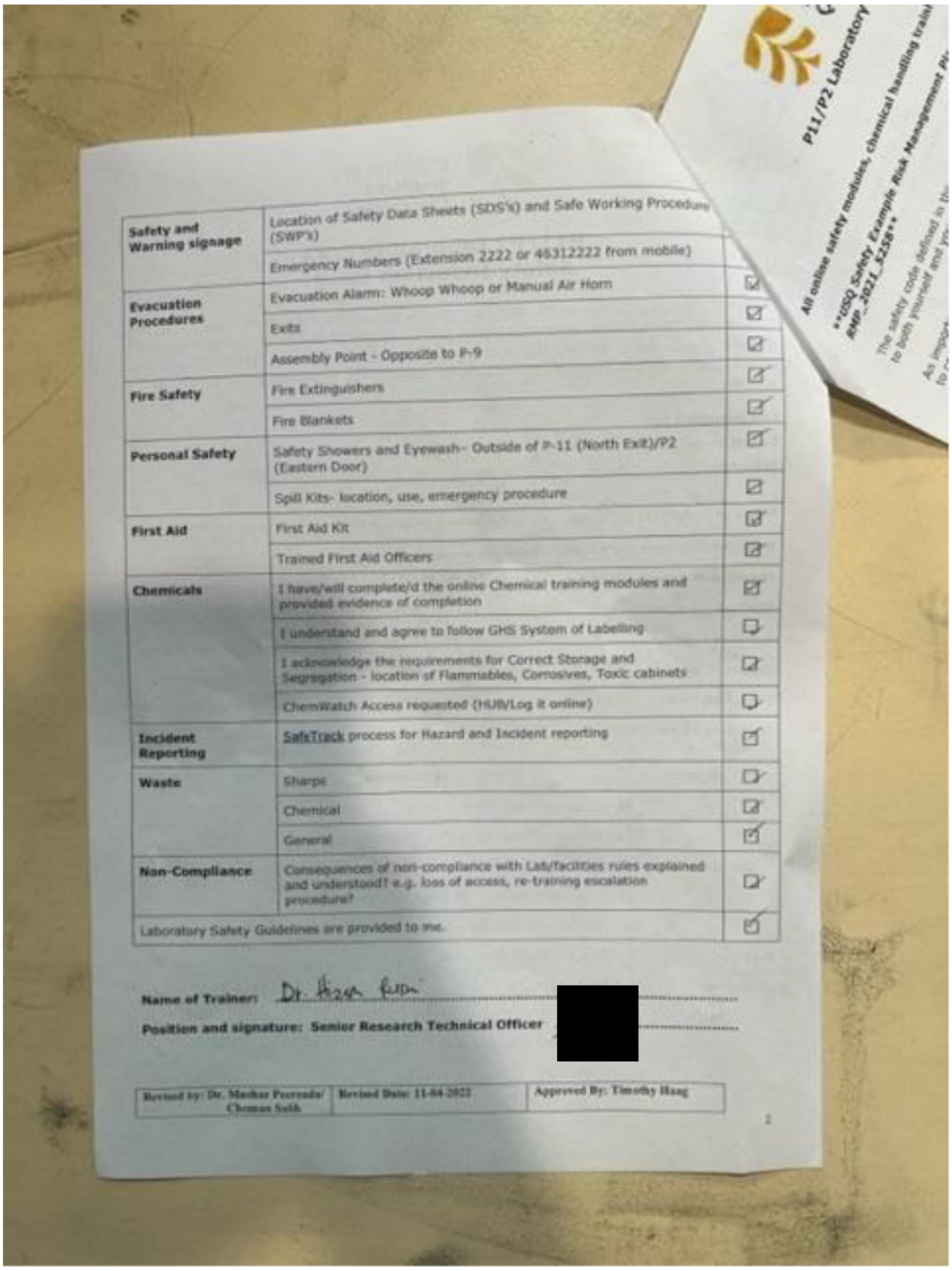

Safety and Warning signage	Location of Safety Data Sheets (SDS's) and Safe Working Procedures (SWP's)	
	Emergency Numbers (Extension 2222 or 46312222 from mobile)	
Evacuation Procedures	Evacuation Alarm: Whoop Whoop or Manual Air Horn	☑
	Exits	☑
	Assembly Point - Opposite to P-9	☑
Fire Safety	Fire Extinguishers	☑
	Fire Blankets	☑
Personal Safety	Safety Showers and Eyewash- Outside of P-11 (North Exit)/P2 (Eastern Door)	☑
	Spill Kits- location, use, emergency procedure	☑
First Aid	First Aid Kit	☑
	Trained First Aid Officers	☑
Chemicals	I have/will complete/d the online Chemical training modules and provided evidence of completion	☑
	I understand and agree to follow GHS System of Labelling	☑
	I acknowledge the requirements for Correct Storage and Segregation - location of Flammables, Corrosives, Toxic cabinets	☑
	ChemWatch Access requested (HUB/Log it online)	☑
Incident Reporting	SafeTrack process for Hazard and Incident reporting	☑
Waste	Sharps	☑
	Chemical	☑
	General	☑
Non-Compliance	Consequences of non-compliance with Lab/facilities rules explained and understood? e.g. loss of access, re-training escalation procedure?	☑
Laboratory Safety Guidelines are provided to me.		☑

Name of Trainer: Dr. [illegible] [redacted]

Position and signature: Senior Research Technical Officer [redacted]

Revised by: Dr. Mazhar Peerzada/ Choman Salih	Revised Date: 11-04-2022	Approved By: Timothy Haag

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Appendix D – Consequences and Ethics

By conducting this research project, it is expected that the outcomes will have some consequences. It is important as professional engineers to recognise these consequences and ensure that we are practicing ethically.

This project aims to provide knowledge regarding the use of pond ash in engineered cementitious composites. This has the potential to encourage further research regarding the use of pond ash and could lead to concrete manufacturers utilising pond ash within their engineered cementitious composite mixtures.

Pond ash has similar effects as fly ash in terms of negative impacts on the environment and human health as it is a by-product from power plants and usually occupies a large amount of area. By using pond ash in engineered cementitious composite mixtures, this could reduce the negative impacts the by-product has on climate change and human health.

The Engineers Australia Code of Ethics provides a framework for professional engineers to ensure that the values and principles that influence the decisions we make, demonstrate good engineering practice. As professional engineers, it is important to ensure we are practicing in accordance with the values and principles outlined in the Code of Ethics. To ensure the research is conducted ethically, it is important to practice by using the following values and principles:

- Demonstrating integrity
- Practising competently
- Exercise leadership
- Promote sustainability

To avoid ethical issues by conducting this project, it is important that these values and principles are followed. This can be achieved by:

Demonstrating integrity:

- Conducting the research in a professional manner, being honesty and trustworthy and also applying knowledge and skills without bias.

Practising competently:

- Develop further knowledge and expertise and practice in accordance with all relevant legal and statutory requirements.

Exercise leadership:

- Advocate the importance of practicing ethically, support diversity and provide clear communication.

Promote sustainability:

- Practice in a manner that adopts the health, safety and wellbeing of the environment and people of the public. Ensure the research meets the needs of the present and future generations.

Appendix E - Timeline