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WORKABILITY AND COMPRESSIVE STRENGTH OF ECO-FRIENDLY CONCRETE BASED ON WASTE CERAMIC PARTICLES

Faculty of Health, Engineering and Sciences

ENG4111 Research Project Part 1 & ENG4112 Research Project Part 2

Final dissertation

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ABSTRACT

Eco-materials are becoming the one of the important matters to be addressed in industries and academics owing to reduce the impact of synthetic materials on environment. On the other hand, waste materials have becoming an equal important matter in term of disposal and their impact on environment. In civil engineering, exploring any potential eco-materials for structural components is the ambition of many engineering and environmental researchers.

In this project, an attempt is made to explore the potential of using waste ceramic particles in concrete. The structure and the compressive characteristics of the developed materials with different waste ceramic particle percent are investigated. Different concrete samples were prepared and tested. The failure mechanisms were determined after the completion of the experiments. The optimum percent of waste ceramic particles in concreate were determined from workability, compressive strength and structure of the concrete. Compressive strength of the developed concretes were tested at different curing duration of 7, 14 and 28 days. Visual examination and scanning electron microscope were used to observe the failure mechanism.

The experimental results were in high agreement with the published recent and related works. The content of the waste ceramic particle controlled all the characteristics of the ceramics, i.e. workability, compressive strength, and the structure. Increase in the content of the waste ceramic particles deteriorate the strength of the concrete especially at content of above 25 wt. %. Despite of that the reduction in the strength at low percent of waste ceramic particle were within the industrial recommended ranges. Also, from environmental point of view, a promising results are identified and 25 wt % of waste ceramic particles in concrete is highly recommend. The failure of the concreate was commonly due to the crack generation and/or propagation in the bonding region of the particles and the cement. At high percent of waste ceramic particles, there is micro- and mac-cracks propagated which resulted in the poor performance of the concreate at this high percent of particle.

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ENG4111/ENG4112 Research Project

Limitations of Use

CERTIFICATION

I certify that the ideas, designs and experimental work, results, analysis and Conclusions set out in this dissertation are entirely my own efforts, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Fahad Alenezi

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Signature of Candidate Date

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The natural resources in the world are continuously decreasing due to manufacturing of the products and their impact on the environment since disposing the unwanted products is becoming an issue which need to be addressed and resolved. This can be possible by adopting the policy of 3Rs; Reduce, Reuse, Recycle (Umar, Shafiq, Malakahmad, Nuruddin, & Khamidi, 2016). To manufacture a new product, a lot of energy and material is required. Most of the construction materials are very expensive and the energy and cost required for their manufacture is very high. In this situation alternative materials need to be found in order to decrease the construction cost and save the natural resources.

It has been found that certain waste materials produced by different industrial processes can be very useful in construction; they can provide the required properties, strength and safety, Dousova et al. (2017). These materials, if released into the environment and atmosphere, can severely harm human health and create pollution. So the best way to protect the environment and human health from such waste materials is to reuse them in construction. As these are waste materials so there is no manufacture cost and hence they are very cheap. The advantages of using these waste materials include cost saving, energy saving, reducing pollution and sustaining the environment of the future generations.

Recycling of waste materials is, therefore, necessary in order to generate useful products and protect the environment and future generations (Bhada-Tata & Hoornweg, 2016). Suitable proportions of waste materials can be used as a replacement of cement to produce a required strength concrete with desired workability. Different proportions of powdered ceramic waste and granite powder ranging from 5-45% replacement will be used to produce concrete and tests will be carried out to determine the properties of concrete (Sarkar, Sahani, Roy, & Samanta, 2016).

Compressive strength is defined as the maximum compressive stress that a solid material can carry when a load is applied on it gradually. It can be determined by dividing the total load carried by the specimen by the original cross-sectional area of the specimen. Tensile strength is defined as the maximum tensile stress that a material can carry prior to failure. For measurement of compressive and tensile strength of concrete, blocks or cylinders are tested in universal testing machine. Workability is that property of concrete which tells the amount of useful work required producing full compaction of concrete. In simple words workability is the ease to work with concrete. Slump test is conducted in order to determine the workability of concrete.

1.2 PROBLEM STATEMENT

Cement is a very expensive construction material which is used as a binding agent in concrete. Due to high process of cement construction costs are quite high. On the other hand wastes produced by different industries like coconut husk, ceramics waste and bricks waste are getting useless and are a threat for the environment. If these wastes are not properly disposed they may cause serious environmental pollution and health hazards. So, to reduce the construction cost and to protect our environment it is necessary to use the wastes from different industries in construction. Ceramics waste is one of such wastes which is produced in large quantities by the ceramic industry and can be used as a partial replacement of cement. So, this research project will aim on using ceramic waste as a partial replacement of cement and to determine the compressive strength and workability of concrete.

Taking in account the research already carried the objectives of this study are to quest for the answer of following questions,

1- What is the effect of partial replacement of cement with ceramic waste on the compressive strength of concrete?

2- What is the effect of partial replacement of cement with ceramic waste on the workability of concrete?
3- What percentage of ceramic waste replacement is suitable to obtain the design strength of concrete?

In this project to important parameters compressive strength of concrete and workability of concrete will be determined using the laboratory testing. Cement will be replaced with 5%, 15%, 25%, 35% and 45% waste ceramic particles and results will be analyzed. Compressive strength and workability of concrete will be determined. Compressive strength tests will be conducted on 7, 14 and 28 days of concrete casting. This research will not take into the account other properties of concrete since that requires more resources and more time to complete the project. Comparison of the results will be made with the studies carried out in past.

1.3 OBJECTIVES

The main objective of the current study to identify the possibility of using waste ceramic particles in concrete and determined the optimum amount of the ceramic content in the concreate. To achieve this goal sub-objectives need to be considered which are as follows:

1. to study the workability of cement/waste ceramic particles at different content of 0 – 45 wt %,
2. to study the compressive strength of the prepared samples of concreate,
3. to identify the optimum percent of the waste ceramic content from workability and strength of the samples, and
4. categorize the damage features on the sample and understand the failure mechanism

1.4 EXPECTED OUTCOMES

This research will be carried out in order to find alternative material for cement in concrete to reduce the cost of concrete. The results obtained will be very valuable in the sense that it can be determined what percentage of powdered ceramics waste is suitable to produce concrete of required strength. If required strength will be achieved by replacing some percentage of cement with powdered ceramic waste then it will confirm the usefulness of ceramic waste. Using ceramic waste in concrete can reduce cost of construction to a large extent. It will also enable to control the environmental pollution caused by the ceramic industry.

1.4 ORGANIZATION OF THE DISSERTATION

Table 1. 1 Description of the dissertation layout

TOPIC	DESCRIPTION
Chapter 1	**INTRODUCTION**: Briefly describes the overview of the project and also states the motivation and objectives of the project. The scope of the project was also included in this chapter.
Chapter 2	**BACKGROUND AND LITERATURE REVIEW:** The detailed introduction of the project, including the background and history of eco-materials were explained.
Chapter 3	**METHODOLOGY:** This chapter was divided into two main parts. The first part is the material selection and preparation. The second part describes the experimental procedure
Chapter 4	**RESULTS AND DISCUSSIONS:** The results of the experiments are presented in the form of graphs associated with some photos and micrographs.
Chapter 5	**CONCLUSION AND RECOMMENDATIONS** - The conclusion of the project was presented. The conclusions were written based on the main objective of the project, and future recommendations were included so that more work could be done to provide more information on this work.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, the literature view on the recent works on the cement and the potential of using eco-alternative materials is addressed. The most recent application of the eco-materials is covered in part of the chapter. At the end the summary of the literature is introduced.

2.2 INTORDUCITON TO CERAMICS

Low-firing earthenware appeared 10 000 years ago which has been developed by humans when they started mastering the use of fire (Somiya, 2012). In the last decade, the word ceramics (meant to be pottery) explored and have nee manufactured in limited products such as table, roofing tiles, clay pipe and bricks. Rawlings, Wu, and Boccaccini (2006) defines it as polycrystalline materials of fine microstructure that are produced by the controlled crystallisation.the world production of silicon carbide is given in table 2.1 which has been extracted from **http://www.usgs.gov/** . From this table, one can be see that there is a large amount of ceramics produce overall and it is going to increase as reported as reported by Tite (2008) and Coletti, Maritan, Cultrone, and Mazzoli (2016). Coletti et al. (2016) addressed several issues related to the ceramics in the current era. The main point worries the industries, environment, and the researcher is the impact of the ceramic waste and its products on the environment. Many attempts have been carried out owing to create new types of bricks using additives, often consisting of residual urban and industrial materials such as (Demir, 2008), (Raut, Ralegaonkar, & Mandavgane, 2011), (Zhang, 2013), (Muñoz Velasco, Morales Ortíz, Mendívil Giró, & Muñoz Velasco, 2014a) and (Bories, Borredon, Vedrenne, & Vilarem, 2014). The main findings of those works are summarized by Coletti et al. (2016) which can be as follows:

- the is good potential of using alternative materials such as waste ceramics,

- those substitutes have technical advantages and can reduce the environmental impact,
- using industrial waste in brick production assists in resolving the problem of the disposal of large amounts of waste materials, and finally
- waste materials would results in global environmental hazard which in turn increases the demand and the development of sustainable alternatives.

Table 2. 1 World production of aluminum oxide and silicon carbide (metric tons) in 2014. http://www.usgs.gov/

Region	Aluminum Oxide	Silicon Carbide
Argentina	n/a	5,000
Australia	50,000	n/a
Austria	60,000	n/a
Brazil	50,000	43,000
China	800,000	455,000
France	40,000	16,000
Germany	80,000	36,000
India	40,000	5,000
Japan	25,000	60,000
Mexico	n/a	45,000
Norway	n/a	80,000
U.S. and Canada	60,400	42,600
Venezuela	n/a	30,000
Other countries	80,000	190,000
World total (rounded)	**1,290,000**	**1,010,000**

**estimated (Source: U.S. Geological Survey, www.usgs.gov.)*

2.3 THE IMPORTANCE OF ECO-MATERIALS

In the recent era with increase of awareness about the impact of different products on environments, academic and industrial sectors come together owing to identify the main issues related and the resolutions to those issues. In the recent published work by Dinar and Rapoport (2013), growing number of environmental dilemmas and political conflict have been addressed emphases on the need of solution to the problem of environments in different engineering sectors. From engineering point of views, there are many areas of interest are indicated by researchers focusing on the material sides especially sustainable and alternative materials, (Yousif & El-Tayeb, 2007). Dhir and Dyer (1999) argue the scientist and the industries to be caution and put an effort towards the possibility of using alternative eco-materials in buildings. Based on the data reported on the large high standard database (www.sciencedirec.com), the number of the published works related to the eco-materials since 2009 is extracted and plotted in Figure 2.1. This figures indicates the importance of eco-materials in current era. The increase in the number of reported works shows the effort done toward friendly materials owing to overcome some of the negative impact of synthetic materials on environment. Nie (2016) stated that "*For the resource extraction, manufacture, application, and disposal of materials, numerous resources and energy are consumed, and environment deterioration occurs with the inputs and outputs of various raw materials, energy, by-products, and wastes*". Ghafari, Costa, and Júlio (2015) stated that sustainability of the construction sector should be the priority for the scientific and industrial communities. With regards to the building materials, Mehta (2009) recommended few approaches for concrete industry which involve consumption of less concrete by developing innovative architectural and structural designs, reducing the Portland cement usage in concrete mixtures by using different eco-aggregates, or reducing the Portland cement by using different cements. On the other hand, L. Wang, Chen, Tsang, Poon, and Shih (2016) proposed a different technics to reduce to the impact of the cement and building materials on the environments by using magnesia cement and CO_2 curing to transform contaminated wood waste into eco-friendly cement-bonded particleboards. The findings of the work showed a promising results. However, fire resistance becomes an important issue which need to be further studied. Stabnikov and Ivanov (2016) reported that the usage of some of the eco-materials which are produced from bio-resources can be an issue with regards of producing fungal and bacteria. This limits the usage of bio-materials in constructions despite there are ongoing works to overcome this issues. In this year 2016, Liu et al. (2016) suggested an alternative solution to reduce the impact of the synthetic cements on environment by introducing waste ceramics. In the graphical abstract of this work, it is clearly that the introducing of the ceramic improves the hardness properties. In addition, the micrographs shows good bonding between the particles which indicates the possibility of transferring the loads during the operating between the particles.

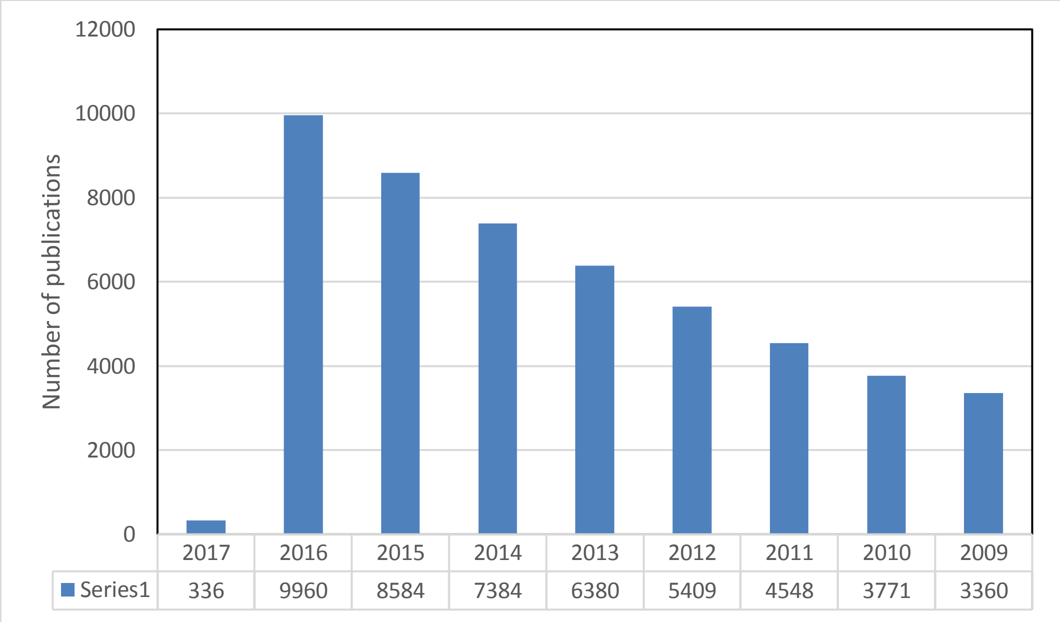

Figure 2. 1 number or scientific articles on eco-materials thought the past seven years.

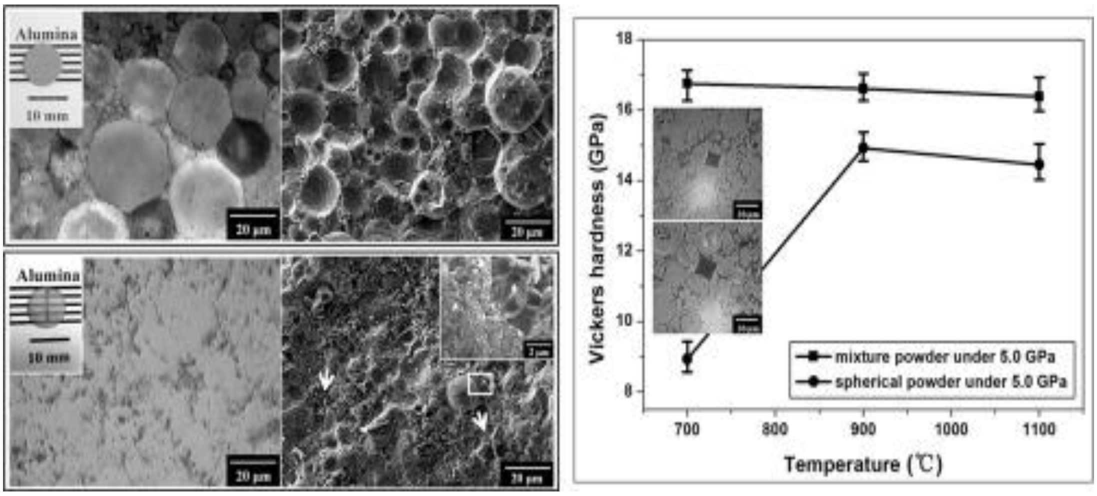

Figure 2. 2 graphical abstract of Liu et al. (2016).

2.3 POTENTIAL REPLACEMENT MATERIALS OF CEMENT

Recently, different studies have been conducted using different waste materials as a partial replacement of cement. Some of the waste materials that were used in the previous studies include marble waste, brock waste, ceramic waste, glass waste, rice husk and stone waste (Naceri & Hamina, 2009) . Recycled rubber tire fibers have been used in concrete to avoid crack opening in concrete and to increase the energy of absorption (Siddique & Naik, 2004). Palm oil shells have been used to produce light weight structural concrete (Shafigh, Jumaat, & Mahmud, 2011). Demolished masonry waste has also been used to produce light weight concrete. Crushed vitrified soil aggregate has been used as a partial replacement of cement and increased the modulus of elasticity of concrete. Wood waste ash has been used as a partial replacement of cement for producing structural grade concrete. Fly ash is a pozzolan, it has cementations properties. It can be used as filler for concrete which turns out strong. Bagasse is the waste from sugar cane and can be used to manufacture fiber boards. Coconut husk can be used to manufacture coconut ply boards.

A research conducted by Raval, Patel, and Pitroda (2013) revealed that ceramic industry produced a huge quantity of waste despite of the improvements made to the manufacturing processes. Nearly, 15-30% of the production becomes a waste. This waste is hard, durable and can resist degradation forces. He partially replaced cement with 10%, 20%, 30%, 40% and 50% powdered ceramic waste and found that partial replacement of cement with ceramic waste increased the compressive strength of M20 grade concrete up to 30 percent addition of waste while the cost of concrete reduced to 13.67 %. The compressive strength of concrete at 30% replacement was 22.98 N/mm2. Another study conducted by Vedalakshmi, Raj, Srinivasan, and Babu (2003) on M30 grade concrete revealed that compressive strength of concrete increased up to 40% replacement of cement with ceramic powder and the compressive strength at 40% replacement was 31.83 N/mm^2 and the cost of cement was reduced to 18.62%. In another study by Raval et al. (2013) on M25 grade concrete revealed that upon 30% replacement of cement with powdered ceramic waste the compressive strength of concrete was 26.77 N/mm^2 while the reduction in concrete cost was 13.27%.

2.4 WASTE CERAMICS

Construction and demolition wastes impacts the highest percentage of wastes in the world, (Zimbili, Salim, & Ndambuki, 2014). Ceramic materials cover different types such as brick walls, ceramic tiles and all other ceramic products which introduces high percentage of wastes as reported by Juan et al. (2010). Table 2.2 is extracted form the book published by Juan et al. (2010) which shows clearly the high percent of the ceramics waste in demolition and construction waste . It should be bear in mind that this was reported six years ago.

Table 2. 2 Composition of Construction and Demolition Wastes by Juan et al. (2010)

MATERIALS	COMPOSITION (%)
STONY FRACTION	75
Bricks, wall tiles and other ceramic materials	54
Concrete	12
Stone	5
Sand, gravel and other aggregates	4
NON STONY FRACTION	25
Wood	4
Glass	0.5
Plastic	1.5
Metals	2.5
Asphalt	5
Plaster	0.2
Rubbish	7
Paper	0.3
Others	4

There are two main sources of ceramic waste; first one is the ceramic industry while the second source is the construction waste such as demolition waste, bricks, ceramic materials and roof tiles. Waste obtained from ceramic industry is classified as a non-hazardous waste. The figure below shows the classification of ceramics waste.

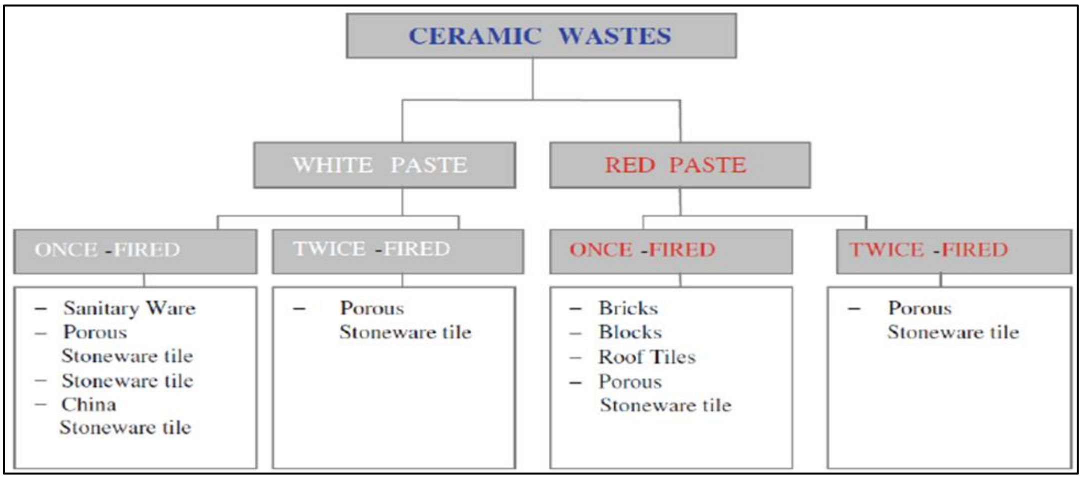

Figure 2. 3 Classification of Ceramics waste, (Donald, 2010).

Ceramics products are manufactured using different natural materials that contain relatively high percentage of clay. The main components of ceramics include clay, feldspar, stone, caustic soda, and silicate and quartz powder. Clays do not exhibit pozzolanic properties; however, they can be activated by heating at high temperatures. Kaolinite which is a clay mineral gains pozzolanic characteristics by calcination at temperature ranging between 540-980˚C, Rakhimova and Rakhimov (2014). Ceramic masonry rubble has pozzolanic properties and is acidic in nature with 75.97% of silica, iron oxide and aluminum oxide, 12.41 % calcium oxide and 4.22 % alkali proportion (Juan et al., 2010). The specific gravity of ceramics waste usually ranges between 2.4 to 2.7.

In the recent era, there is a motivation of using waste materials in ceramics production. Muñoz Velasco, Morales Ortíz, Mendívil Giró, and Muñoz Velasco (2014b) address the recent issues of the waste ceramics and the potential of using the waste ceramics in their review article. In that work, it is suggested to mix the clay with the waste as illustrated schematically in figure

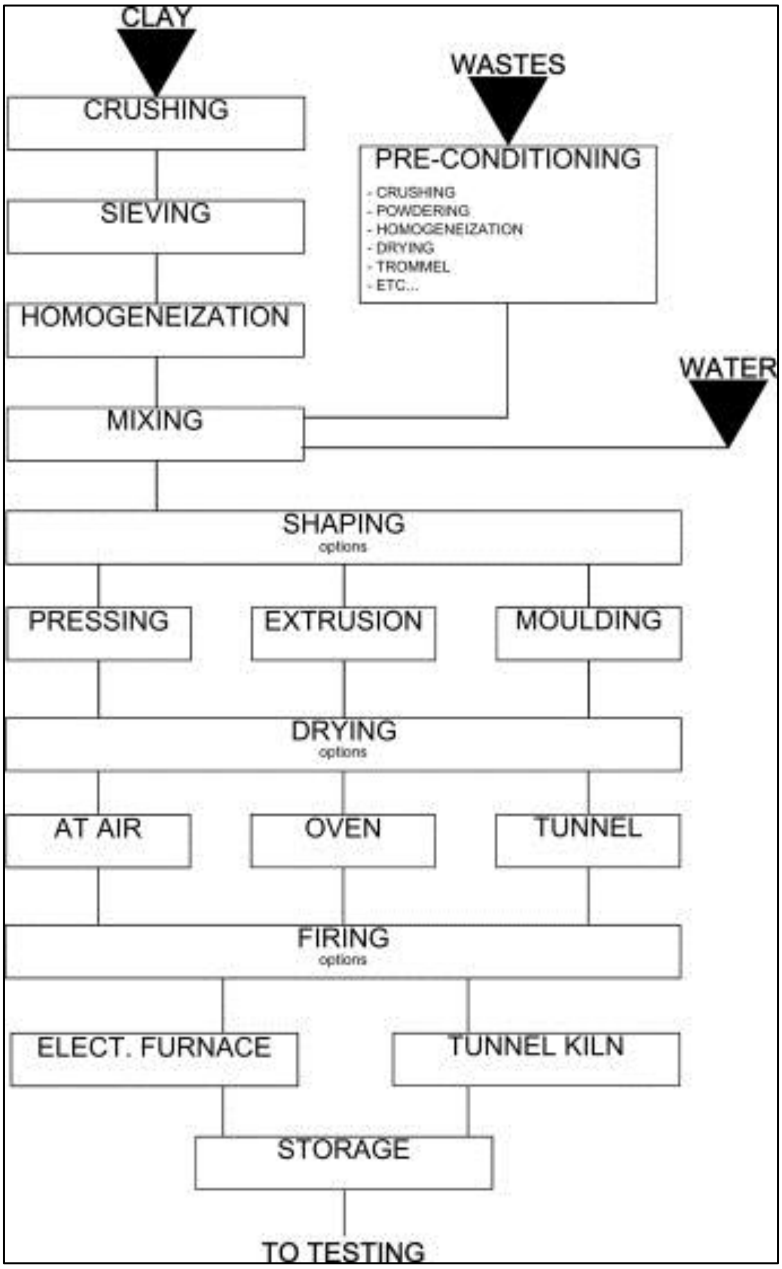

Figure 2. 4 Flow diagram illustrating procedures followed by reviewed papers, extracted from Muñoz Velasco et al. (2014b).

2.4.1 CERAMIC WASTE IN CEMENT

Ceramic materials including roof tiles and hollow bricks can be considered as one of the mainstays in terms of construction materials, (de Brito, Pereira, & Correia, 2005). In has been reported that 30% of the daily production in the ceramic industry is considered as non-recyclable waste materials; however, such waste materials have good characteristics such as durable, hard and highly resistant to biological, chemical and physical degradation forces (Senthamarai & Devadas Manoharan, 2005). "Leaf-nosed bat" 2009) reported that, in 2010, of the total waste produced from construction and demolition activities, and mining and quarrying operations, 97% was mineral waste or soils (excavated earth, road construction waste, demolition waste, dredging spoil, waste rocks, tailings, and others), refer to figure 3.5.

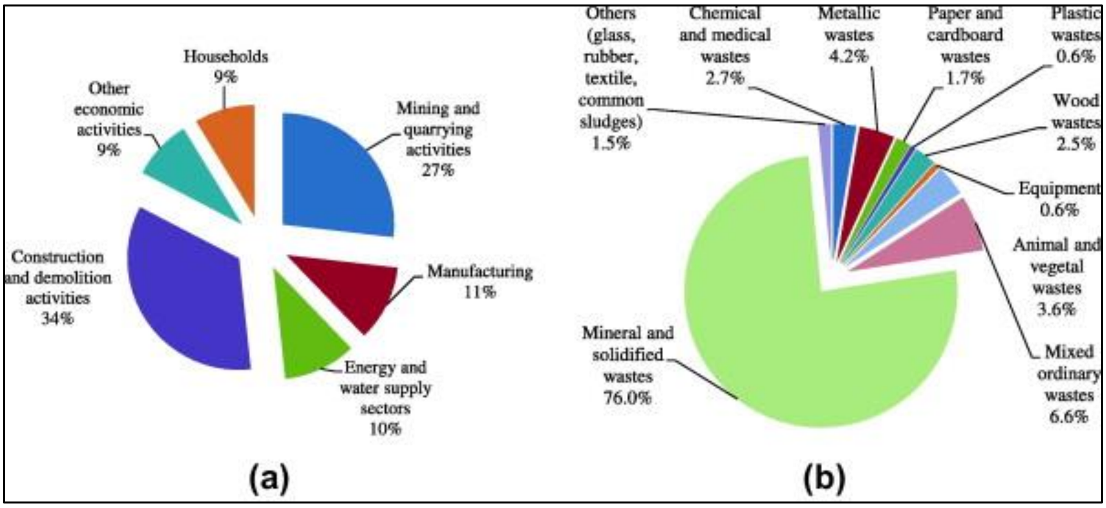

Figure 2. 5 Total waste generated in European Union according to: (a) economic activity; (b) waste category adopted from (Silva, de Brito, & Dhir, 2014).

Cement has excellent pozzolanic properties and it is the binding agent in concrete and is relatively expensive compared to other materials, (Raval, Patel, & Pitroda, 2013). Raval et al. (2013) recommended the usage of the ceramics waste in cement and some initial chemical analysis indicated that. The table 2.3 introduces a comparison between the chemical composition of Portland cement and ceramics waste.

Table 2. 3 Comparison between composition of cement and ceramics waste as reported by (Raval et al., 2013)

Chemical Composition	Portland Cement	Ceramic Waste
SiO_2 (%)	21.16	63.29
Fe_2O_3 (%)	1.89	4.32
Al_2O_3 (%)	4.71	18.29
CaO(%)	68.08	4.46
P_2O_5 (%)	0.28	0.16
MgO(%)	0.48	0.72
Na_2O(%)	0.29	0.75
K_2O(%)	0.48	2.18
Loss on ignition(%)	2.39	1.61

2.4.2 Recent Works on the Usage of Ceramic Waste in Cements

The possibility of suing the waste ceramics is an ongoing research in different engineering areas. Zarina, Mohd Mustafa Al Bakri, Kamarudin, Nizar, and Rafiza (2013) investigated the strength of concrete by partially replacing aggregate with powdered ceramic waste. Ceramic waste was obtained from industry in Malaysia. Concrete mixes with targeted 28 days strength of 20 MPa were prepared with a water cement ratio of 0.4, 0.5 and 0.7. The strength development in concrete was compared to the strength development of ordinary concrete. Results indicated that concrete made by partial replacement of ceramic waste had 80 to 95% strength compared ti the normal concrete mixes. They concluded that ceramic waste can be successfully used as a partial replacement of cement. There is a very minor loss in the compressive strength of concrete (Zarina et al., 2013). Pacheco-Torgal and Jalali (2011) did a research to determine the properties and durability of concrete containing ceramic wastes. It proved that concrete with partial cement replacement by ceramic powder has some strength losses but it increases durability performance of concrete.

In another study by Sukesh, Krishna, Teja, and Rao (2013), several concrete mixes were prepared with a target strength of 30 MPa and with 20 percent replacement of cement with powdered ceramic waste. Concrete mixes with ceramic sand and granite aggregate and concrete mixes with natural sand and coarse ceramic waste were also prepared. Study showed that addition of ceramic waste had minor strength losses but it increased the durability of concrete.

Recently a studied conducted by Anwar, Ahmad, Husain, and Ahmad (2015) focused on the partial replacement of cement with ceramic waste powder and marble dust powder. Cement was replaced by ceramic waste in reach of 0-50% for M20 grade concrete. The aim was to study the compressive strength and durability of concrete due to addition of ceramic waste. The water cement ratio was 0.5. They concluded that with addition of ceramic waste concrete strength decreases. However, at 30% replacement there is a minor loss in strength. The compressive strength of concrete at 30% replacement with ceramic waste was 32.2 N/mm^2. They found that ceramic waste was more economical than marble waste without compromising the concrete strength and standards. A study conducted by Jackiewicz-Rek, Załęgowski, Garbacz, and Bissonnette (2015) intended to access the effect of addition of ceramic waste as aggregate in cement based mortars. The focused on workability, mechanical properties and freeze thaw resistance. They found that replacement of cement with 20% ceramic waste improves compressive and flexural strength of mortars and reduces shrinkage.

Kharade, Kapadiya, and Chavan (2013), conducted a study on partial replacement of ceramic waste as coarse aggregate and egg shell as fine aggregate. Egg shell and ceramic waste were replaced in reach of 5%, 7.5%, 10%, 12.5% and 15% during production of concrete. Concrete cubes and cylinders were cased and their compressive and tensile strength was determined to find the optimum percentage of waste replacement. Results showed that using ceramic waste as aggregate increased the compressive and tensile strength of concrete and also its durability. Their results also showed that concrete mixtures with ceramic aggregates perform better than the control concrete mixtures concerning compressive strength, capillarity water absorption, oxygen permeability and chloride diffusion. The replacement of cement and aggregates in concrete by ceramic wastes will have major environmental benefits.

Zimbili et al. (2014) conducted to review the use of ceramic wastes in concrete production. They found waste recycling as one of the best methods for sustainable development. They concluded that ceramic wastes are suitable for use as a replacement of fine and coarse aggregate and partial replacement of cement in concrete. Concrete produced using ceramic wastes have many advantages over normal concrete which are in terms of density, permeability, durability and compressive strength. Another study conducted by S. Keerthipriyan and M. Sathya et al., 2015, on the assessment of strength characteristics of concrete by incorporating ceramic waste in place of cement shows that compressive strength, split tensile strength and flexural strength of concrete reduce with the increase in the percentage of the ceramic waste powder. However, strength is optimum at 20% replacement for M25 grade of concrete. For the mortar cubes strength was optimum at 10% replacement of cement with powdered ceramic waste.

Prajapati and Patel (2014), conducted a study on the analysis of strength and durability of the concrete replaced by ceramic waste powder. M25 grade concrete was made by replacing ordinary Portland 53 grade cement by 0% to 30% of powdered ceramic waste passing through 90 microns. They determined compressive strength, flexural strength and absorption of concrete at a water cement ratio 0f 0.48. Results indicate that compressive strength of concrete decreased with addition of ceramic wastes and was less as compared to the conventional concrete. However, replacement up to 30% didn’t affect the strength to a large extent. Flexural strength was comparable to the conventional concrete and was insignificantly reduced by the addition of ceramic waste. Absorption increased with the increase of the powdered ceramic waste; however, after 10% replacement increase in absorption was less. Another study was conducted by Jay Patel & B.K. Shah et al., 2014, on the ceramic powder in concrete as a partial replacement of cement. They concluded that ceramic powder as a cementious material was good for environment and economy. The optimum percentage of ceramic powder as a replacement of cement was between 20% to 30%. Compressive strength of concrete increased up to 30% to 40% based on the pozzolonic activity of the ceramic waste. Addition of ceramic waste more than 30-40% decreased the compressive strength of concrete.

2.5 CHARACTERISTICS OF WASTE CERAMIC MIXED WITH CEMENTS

In the literature, there are some works have been made attempting to investigate the influence of the addition of waste ceramics in cement. Medina, Sánchez de Rojas, and Frías (2012) attempted to investigate the micrograph of recycled concrete, with a microanalysis of the different constituents revealing that the interfacial transition zone between the recycled aggregate and the paste was narrower. This was shown in the scanning electron microscopy which is extracted and displayed in figure 2.6. In addition, there is a clear reduction in the porosity of the cement with the addition of the recycled aggregates which resulted in a promising improvement into the mechanical characteristics. Similar findings have been previously reported by Monteiro (2006). Medina et al. (2012) studied the compression strength of cements with different volume fraction of waste ceramics as aggregates, at 7, 28 and 90 days, and splitting tensile strength, at 28 days, for the different concretes have been studied. The results shown in figure 2.7 revealed that mechanical properties of the cement, compression and splitting tensile strengths, gained good improvements with the addition of the recycled concretes than for the reference concrete, i.e. "*there was an increase from 12% to 25% in compressive and splitting tensile strength compared to the reference concrete*".

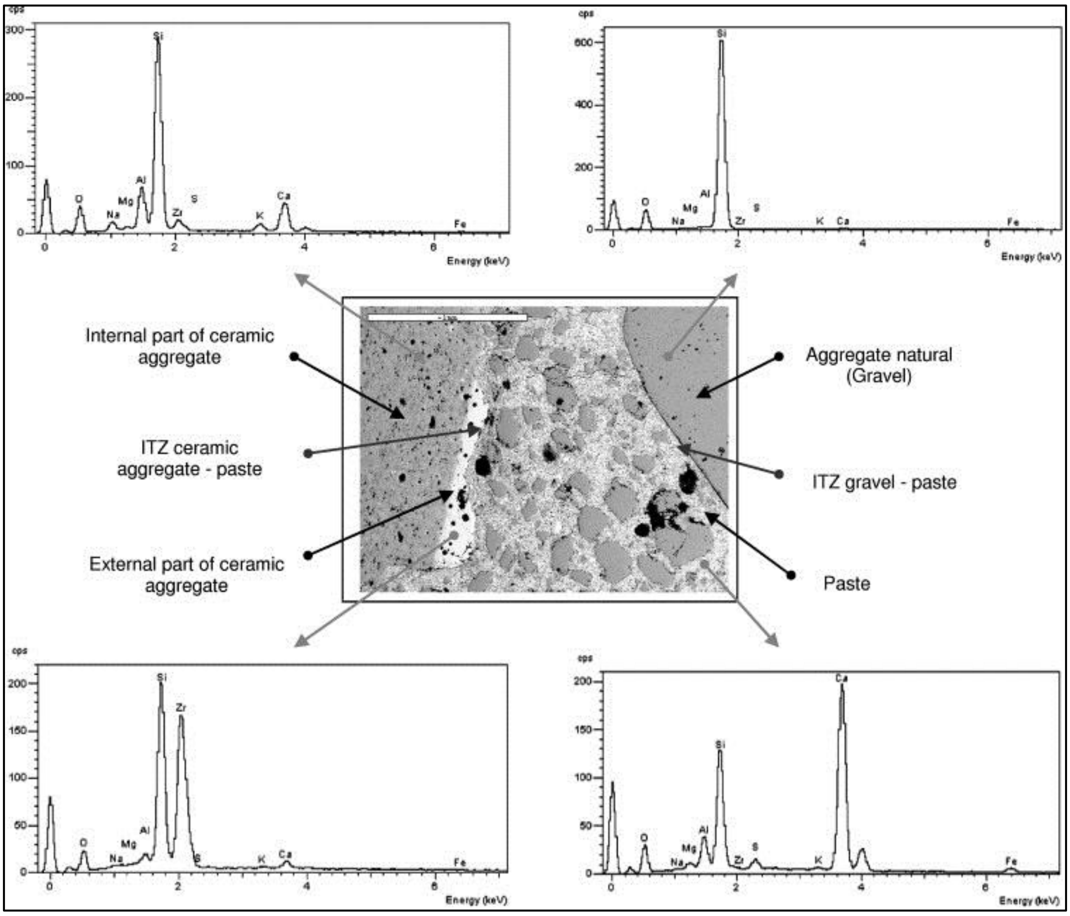

Figure 2. 6 Micrographs of the cement with the addition of recycled aggregates by Medina et al. (2012).

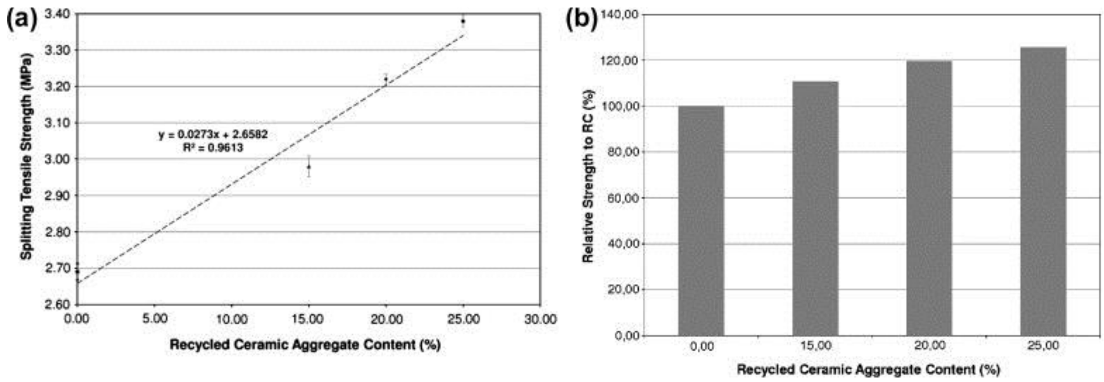

Figure 2. 7 Influence of the recycled ceramic as aggregates on the strength of ceramics by Medina et al. (2012).

In an attempt by Yen, Tseng, and Lin (2011), marble sludge, sewage sludge, drinking water treatment plant sludge, and basic oxygen furnace sludge replaced limestone, sand, clay, and iron slag, respectively and the properties of the new material have been tested. The results of that work showed that the usage of marble sludge to replace up to 50% of the limestone would serve as total replacements for the raw materials. The compressive strength and microstructural evaluations showed that strength correlated proportionally with the volume fraction of the replacement. Fantilli and Chiaia (2013) used Fly ash (65 kg/m3) and Silica fume (30 kg/m3) as aggregates separately in two different cements. In that work, substituting the cement with fly ashes or silica fumes exhibited same strength of the cement; however, more brittle failure occurred. Moreover, reduction in the environmental impact and a better durability have been introduced. This has been measured with new ratios between the quantity of CO_2 released by the production of cement the basic mechanical performances.

In a series of *Composite Technologies for 2020* and according to (Sobolev, Iscioglu Bem Cement, T¨rker, Yeğinobali, & Ert¨in, 2004), ECO-cement (with 50% of waste glass) can be very good cement product since the compressive strength at a level similar to normal portland cement, i.e. this has been demonstrated by the ECO-cement based on waste window and green bottle glass. Form thermal characteristics point of views, a study of eco-aggregates (ashes with carbon dioxide) revealed that carbonated aggregates are promising additives to the cements with several advantages: mechanical strength, thermal and hygric inertias as reported recently by Bourdot et al. (2016).

2.6 SUMMARY OF THE LITERATURE

In this chapter, most recent works on the eco-cements and materials have been reviewed, i.e. about 50 international reports and articles have been taken into account. According to the information and results provided by the literature, there is a need to identify new eco-material owing to reduce the impact of synthetic materials on environment. Furthermore, there is less work has been reported on the usage of waste materials in cements despite there are few recent reported works. In this light of this, the current project is motivated to investigate the influence of waste ceramics in cements. The compressive strength and structural of the cements with the addition of different ratio of waste ceramics are considered in this study.

CHAPTER 3

METHODOLOGY

MATERIALS SELECTION AND EXPERIMENTAL PROCEDURE MATERIALS

3.1 INTRODUCTION

In this chapter, materials selection and characteristics are introduced. The methodology of preparing the sample and the design approached are based on recent published work by Silvestre, Medel, García, and Navas (2013). The material characteristics and risk assessment is given in appendix A. Figure 3. 1 shows schematically the procedure adopted in the current study based on the published work. The cement samples were prepared with different ratio of waste ceramics and optimization were conducted to identify the optimum amount of waste ceramic can be used. In addition, the structure of the prepared samples have been examined using scanning electron microscopy after the test completion.

3.2 MATERIALS SELECTION

3.2.1 Waste Ceramic

In this project, waste ceramics are used as aggregate in cement. The waste and unwanted ceramics were obtained from tile shop in Toowoomba, Beaumont Company. Some of the specification of the tile used in this project can be found in appendix C. sample of the collected ceramics is given in Figure 3.2. The figures shows the collected ceramics before cleaning and separation. Ceramic wasted was obtained in form of large pieces which required crushing. This waste is generated during the process of polishing and dressing of ceramic products.

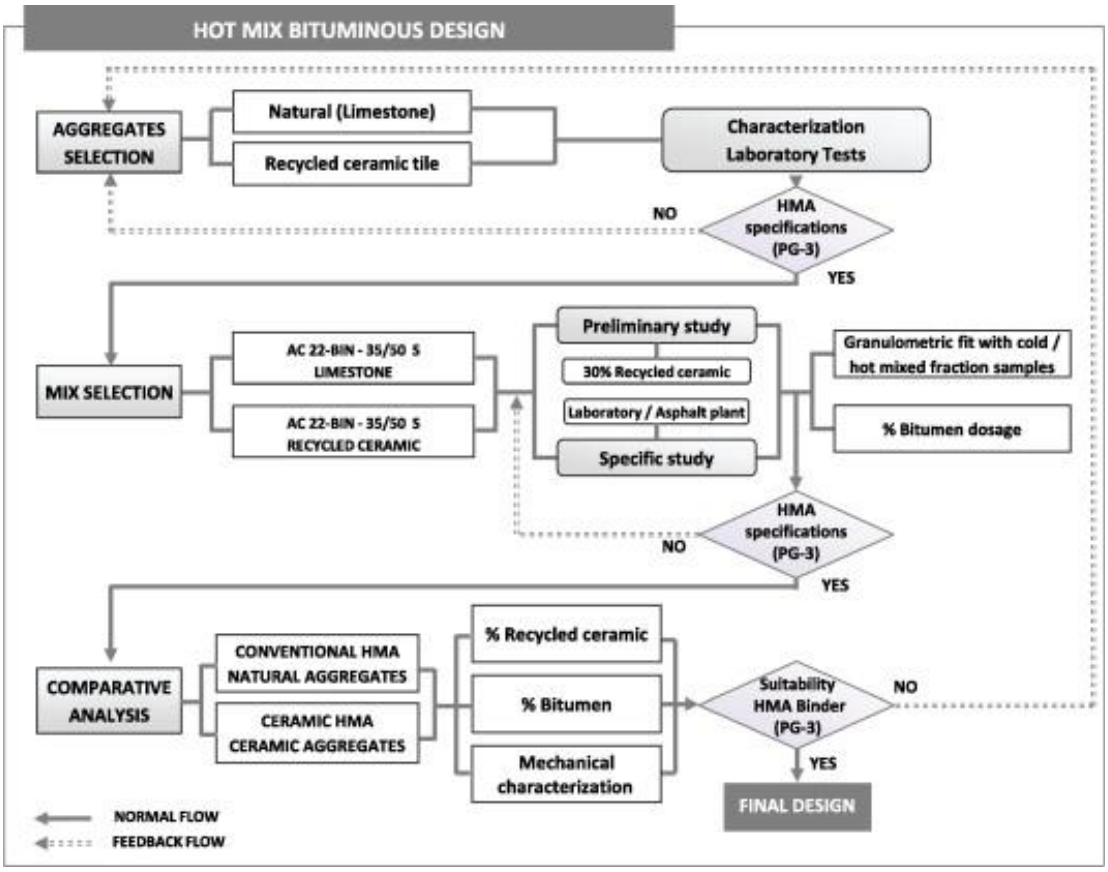

Figure 3. 1 scope of the methodology of the current study based on the published procedure by Silvestre et al. (2013).

Figure 3. 2 Sample of the collected waste ceramics

Ceramic waste was crushed into small pieces. Standard Mesh sieve size of 3.5 and then 5 were used to extract the small size of waste ceramic, i.e. the size of the aggregate waste ceramic is between 0-5 mm. Sample of the cleaned crashed waste ceramic is displayed in Figure 3.3. The micrographs of the waste ceramic particles are given in figure 3.4 showing different sizes of the particles. The average size of the particle is confirmed to be form 0 - 5mm. In addition, the figure shows that there is different geometry of the particles and there are not in one uniform shape due to the crashing process before the preparation. Greater sizes of particles and component of SiO_2 (65.24%), followed by Al_2O_3 (19.1%) and CaO (2.85%) have been used by Jang and So (2015). In that work, the ceramic were crashed to powder and the increase in the strength of the prepared concrete was not that remarkable. This could be mainly due to the very small sizes used of ceramic particles which could not bear the load and support the cement structure in the concrete. In the current work, it is proposed to use the ceramic as aggregate which can give better support to the compressive strength of the concreate. Further discussion will be given in chapter 4 (results and discussion).

Figure 3. 3 Waste ceramic after crashing

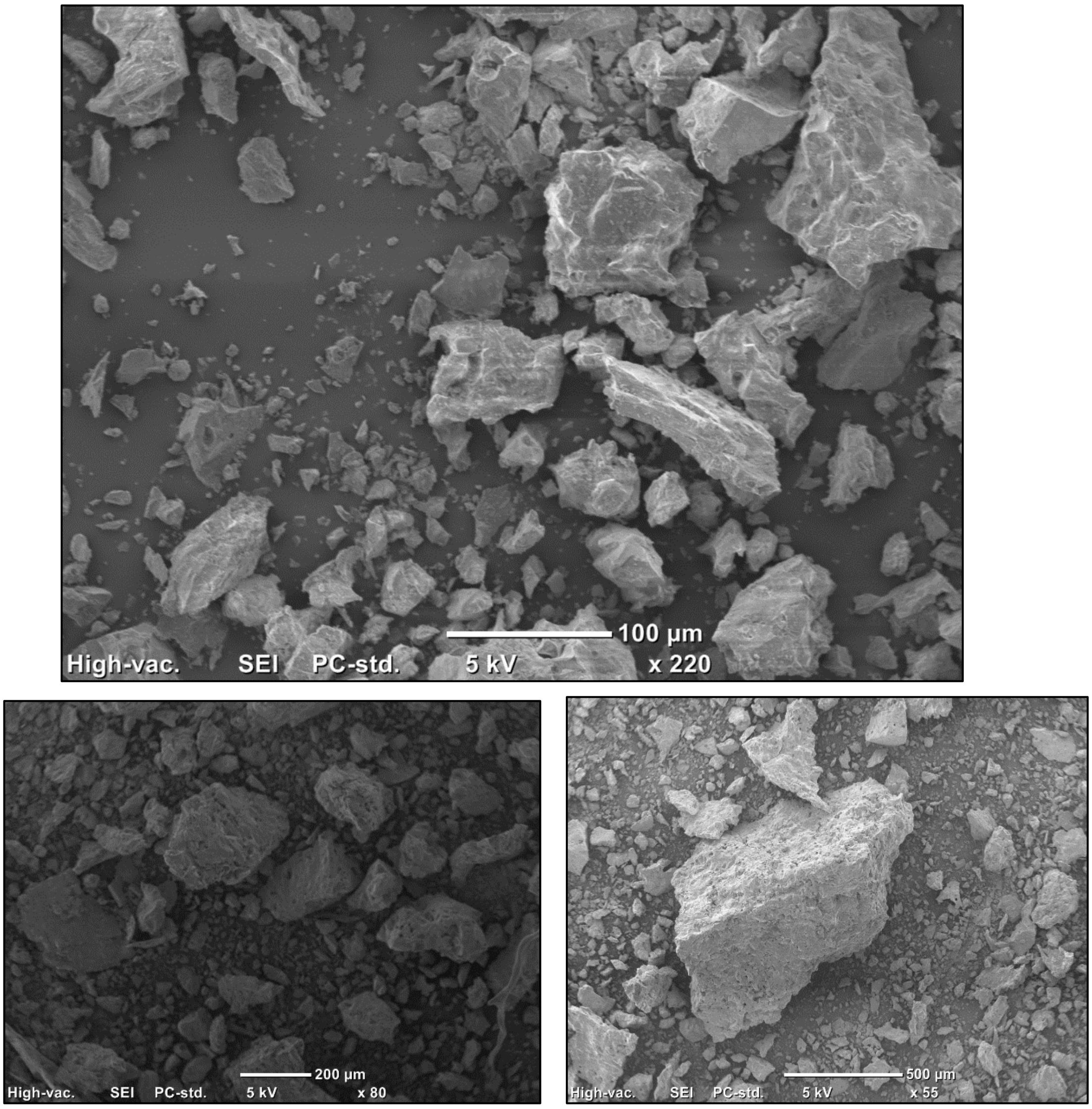

Figure 3. 4 Micrographs of the waster ceramics after cleaning

Sand was used as an aggregate in concrete; without sand concrete cannot perform the intended work. It is relatively cheaper than the other materials; however, it is the larger component of concrete than cement. It is usually used as an inert material in concrete to reduce the cost. It provides surface area required for cement to spread and adhere. It is the component that prevent shrinking and cracking of concrete. It provides density to the concrete. The sand used was coarse and has higher surface area. The sand were supplied by Bunnings Company from Toowoomba, QLD, Australia. Water is a very important component of concrete. The chemical reaction between cement and water is responsible for the bonding of all the ingredients of concrete. Hydration reaction occurs between water and cement.

3.2.2 Selection of Cement

The other material used is Portland cement (PCC). Cement has excellent pozzolanic properties and it is the binding agent in concrete and is relatively expensive compared to other materials. The table below shows a comparison between the chemical composition of Portland cement and ceramics waste. For use in concrete, the ceramic waste must be very fine so that it exhibit pozzolanic properties and should have a specific surface. The ceramics waste is the most important variable in this study. It will be replaced in increment of 5%, 15%, 25%, 35% and 45% with simultaneous decrease of cement from 100 to 50%. Previous studies show that increasing percentage of ceramics waste more than 50% tends to decrease the strength of concrete; therefore, it will be replaced up to 45% in this research. Table 3.2 shows typical properties of normal strength Portland cement concrete which has been supplied by Bunnings Company, Toowoomba, Australia. Bastion Premix Concrete Type GP cement in Australian Standard AS3972 is used in the current study due to its general purpose usage and the common cements used in buildings. Figure 3.5 shows the provided 20 Kg of cement from Bannings ware house in Toowoomba. In the recent reported works, such type of cement has been used by many researcher such as (Muttashar, Manalo, Karunasena, & Lokuge, 2017; Richardson & Heather, 2013; Scherbatiuk & Rattanawangcharoen, 2010). This mainly due to several applications of this type in different structures.

The selected cement has high strength concrete which can be suitable for structural application. As recommended by www.cementaustralia.com, such type of cement can be used for small slabs, garden edging, fence posts, clotheslines, pathways, letter boxes and light posts. Further information about the cement properties and other information is given in appendix C. In addition, the micrographs of the cement particles are displayed in figure 3.6.

Figure 3. 5 Bastion brand of cement used in the current study.

Table 3. 1 Properties of normal Portland cement,

http://www.cementaustralia.com.au

Property		AS3972 – 1997 Type GP	Typical GP
Setting Time	Min	45 min	100-150 min
	Max	10 hrs	3.0-4.0 hrs
Soundness	Max	5mm	< 3mm
SO_3	Max	3.50%	< 2.5%
ISO Mortar Compressive Strength	3 Day (min)	–	21-32 MPa
	7 Day (min)	15 MPa	30-41 MPa
	28 Day (min)	30 MPa	46-58 MPa

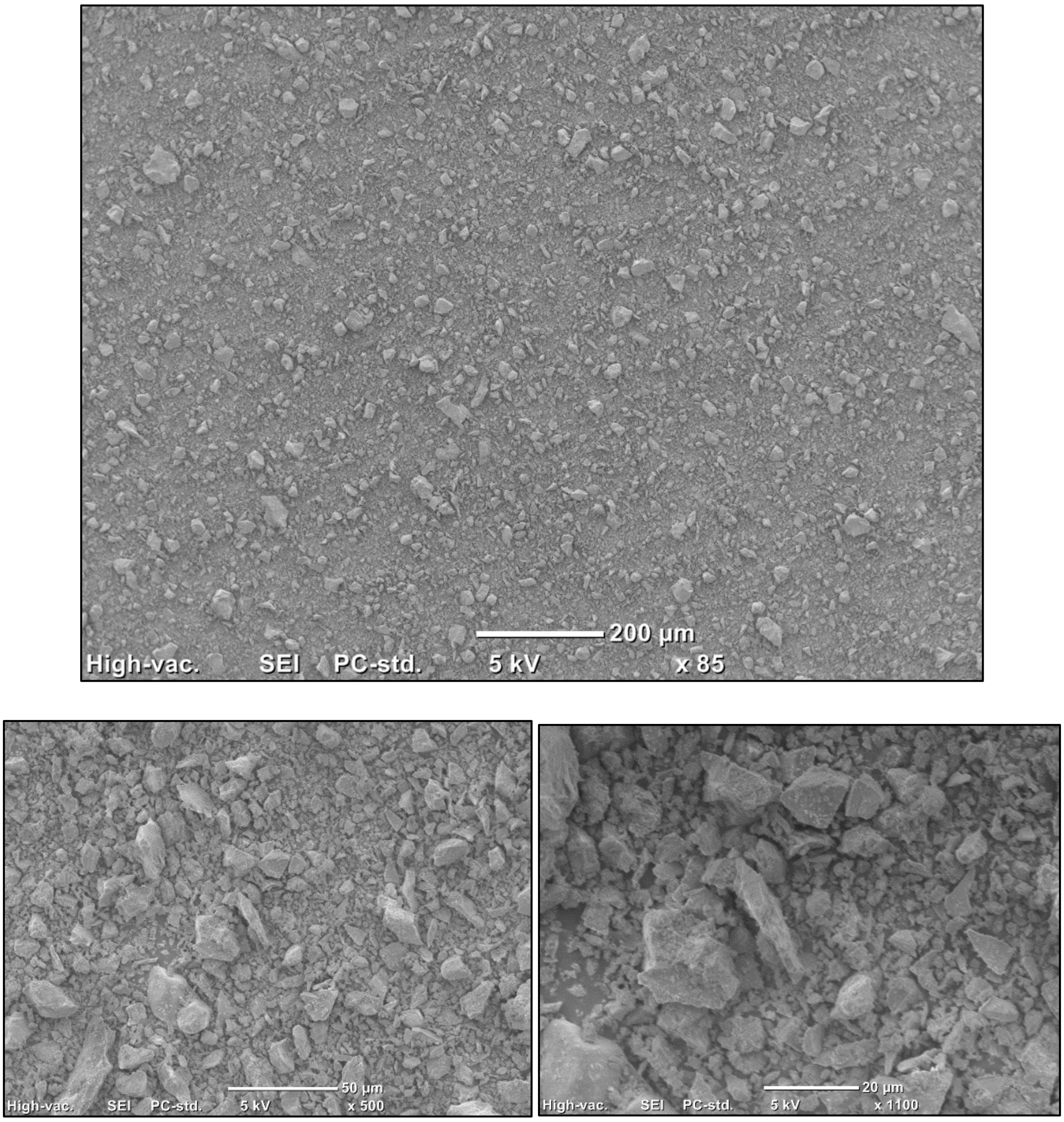

Figure 3. 6 Micrographs of the selected cement particle before fabrication

3.3 SAMPLE PREPARATION: MOULDING AND CURING

First of all, the materials and equipment required to carry out the project were collected. The list of materials required has been explained in the material requirement section in appendix A. Concrete was produced by varying the percentage of ceramic waste in concrete and cylindrical shape were casted. A total of 9 sample were casted for each percentage of cement replacement with ceramic waste. The sample prepared based on the reported work by recent work of (Festugato, Menger, Benezra, Kipper, & Consoli, 2017), (Luo, Ajaxon, Ginebra, Engqvist, & Persson, 2016), and (Ghanbari, Hadian, Nourbakhsh, & MacKenzie). The samples were prepared based on the ASTM C39 / C39M - 16b , i.e. Standard Test Method for Compressive Strength of Cylindrical

Concrete Specimens, (ASTM, 2001). The waste ceramic aggregates mixed with the cement samples were prepared by hand-mixing dry soil, cement waster and the ceramics, figure 3.57

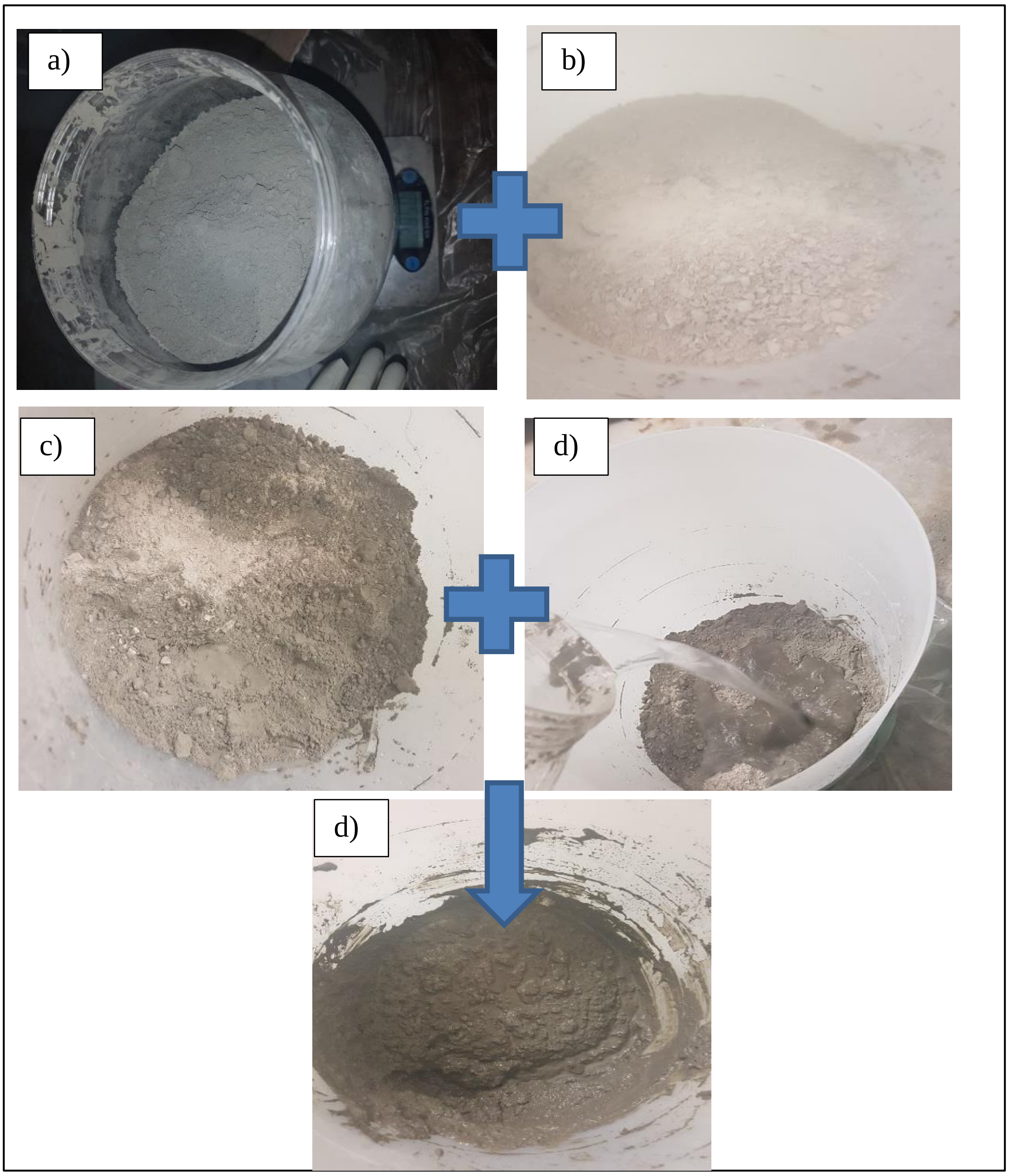

Figure 3. 7 Preparation steps for the concrete: *a) weight the cement; b) weight the prepared waste ceramics; c) mixing a and b; d) adding the water and e) mixing all the materials together.*

The cement were mixed without prepared ceramic aggregates prior adding the water. The amount of the ceramic added in the mixture is based on the weight percentage. Weight balance was used to determine the amount with an accuracy of ±10 mg. Visual examination and later SEM used to ensure the satisfactory of the prepared sample. The prepared mixture were kept in contained to avoid moisture losing form the sample during the curing. The mixture were slowly poured inside the prepared cylinders to avoid any bubble generation. At the same time, the inner wall of the cylinder were coated with a thin layer of grease to ease the removal of the sample after curing. After the casting process, the samples were extracted from the mould, and its weight, diameter and height were determined. The prepared sample were kept in plastic bags to ensure the same content of moisture will remain the same for all the samples. Three samples of each concrete replacement were tested on third days, fourteenth days and twenty eighth days. Samples of the prepared specimens are given in figure 3.8.

Figure 3. 8 Prepared samples of cements with different ratio of waste ceramic aggregates

A visual examination using the naked eyes were used to ensure the quality of the prepared samples. In addition, some the prepared mixed were molded in small samples for the SEM examinations as well to ensure the homogeneity of the concrete and the good interaction between the waste ceramic particles and the cement. Figure 3.9 shows the micrographs of the prepared sample of the concrete. In the recent work on the microstructure of concrete based on waste ceramics, Zegardło, Szeląg, and Ogrodnik (2016) proposed that the waste ceramic particles have voids and holes which allow the cement to penetrate into the particle and generate an interlocking mechanics. This will significantly improve the structure of the concrete. The proposed interlocking behavior between the particle and the cement were given schematically and have been extracted and represented here in figure 3.10. Despite of that work, the current micrographs indicate very good interaction between the waste ceramic particles and the cement; however, there is no indication of voids or holes in the particles. On the other hand, the micrographs of the waste ceramic particle shows some voids previously in figure 3.4. In another work by Awoyera, Akinmusuru, and Ndambuki (2016), the structure characteristics of concrete with the addition of ceramic wastes obtained from construction and demolition activities were investigated. In that work, the SEM obtained after 28 days showed very poor structure as can be seen in figure 3.11. Fragmentation and poor structure of the concrete can be seen which could be due to the high percentage of the waste ceramics or the poor quality of the ceramic used. This is very questionable issue and can be addressed in future work.

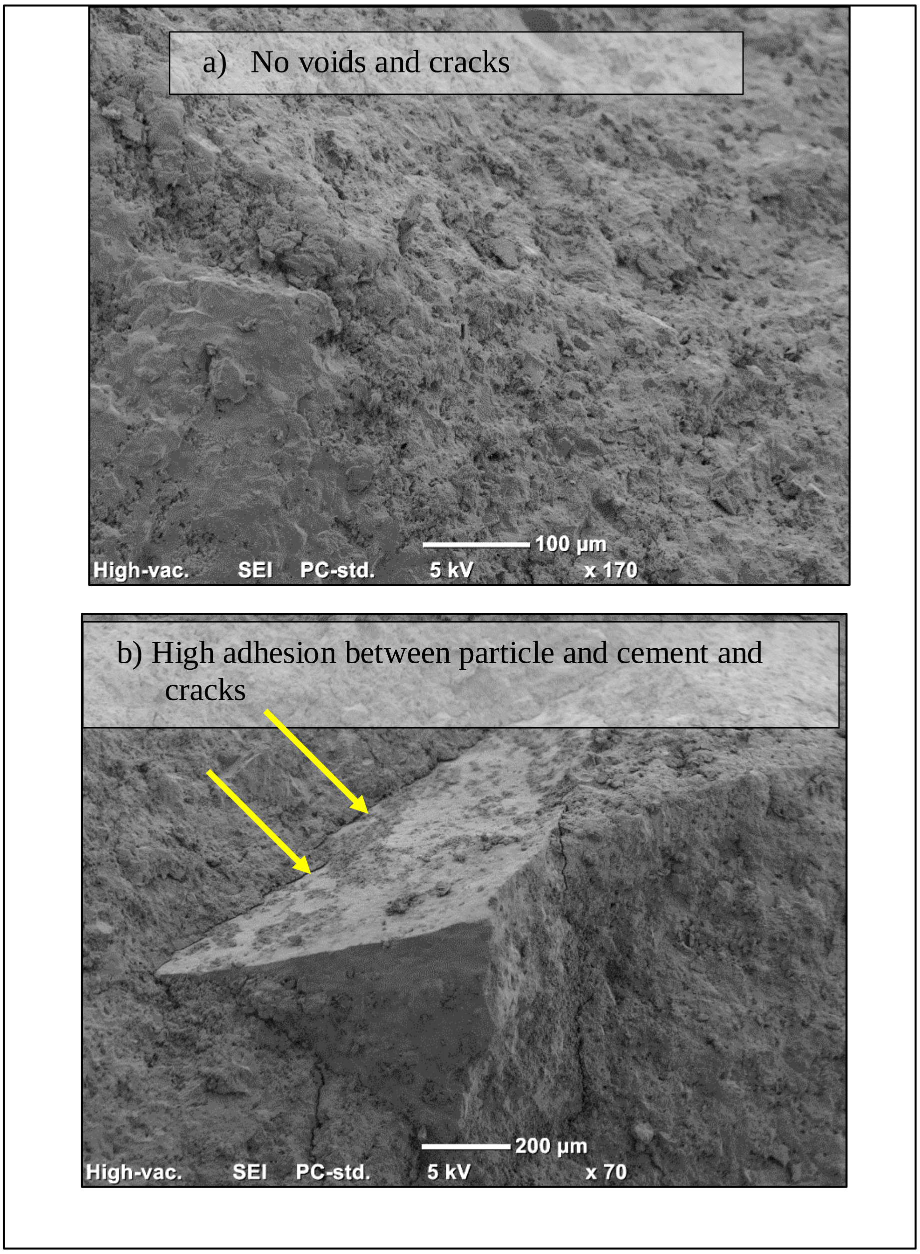

Figure 3. 9 Prepared concrete sample showing the interaction between the ceramic particles and the cement

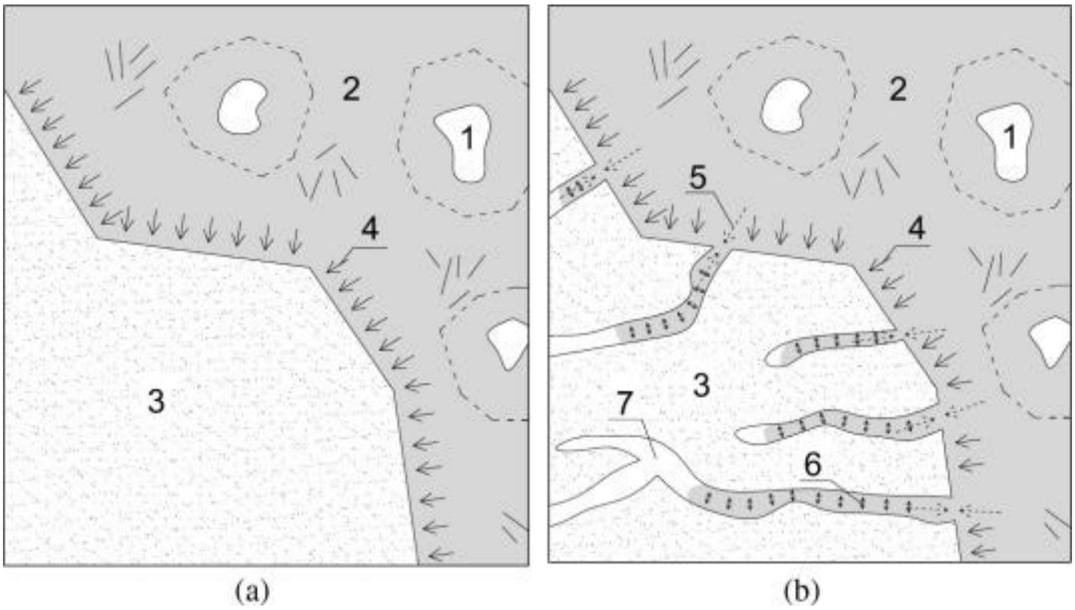

Figure 3. 10 A model suggested by Zegardło et al. (2016) showing microsilica adhesion to the surface of basalt (a) and ceramic aggregate (b).

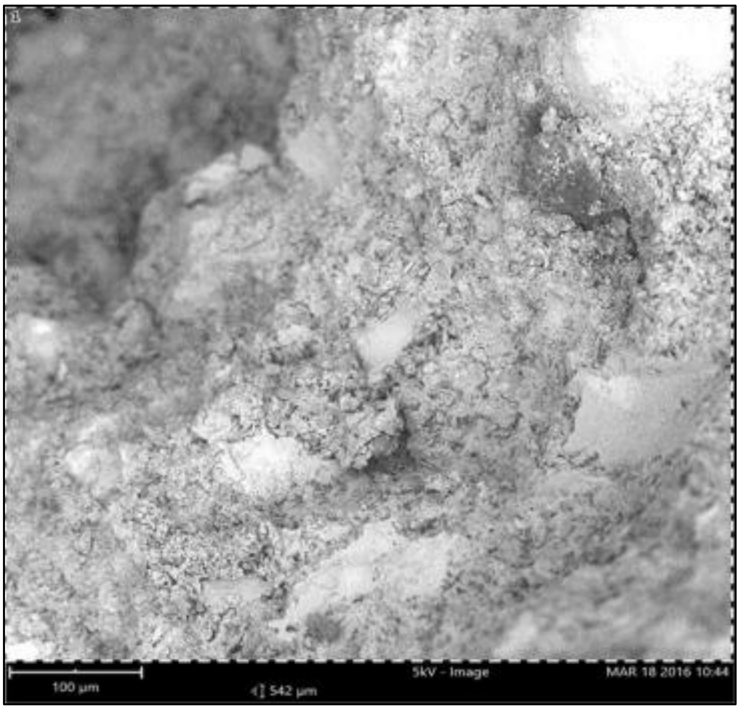

Figure 3. 11 Micrograph of prepared concrete by Awoyera et al. (2016) after *28 days; the concrete was made of Mix 100% CEM: 10% Laterite + 90% ceramic fine: 25% Gravel + 75% CER coarse.*

3.4 EXPERIMENTAL PROCEDURE

Slump test was carried out after the mixing of concrete for each percentage of cement replacement. Slump cone was used for conducting this test. Then there was a phase of curing concrete. Concrete cylinders were placed in water bath to facilitate hydration process.

Compressive strength tests were carried out on the concrete cylinders to determine compressive strength. 3 cylinders were tested after 7 days, 3 cylinders after 14 days and 3 were tested after 28 days for each percentage of ceramic waste in order to obtain average result. The data was analyzed on computer using excel (plots) to determine the optimum percentage of ceramic waste that provided highest compressive strength and required workability. Plots that were generated include; slump versus percentage of ceramic waste, days versus average compressive strength of concrete cylinders and percentage of cement replaced versus average compressive strength of concrete cylinders. Comparison of the results with previous studies was also carried out. The last phase of the project was the write up phase in which the dissertation was prepared for submission to the supervisors.

Compressive strength test was conducted on concrete cylinders to determine the maximum compressive strength. Three cylinders of each concrete replacement were tested on third, fourteenth and twenty eight day. So a total of 9 cylinders of each replacement were tested. Universal testing machine was used for testing. The loading rate on the cylinders was 35 N/mm^2. Dimensions of the cylinders before the test were accurately measured in order to determine the compressive strength per unit area. Slump test is used to determine the workability of concrete. Slump of concrete was measured in millimeters. Slump cone was used for the purpose. The test was conducted immediately after preparation of concrete mix.

Universal tensile test machine was used at the University of Southern Queened. The machine is equipped with hydraulic system to generate. Figure 3.12 shows the placing of the sample on the machine before starting the compressive test. The machine is equipped with the load cell to measure the force subjected on the sample. Strain gauges will be fixed to measure the deformation with the increase of the force. The test were perform at loading rate of 2mm/min. During the test, the samples were monitored with the aid of camera to record the failure behavior under the increase of the load. For east set of test, three samples were tested and the average of the strength and strain were determined. After the compressive test completion, stress –strain diagrams were obtained and the modulus were calculated. Furthermore, the fractured samples were examined and small pieces of each sample were observed under the scanning electron microscopy (Desktop JOEL) at the University of Southern Queensland.

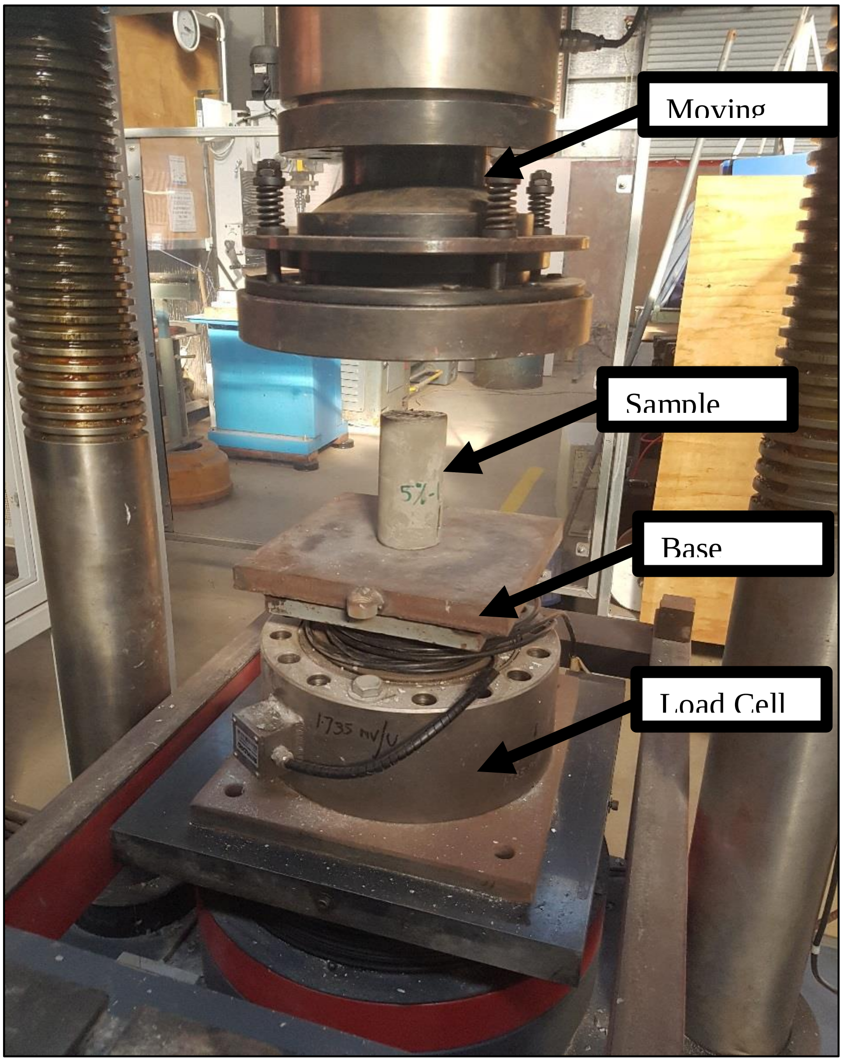

Figure 3. 12 Compressive set up at the University of Southern Queensland

The detail of the scanning election microscopy observation for the sample is provided in figure 3.13 a-e. At the first stage, the small pieces of the fractured concrete were placed on a holder with sticky conductive tap to ensure that the sample will not fall down in the SEM chamber and also for gold coating purposes. The next stage was to coat the surface of the sample since it is not conductive and to gain high quality images, the coating process is recommended by JOEL company guideline. The sample were place in a smart coater machine at the University of Southern Queensland. During the coating process, the chamber were vacuumed and thin layer of gold were placed on the surface of the fractured sample. The coting process took 1 min. after that, the coated sample were placed in the SEM chamber and the door of the SEM closed for vacuuming process. After the volume process completed, the image appears on the screen of the computer and adjustment made to gain high quality images. Scanning starting after word to observe the damages and/or any interesting phenomenon.

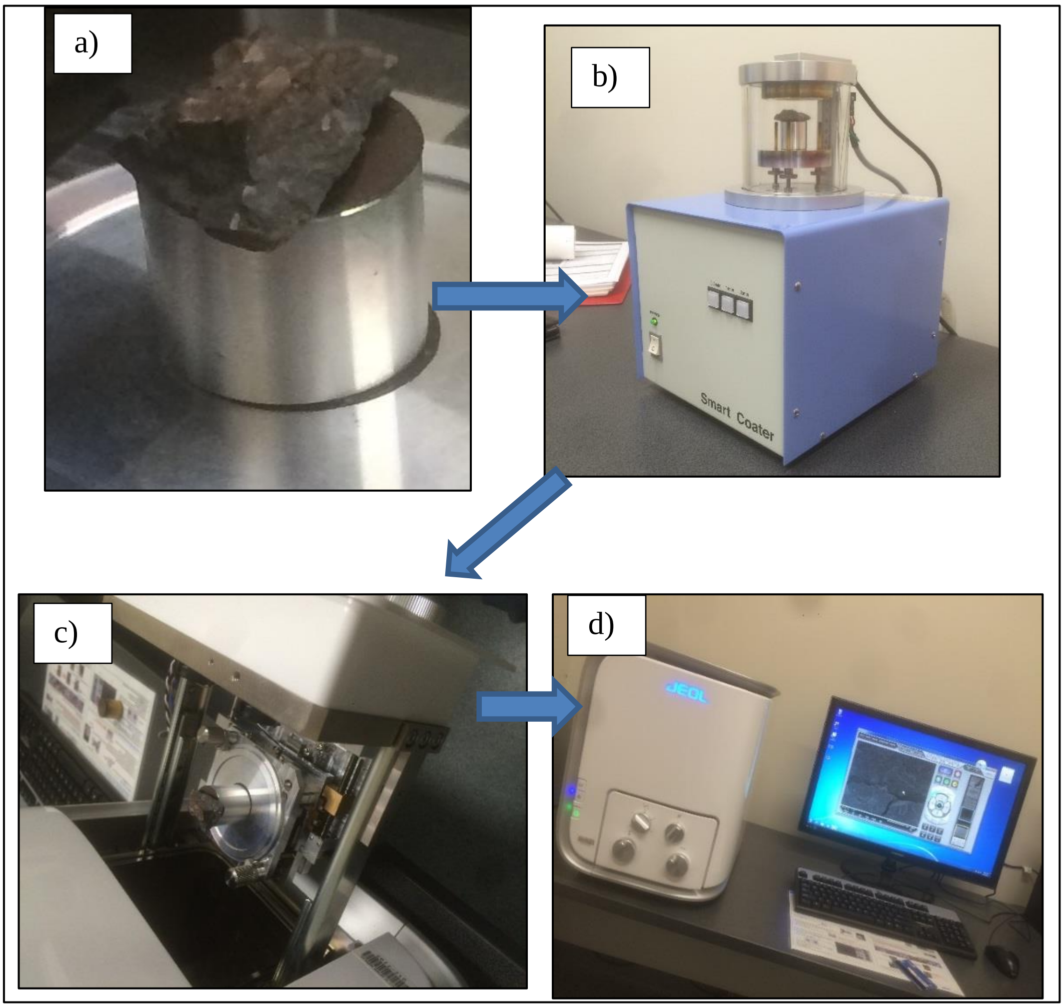

Figure 3. 13 Steps of the Scanning election microscopy examinations. *a) place the sample on the holder; b) gold coating process in the smart coater; c) place the coated sample in the JEOL SEM machine; d) examine the surface using the PC software.*

CHAPTER 4

RESULTS AND CONCLUSIONS

4.1 INTRODUCTION

In this chapter, the workability of the prepared samples is determined for the concrete mixture at different ratio of waste ceramic particles (0 - 45 wt %). The compressive strength of the concrete with the different ratio of waste ceramic particles is presented. Failure mechanism is determined for each sample based on the visual monitoring of the sample during the test with the aid of camera. Scanning electron microscopy is used to examine the interaction between the waste ceramic particles and the cement after the test completed. The current results are discussed with the previous published works and proposed failure mechanisms are introduced.

4.2 Workability of the prepared samples

Workability of the cement mixture is very important parameter to determine the quality of the mixture and the way can be handled. In the current study, the workability of different the prepared mixture of cement with different ratio of waste ceramic particles were determined through slump test. The raw date of the tests are introduced in table 4.1. The different prepared mixture were given a different names as given in the table which will be used later in this chapter. The names of the mixture are initiated with A1, A2…A6 for the mixture content of 0% ceramic waste, 5% of ceramic waste….40% of waste ceramic. The table indicates that the range of the slump results are in between 50 mm -90 mm. This is similar to the published work by. Awoyera et al. (2016) whom the value obtained ranged between 50 and 90 mm for the ceramic course particles with cement mixture. This confirms the high quality of the prepared samples as reported by the same authors, (Awoyera et al., 2016).

Table 4. 1 Results of Slump Test

Concrete Type	Percentage of Cement (%)	Percentage of Ceramic waste (%)	Slump (mm)
A1	100	0	76
A2	95	5	86
A3	85	15	89
A4	75	25	56
A5	65	35	51
A6	55	45	64

To show the influence of the waste ceramic content in the mixture with regards to the workability, the data presented in table 4.1 is plotted in figure 4.1 showing the workability vs. the ceramic ratio. It seems there are three regions on the trend of the workability of the mixture with the addition of the ceramics. At low percent of waste ceramic, intermedia value of the workability can be seen, which is about 76 mm. When the percent of the waste ceramic increased, the workability with respect to the slump is increased as well; this is the case when the ceramic particles content not more that 15%. In other words, the workability of concrete is maximum at 15% replacement of cement with powdered ceramic waste. At high percent of waste ceramic content, the workability start deteriorating and reduction in the slump data can be seen. Despite of that the range of the slump date is good. In published work, seven concrete mixes at different dosages of colloidal Nanosilica (0-3 wt.%) exhibited workability in the range of 25 mm to 50 mm as reported by Chithra, Senthil Kumar, and Chinnaraju (2016). Kim, Jeon, and Lee (2012) studied the workability of waste recycled aggregates obtained from building demolition and also from the ceramic industry showing very high workability for the mixture in values between 100 mm- 200 mm. this considered to be very high and out of the recommended range.

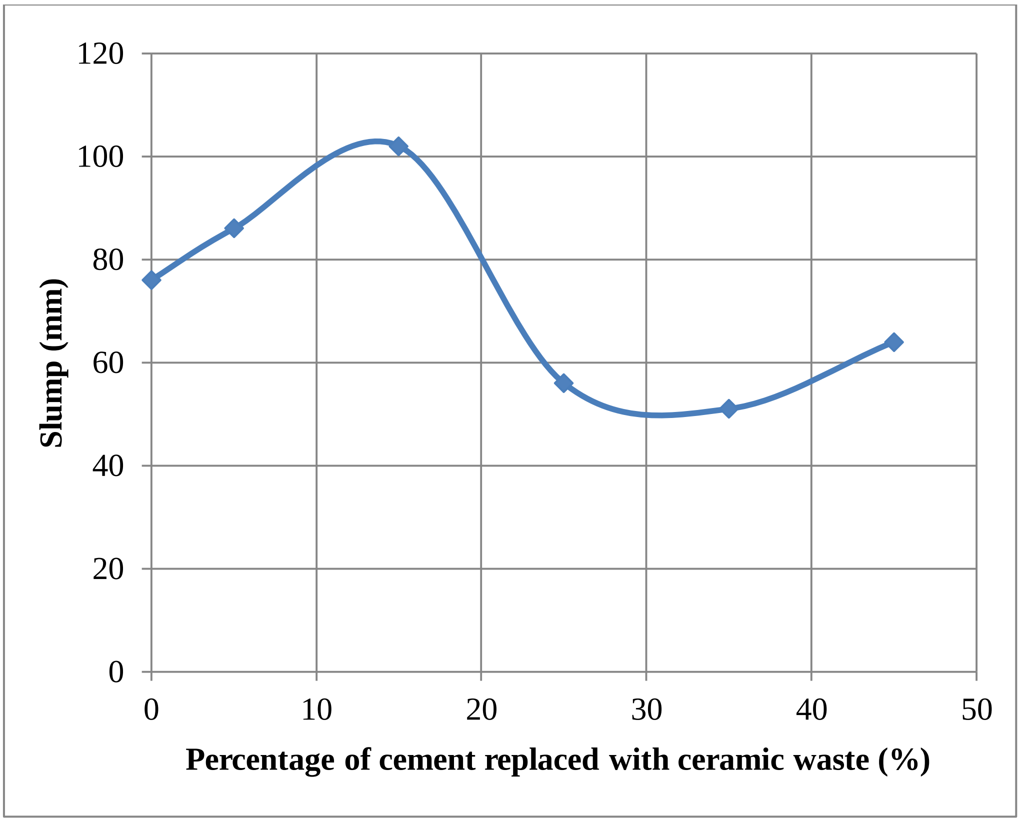

Figure 4. 1 Slump of concrete versus Percentage of cement replaced with ceramic waste

4.3 COMPRESSION STRENGTH

The compressive strength of different concentrate prepared with different ratio of cement/waste ceramic particles were tested. The tests were conducted with different days after preparation as seven, fourteen and twenty eight. Each test has been repeated four times and the closet value of three has been considered. The average of the concrete strength is given in table 4.2. In general, the concrete exhibited brittle failure and the strength of the samples were taken at the fracture point. The value of the compressive strength of the pure cement, without the addition of the ceramic, after 28 days is above 31 MPa. From industrial point of view, this can be considered as good results and indicate that the prepared sample were well prepared without any voids and initial cracks.

Table 4. 2 Results of Cylinders Compressive Strength Test

Concrete type	Partial replacement of cement (%)	Average Compressive strength (MPa)		
		7 days	**14 days**	**28 days**
A1	0	16.4	23.5	31.2
A2	5	15.1	21.4	28.8
A3	15	12.8	17.8	23.1
A4	25	10.9	14.9	17.3
A5	35	7.2	11.3	14.1
A6	45	5.4	8.5	9.5

Figure 4.2 shows that as the age of concrete increases, its strength also increases. Usually concrete gains its maximum strength at 28 days. Results are very consistent with nature behavior of concreate. Similar trends of compressive vs. strain have been reported previously by Reddy, Dinakar, and Rao (2016). In that work, poor strengths have been exhibited with either too high or too low SiO_2 and Al_2O_3 contents in concreate and particularly when they were not in the aforementioned typical range. In another related work by Awoyera et al. (2016), concrete with 10% laterite content and 75% ceramic coarse aggregate yielded at 26.54 MPa compressive strength at 28 days. In other words, the current results are in agreement with the reported works. In addition, Senthamarai and Devadas Manoharan (2005) and Abdullah et al. (2006) reported close compressive strength to the materials tested in their works. The material were concreate based on course ceramic particles. However, in those works, it has been reported that the high addition of the ceramics increase the strength of the pure materials which is not in agreement with the current trend. On contradict, Awoyera et al. (2016) argued with their findings showing decrease in the strength of the concrete with the addition of the ceramics. The late questioned the findings of the previous published work and this is confirmed with the current findings in this report. Further discussion will be given with the aid of the SEM in the next section of this chapter.

With regards to the influence of the curing period on the compressive strength of the concreate, figure 4.2 clearly shows that the increase in the period increases the strength of the concreate and this is a well-known fact and reported in all the related works such as (Anderson, Smith, & Au, 2016; Kin, Don, & Ahmad, 2012; Zegardło et al., 2016). American Concrete Institute recommended "*minimum curing period corresponding to concrete attaining 70 percent of the specified compressive strength*" (ACI, 2005). This can be achieved with either high temperature & short time curing, or longer time at low temperature curing. The curing process is a strengthen process to the concreate.

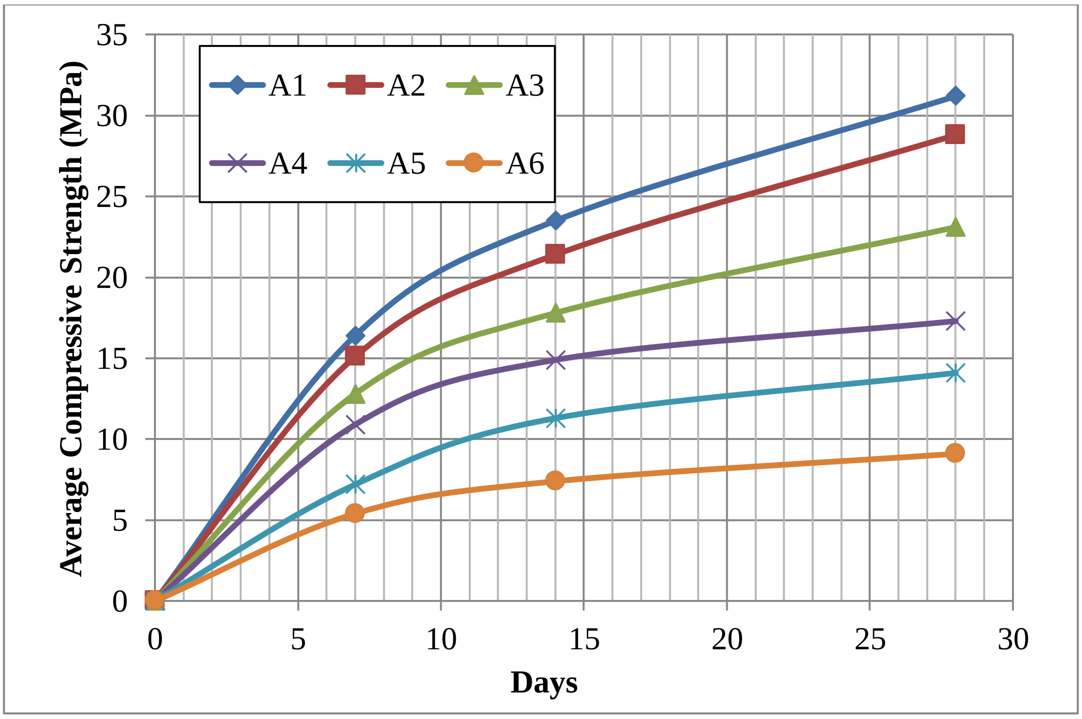

Figure 4. 2 Average Compressive strength of cylinders versus number of days

With relation to the influence of the ceramic percent and the curing period, the trend seems to be the same for all the period of curing as shown in figure 4.3. It should be mentioned here that the compressive strength of the ceramic is higher than the pure cement A.-j. Wang et al. (2013) reported that the ceramic compressive strength can reach up to 60 MPa. Accordingly, it seems that the addition of the ceramic in the current study did not carry the subjected load; otherwise, there must be an increase in the strength the addition of the ceramics. This could be due to the smooth surface of the ceramics which resulted in poor interaction with the cement and/or there could be some chemical reaction took place which separated the particle from the bulk of the cement. Further study need to be taken to understand this phenomenon. SEM in the current study will assist to understand the bonding area between the cement and the particle but cannot chemically analysis the surface.

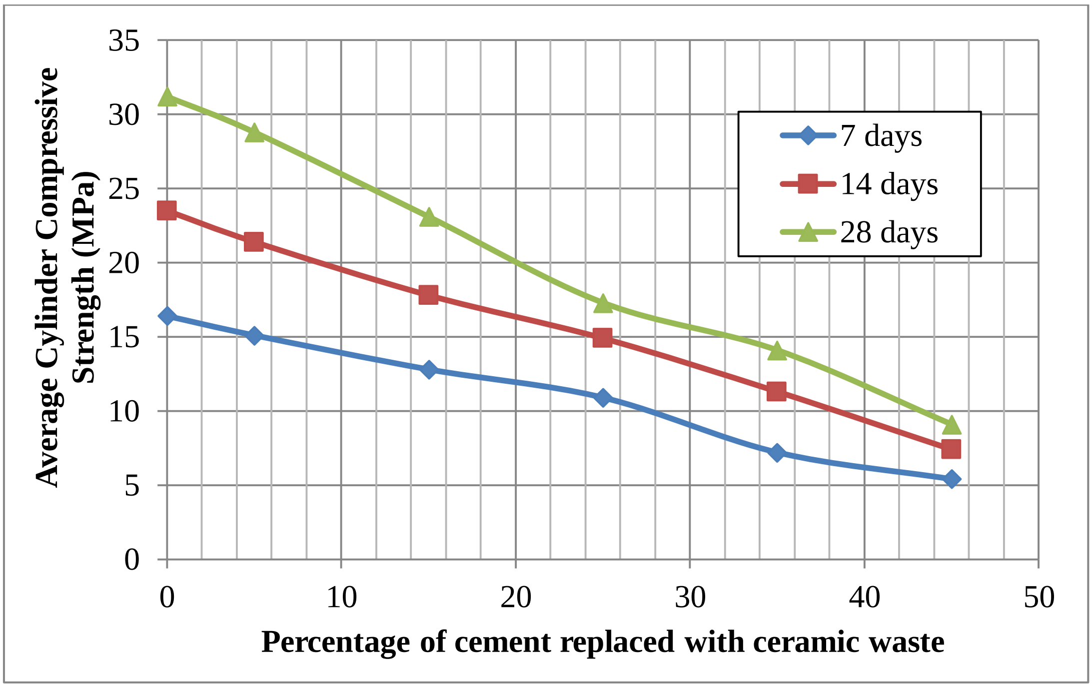

Figure 4. 3 Average Compressive strength versus percentage of cement replacement

4.4 FAILURE BEHAVIOUR

Visual monitoring to the failure of the samples were observed during the tests and process of failure were captured using digital camera. Sample of the captured photo is given in figure 4.4 for the 5% ceramic mixed with cement for A2 Material type. All the captured photo for the rest of the samples are given in Appendix E. Figure 4.4 shows typical failure mechanism for general concrete. At the initial stage of the failure, a micro-crack is initiated as can be seen in the photo. At the second stage, propagation to that crack was progressing with an angle of about 90 degrees.

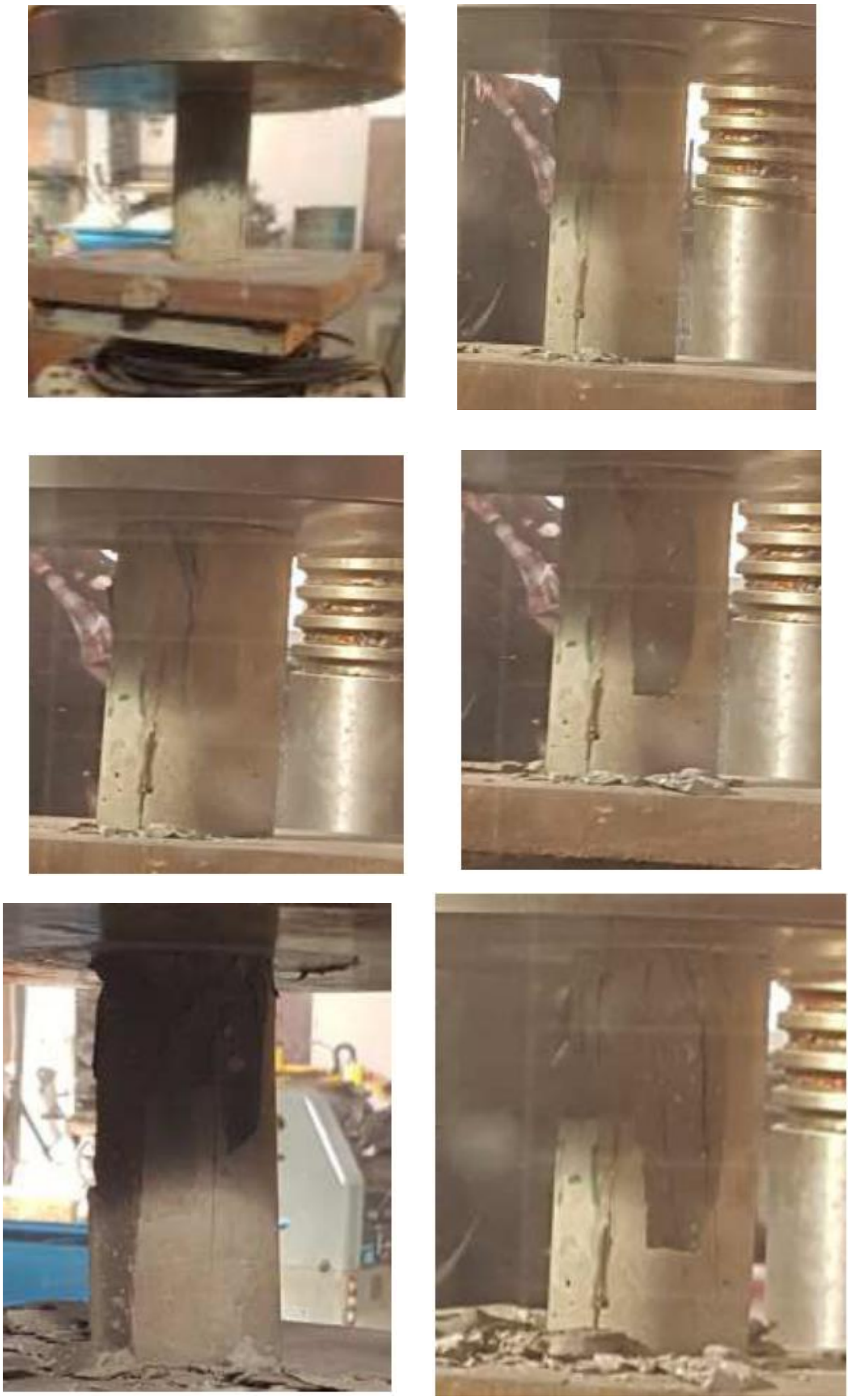

Figure 4. 4 Failure behavior of the sample with the increase of the applied load

This is shows the high brittleness of the concrete. In addition, fracture behavior can be seen on the surface of the sample and small pieces of the sample state to break out which resulted in small surfaces in contact with the applied force, i.e. high stress generated. This is associated with shortening in the length of the sample, i.e. deformation. It seems the trend of the stress undergone different stages which started with initial elastic deformation and then followed by short stage of plastic deformation. The deformation was increasing with the start load after reaching the ultimate compressive strength. Similar trend has been reported by Singh, Ishwarya, Gupta, and Bhattacharyya (2015) when aluminosilicates were used in concreate at different ratio.

4.4.1 SEM Observations

The micrographs of the fractured surfaces of the samples are given in figures 4.5 and 4.6 low percent of ceramic of 5% and high content of 45%, respectively, after 28 days curing period. At low percent of ceramic, there are different damages can be seen on the micrographs which are detachment of particles, micro-crakes, macro-cracks, and decompositions. This can explained the lowering of the strength of the concrete with the addition of the ceramic since the load could not be transferred to the particle since the boding between the particles and the cement seems to be weaker than the shear force. This support the current presented data and reported results by Awoyera et al. (2016). In addition, at higher percent of the ceramics, there is similar fracture mechanism and the cement regions seems to have high porosity (see figure 4.6 in compare to figure 4.5). This is in support to the experimental results given in figure 4.3. Singh et al. (2015) also suggested that the high porosity in the concreate deteriorate the strength of the materials since it works as week point. In addition to that, the SEM shows that the cracks is initiated close to the particles and propagated from there. In other words, the bonding region between the particle and the cement is the critical zone need to be considered in the future work.

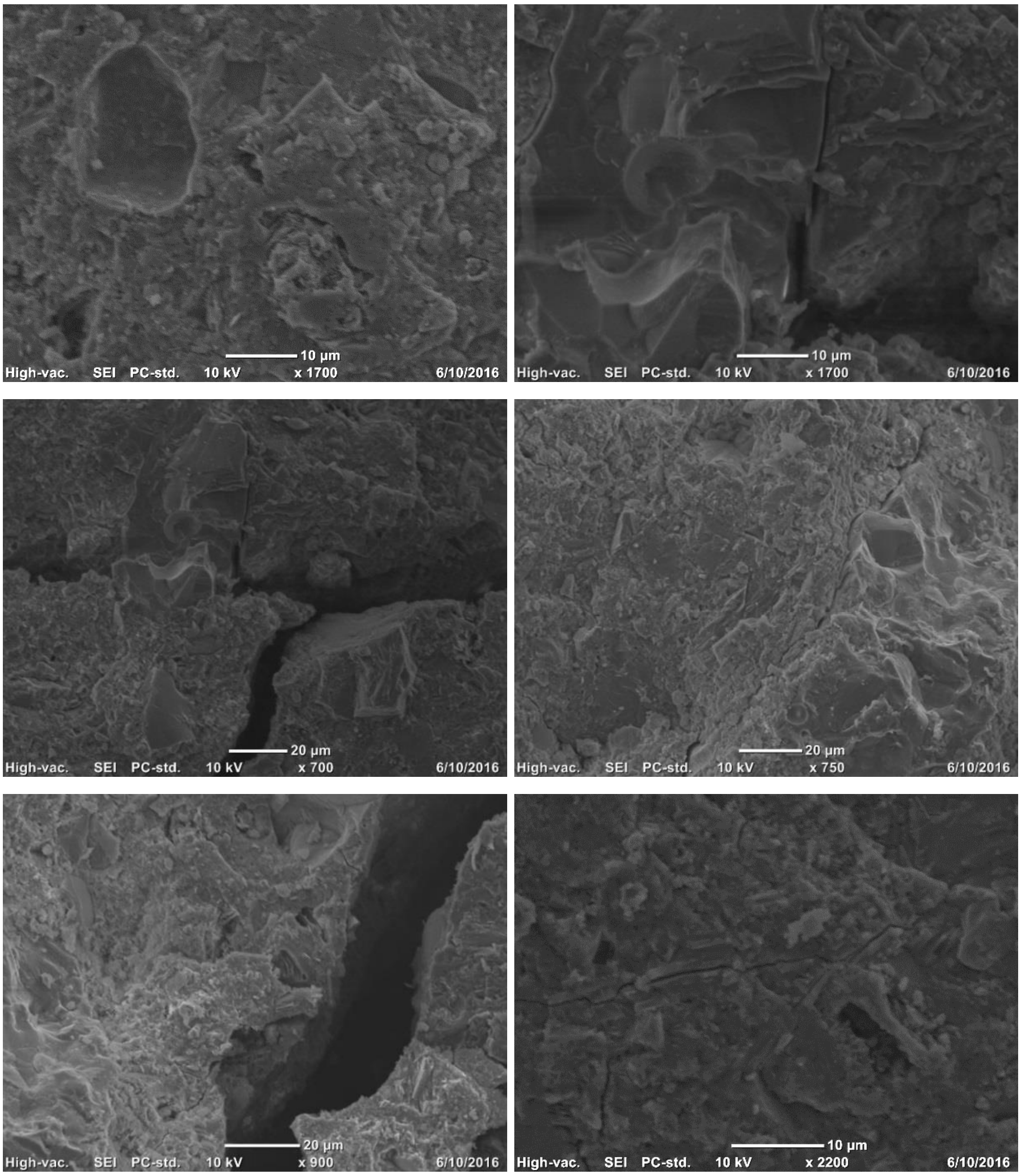

Figure 4. 5 Micrographs of concreate at low volume fraction of waste ceramics at 5%

Both figures (4.5 and 4.6) did not show any voids and/or defects in the inner structure of the samples which indicates the good quality of the fabrication process. Łaźniewska-Piekarczyk (2013) studied the influence of the air voids on the structure of concreate and the concreate characteristics. In that work, several attempts have been used to avoid the air-void generation in the concreate to ensure the quality of the structure. Jóźwiak-Niedźwiedzka (2005) and Du and Folliard (2005) described the importance of avoiding he air bubbles in the concrete owing to to enable the cement to take up volume extension of the freezing water without suffering any damage.

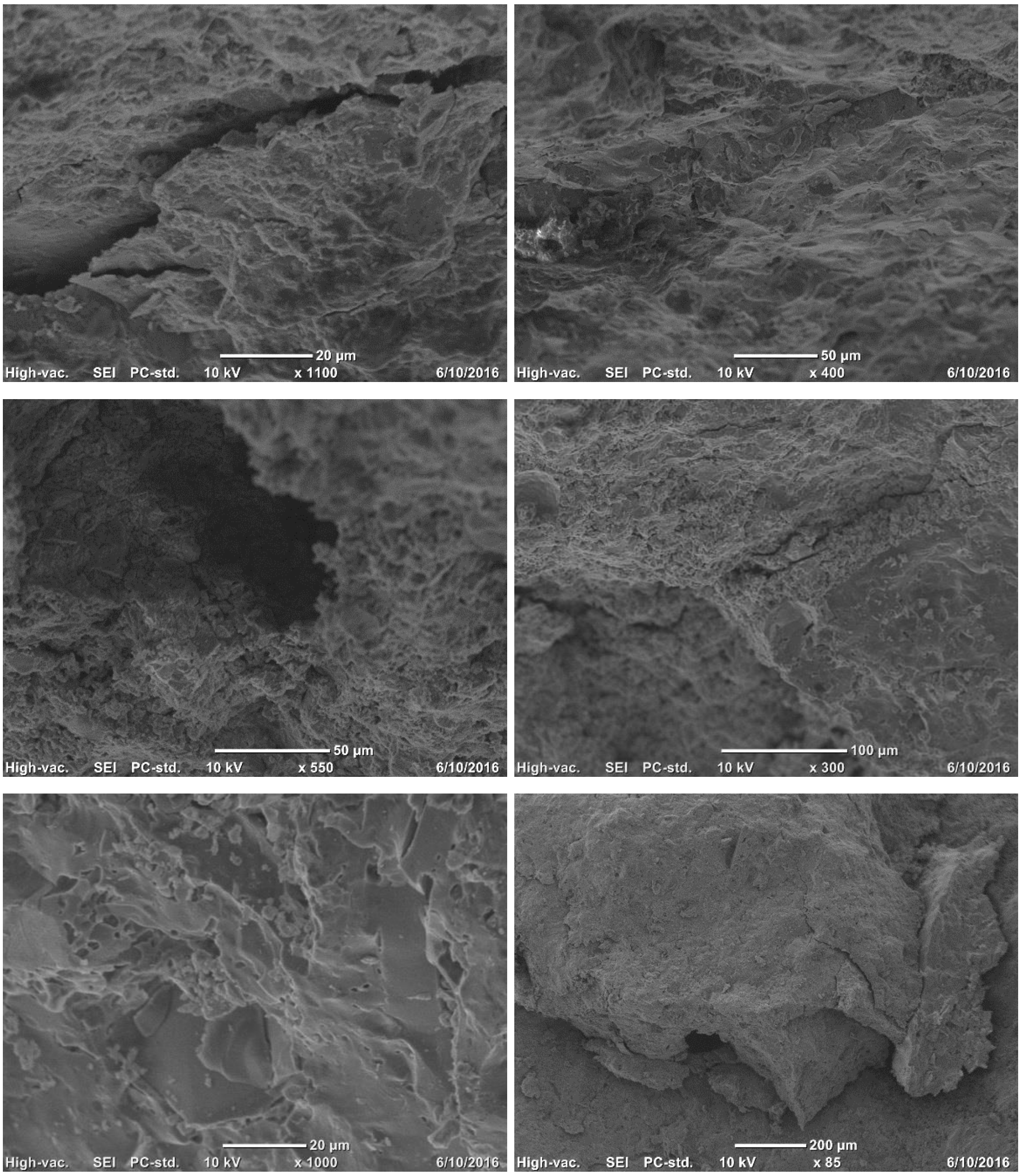

Figure 4. 6 micrographs of concreate at Low volume fraction of waste ceramics at 45%

The proposed schematic drawing of the air interaction with the cement has been introduced by Du and Folliard (2005) and displayed in figure 4.7. The proposed schematic displays the impact of the air bubble presence in the cement and their adhesion with cement particles. It is suggested that the presence of the air in the concreate is due to the fact that cement particles assist in dispersing the air bubbles in the mixture and preventing them from floating to the surfaces.

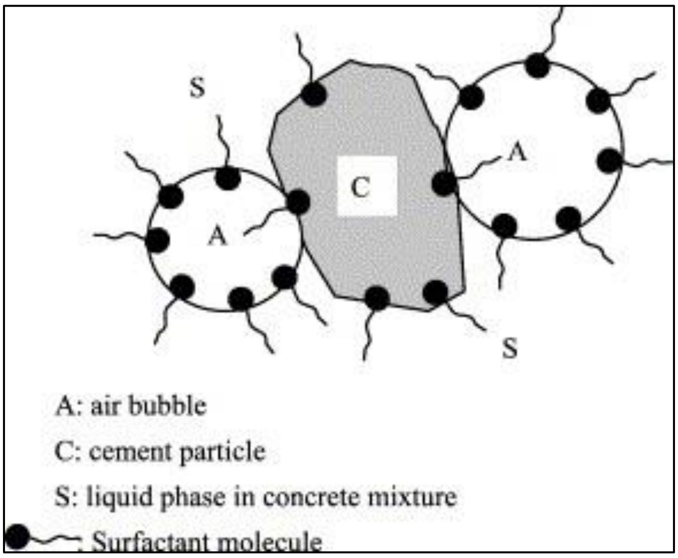

Figure 4. 7 Interaction between air bubbles and cement particles, extracted from (Du & Folliard, 2005).

In the current SEM observation of the prepared concreate (Figure 3.9), there is no initial cracks can be seen. Pyo, Alkaysi, and El-Tawil (2016) proposed that the initial cracks are the main reason for the low strength of the concreate. It can be identify that the main reason of the low compressive strength of the current prepared concreate at high level of waste ceramic particles is due to the generation of cracks during the loading due to the weak interfacial adhesion of the particle with the cement. This can be illustrated with the aid of schematic drawing displayed in figures 4.8 and 4.9 for low and high content of waste ceramic particles in concreate. It is proposed here that the micro-cracks will be generated at low content of waste ceramic particles without linkage to another neighbor cracks. In other words, despite of the fact that the SEM (Figure 4.5) showed micro-cracks in the structure after the testing, but it is suggested that the crack did not propagate to the surface of the sample. This introduces higher strength to the material in compare to the case where the cracks propagated and linked to each other. This can be the case in figure 4.8. This thought supports the experimental results given in figure 4.3 and explain the high strength of the concreate at low percent of waste ceramic particles.

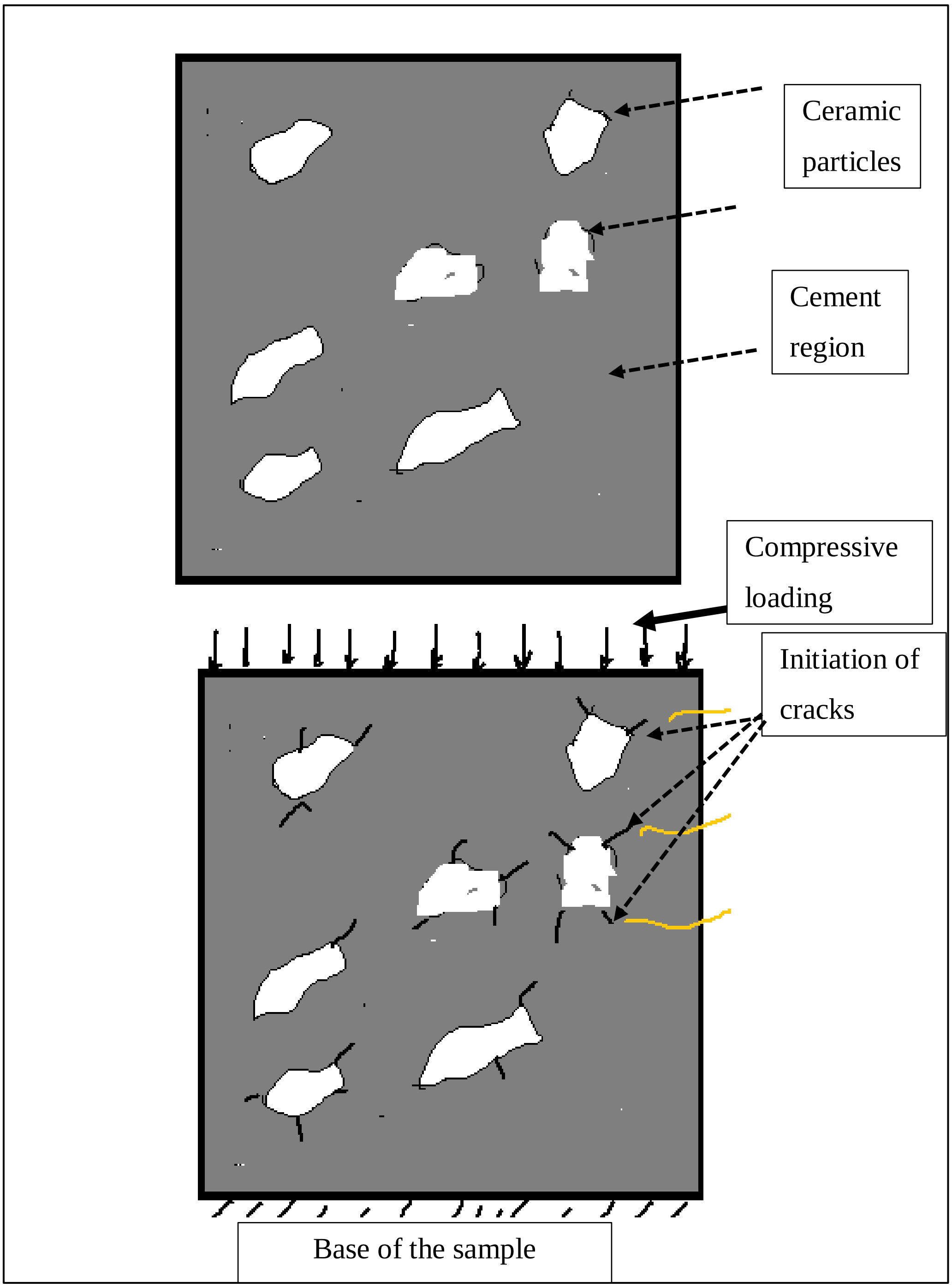

Figure 4. 8 proposed failure mechanism of concrete with low percent of waste ceramic particles

On the other hand, when the content of the waste ceramic particle increases, there is high possibility of crack propagation and linkages among the cracks which results in deteriorating the compressive strength of the concrete. Figure 4.9 proposed this thought; with the high applied compressive loading, a crack star to initiate close to the waste ceramic particles and propagate with the increase of the load. At this stage, the cracks start propagating and links to the closure propagated crack and resulted in the failure of the samples.

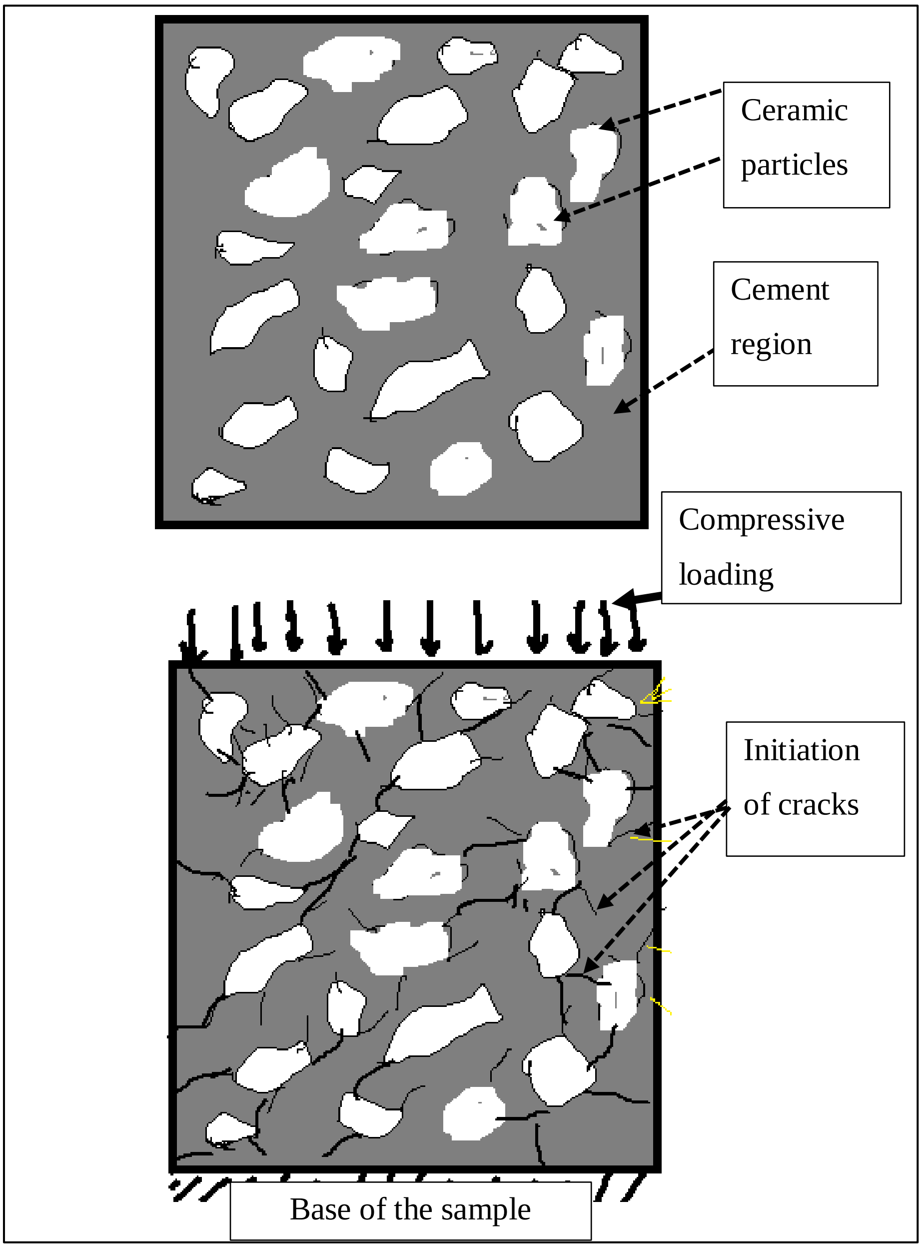

Figure 4. 9 Proposed failure mechanism of concrete with high percent of waste ceramic particles

This thought is supported with the SEM given in figure 4.6 and the photos presented in appendix E (section E.4 and E.5). Also, the experimental date in agreement with this thought. In the light of the above, it can be confirm that the failure mechanism is due to the crack propagation and the cracks initiates within presence of the waste ceramic particles, i.e. the high percent of the waste ceramic particle encourages the initiation of the cracks and worsen the compressive strength of the concreate.

Despite of the above and from the environment point of view, the reduction in the compressive strength with the percent of about 25% of waste ceramics can be acceptable from industrial point of view. It can be recommend that the low percent of waste ceramics will be highly desirable amount from industrial and environmental point of views. In addition, this will reduce the cost of the concrete and assist in deposing the waste ceramic in useful applications. I wish to recommend further study at this stage to evaluate the interaction between the waste ceramic particles and cement owing to improve the adhesion which can allow to increase the content of the waste ceramics without compromising the compressive strength of the structure.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The purpose of this research is to determine the optimum content of ceramic particles that can be used in concrete as a partial replacement of cement and also to find its workability. The cement replacement was restricted to 45% in order to determine the optimum percentage of ceramic waste that can be used as a replacement of cement. Based on the experimentation, following results can be deduced,

1. The workability (slump) of concrete is maximum at 15% replacement of cement with powdered ceramic waste. After 15%, the slump starts to decrease up to 35% after which a decreasing behavior is seen again. Despite of that, all the workability of the prepared mixture are within the recommended values and are in high agreement with the related published works.
2. As compared to the conventional concrete, the strength of concrete consisting of waste ceramic particles as a partial replacement of cement seems to be lower than the pure concreate. Compressive strength of concrete on 25% replacement is 17.3 MPa which is slightly lower than the ordinary strength range of the conventional concrete. However, on 15% replacement with waste ceramic particles, strength of concrete is 23.1 MPa which lies in the range of the conventional concrete.
3. This indicates that waste ceramic particle can be used as a replacement of cement up to 15% and can produce a good strength concrete with excellent workability. Consequently it can reduce the construction costs to a large extent since it will reduce the quantity if cement to be used which is a very expensive material.
4. Using ceramic waste in construction industry will allow for sustainable development. On one hand it will be economical and on the other hand will be helpful in controlling the environmental pollution. It will ensure the usefulness of the ceramic waste.
5. A proposed failure mechanism is introduced which explained the failure of the concrete at high content of waste ceramic particles. It is found that the main reason

of the failure is the cracks. At the low percent of waste ceramic particle, there is cracks close to the bonding region of the particles with the cement which deteriorate the strength of the concreate relatively to the pure cement. Despite of that the reduction of the strength is within the acceptable industrial range. However, at the high percent of waste ceramic particle (above 35%), significant reduction in the strength exhibited and 25% of ceramic can be recommended from environment and industrial point of views.

5.2 RECOMMENDATIONS

This research project has be done through two semesters and there are a lot of work need to be done to confirm the possibility of using the waste ceramic particle I concreate. There are few proposed research area to solve some of the issues which could not be done due to the time limit. Those area are as follows:

1. Interfacial adhesion of the waste ceramics with the cements need to be understood. In addition, chemical treatment would assist to improve the strength of bonding the cement with the waste ceramic particles. It can significantly maintain high compressive strength to the concrete by avoiding the generation of cracks.
2. Different particle sized could be another research area since it plays an important role in carrying the load and determine the failure mechanism.
3. Other tests are recommended to evaluate the characteristics of the new eco-concreate at different loading conditions and environmental conditions as well.

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Appendix A: Resource Requirement

The table below shows the list of resources required to carry out the research.

Table A. 1 Required Resources

Item	Quantity	Source	Cost
Ceramic Waste	Nearly 50-60 kg	Industry	Not confirm (but little)
Portland Cement	Nearly 50 kg	Market	20-30$
Aggregate	Nearly 50-60 kg	Laboratory	Nil
Los-Angeles Abrasion machine	1	Laboratory	Nil
Slump test apparatus	1	Laboratory	Nil
Molds	18	Laboratory	Nil
UTM	1	Laboratory	Nil
Water bath	1	Laboratory	Nil

A.1 Required Testing

Following are the tests required for the research,

Table A. 2 Required Tests

Test	Standard
Specific Gravity of Ceramic waste	ASTM D-854
Workability test(Slump Test)	ASTM C143 / C143M –12
Compressive Strength of Concrete	BS 1881-116:1983

Appendix B Risk Assessment and Implications Of Activities

The project involved preparation of concrete cylinders using cement and powdered ceramic waste. This step does not involve any risk since it just requires mixing of ingredients to produce concrete. However, all the equipment must be handled carefully and care should be taken while weighing and mixing equipment. As a result of this step, concrete cylinders were produced which were kept in water bath. Slump test for measuring workability of concrete is also very safe and does not involve any kind of risk. The other stage of project is compression testing of concrete cylinders to determine the compressive strength. In this step cylinders were tested in universal testing machine and crushed till failure. Cylinders were of no use after the test and were thrown away after being tested. Testing should be conducted carefully so that there are no errors in the results. Care must be taken while placing the cylinders in the machine and application of load.

B.1 Risk Assessment

The risk associated with this research project is very low. However, care must be taken while conducting Los Angeles Abrasion Test, Compressive Strength test and while mixing the concrete. Gloves should be used while performing the tests. UTM should be covered by a steel cage so that there may be no damage due to the broken pieces of concrete when concrete fails. All the material and equipment should be handled very carefully so that there is no damage to ourselves, materials and equipment. None of the material has any health hazards. However, concrete cylinders are heavy so they must be handled with care.

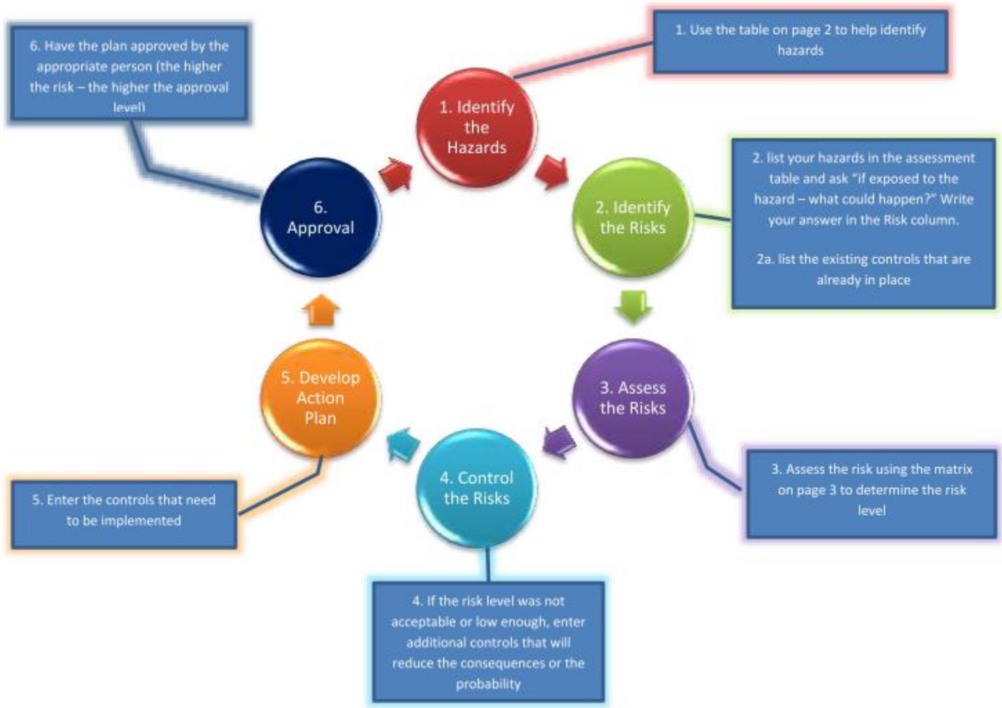
Risk associated with successful and timely completion of project was also low. There was no delay in the availability of the materials and testing equipment was also available in the laboratory so the project was timely completed. However, special care was required to keep the concrete cylinders save. If cylinders are lost then it may be required to cast them again which can cause little delay. The form prepared by the supervisor is shown as below

University of Southern Queensland

Generic Risk Management Plan

Workplace (Division/Faculty/Section): Civil Engineering Lab		
Assessment No (if applicable):	Assessment Date: 01/09/2016	Review Date: (5 years maximum) / /
Context: What is being assessed? Describe the item, job, process, work arrangement, event etc: compressive testing and preperation of samples		
Assessment Team – who is conducting the assessment?		
Assessor(s): Dr. Belal Yousif Others consulted: (eg elected health and safety representative, other personnel exposed to risks)		

The Risk Management Process



Step 1 - Identify the hazards (use this table to help identify hazards then list all hazards in the risk table)		
General Work Environment		
☐ Sun exposure	☐ Water (creek, river, beach, dam)	☐ Sound / Noise
☐ Animals / Insects	☐ Storms / Weather/Wind/Lightning	☐ Temperature (heat, cold)
☐ Air Quality	☐ Lighting	☐ Uneven Walking Surface
☐ Trip Hazards	☐ Confined Spaces	☐ Restricted access/egress
☐ Pressure (Diving/Altitude)	☐ Smoke	☐
Other/Details:		
Machinery, Plant and Equipment		
☒ Machinery (fixed plant)	☐ Machinery (portable)	☒ Hand tools
☐ Laser (Class 2 or above)	☐ Elevated work platforms	☐ Traffic Control
☐ Non-powered equipment	☐ Pressure Vessel	☐ Electrical
☐ Vibration	☐ Moving Parts	☐ Acoustic/Noise
☐ Vehicles	☐ Trailers	☐ Hand tools
Other/Details:		
Manual Tasks / Ergonomics		
☒ Manual tasks (repetitive, heavy)	☐ Working at heights	☐ Restricted space
☐ Vibration	☐ Lifting Carrying	☐ Pushing/pulling
☐ Reaching/Overstretching	☐ Repetitive Movement	☐ Bending
☐ Eye strain	☐ Machinery (portable)	☒ Hand tools
Other/Details:		
Biological (e.g. hygiene, disease, infection)		
☐ Human tissue/fluids	☐ Virus / Disease	☐ Food handling
☐ Microbiological	☐ Animal tissue/fluids	☐ Allergenic
Other/Details:		
Chemicals Note: Refer to the label and Safety Data Sheet (SDS) for the classification and management of all chemicals.		
☒ Non-hazardous chemical(s)	☐ 'Hazardous' chemical (Refer to a completed hazardous chemical risk assessment)	
☐ Engineered nanoparticles	☐ Explosives	☐ Gas Cylinders
Name of chemical(s) / Details:		
Critical Incident – resulting in:		
☐ Lockdown	☐ Evacuation	☐ Disruption
☐ Public Image/Adverse Media Issue	☐ Violence	☐ Environmental Issue
Other/Details:		
Radiation		
☐ Ionising radiation	☐ Ultraviolet (UV) radiation	☐ Radio frequency/microwave
☐ infrared (IR) radiation	☐ Laser (class 2 or above)	☐
Other/Details:		
Energy Systems – incident / issues involving:		
☐ Electricity (incl. Mains and Solar)	☐ LPG Gas	☐ Gas / Pressurised containers
Other/Details:		
Facilities / Built Environment		
☐ Buildings and fixtures	☐ Driveway / Paths	☐ Workshops / Work rooms
☐ Playground equipment	☐ Furniture	☐ Swimming pool
Other/Details:		
People issues		
☐ Students	☐ Staff	☐ Visitors / Others
☐ Physical	☐ Psychological / Stress	☐ Contractors
☐ Fatigue	☐ Workload	☐ Organisational Change
☐ Workplace Violence/Bullying	☐ Inexperienced/new personnel	☐
Other/Details:		

Risk 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

Risk register and Analysis

Step 1 (cont)	Step 2	Step 2a	Step 3			Step 4				
Hazards: From step 1 or more if identified	**The Risk:** What can happen if exposed to the hazard with existing controls in place?	**Existing Controls:** What are the existing controls that are already in place?	**Risk Assessment:** (use the Risk Matrix on p3) Consequence x Probability = Risk Level			**Additional controls:** Enter additional controls if required to reduce the risk level	**Risk assessment with additional controls:** (use the Risk Matrix on p3 – has the consequence or probability changed?)			**Controls Implemented? Yes/No**
			Consequence	Probability	Risk Level		Consequence	Probability	Risk Level	
Example										
Working in temperatures over 35º C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	Regular breaks, chilled water available, loose clothing, fatigue management policy.	catastrophic	possible	high	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
pinch the fingure during the preperation of samples	cut in fingers	wearing gloves during the experiemnts	Minor	Unlikely	Low		Select a consequence	Select a probability	Select a Risk Level	Yes or No
pinching the finger during the compressive testing	cut in fingure	wearing gloves	Minor	Unlikely	Low		Select a consequence	Select a probability	Select a Risk Level	Yes or No
debrise fly into eyes	injure the eye	wearing googles	Minor	Unlikely	Low		Select a consequence	Select a probability	Select a Risk Level	Yes or No
			Select a consequence	Select a probability	Select a Risk Level		Select a consequence	Select a probability	Select a Risk Level	Yes or No
			Select a consequence	Select a probability	Select a Risk Level		Select a consequence	Select a probability	Select a Risk Level	Yes or No
			Select a consequence	Select a probability	Select a Risk Level		Select a consequence	Select a probability	Select a Risk Level	Yes or No
			Select a consequence	Select a probability	Select a Risk Level		Select a consequence	Select a probability	Select a Risk Level	Yes or No
			Select a consequence	Select a probability	Select a Risk Level		Select a consequence	Select a probability	Select a Risk Level	Yes or No
			Select a consequence	Select a probability	Select a Risk Level		Select a consequence	Select a probability	Select a Risk Level	Yes or No
			Select a consequence	Select a probability	Select a Risk Level		Select a consequence	Select a probability	Select a Risk Level	Yes or No
			Select a consequence	Select a probability	Select a Risk Level		Select a consequence	Select a probability	Select a Risk Level	Yes or No
			Select a consequence	Select a probability	Select a Risk Level		Select a consequence	Select a probability	Select a Risk Level	Yes or No

Step 5 – Action Plan (for controls not already in place)			
Control Option	Resources	Person(s) responsible	Proposed implementation date

Step 6 – Approval

Drafter's Comments:

Fahd

Drafter Details:

Name: Fahad T Alenzi | Signature: FTA | Date: 1/9/2016

Assessment Approval: (Extreme or High = VC, Moderate = Cat 4 delegate or above, Low = Manager/Supervisor)

I am satisfied that the risks are as low as reasonably practicable and that the resources required will be provided.

Name: Dr. Belal Yousif | Signature: BFY | Date: 1/9/2016

Position Title: AP.

B.2 Communication Plan

The communication plan for the research is as follow,

- Reporting to supervisor weekly about the progress of the plan.
- Notifying the associated labs before conducting any test.
- Notifying about any issues to be resolved
- Ensuring the timely availability of materials

The important milestones in the project included,

- Casting of concrete cubes
- Testing of concrete cubes
- Analysis of results
- Completion of dissertation draft

Appendix C Tile properties

wear ratings

Beaumont Tiles uses a Wear Rating of 0 – 5 to measure wear resistance of glazed porcelain tiles.

Wear Rating	Suitable For (examples only)
0	Not recommended for use on floors.
1	Bathrooms, bedrooms: private homes that are walked on with soft soled shoes or bare feet without abrasive dirt.
2	Living areas: General residential areas where soft soled or normal footwear is worn and with an occasional small amount of abrasive dirt.
3	Kitchens, hallways, balconies: All residential and light commercial areas where normal footwear is worn and with a small amount of abrasive dirt.
4	Entrances, commercial kitchens, restaurants: Any areas with regular traffic and some abrasive dirt where conditions are more severe than 3 above.
5	Public areas, shopping centres, airports: In severe pedestrian traffic over sustained period with some abrasive dirt.

slip ratings

Beaumont Tiles uses the Pendulum Test and the Oil-Wet Ramp Test to measure slip resistance in accordance with Australian Standard AS4663.

PENDULUM TEST (P0 – P5)

The Pendulum Test measures the frictional resistance between a rubber slider mounted on a pendulum arm and a wet tile, mimicking a shoe heel striking a wet tile.

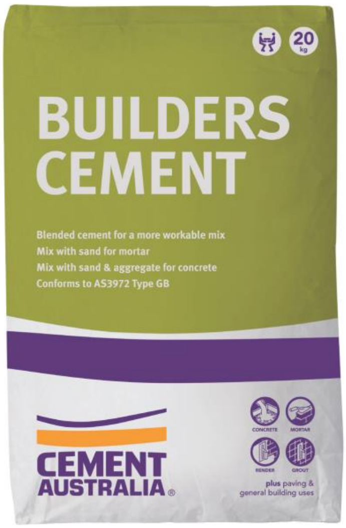
Pendulum Classification	Suitable For (examples only)
P0	-
P1	Lift lobbies above entry level
P2	-
P3	Shopping centre – food court
P4	External colonnade and walkway
P5	External ramps

OIL-WET RAMP TEST (R9 – R13)

The Oil-Wet Ramp Test involves laying the tiles on a ramp and applying lubricating oil to them. Testers walk on the inclined tiles to determine the angle at which they become unsafe for testing. This angle is used to determine the degree of slip resistance.

Slip Resistance	Corrected Mean Overall Acceptance Angle (Degrees)	Suitable For (examples only)
R9	6-10	Entry foyers – dry
R10	10-19	Entry foyers – wet
R11	19-27	External ramps (suitable for most locations)
R12	27-35	Suitable for most locations
R13	Over 35	Suitable for most locations

APPENDIX D SELECTED CEMENT PROPERTIES AND OTHER INFORMATION



Cement Australia Builders Cement is a Fly Ash blended Portland cement that fully complies with the requirements of Australian Standard AS3972 - General purpose and blended cements for Type GB (General Purpose Blended) cement.

BUILDERS CEMENT PROPERTIES

Property		AS3972 – 1997 Type GP	Typical GP
Setting Time	Min	45 min	100-150 min
	Max	10 hrs	3.0-4.0 hrs
Soundness	Max	5mm	< 3mm
SO_3	Max	3.50%	< 2.5%
ISO Mortar Compressive Strength	3 Day (min)	–	21-32 MPa
	7 Day (min)	15 MPa	30-41 MPa
	28 Day (min)	30 MPa	46-58 MPa

All testing is conducted in accordance with the relevant Australian Standards test methods, at a NATA registered laboratory. Results are reflective of the testing results across all Cement Australia's manufacturing plants.

Builders Cement is primarily a Type GB cement but also meets the requirements of AS3972 for classification as both Shrinkage Limited (Type SL) and a Sulfate Resisting (Type SR) cements. Use of this product does not guarantee sulfate resistant or low shrinkage concrete as there are other factors which may influence concrete performance including cementitious content, water to cement ratio, compaction and curing as well as aggregate type. Further advice should be sought on the use of this product where high performance requirements exist.

APPLICATIONS

Builders Cement can be used as a cementitious binder in a broad range of applications including:

- Concrete
- Mortars
- Renders
- Grouts
- Stabilisation

Where specific properties such as rapid setting or high early strength are required a more specialised cement should be considered.

AVAILABILITY

Builders Cement is available in 20kg bags, 500kg and 1 tonne bulk bags.

COMPATIBILITIES

Builders Cement is compatible with:

- Admixtures that comply with **AS 1478 Chemical Admixtures for Concrete.**
- Fly Ashes complying with **AS 3582.1 Supplementary Cementitious Materials for Use with Portland cement: Fly Ash.**
- Ground granulated blast furnace slags complying with **AS3582.2 – Supplementary cementitious materials for use with Portland cement: Slag – ground granulated Iron blast-furnace.**
- Other cements complying with **AS3972 – General purpose and blended cements.**

Caution: Builders Cement must not be mixed with high alumina cement as this may result in uncontrollable expansion and short setting times.

CONCRETE PROPERTIES

Compressive Strength Development:

Strength development in Portland cement concrete is affected by a number of factors such as the physical and chemical properties of the cement, water to cement ratio, admixtures, curing and environmental conditions.

For more information
call **1300 CEMENT (1300 236 368)**
or visit **www.cementaustralia.com.au**

mix it with the best.

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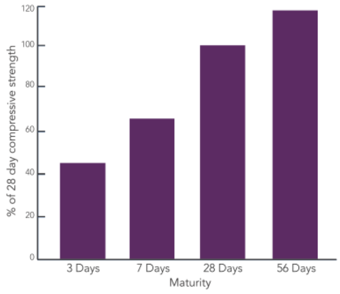
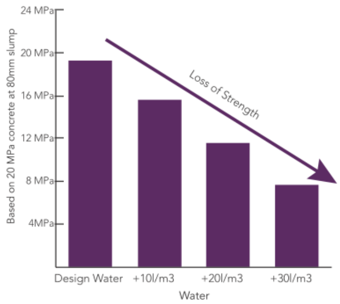
The following graph depicts the indicative compressive strength development of Builders Cement concrete over time.

COMPRESSIVE STRENGTH DEVELOPMENT



EFFECT OF EXCESS WATER ADDITION ON CONCRETE COMPRESSIVE STRENGTH



Mix Design

The proportioning of constituent materials in a concrete mix is a complicated matter which can be influenced by many factors. We recommend that trials be conducted with the available materials.

Workability/Setting Times

Concrete produced with a Type GB cement may require less water to achieve a specified level of workability when compared to concrete produced with a Type GP cement. Setting times may also be extended when using Type GB cement.

Curing

A minimum curing period of seven days is recommended for all exposure classifications. Concrete should be maintained in a continually moist condition wherever practicable. Water sprays, wet sand or moisture retaining techniques, such as clear polyethylene sheets or curing compounds are recommended.

Curing should begin as soon as the concrete has been finished or in accordance with manufacturers instructions where proprietary curing compounds are used.

In concrete, the practice of curing can deliver compressive strength results up to 100% greater than concrete not subjected to curing. Water application or moisture retaining curing is more effective for most concrete. Curing will also beneficially affect other concrete properties including:

- Reduction in the potential for plastic cracking
- Improvements in surface quality, durability and impermeability
- Improvement in abrasion resistance
- Reduction in the carbonation rate

Mortar/Render Mix Properties

Builders Cement is suitable for use in brick mortars, wall renders and concretes. The following table gives a guide to the proportions (by volume) to be used (Note: This information is a guide only, specific advice for your project should be obtained for the materials you are using.)

Additives such as air entrainers, thickening agents or plasticisers can be used but should always be used in accordance with the manufacturers recommendations.

Application	Cement	Sand	Aggregate	20kg bags per m3
Concrete – Improved Water Tightness High Strength	1	1.5	3	17
Concrete – Paths and Driveways	1	2	3	16
Concrete – Foundations, Footings	1	3	3	13
Mortar (general purpose)	1	4	-	15
Mortar (enhanced workability)	1	6 +1 hydrated lime	-	8
Render	1	3	-	20

STORAGE, HANDLING & SAFETY

- The 'shelf life' of Portland cement products is dependent on the storage conditions. It is necessary for bagged Portland cement to be stored in dry conditions and protected from rain, dew or any other moisture source. Bagged cement that has hardened or is lumpy as a result of exposure to moisture should not be used.
- Portland cement products are highly alkaline materials and are significantly affected by exposure to water.

NOTE:
The Builders Cement Material Safety Data Sheet (MSDS) is available at **www.cementaustralia.com.au**

Cement Australia Pty Ltd
ABN 75 104 053 474

12 Station Avenue Darra QLD 4076
1300 CEMENT (1300 236 368)
www.cementaustralia.com.au

CEMENT AUSTRALIA®

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SAFETY DATA SHEET

Blended Cement

Section 1: Identification of the Material and Supplier

Company Details

Cement Australia Pty Limited

ABN 75 104 053 474

18 Station Avenue
Darra, Queensland 4076

Tel: 1300 CEMENT (1300 236 368)
Fax: 1800 CEMENT (1800 236 368)
Website: www.cementaustralia.com.au

Emergency Contact Number:

Contact Person: Technical Manager
Telephone: 1300 CEMENT (1300 236 368 - Business Hours) or
Poisons Information Centre 13 11 26

Manufacturing Plants

Newcastle:	Highgate Street, Auburn NSW 2144
Gladstone:	Landing Rd, Fisherman's Landing, Gladstone QLD 4680
Brisbane:	77 Pamela St, Pinkenba QLD 4008
Railton:	Cement Works Rd, Railton, TAS 7305

Terminals

Glebe:	Sommerville Rd, Glebe Island, NSW 2037
Clyde:	Highgate St. Auburn, NSW 2144
Melbourne:	Currajong St. West Footscray, VIC 3012
Townsville:	Benwell Rd, Townsville Port Townsville, QLD 4810

Product

Name: **Blended Cement**

Other Names:
General Purpose Blended Cement
Low Heat Cement
Shrinkage Limited (SL)
Sulphate Resisting Cement –Slag
Sulphate Resisting Cement
Sulphate Resisting Cement – Fly Ash

Use: Blended Cement is used as a binder in concrete, concrete masonry, mortar and grouts. It is also used in the manufacture of fibre cement products, in soil stabilisation in building construction and civil engineering projects.

Section 2: Hazards Identification

Hazardous Substance. Non-dangerous Goods

Risk Phrases

R20/21/22: Harmful by inhalation, in contact with skin and if swallowed.

R36/37/38: Irritating to eyes, respiratory system and skin.

R43: May cause sensitisation by skin contact.

R66: Repeated exposure may cause skin dryness or cracking.

R48/20: Danger of serious damage to health by prolonged exposure through inhalation

Safety Phrases

S22: Do not breathe dust.

S24/25: Avoid contact with skin and eyes.

S29: Do not empty into drains.

S36/37/39: Wear suitable protective clothing, gloves and eye/face protection.

S38: In case of insufficient ventilation, wear suitable respiratory equipment.

Section 3: Composition/Information on Ingredients

Blended Cement consists of a crystalline mass manufactured from substances mined from the earth's crust. It contains trace amounts of naturally occurring, but potentially hazardous chemical entities including metals such as chromium and nickel and crystalline silica. It also contains added supplementary cementitious material (fly ash or ground granulated slag). All significant constituents are listed below:

Chemical Entity	Proportion	CAS Number
Portland Cement Clinker	20-95%	65997-15-1
Gypsum ($CaSO_4 \cdot 2H_2O$)	0-5%	10101-41-4
Calcium Oxide	0-3%	1305-78-8
Fly ash (where applicable)	8-50%	69131-74-8
Ground Granulated Blast Furnace slag (where applicable)	8-85%	65999-69-2
Limestone ($CaCO_3$)	0-5%	1317-65-3
Hexavalent Chromium Cr (VI)	<20 ppm	1333-82-0
Crystalline Silica (Quartz)	<1-10%	14808-60-7

Section 4: First Aid Measures

Swallowed: Rinse mouth and lips with water. Do not induce vomiting. Give water to drink to dilute stomach contents. If symptoms persist, seek medical attention.

Eyes: Flush thoroughly with flowing water for 15 minutes to remove all traces. If symptoms such as irritation or redness persist, seek medical attention. If wet cement is splashed in the eye, always treat as above, and seek urgent medical attention.

Skin: Remove heavily contaminated clothing immediately. Wash off skin thoroughly with water.

Use a mild soap if available. Shower if necessary. Seek medical attention for persistent irritation or burning of the skin.

Inhaled: Remove to fresh air, away from dusty area. If symptoms persist, seek medical attention.

First Aid Facilities: Eye wash station. Washing facilities with running water.

Advice to Doctor: Treat symptomatically. Wet cement burns to skin or eye may result in corrosive caustic burns.

Ingestion of significant amounts of cement dry or wet is unlikely. Do not induce emesis or perform gastric lavage. Neutralization with acidic agents is not advised because of increased risks of exothermic burns. Water-mineral oil soaks may aid in removing hardened cement from the skin.

Ophthalmological opinion should be sought for ocular burns.

CONCRETE, MORTAR & RENDER
VOLUME BATCHING MIX TABLE

APPLICATION	CEMENT	SAND	AGGREGATE	20kg BAGS OF CEMENT PER m^3
CONCRETE Improved water tightness High strength	1	1.5	3	17
Paths, driveways, patios, floors	1	2	3	16
Foundations, footings	1	3	3	13
MORTAR General purpose	1	4	–	15
Improved workability	1	6	+1 Hydrated Lime	8
RENDER	1	3	–	20

✔ **Always use clean drinking water in precise quantity specified**
✔ **Always use an accurate volume measure like a bucket or gauge box**

✗ **Excess mixing water can ruin good concrete, mortar and render**

mix it with the best.

To find out more about the entire range of Cement Australia products, visit **www.cementaustralia.com.au** or call **1300 CEMENT (1300 236 368)**.

CEMENT AUSTRALIA®

TPT MIX TABLES CMR Revision 1.0 issued 01/02/12

APPENDIX E FAILURE BEHAVIOR OF THE SAMPLES DURING THE TESTS

E.1 5% of ceramics







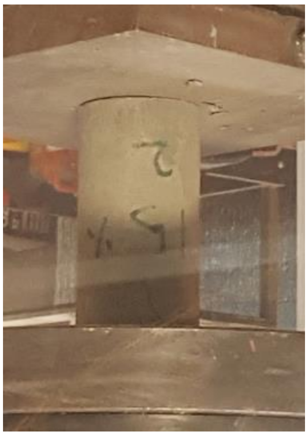
E.2 15% of ceramics









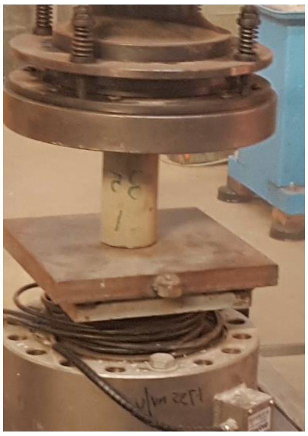


E.3 25% of ceramics

E.4 35% of ceramics








E.5 45% of ceramics