IMPROVEMENT OF AGGREGATE PACKING MODEL OF INTERLOCKING CONCRETE BLOCK PAVEMENT (ICBP) MIXTURE USING FLY ASH

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Degree of Master of Engineering

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Thesis submitted in partial fulfilment of the requirements for the degree
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DECLARATION

“I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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Abstract

Use of concrete paver blocks is becoming increasingly popular. They are used for the paving of approaches, paths and parking areas including their application in pre-engineered buildings and pavements. Interlocking Concrete Block Pavements (ICBP) have been extensively used in a number of countries for quite some time as a specialized problem-solving technique for providing pavements in areas where conventional types of construction are prove to be less durable due to many operational and environmental constraints. As it was observed that “Sri Lanka, Lak Vijaya Coal Power Station at Norocholai, Puttalam generates large amount of fly ash per day as a byproduct” which was considered as a waste & an environmental hazard ,leading to the limitation of its usage, this research focuses on utilizing the fly ash to improve the aggregate packing model of ICBP. Fly ash is used as a filler material in the paving block mixture to optimize the packing of the aggregate. Fly ash includes samples and control samples were tested for compressive strength, water absorption and were made to go through a Scanning Electron Microscope Analysis. Experimental results showed that 23 and 21 percent of cement can be replaced by Fly Ash in Grade 15 & 20 for OPC mixtures while 26 and 21 percent of cement can be replaced in Grade 15 & 20 for PLC mixtures. Optimization of the packing of aggregates is the process of determining the most suitable aggregate particle size and distribution to minimize the void content of an aggregate mix. An optimized aggregate mix will have a lesser amount of voids which needs to be filled with cement paste. Further, fly ash has improved the workability of the mixture due to the special nature of the particle. Better economy and durability also have been achieved as its utilization leads to the reduction of needed cement content and heat of hydration. To elaborate further, it will also help in safe-guarding the environment from ill effects of CO2 emissions from cement industry and contribute towards providing a solution for the disposal of fly ash produced by thermal power plants.

Keywords: Fly Ash, Interlocking Concrete Block Pavement, packing of aggregate, Optimization, Compressive Strength, Scanning Electron Microscope ,Portland lime cement(PLC),Ordinary Portland cement(OPC).

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LIST OF ABBREVIATIONS

Abbreviation	Description
ICBP	Interlocking concrete block pavers
OPC	Ordinary Portland cement
PLC	Portland Lime cement
SEM	Scanning Electron Microscope
TCLP	Toxicity Characteristics Leaching Procedure
HVFA	High volume Fly Ash
BS	British Standard
EN	European Standards
SLS	Sri Lanka Standard
ICTAD	Institute for Construction Training and Development
W/C	Water/Cement
ITI	Industrial Technology Institute
AIV	Aggregate Impact Value

LIST OF APPENDICES

CHAPTER 1.INTRODUCTION

1.1 General

The Interlocking Concrete Block Pavement (ICBP) can be used in many places unlike conventional type methods of road construction. Due to that ICBP are used in many countries. In this research, waste material (Fly ash) is used as filler aggregate for ICBP mixture for optimize the packing density of aggregate. The optimized aggregate packing density, minimize the voids contain of mixture. Due to that voids need be fill by cement is reduced. Fly ash is a waste product generated in electric power generating plant due to the burning of pulverized coal. When coal is burnt, mineral fuses and floats out with the exhaust gasses and these solidified gasses are collected by filters. The solidified particles are called as fly ash.

Due to use of fly ash in ICBP packing optimization, it reduces cement need for mixture and it reduces the cost and environmental impact which generate due to use of cement and utilize waste fly in proper way. Within this research, two types of cement were used to identify the filling effect of fly ash with the change in cement type.

1.2 Objectives

The objective of this research is to improve the aggregate packing model of ICBP by using Fly ash. Due to the improvement of the packing model of ICBP, decrease in the amount of porosity in ICBP can be observed. This leads to the possibility of decreasing the amount of anhydrate cement which is needed to fill porosity. The SEM method is used to identify the behavior of fly ash in the ICBP mixture.

1.3 Thesis overview

Chapter 01 presents an introduction to the importance of the improvement of aggregates packing model of ICBP. This chapter describes significance of fly ash usage in the ICBP industry to give a solution to waste material coming from the thermal power plant in Sri Lanka. And it is also a good solution to avoid the adverse environmental impact which a rises from land filling with Fly ash.

Chapter 02 discusses about the literature review on the packing model of paving blocks, fly ash usage and its use as a filling material in application & ICBP in highway .It also discusses about the type of cement used in this research. Moreover the type of Fly ash, its methods of categorization and it effects for ICBP described under this chapter.

Chapter 03 discusses about the methodology of research. Within this chapter sample preparation procedure, machinery used, mix deign of ICBP, testing and testing specifications are described.

Chapter 04 is about the test results and analysis of the tested samples. Within this chapter test results are described aiding graphics and it provides a sound background for the discussion of results and conclusion.

Chapter 05 is dedicated for the discussion and conclusions of test results of ICBP, fly ash and cement samples. Moreover recommendations for future research also described.

CHAPTER 2.LITERATURE REVIEW

2.1 Interlocking concrete block pavement (ICBP)

Interlocking concrete block pavements are precast modular concrete units with different shapes, colors and sizes. Due to segmental units of ICBP, it can articulate under load like a flexible pavement. However, unlike in a flexible pavement, its interlocking behavior increases under traffic. ICBP has very good skid resistance, ride quality and favorable safety. Moreover, the concept of ICBP can be easily adapted to conventional flexible pavement design and methods. Therefore, ICBP can be used in many places: roads, commercial projects, industrial, specialized applications and domestic paving. (Sharma, S.D., Prashant Kumar, Nanda, P.K., 2005)

Roads:-Main roads, Residential roads, Urban renewal, Intersections, Toll plazas, Pedestrian crossing, Taxi ranks, Steep slopes, Pavements (sidewalks).

Commercial projects: - Car parks, Shopping centers and malls, office parks.

Industrial: - Factories and warehouses, container depots, Military applications, Mines, Quarries, Airports and Harbors

Specialized applications: - Embankment protection under free ways, storm water channels, Cladding vertical surfaces.

Domestic paving: - Pool surrounds, Drive ways etc…

2.2 Packing Model for ICBP

According to Chan.K.W and Wong.V (2013), in the construction industry, one of the most required materials is cement. However, use of cement is not environmental friendly, and manufacturing of cement produces a large amount of CO_2, causing it to have a high carbon foot print. Consequently, people try to use alternative materials and materials with low cement content for concrete mixtures. The need to utilize cement can be further reduced by minimizing the content of voids that need to be filled by cement. Thus, giving rise to the need of optimizing packing density of aggregates in mixture. Aggregate packing density can be optimized by proper mixing proportions of the aggregate particles which have different sizes.

A theoretical aggregate packing model for interlocking concrete block pavers was developed by Hettiarachchi and Mampearachchi (2018). According to their studies, three parameters affect the packing density of ICBP: vibration, shape and surface texture. The 3-parameter model, developed by Kwan et al. (2013) to accurately predict the packing density of a binary spherical particulate mixture, was used as a base model for their study.

2.2.1 Path for the 3-parameter model

This model was developed based on the conventional two parameter model with the loosening effect and wall effect. The 3-parameter model added a new effect called the wedging effect to the conventional model. (Kwan et al., 2013)

2.2.1.1 Conventional model with 2-parameters

When large particles are dominant (amount of small particles are lesser than the amount of large particles), the filling effect occurs when small particles fill the voids among large particles. When small particles are dominant (amount of small particles are higher than the amount of large particles), the occupying effect occurs where large particles occupy the solid volume of the porous bulk volume of the small particle mixture. These two effects would improve the packing density of the mixture. The loosening effect occurs in a mixture of dominant large particles, when the small particles cannot fit into the voids between large particles due to their size. The small particles attempt to fill the voids and it disturbs the already formed packing arrangement of large particles, causing a reduction in the packing density of the mixture.

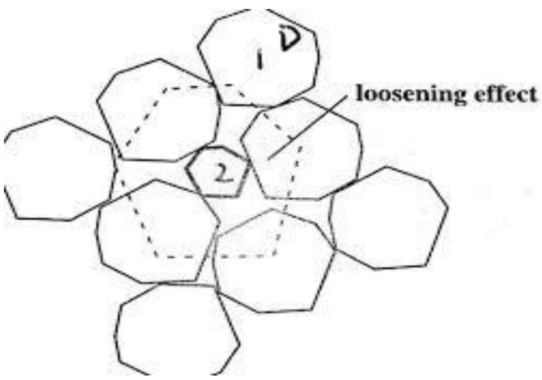


Figure 2.1: The loosening effect caused by the fine grain particle (after De Larrard 2)

The wall effect occurs when smaller particles are dominant. The large particles are introduced into the packed small particles mixture; it is disturbed by the solid surface of large particles.

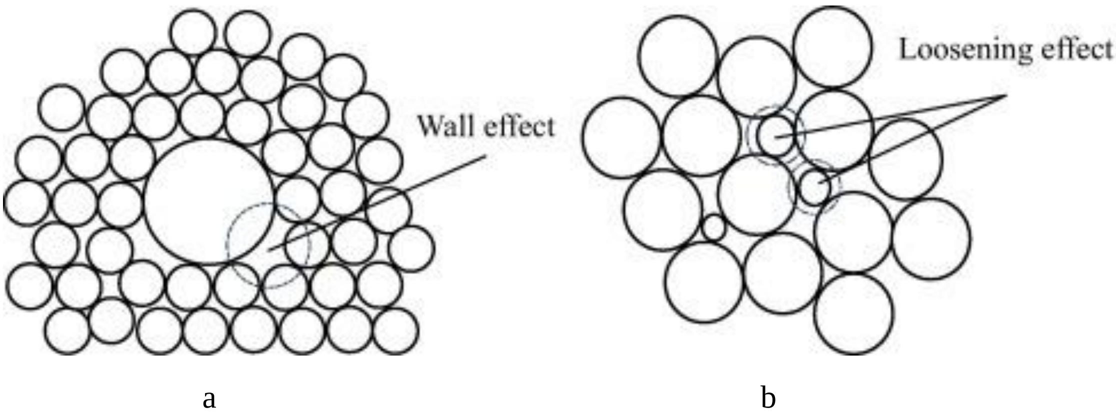


Figure 2.2: wall effect and loosening effect in particles mixture (Kwan et al., 2013)

The wall effect and loosening effect reduce packing density of the mixture by disturbing the proper arrangement. Figure 2.2 (a) shows the wall effect in a mixture and Figure 2.1 and 2.2(b) shows the loosening effect in a mixture. The 2-parameter model generates two packing density curves for two equations. The curves will join at a mid-point, creating a sharp peak at the point of intersection. Figure 2.5 shows the typical variation of the 2-parameter model with experimental results made by Kawan et al. (2013). According to Kwan et al. (2013), the variation does not create a sharp peak. It produces a very smooth curve with a rounded peak. The sensitivity observed in experimental results was not that high as in the 2-parameter model. Further Kwan et al. (2013) suggested that the difference of the predictions and experimental values due to wedging effect.

According to Chan.K.W and Wong.V (2013), when the large particles are dominant, the small particles would fill the voids created among the large particles. There should be some isolated small particles trapped in between walls of two large particles that may act as a wedge to create a small open space in between two large particles. On the other hand, large particles will be introduced to the sea of small particles when small particles are dominant. So there is no possibility for large particles to get close to other large particles. Therefore, gaps between two large particles are not uniform and sometimes there may be two large particles with a relatively narrow gap. These gaps can be wedged by fine particles, reducing the packing density of the mixture. The wedging effect occurs due to the incomplete layers of small particles which are closer to the gaps between large particles. When large particles are introduced to the mixture, the small particles will yet again loose the dominancy, while the voids are almost filled by small particles. Therefore, it also acts as a wedging effect. The 3-Parameter model is developed by adding wedging effect to the 2-parameter model.

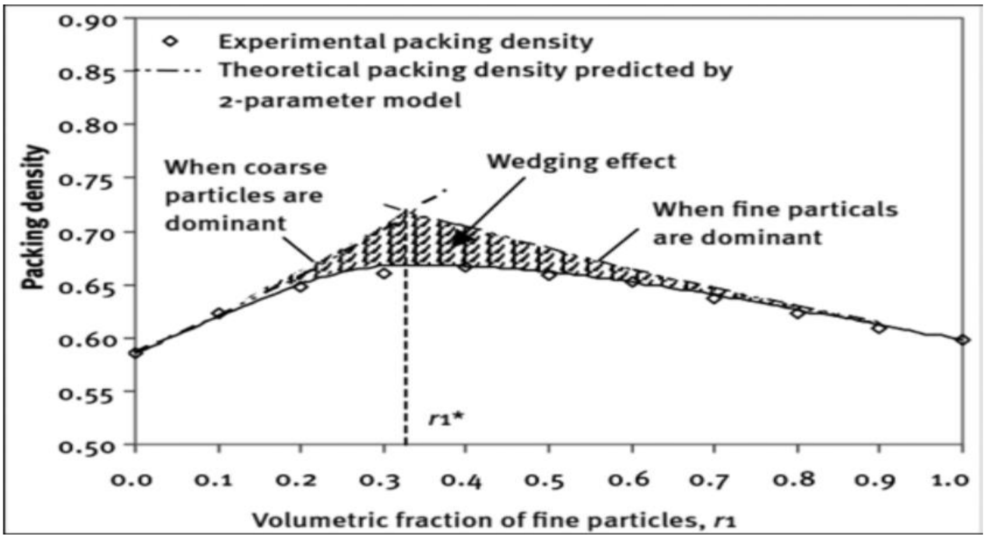


Figure 2.3: Packing density against volumetric fraction of fine particles (Kwan et al., 2013)

2.2.2 3-Parmeter model

The 3-parameter model for binary spherical mixtures can be explained using Equation 2.1 and Equation 2.2. Equation 2.1 is to be used when small particles are dominant while Equation 2.2 is to be used when large particles are dominant. However, one can simply use both equations at the same time and the final packing density of the mixture will be the minimum value of both equations.

$\frac{1}{\emptyset_i^*} = \left(\frac{r_i}{\emptyset_i} + \frac{r_j}{\emptyset_j}\right) - (1 - b_{ij})(1 - \emptyset_j)\frac{r_j}{\emptyset_j}\left[1 - c_{ij}(2.6^{r_j} - 1)\right]$……Eq.2.1

$\frac{1}{\emptyset_j^*} = \left(\frac{r_i}{\emptyset_i} + \frac{r_j}{\emptyset_j}\right) - (1 - a_{ij})\frac{r_i}{\emptyset_i}\left[1 - c_{ij}(3.8^{r_i} - 1)\right]$……………..Eq.2.2

Where,

a=1-$(1 - s)^{3.3}$-2.6 x s x $(1 - s)^{3.6}$…………………………….eq.2.3

b=1-$(1 - s)^{1.9}$-2.0 x s x $(1 - s)^{6.0}$…………………………….eq.2.4

c=0.322.tanh(11.9s)…………………………………………eq.2.5

The parameter a, b and c respectively the loosening effect, wall effect and wedging effect, are derived using back calculation of experimental data through curve fitting. The equation can be modified to incorporate the vibration, surface texture and shape factor.

2.2.3 Effect of vibration, shape and surface texture on packing density.

According to Mamperarachchi and Hettiarachchi (2018), the vibration frequency affects the packing density. There is an optimum vibration frequency that produces maximum packing density. When vibration frequency is increased continuously, packing density reaches a maximum value and then decreases. The wall effect is affected by the vibration frequency. The particle shape affects the packing density linearly. Higher the shape factor, higher the packing density. When particles are more irregular in shape, the packing density reduces due to the occurrence of voids in the mixture. The loosening effect is affected by only the particle shape. When the surface is smooth, the particles pack easily, increasing the packing density of the mixture. When the surface is rough, antiparticle friction resists the particle movement. Due to that packing density of mixture decreases.The wall effect is affected by the surface texture.

2.3 OPC, PLC & Voids in concretes

Portland cement is the most common type of cement in general use around the world. This cement is made by heating Calcareous and Argillaceous (Lea, F. M., 1970). According to Steven, K. H., and Michelle, W. L. (2011), calcareous and argillaceous are heated at a temperature around 1450°C in a kiln. Due to the heating of Calcareous and Argillaceous materials, cementations compounds are produced. This process is known as calcination. The result of calcination is known as clinker. Then clinker is grounded and mixed with gypsum to make Ordinary Portland Cement (OPC). In addition, the production of cement (OPC) is responsible for 5-7% of global greenhouse gas emissions (Benhelal et al., 2013).

Portland limestone cement (PLC) is designed to enable a more sustainable concrete production by replacing up to 15% of clinker with interground limestone particles (Barrett et al., 2013).

Due to the positive impact of Portland limestone cement (PLC), it has been widely used in the world. PLC reduces the use of cement clinker. Because of that PLC reduces carbon dioxide emission, generated from cement manufacturing. Moreover, it supports to improve the dense of concrete microstructure by producing the filler (monocarboaluminates) (LIU Shuhuna and YAN Peiyu, 2008). It also increases the strength of concrete by providing large nucleation sites in mixture. (Gyu Don Moon et al., 2017).

Concrete has a complex microstructure. It has different materials and voids which have a wide range of scale. These materials and void lengths range from millimetre to nanometers (Garboczi, .E.J., 1996). Aggregate particles are the large sized particles in a mixture at a millimetre scale. Unhydrate particles of cement and hydrate particles in the concrete mixture are the largest at a micrometer level. The hydration product has large capillary pores (diameter 50-10,000 nm), medium capillary pores (diameter 10-50 nm) and gel pores (diameter less than 10 nm) at a nanometer scale (Mindess S and Young JF.,1981).

2.4 Fly ash

In Sri Lanka, LakVijaya Coal Power Station at Norocholai, Puttalam generates approximately 700 tons of fly ash per day as a byproduct, when the plant is functioning at its full capacity. The maximum possible consumption of fly ash per day by the cement industries in Sri Lanka is approximately 350 tons. The balance is dumped as open land filling and has limited uses. Due to that, negative environmental impacts arise.

Globally, approximately 620-660 million tons of fly ash is generated per year. However, approximately 53.5% of fly ash is utilized while approximately 46.5% of fly ash is used for landfills (Heidrich et at., 2013). Due to that a large amount of money has been spent to minimize the disposal problem of unutilized fly ash (American coal ash association, 2014).

Replacing cement by fly ash gives many benefits. Mainly it increases the use of the industrial by product and reduces the carbon emission which is associated with cement manufacturing. Not only that, fly ash improves the fresh concrete and hard concrete properties (Sata et al., 2007; Liu, 2010). According to Hansen (1990) and Sivasundaram et al., (1990), fly ash improves physical properties and durability of concrete .According to Nakarai and Ishida (2008), fly ash decreases the shrinkage property of concrete. Furthermore, fly ash also decreases the water absorption properties of concrete. (Malhotra and Mehta, 2002). Due to the use of fly ash, Chloride permeability reduces (Nagataki and ohga, 1992), resistance to sulphate attacks increases (Turanli et al., 2005) and alkali aggregate reactivity decreases (Pepper and Mather, 1959). As proved in the above mentioned research, fly ash gives many advantages for concrete. However, fly ash has low reactivity thus; the amount of fly ash used in the concrete mixture needs to be selected very carefully (Liu 2010; Sahmaran et al., 2009).

Fly ash has complex physical, chemical and minerogical properties. Cementation properties of fly ash mainly depend on the heating process, cooling process and composite of fly ash. Low calcium fly ash has a less complexity than high calcium fly ash (Gang Xu,Xianming Shi, 2018). Pozzolonic potential of fly ash mainly depends on the percentage of reactive silica in fly ash. Reactive silica reacts with calcium hydroxide and produce binding properties (S.K.Antiohos&S.Tsimas, 2006).

Over the decades, the use of green construction material has been promoted for sustainable construction. There are two methods to find sustainable materials: using recyclable materials and Portland cement replaced by fly ash, blast furnace slag etc.(Marinkovic'et al.,2017). Today, replacing Portland cement by fly ash is rapidly being made popular. Replacing cement by fly ash gives rise to cleaner production by minimizing carbon emission and air pollution which are related to the manufacturing of cement (Bernal et al., 2015). On the basis of silica , Aluminium and Iron content the fly ash can be divided in to two classes: class F and class C (Bhatia*,A, Gakkhar,N ,2017). Table 2.1 depicts the difference between class F and class C.

Fly ash in the concrete has a lower degree of reaction. For example, after 90 days of 45% and 50% replacement, concrete has more than 80% of unreactive fly ash in the mixture. However, fly ash increases the effective water cement ration of the mixture, leading to an increase in the hydration process in the concrete mixture. Consequently, fly ash improves the strength of concrete (Poon et al., 2000). Fly ash also can be used as a fine aggregate in concrete. The filling effect of fly ash increases with the increase of fly ash and decreases with the age of concrete (Wang et al., 2003). Performance of fly ash mainly depends on its chemical, mineralogical and physical properties. For an example, high finesse and less carbon fly ash concrete has low water demand than Portland cement concrete. Therefore, it is evident that fly ash supports to make concrete with a lower water content than Portland cement concrete with same workability, thus improving the quality of concrete (Shamshad,A, Fulekar,M.H et al., 2012).

According to Feng,J,sun,J et al., (2018), during the cement hydration process, Ca^{2+} concentration is required for precipitation of cementation gel and $Ca(OH)_2$,.but fly ash in the concrete mixture absorbs some particle of Ca^{2+} and reduces concentration in the mixture. Therefore, hydration process of cement is delayed. In consideration it can be concluded that fly ash delays the early strength of concrete.

According to M.Thomas (2007), the flow of fly ash in concrete mixture depends on morphological properties of fly ash. Moreover, properties of concrete can be changed by adding fly ash to the mixture. Table 2.2 shows the effects of fly ash on properties of concrete. Fly ash usage is limited due to lack of understanding of fly ash properties and properties of concrete which contains fly ash.

According to Chindaprasirt,P et al.(2005), pozzolonic materials improve concrete properties due to pozzolonic reactions. During the pozzolonic reaction, pozzolonic materials react with Calcium hydroxide and produce cementation gel. This gel can reduce the pores of crystalline hydration products. Due to that, it creates a more uniform microstructure. Therefore, decreasing the permeability and increasing the durability of concrete.

Table 2.1: Different of Class F fly ash & Class C fly ash. (Bhatia*,A, Gakkhar,N, 2017)

Class F	Class C
Produced by burning harder anthracite and bituminous coal.	Produced by burning of younger lignite or sub bituminous coal.
Contains less than 20% of lime.	Contains more than 20% of lime.
Alkali and sulfate content is generally lower	Alkali and sulfate contents are generally higher.
The quantities of Si, Fe & K oxides are higher.	The quantities of Si, Fe & K oxides are lower.
The CaO,MgO,SO_3, & Na_2O quantities are lower .	The CaO, MgO,SO_3 & Na_2O quantities are higher.
Has been rarely cementitious when mixed with water.	Usually has a cementatious property in addition to pozzolanic properties.

According to Chindaprasirt,P et al.(2007), the spherical shape of fly ash helps to increase the packing density of mixture. Due to the morphological shape of fly ash, it can penetrate the cement paste and make homogeneous cement paste. Therefore, small sized spherical particles of fly ash fill the voids in concrete and give a more dense mixture. In line with the study of Tangpagasit,J et al. (2004), in early ages (between 3 to 28 days) the strength activity index of fly ash mortar due to packing effect is higher than due to pozzolanic reaction.

However, few researches were discovered, which studied the filling effect of fly ash on the pores, and improvement of packing density of mixture. The utilization of fly ash is still limited due to lack of understand of micro filling effect of fly ash on the pores and microstructure of cement paste (Chindaprasirt,P et al., 2007).

Table 2.2: The effect of fly ash on properties of concrete (Thomas,M.D, 2007).

Property	Effect of fly ash
Fresh concrete	• Improve workability • Reduce water demand for most fly ash • Improve cohesive and pump ability • Reduce segregates and bleeding
Set time	• Can increase by certain combination of fly ash, cement and admixture.
Heat of hydration	• High replacement has high reduction • Reduce by normal levels replacement of Class F fly ash and higher levels replacement of Class C fly ash
Early age strength	• Class F has good reduction. Reduced the early strength of concrete especially at first day.
Long term strength	• Improve
Permeability and chloride resistance	• Reduced by time.
Expansion(alkali-silica reaction)	• Reduced (Sufficient level of replacement can completely suppressed deleterious).
Sulfate resistance	• class F fly ash has good resistance.
Resistance to carbonation	• Significant decreases when high levels of fly ash are used in poorlycured, low-strength (high w/cm) concrete. • Decreased.

CHAPTER 03.METHODOLOGY

3.1 Aggregate packing models mix design for interlocking concrete block pavement.

According to the literature survey, mix designs for ICBP are designed for fly ash filling and cement filling. Within the fly ash filling design, fly ash is used as an aggregate packing material for ICBP while in the cement filling design the amount of cement is used as an aggregate packing material for ICBP. The packing aggregates which are used in mix design are sand, quarry dust and chips (coarse aggregate) .The mix designs are shown in Table 3.1and Table 3.2. Within this design there are two parts. One is for aggregate packing design to achieve optimum packing density which minimizes the requirement of binder as filling material and increases the utilization of binder. The second part is for the binder which is for the bonding purpose of design. This design was carried on for 12 ICBPs (3 ICBPs for 7 days testing, 3 ICBPs for 14 days testing, 3 ICBPs for 28 days testing & 3 ICBPs for water absorption test).

Table 3.1: Aggregates and cement mix proportions for cement filling design (without fly) for 12 samples of ICBP

Aggregate for mix design for (1st part)			
Coarse aggregate(kg)	River Sand(kg)	Quarry dust(kg)	Cement (kg)
21.9	9.53	22.25	1.87
Cement for Bonding(kg)(2nd part)			
2.61	5.23	6.53	7.05

The Table 3.1 mix designs were used for make control samples .Due to that there is no fly ash within this design. So cement is the only material which fills the fine macro level porosity in the mixture .Therefor, a certain amount of cement is employed for filling purposes in the design to obtain optimum packing density. In Table 3.2 mix designs, fly ash was used to obtain optimum packing density. So cement is not used as a filling material when designing. Because of that cement is optimized for bonding purposes. Prior to making ICBPs, materials were tested according to their standards.

Table 3.2: Aggregates and cement mix proportions for fly ash filling design for 12 samples of ICBP

Aggregate for mix design(1st part)			
Coarse aggregate(kg)	River Sand(kg)	Quarry dust(kg)	Fly ash (kg)
21.9	9.53	22.25	2.91
Cement for Bonding(kg) (2nd part)			
2.61	5.23	6.53	7.05

3.1.1 Cement in packing models mix design of ICBP

Within this research, two types of cements were used in Optimum packing mix design of ICBPs. Two cement types are,

1. Ordinary Portland Cement(OPC)
2. Portland Lime Cement(PLC)

These types of cement were tested for physical and chemical testing according to SLSI standards. OPC was tested according to SLS 107:2008 from Industrial Technology Institute Sri Lanka and PLC is tested according to SLS 1253:2015 from National Building Research Organization Sri Lanka .In addition to that, cements are tested for specific gravity test. The specific gravity equipment is shown in Figure 3.1.

Figure 3.1: Specific gravity equipment

3.1.2 Fly in packing models mix design of ICBP

Fly ash is tested for Chemical and physical test according to BS EN 450-1:2012 from Industrial Technology Institute Sri Lanka. The radio activity of Fly ash and leaching of heavy metal are also tested according to standards from Atomic authority Sri Lanka and Beura VERITAS Sri Lanka. Additionally, specific gravity test was done. In this study, research fly ash was stored in PVC tank to avoid the change of chemical and physical properties due to weathering. The storage tanks are shown in Figure 3.2.

Figure 3.2 : Fly ash storage tanks

3.1.3 Aggregate in packing models mix design of ICBP

Sand, quarry dust (M-Sand) and coarse aggregates were tested for sieve analysis and specific gravity test. The coarse aggregate was tested for Aggregate Impact value test according to the BS 812 standard. Sieve analysis test equipment is shown in Figure 3.3 and Impact value test equipment is shown in Figure 3.4.

Figure 3.3: Sieve analysis test　　Figure 3.4: Aggregate Impact Value test

According to test results of materials and literature survey (Mamperarachcchi and Hettiarachchi(2018)), optimum packing mix designs were designs for ICBPs (See Appendix A). ICBP materials were mixed as in Table 3.3 and Table 3.4 for two types of cements. Water cement ratio was selected as 0.4(W/C=0.4).

Table 3.3: Aggregates and cement (OPC) mix proportions for 12 samples of ICBP.

Samples	Cement(kg)	Fly ash(kg)	Sand(kg)	Quarry dust(kg)	Coarse aggregate(kg)
A1	2.61	2.91	9.53	22.25	21.19
B1	5.23	2.91	9.53	22.25	21.19
C1	6.53	2.91	9.53	22.25	21.19
D1	7.05	2.91	9.53	22.25	21.19
E1	4.48	0	9.53	22.25	21.19
F1	7.1	0	9.53	22.25	21.19
G1	8.4	0	9.53	22.25	21.19
H1	8.9	0	9.53	22.25	21.19

Note: - Each design has 12 ICBPs. Due to that 96 ICBP samples are made for OPC cement

Table 3.4: Aggregates and cement (PLC) mix proportions for 12 samples of ICBPs.

Samples	Cement(kg)	Fly ash(kg)	Sand(kg)	Quarry dust(kg)	Coarse aggregate(kg)
A2	2.61	2.91	9.53	22.25	21.19
B2	5.23	2.91	9.53	22.25	21.19
C2	7.05	2.91	9.53	22.25	21.19
E2	4.48	0	9.53	22.25	21.19
F2	7.1	0	9.53	22.25	21.19
G2	8.9	0	9.53	22.25	21.19

Note: -Each design has 12 ICBPs. Due to that 72 ICBP samples are made for PLC cement

3.2 Making of ICBP

According to the Mamperarachcchi and Hettiarachchi(2018),mechanical vibration is essential for packing model mix design of ICBP. Due to that vibration machine was used for in this study. Vibrator ICBP machine and ICBP making process is shown in Figure 3.5.

Figure 3.5: ICBP making machine

The ICBP machine's vibration is used to get better packing for aggregate mixtures. After that mechanical force is applied to achieve better compaction for ICBP. Aggregate mixing process is also very important in ICBP manufacturing. Due to that mortised mixture (Shown in Figure 3.6) was used for the mixing process.

Figure 3.6: materials mixture

3.3 Testing of ICBP

The ICBP samples were tested for compressive strength and water absorption according to standards. Furthermore Scan Electron Microscope (SEM) test is done for ICBP samples. Compressive strength of ICBP samples are tested for the age of 7 days, 14 days and 28 days. The ICBP samples are cured using water and samples are immersed in a water tank until they archive their testing date. Water absorption test is done for 28 days samples. The SEM test is done for ICBP samples of age 28 days. In Figure 3.7 shows compressive test of ICBP and Figure 3.8 shows SEM test of ICBP.

Figure 3.7: Compressive strength testing equipment

Figure 3.8: SEM equipment

CHAPTER 04. RESULT AND ANALYZE

4.1 Result

Within this section, describe about result which is obtained from testing of raw material & finish product of ICBP.

4.1.1. OPC and PLC cement are tested according to SLSI standards.

OPC and PLC cement were tested according to SLSI standards from National Building Research Organization Sri Lanka and Industrial Technology Institute Sri Lanka. The physical test results of OPC cement are show in Table 4.1.The chemical results of OPC are shown in Table 4.2

Table 4.1: Physical test results of OPC

Test/Unit	Test Method	Result	Requirement (SLS 107:2008 part 1)
Compressive Strength(N/mm2) 2 days 28 days	SLS ISO 679 (2011)	28.0 62.4	≥10.0 ≥ 42.5 & ≤ 62.5
Setting time Initial	SLS 107:2008 part II	2 h40 min	≥ 1h
Fineness(m^2/kg)	SLS 107:2008 part II	323	Not less than 225
Soundness(mm)(Expansion)	SLS 107:2008 part II	0	Not less than 10
Standard Consistency (%)	SLS 107:2008	28.4	---

Table 4.2: Chemical test results of OPC

Test/Unit	Test Method	Result	Requirement (SLS 107:2008 part 1)
Lime Saturation Factor(LSF)	SLS 107:2008 part II	0.92	0.99 – 1.02
MgO(% by mass)	SLS 107:2008 part II	1.4	Shall not exceed 5.0
Insoluble Residue(% by mass)	SLS 107:2008 part II	1.2	Shall not exceed 1.5
Loss on Ignition(% by mass)	SLS 107:2008 part II	2.5	Shall not exceed 4.0
Chloride (% by mass)	SLS 107:2008 part II	0.01	Shall not exceed 0.1
SO_3((% by mass)	SLS 107:2008 part II	2.7	Shall not exceed 3.0

The physical test results of PLC are shown in Table 4.3 & chemical results of PLC are shown in Table 4.4.

Table 4.3: Physical test results of PLC

Test/Unit	Test Method	Result	Requirement (SLS 107:2008 part 1)
Compressive Strength(N/mm2) 2 days 28 days	SLS 1253:2015	 27.1 N/mm^2 51.0 N/mm^2	 ≥20.0 ≥ 42.5 & ≤ 62.5
Setting time Initial Final	SLS 1253:2015	 2 h 45 min 3 h 15 min	 ≥ 1h
Fineness(m^2/kg)	SLS 1253:2015	369	Not less than 330
Soundness(mm)(Expansion)	SLS 1253:2015	0	Not less than 10

Table 4.4: Chemical test results of PLC

Test/Unit	Test Method	Result	Requirement (SLS 107:2008 part 1)
Insoluble Residue(% by mass)	SLS ISO 29581-1:2011	6.2	NM
Loss on Ignition(% by mass)	SLS ISO 29581-1:2011	1.6	Shall not exceed 10
Chloride (% by mass)	SLS ISO 29581-1:2011	0.07	Shall not exceed 0.1
SO_3((% by mass)	SLS ISO 29581-1:2011	5.8	Shall not exceed 4.0

4.1.2 Sieve analysis test results of river sand and Quarry dust(M-sand)

Sieve analysis test was done for river sands according to Institute for Construction Training and Development requirements. The test results of river sand are shown in Table 4.5.The sieve analysis graph for river sand are show in Figure 4.1.

Table 4.5: Sieve analysis test results of river sand

Sieve Size mm	Weight Retained g	Retained %	Cumulative % Weight Retained	% Passing	Specification Limits	
					Lower Limits	upper Limits
10.00	19.70	0.99	0.99	99.02	100	100
5.00	102.70	5.14	6.12	93.88	91	100
2.36	679.40	33.97	40.09	59.91	60	95
1.18	521.80	26.09	66.18	33.82	30	70
0.60	392.00	19.60	85.78	14.22	15	34
0.30	165.40	8.27	94.05	5.95	2	20
0.15	20.00	1.00	95.05	4.95	0	10
Pan	5.60					
Total	1906.60					

Initial Weight of Dry sample (g)= 2000.00

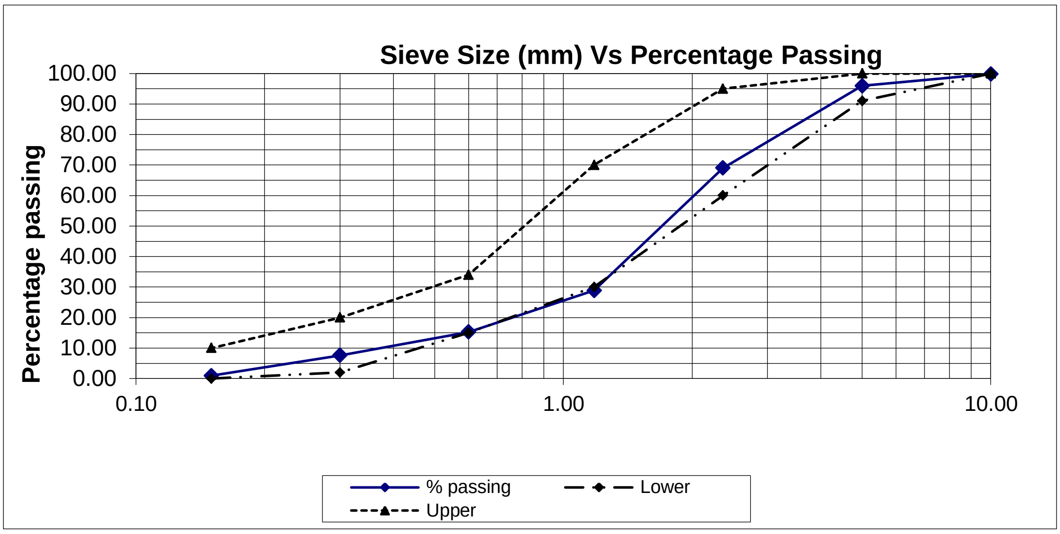


Figure 4. 1: Sieve analysis graph for river sand

Sieve analysis test was done for quarry dust according to Institute for Construction Training and Development requirements. The sieve analysis test results of quarry dust are shown in Table 4.6.The sieve analysis graph for quarry dust are show in Figure 4.2.

Table 4.6: Sieve analysis test results of quarry dust

Sieve Size mm	Weight Retained g	Retained %	Cumulative % Weight Retained	% Passing	Specification Limits	
					Lower Limits	upper Limits
10.00	0.00	0.00	0.00	100.00	100	100
5.00	3.70	0.23	0.23	99.77	91	100
2.36	234.90	14.80	15.03	84.97	60	95
1.18	390.70	24.62	39.65	60.35	30	70
0.60	551.10	34.73	74.38	25.62	15	34
0.30	288.00	18.15	92.53	7.47	2	20
0.15	87.00	5.48	98.01	1.99	0	10
Pan	31.00					
Total	1586.40		**Initial Weight of Dry sample (g)=**		**1587.00**	

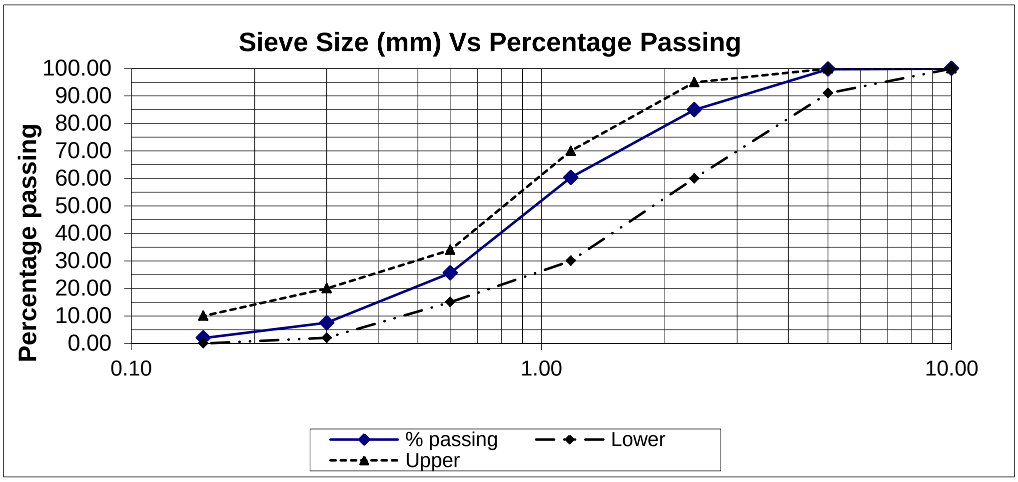


Figure 4.2: Sieve analysis graph for Quarry dust

4.1.3 Sieve analysis test results of coarse aggregates

Sieve analysis test of coarse aggregate (chip) was done according to Institute for Construction Training and Development requirements. Test result are shown in Table 4.7 .The graph of sieve analysis test results of coarse aggregate are shown in Figure 4.3

Table 4.7: Sieve analysis test results of coarse aggregates

Sieve Size mm	Weight Retained g	Retained %	Cumulative % Weight Retained	% Passing	Specification Limits	
					Lower Limits	upper Limits
20.00	0.00	0.00	0.00	100.00	100	100
14.00	0.00	0.00	0.00	100.00	95	100
10.00	350.00	12.50	12.50	87.50	67	88
5.00	2306.90	82.39	94.89	5.11	0	16
Pan	142.10					
Total	2799.00					

Initial Weight of Dry sample (g)=2800

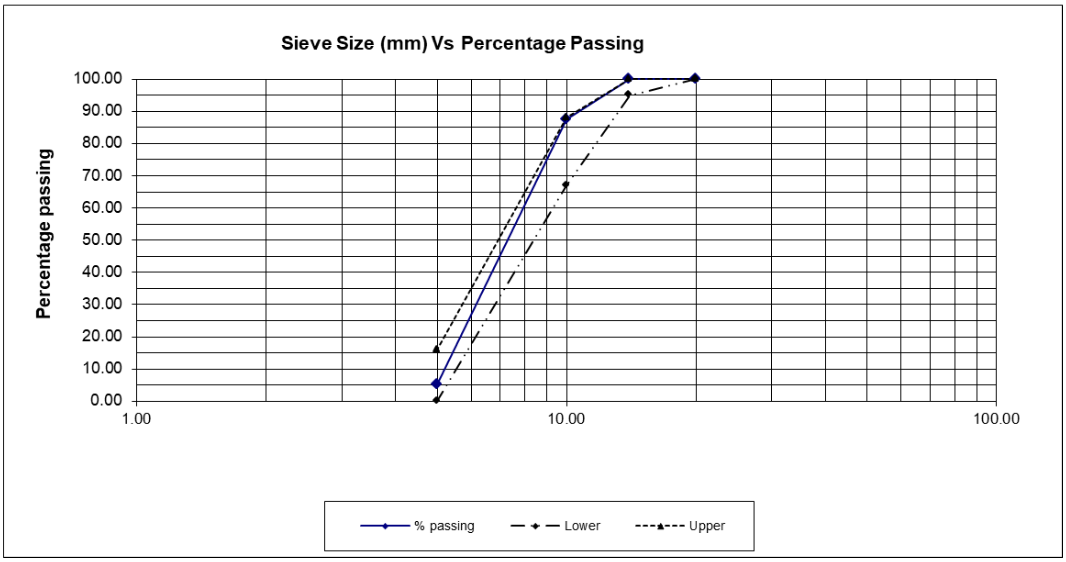


Figure 4.3: Sieve analysis graph for coarse aggregates

4.1.4 Aggregates impact test for coarse aggregates

Aggregate impact value test was done according to BS standards & Institute for Construction Training and Development requirements. The results and requirements are shown in Table 4.8

Table 4.8: AIV test results of coarse aggregates

AIV Results for coase aggregates(%)	AIV requairment according to ICTAD
29	Not grater than 30

4.1.5 Specific gravity of materials in ICBP mixture

Specific gravity of materials was tested. The results are shown in Table 4.9

Table 4.9: Specific gravity of Materials

Type of material	SG
Quarry dust	2.62
River Sand	2.37
Coarse aggregates	2.76
Fly ash	2.03
cement	3.15

4.1.6 Physical and chemical test result of Fly ash

Fly ash was tested according to BS EN 450 from Industrial Technology Institute Sri Lanka. Chemical testing results and it requirements are shown in Table 4.10.

Table 4.10: Chemical testing results of fly ash

Test/Unit	Test Method	Results	Specification given in BS EN 450-1:2012
Loss on ignition/ % by mass	BS EN 450-1: 2012	3.7	Shall not be greater than 5
SiO_2 % by mass		45	
Al_2O_3 /% by mass		31.8	
Fe_2O_3 /% by mass		4.4	
MgO /% by mass		1.1	Shall not be greater than 4
CaO /% by mass		9	--------
Chloride content /% by mass		<0.01	Shall not be greater than 0.10
Total Alkali equivalent as Na_2O/% by mass		0.4	Shall not exceed 5
SO_3 / % by mass		0.5	Shall not be greater than 3
Reactive Silica /% by mass		11	Shall not be less than 25

The physical test results of fly ash and it requirements according to standard are shown in Table 4.11.

Table 4.11: Physical testing results of fly ash

Test/Unit	Test methods	Results	Specification given in BS EN 450-1:2012
Fineness/ % by mass	In house method	24	Category N:shall not exceed 40% & it shall not vary by more than ±10 percentage points from the declared value category S:shall not exceed 12%
Particle Density/kg/m^3	BS EN 450-1: 2012	2224	Shall not deviate by more than 200 kg/m^3 from value declared by producer.
Soundness/mm		1	Shall not be greater than 10 mm
Initial setting /minutes -Fly ash + Cement -Cement		 160 90	Shall not be more than twice of the initial setting time of a 100%(by mass)test cement paste
Water requirement		97	Category N:requirement does not apply,Category S:shall not be greater than 95% of that for test cement alone

4.1.7 Test result of Fly ash for radio activity.

The radio activity of fly ash was tested from Atomic Authority. Test results are shown in Table 4.12.

Table 4.12: Radio activity test results of fly ash

Parameters(Radio Nuclide	Activity(Bq/kg)	MDA
Cs	Not Detected	2.0
K	199.8±20.9	
Pb	202±28.2	
Ba	195.9±18.8	
Th	227.5±26.2	
U	24.7±2.7	

4.1.8 Test result of Fly ash for TCLP heavy metal analysis.

TCLP heavy metal analysis was done form Beura varitas. The test results are shown in Table 4.13.

Table 4.13: TCLP heavy metal analysis test results of fly ash

Parameters/Unit(mg/L)	Test method	Result	Requirement
As	USEPA method 1311-TCLP with ICP-MS	Not Detected	5
Cr		Not Detected	5
Cd		Not Detected	1
Cu		Not Detected	Not given
Pb		Not Detected	5
Mn		Not Detected	Not given
Zn		98.2	Not given
Tl		Not Detected	Not given
Se		Not Detected	1
Ni		Not Detected	Not given
Hg		Not Detected	0.2
Ba		Not Detected	100
Fe		20.6	Not given
Ag		Not Detected	5

Parameters/Unit(mg/kg)	Test method	Result	Requirement
Sulfite	AOAC 980.02	65.6	Not given
sulfate		81.5	Not given
Hexavalent Chromium	CPSD-AN-00597-MTHD	Not Detected	Not given
pH of 10%(w/v) solution	-	10.8	Not given

4.1.9 Test result of compressive strength and water absorption of fly ash filling and cement filing samples of OPC.

Compressive Strength, density and water absorption test results of ICBP with curing age is shown in Table 4.14 for OPC mixture. The A1, B1, C1 and D1 are fly ash filling samples and E1, F1, G1 and H1 are cement filling samples.

Table 4.14 Compressive strength test results of OPC samples

Sample	Compressive Strength(N/mm2)												Density	Water absorption(%)
	7 days				14 days				28 days					
	Sample1	sample2	sample3	Average	Sample1	sample2	sample3	Average	Sample1	sample2	sample3	Average		
A1	2.60	3.70	4.56	3.62	6.83	7.37	7.10	7.10	7.66	8.37	7.91	7.98	2.89	9.00%
B1	10.11	11.11	9.52	10.25	12.71	11.64	12.18	12.18	15.42	15.32	17.15	15.96	2.93	8.34%
C1	11.43	12.43	11.81	11.89	13.68	14.20	14.73	14.20	17.25	16.44	16.03	16.57	2.89	7.10%
D1	14.47	13.81	14.44	14.24	19.73	20.55	20.55	20.28	23.13	21.56	25.26	23.32	2.92	8.44%
E1	4.97	6.44	5.58	5.66	6.39	5.68	6.85	6.31	7.91	6.09	6.49	6.83	2.92	7.62%
F1	11.16	11.41	11.16	11.24	11.16	12.02	13.19	12.12	13.04	13.60	12.73	13.12	2.90	7.19%
G1	14.46	12.78	14.15	13.80	15.83	15.73	15.47	15.68	16.89	16.73	17.57	17.06	2.88	7.84%
H1	20.32	18.22	20.05	19.53	20.19	20.55	19.53	20.09	22.58	21.41	20.80	21.60	2.93	8.78%

4.1.10 Test result of compressive strength and water absorption of fly ash filling and cement filing samples of PLC.

Compressive Strength, density and water absorption test results of ICBP with curing age is shown in Table 4.15 for PLC mixture. The A2, B2 and C2 are fly ash filling samples and E2, F2 and G2 are cement filling samples.

Table 4.15: Compressive strength test results of PLC samples

Sample	Compressive Strength(N/mm2)												Density	Water absorption(%)
	7 days				14 days				28 days					
	Sample1	sample2	sample3	Average	Sample1	sample2	sample3	Average	Sample1	sample2	sample3	Average		
A2	6.70	7.05	7.20	6.98	9.73	8.40	9.10	9.08	10.07	11.50	11.65	11.07	3.19	7.27%
B2	10.26	9.69	11.08	10.34	18.26	20.79	19.96	19.67	19.79	20.65	21.82	20.75	3.00	7.48%
C2	20.79	21.21	20.00	20.67	22.51	25.11	23.72	23.78	25.44	29.97	28.04	27.82	3.07	10.49%
E2	9.59	8.78	10.84	9.74	10.02	8.99	11.02	10.01	14.55	14.59	13.07	14.07	3.05	8.57%
F2	15.95	14.25	15.70	15.30	19.08	20.94	18.43	19.48	20.74	18.46	20.37	19.86	3.00	7.20%
G2	19.35	21.05	23.62	21.34	25.00	26.70	25.05	25.58	27.12	27.53	27.82	27.49	3.26	7.21%

4.1.11 SEM test results of samples

SEM observation was done for ICBP samples .This SEM images are categorized as OPC mixture without fly ash, OPC mixture with fly ash, PLC without fly ash and PLC with fly ash.

4.1.11.1 SEM results for OPC mixture without fly ash (Cement filling)

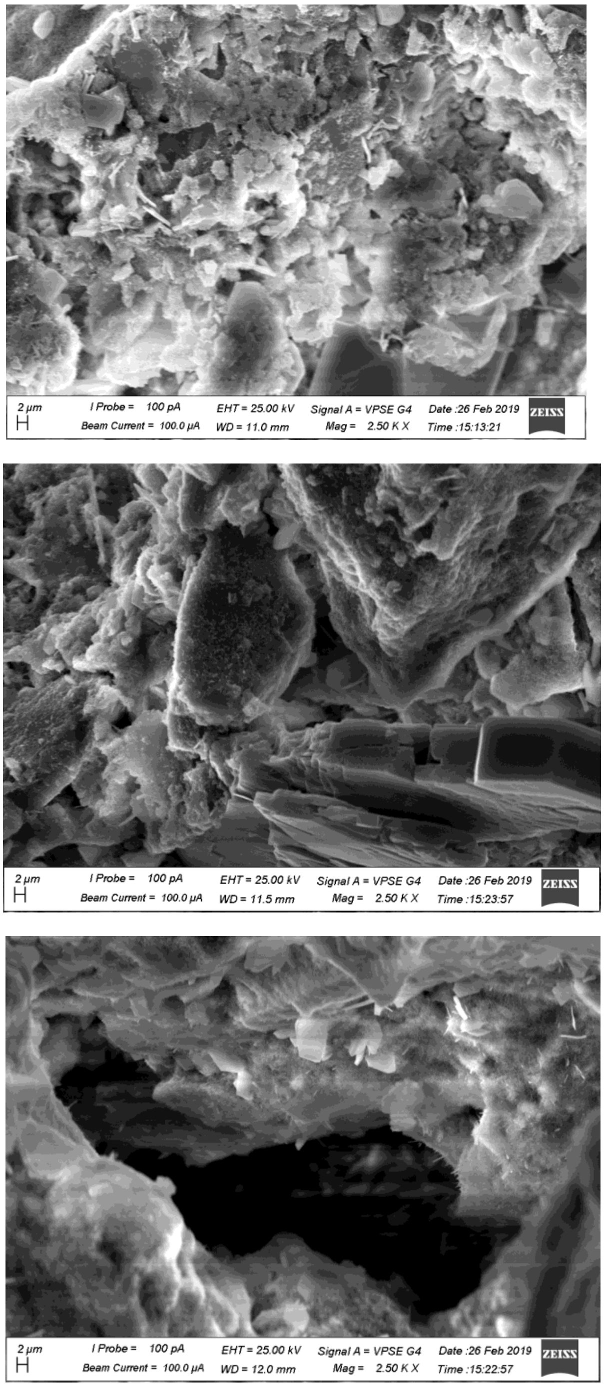


Figure 4.4: SEM image of OPC sample (without fly ash).

In Figure 4.4, there are no spherical particles due to unavailability of Fly ash. Black colour spaces are voids in the mixture. The Figure 4.4 is shown in 2.50KX magnification.

4.1.11.2 SEM results for OPC mixture with fly ash (Fly ash filling)

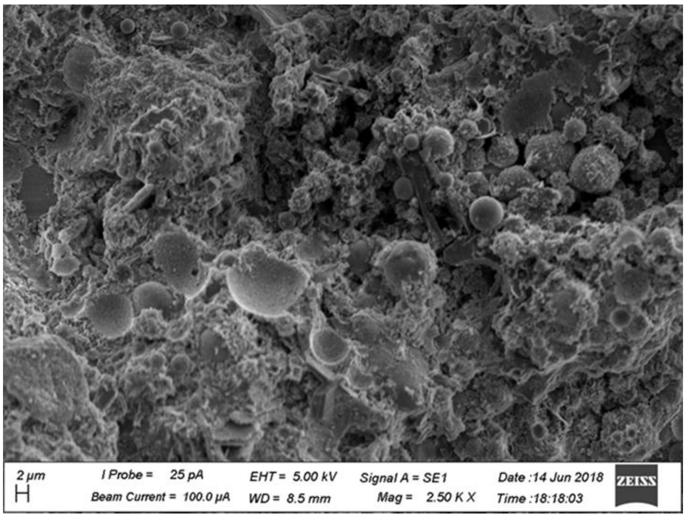


Figure 4.5: SEM image of OPC sample (with fly ash).

In Figure 4.5, there are spherical particles due to the availability of Fly ash. Round voids are made because of the removal of the fly ash particle. (Magnification 2.50KX)

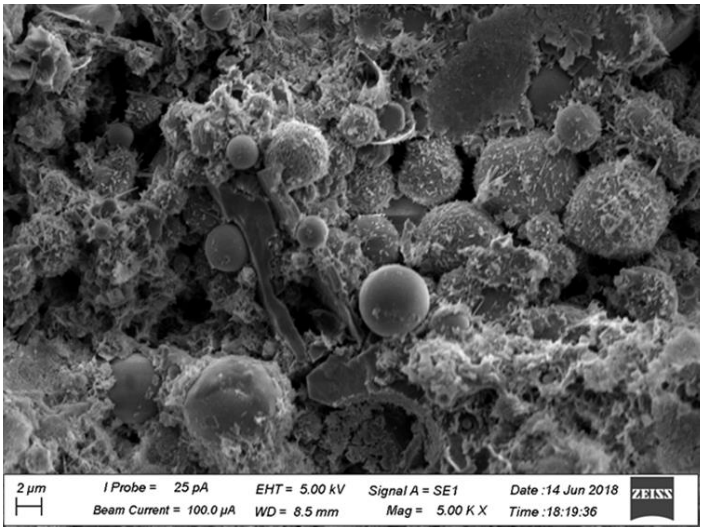
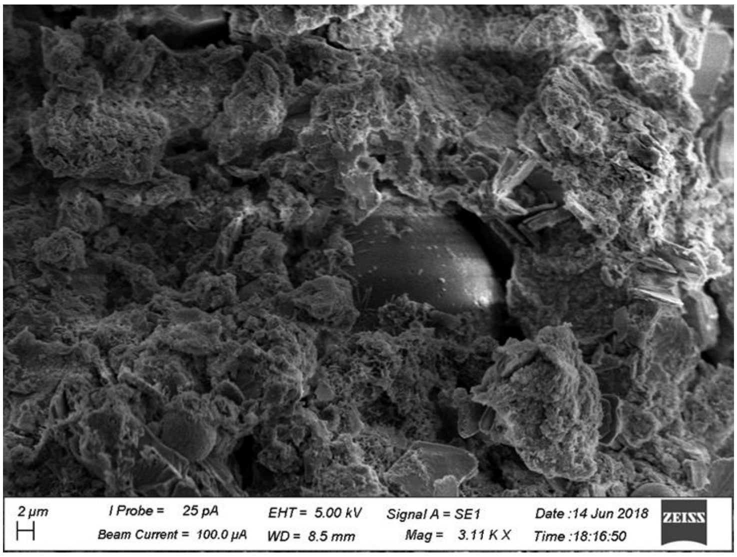
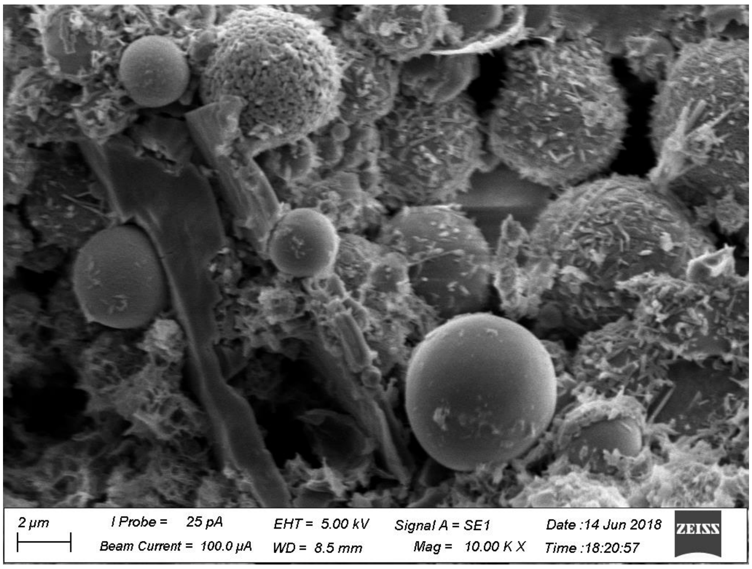


Figure 4.6: SEM image of OPC sample (with fly ash).

In Figure 4.6, there are spherical particles due to the availability of Fly ash. Spherical (Fly ash) particles fill the voids in the ICBP mixture. (Magnification 5.00KX).



(a)



(b)

Figure 4.7: SEM image of OPC sample (with fly ash).

In Figure 4.7 (a) and Figure 4.7 (b), there are spherical particles due to availability of Fly ash. Different sizes of Fly ash particles are available in mixture. Magnifications are respectively 3.11 KX and 10.00 KX.

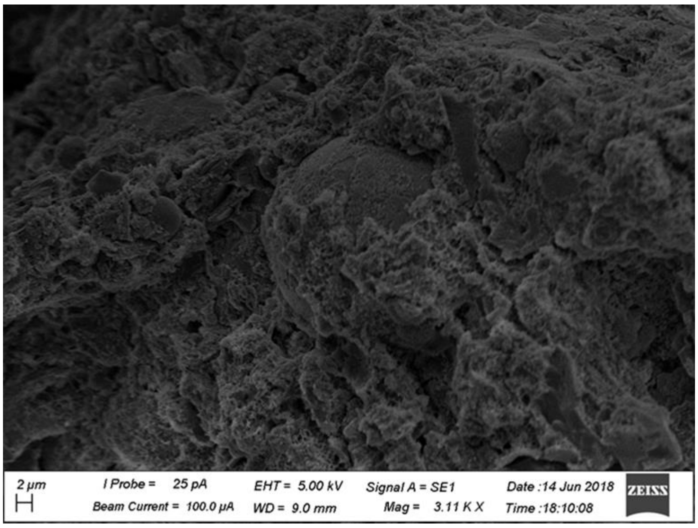


Figure 4.8: SEM image of OPC sample (with fly ash).

In Figure 4.8, there are spherical particles due to availability of Fly ash. Different sizes of Fly ash particles are present in the mixture (only large sized fly ash particle can be seen). (Magnification 3.11KX)

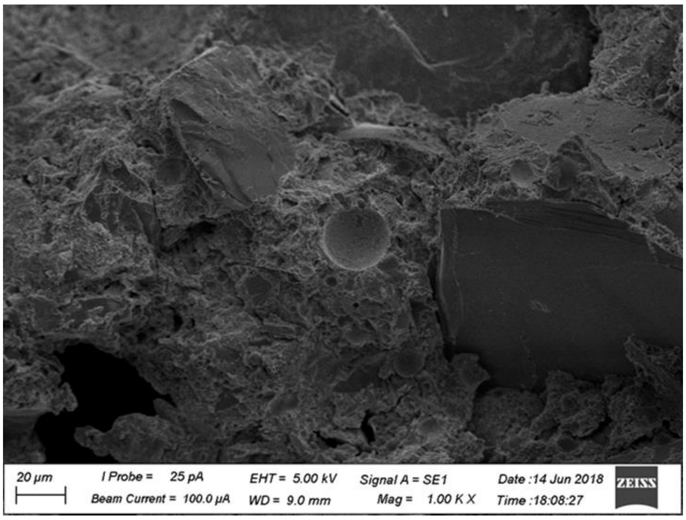
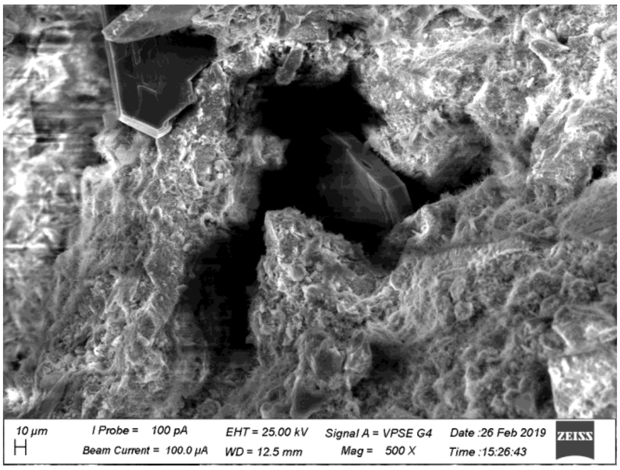


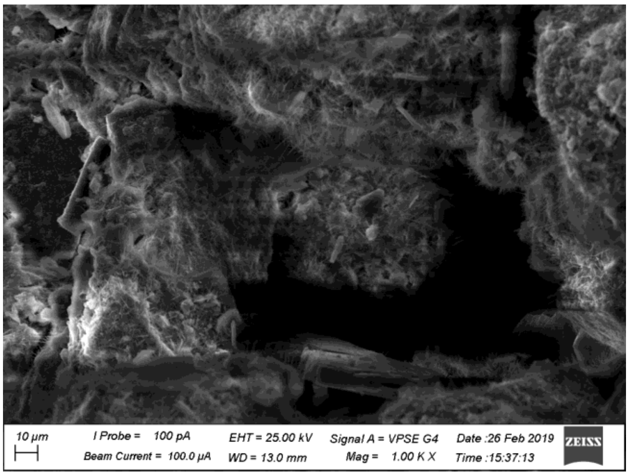
Figure 4.9: SEM image of OPC sample (with fly ash).

In Figure 4.9, there is only one spherical avoid available .but it has a Fly ash. Void was made due to the removal of the Spherical (Fly ash) particles.

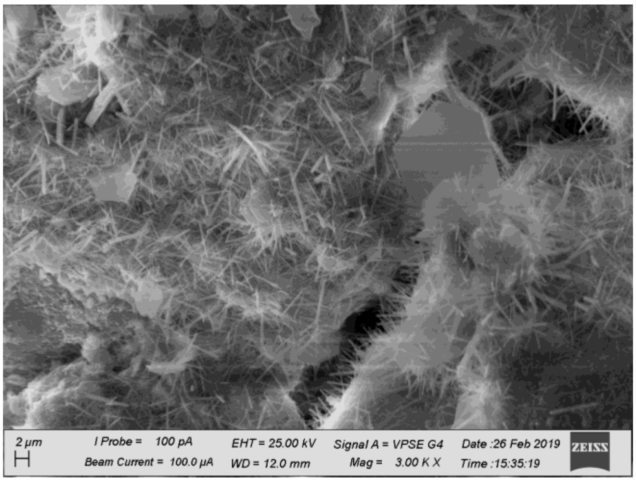
4.1.11.3 SEM results for PLC mixture without fly ash (cement filling)



(a)



(b)



(c)

Figure 4.10: SEM image of PLC sample (without fly ash).

In Figure 4.10 (a), Figure 4.10 (b) and Figure 4.10 (c), there are no spherical particles due to unavailability of Fly ash. Due to the presence of Calcium carbonate, there are calcium carbonate crystals than OPC. There are black spaces due to the unfilled voids in the mixture. Magnifications are respectively 500 KX, 1.00KX &3.00KX

4.1.11.4 SEM results for PLC mixture with fly ash (fly ash filling)

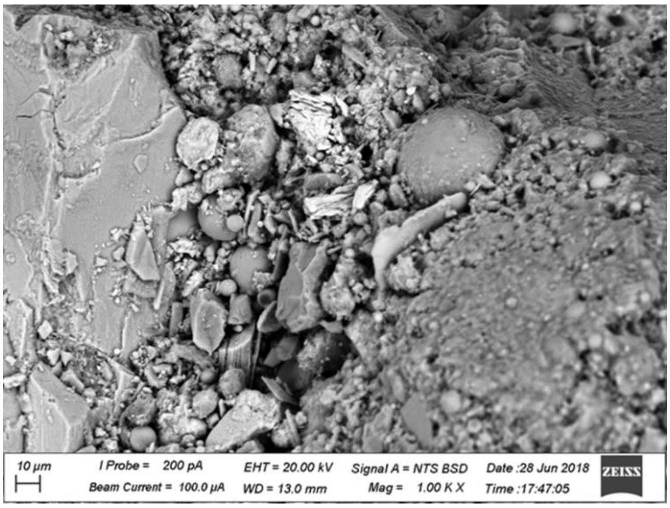


Figure 4.11: SEM image of PLC sample (with fly ash).

In Figure 4.11, there are spherical particles due to availability of Fly ash. Spherical (Fly ash) particles fill the voids in the mixture. Magnification 1.00KX

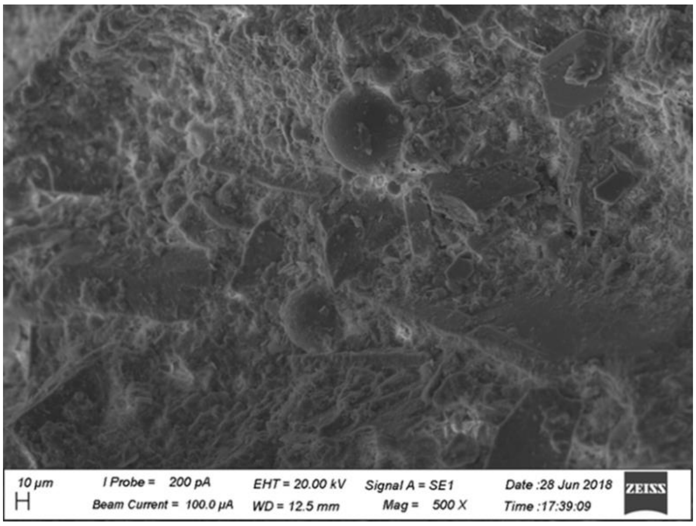


Figure 4.12: SEM image of PLC sample (with fly ash).

In Figure 4.12, there are spherical particles due to available of Fly ash. Different sizes of Fly ash particles are available in the mixture (only large size fly ash particle can be seen). (Magnification 500 X).

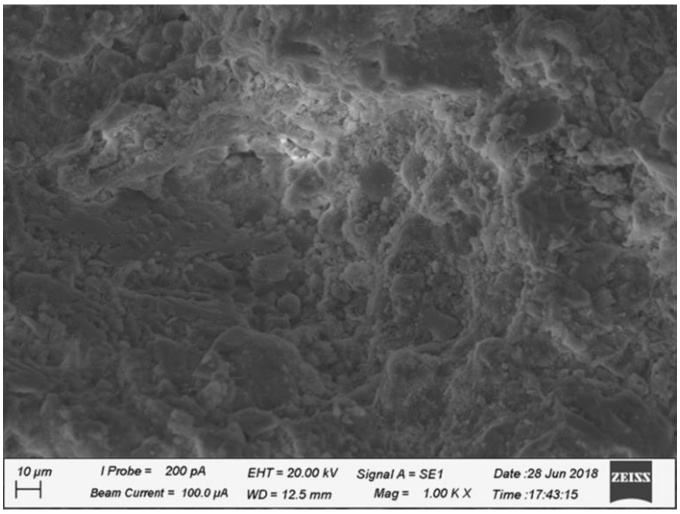


Figure 4.13: SEM image of PLC sample (with fly ash).

In Figure 4.13, there are spherical particles due to availability of Fly ash. Different sizes of Fly ash particles are available in the mixture (only large size fly ash particle can be seen). (Magnification 1.00KX).

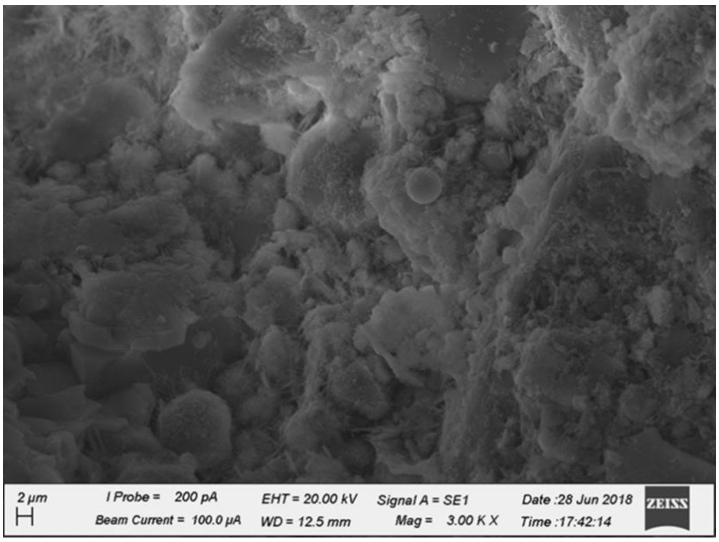


Figure 4.14: SEM image of PLC sample (with fly ash).

In Figure 4.14, there are spherical particles due to availability of Fly ash. Spherical (Fly ash) particles fill the voids in the mixture. (Magnification 3.00KX).

4.2 Analyze

The average values of three samples are taken as the compressive strength of each samples for analyzing propose. Each of A1,B1,C1 ,D1,E1,F1,G1 ,A2,B2,C2,E2,F2 & G2 represent the average value of the compressive strength of three samples.

4.2.1 The compressive strength of OPC samples of ICBP are shown according to the change of fly ash and cement as a filling material.

The grade of concrete and it compressive strength according to ages are shown in Table 4.16 for both Fly ash filling and cement filling samples.

Table 4.16: compressive strength of OPC samples of cement filling & Fly ash filling

Concrete grade	Sample	Compressive strength Filling by Fly ash(N/mm^2)			Samp le	Compressive strength Filling by cement(N/mm^2)			Increase of strength of filling by Fly ash
		7 days	14 days	28 days		7 days	14 days	28 days	28 days
G7	A1	3.62	7.1	7.98	E1	5.66	6.31	6.83	1
G15	B1	10.25	12.18	15.96	F1	11.25	12.12	13.12	3
G16	C1	11.89	14.2	16.57	G1	13.8	15.68	17.06	0
G20	D1	14.24	20.28	23.32	H1	19.53	20.09	21.59	1

4.2.2 The compressive strength of PLC samples of ICBP is shown according to the change of fly ash and cement as a filling material.

The grade of concrete and its compressive strength according to age are shown in Table 4.17 for both Fly ash filling and cement filling samples.

Table 4.17: compressive strength of PLC samples of cement filling & Fly ash filling

Concrete grade	Sample	Compressive strength Filling by Fly ash(N/mm^2)			Samp le	Compressive strength Filling by cement(N/mm^2)			Increase of strength of filling by Fly ash
		7 days	14 days	28 days		7 days	14 days	28 days	28 days
G7	A2	7	9.1	11	E2	9.74	10	14	-3
G15	B2	10.34	19.67	20.75	F2	15.3	19.48	19.86	1
G20	C2	21	23.78	27.82	G2	21.34	25.58	27.49	0

4.2.3 In OPC samples, compressive strength Comparison between Fly ash filling samples and cement filling samples.

Compressive strength comparison of fly ash filling and cement filling with change of concrete grade is done for OPC cement samples. Table 4.18 shows compressive strength change with change of filling material and age for G7 mixture.

Table 4.18: Compressive strength test results of G7 mixture with change of filling material

Concrete grade	G7	
Age of mixture	Fly ash filling	Cement filling
7 day	3.62	5.66
14 day	7.10	6.31
28 day	7.98	6.83

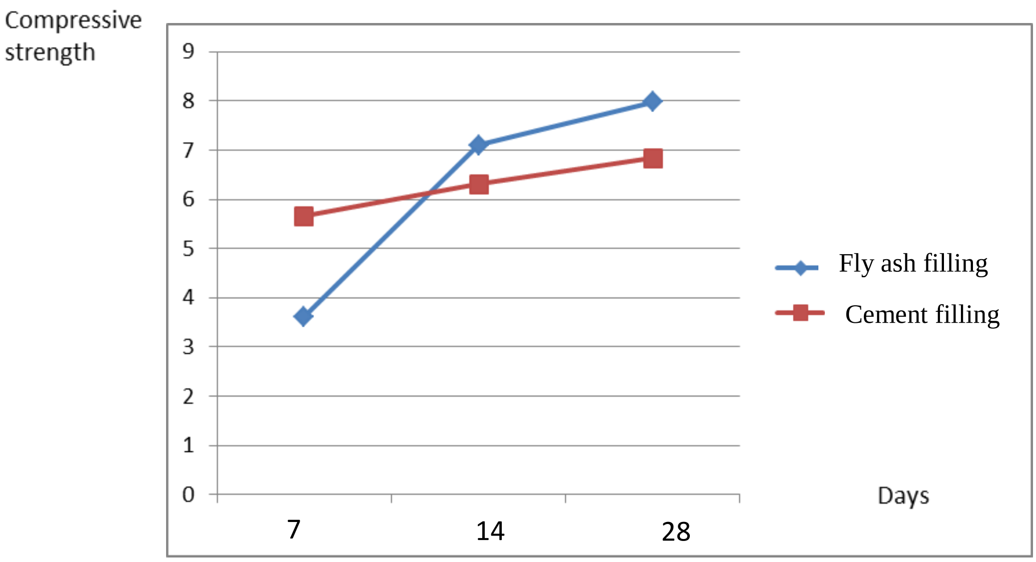


Figure 4.15: Compressive strength comparison for G7 mixture with change of filling material and age.

According to Figure 4.15, compressive strength of cement filling has a higher value at 7 days than fly ash filling. After 14 days, fly ash filling has a higher compressive strength than cement filling. Table 4.19 shows compressive strength change with change of filling material and age for G15 mixture.

Table 4.19: Compressive strength test results of G15 mixture with change of filling material

Concrete grade	G15	
Age of mixture	Fly ash filling	Cement filling
7 day	10.25	11.25
14 day	12.18	12.12
28 day	15.96	13.12

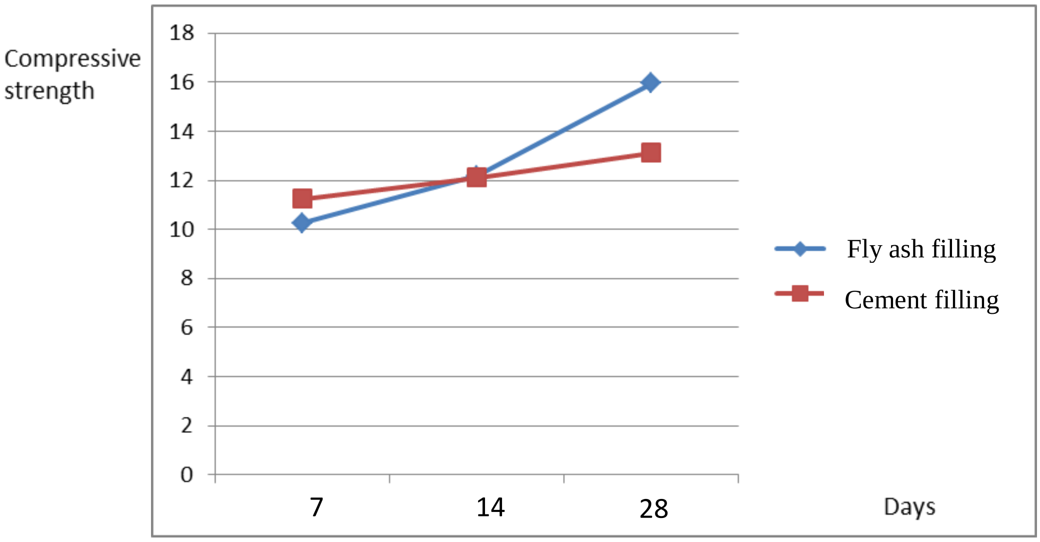


Figure 4.16: Compressive strength comparison for G15 mixture with change of filling material and age.

According to Figure 4.16, compressive strength of cement filling has a higher value at 7 days than fly ash filling. After 14 days, fly ash filling has a higher compressive strength than cement filling. Table 4.20 shows compressive strength change with change of filling material and age for G16 mixture. According to Figure 4.17, fly ash filling has a lower compressive strength than cement filling until achieved 28 days. Table 4.21 shows compressive strength change with change of filling material and age for G20 mixture.

Table 4.20: Compressive strength test results of G16 mixture with change of filling material

Concrete grade	G16	
Age of mixture	Fly ash filling	Cement filling
7 day	11.89	13.80
14 day	14.20	15.68
28 day	16.57	17.06

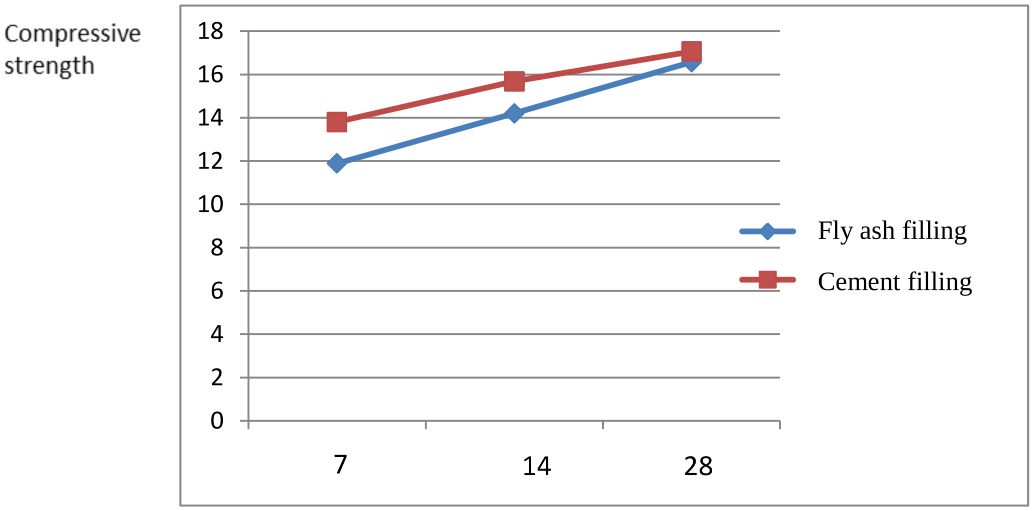


Figure 4.17: Compressive strength comparison for G16 mixture with change of filling material and age

Table 4.21: Compressive strength test results of G20 mixture with change of filling material

Concrete grade	G20	
Age of mixture	Fly ash filling	Cement filling
7 day	14.24	19.53
14 day	20.28	20.09
28 day	23.32	21.59

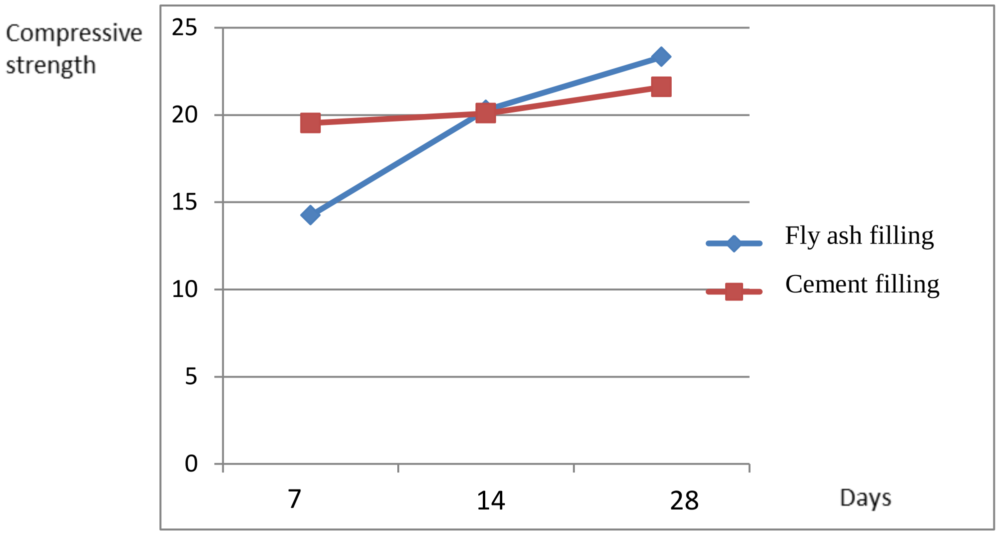


Figure 4.18: Compressive strength comparison for G20 mixture with change of filling material and age.

According to Figure 4.18, compressive strength of cement filling has a higher value at 7 days than fly ash filling. After 14 days, fly ash filling has a higher compressive strength than cement filling.

4.2.4 In PLC samples, compressive strength Comparison between Fly ash filling samples and cement filling samples.

Compressive strength comparison of fly ash filling and cement filling with change of concrete grade is done for PLC cement samples. Table 4.22 shows compressive strength change with change of filling material and age for G7 mixture. According to Figure 4.19, fly ash filling has a lower compressive strength than cement filling. Table 4.23 shows compressive strength change with change of filling material and age for G15 mixture.

Table 4.22: Compressive strength test results of G7 mixture with change of filling material

Concrete grade	G7	
Age of mixture	Fly ash filling	Cement filling
7 day	7.00	9.74
14 day	9.10	10.00
28 day	11.00	14.00

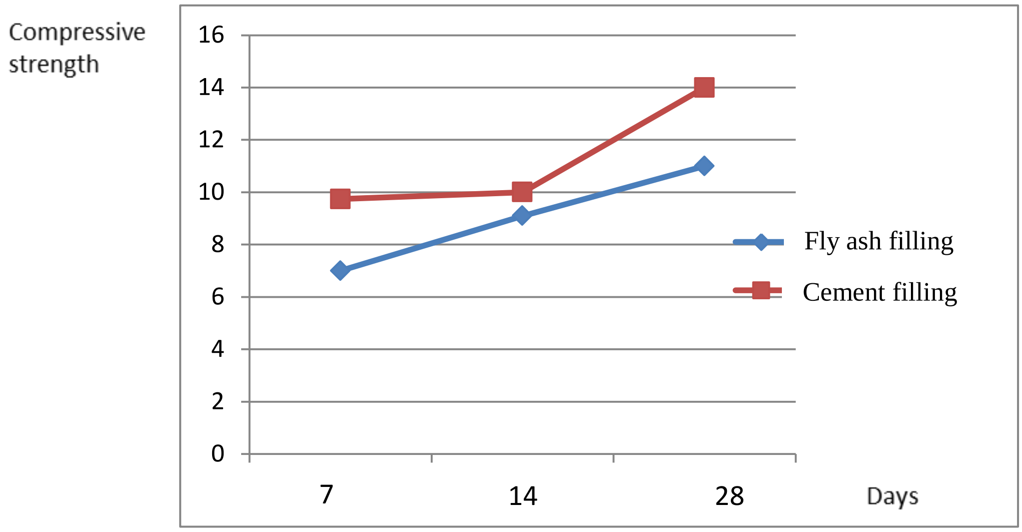


Figure 4.19: Compressive strength comparison for G7 mixture with change of filling material and age

Table 4.23: Compressive strength test results of G15 mixture with change of filling material

Concrete grade	G15	
Age of mixture	Fly ash filling	Cement filling
7 day	10.34	15.30
14 day	19.67	19.48
28 day	20.75	19.86

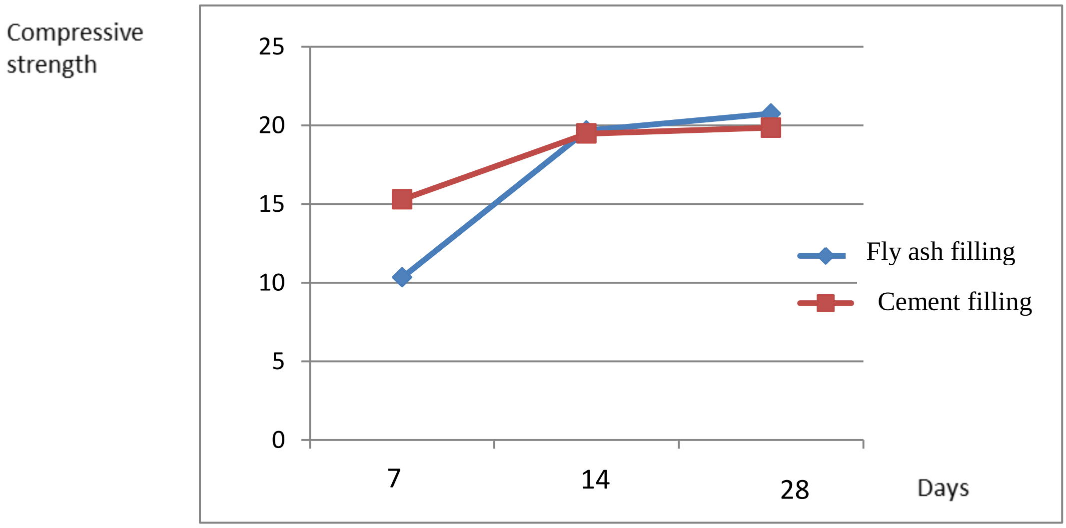


Figure 4.20: Compressive strength comparison for G15 mixture with change of filling material and age.

According to Figure 4.20, compressive strength of cement filling has a higher value at 7 days than fly ash filling. After 14 days, fly ash filling has a higher compressive strength than cement filling. Table 4.24 shows compressive strength change with change of filling material and age for G20 mixture. According to Figure 4.21, cement filling has a higher compressive strength than fly ash filling until reach 28 days. After 28 days, fly ash filling has a higher compressive strength than cement filling.

Table 4.24: Compressive strength test results of G20 mixture with change of filling material

Concrete grade	G20	
Age of mixture	Fly ash filling	Cement filling
7 day	21.00	21.34
14 day	23.78	25.58
28 day	27.82	27.49

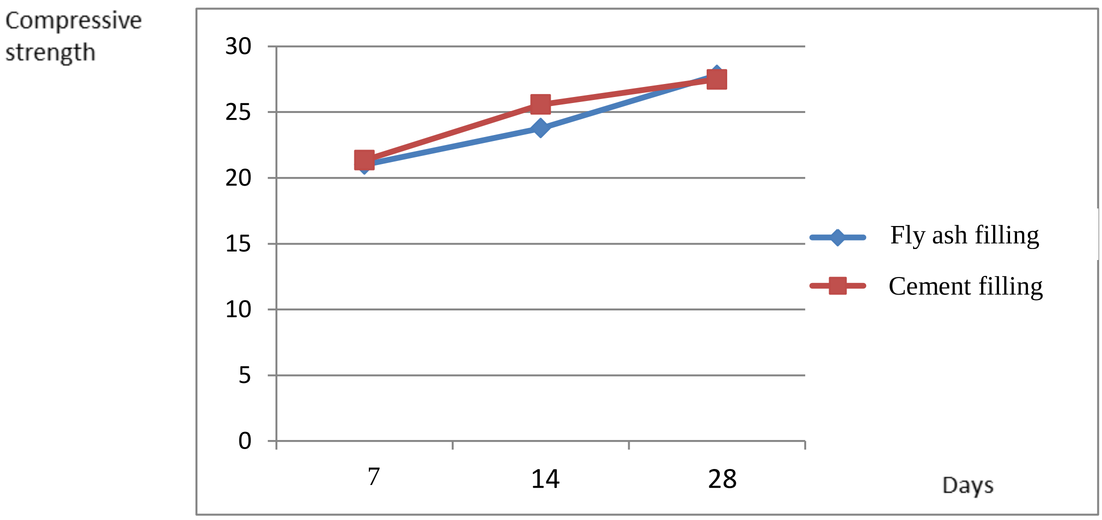


Figure 4.21: Compressive strength comparison for G20 mixture with change of filling material and age.

4.2.5 Compressive strength comparison between OPC (filling by Fly ash) samples and PLC (filling by Fly ash) samples with change of ages.

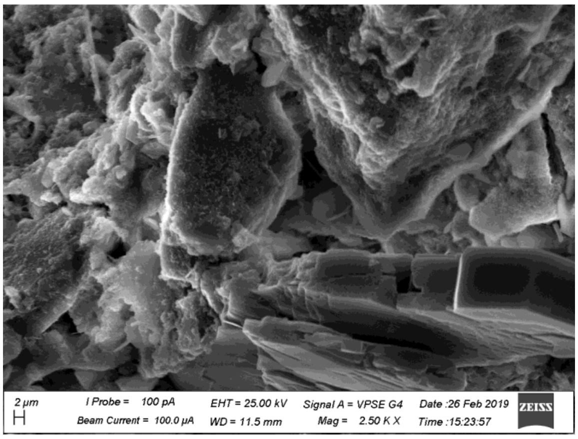
The compressive strength comparison of fly ash filling samples of OPC and PLC are shown in Table 4.25. According to Table 4.25,every grade of fly ash filling PLC mixtures have a higher compressive strength than OPC mixtures at every ages.

Table 4.25: Compressive strength comparison of fly ash filling OPC and PLC

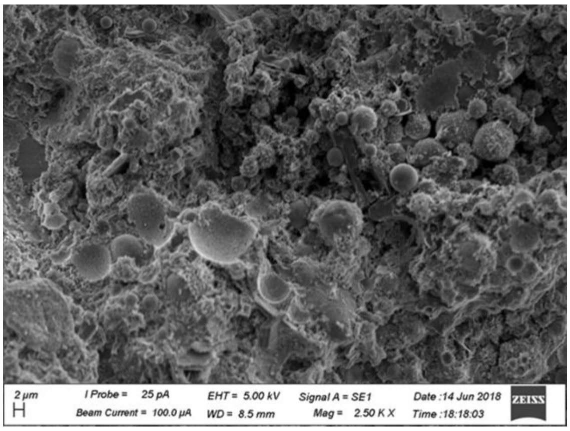
Concrete grade	Sample (OPC)	Compressive strength of sample Filling by Fly ash(N/mm^2)			Sample (PLC)	Compressive strength of samples Filling by Fly ash(N/mm^2)			Increase of strength in PLC than OPC
		7 days	14 days	28 days		7 days	14 days	28 days	28 days
G7	A1	3.62	7.10	7.98	A2	7	9.1	11	3.02
G15	B1	10.25	12.18	15.96	B2	10.34	19.67	20.75	4.79
G20	D1	14.24	20.28	23.32	C2	21.0	23.78	27.82	4.5

4.2.6 Comparison between SEM images of OPC samples with filling of cement and filling of fly ash.

Same magnifications of SEM images are used for comparison of cement filing OPC sample and fly ash filling OPC sample. Images are shown in Figure 4.22.



(a)

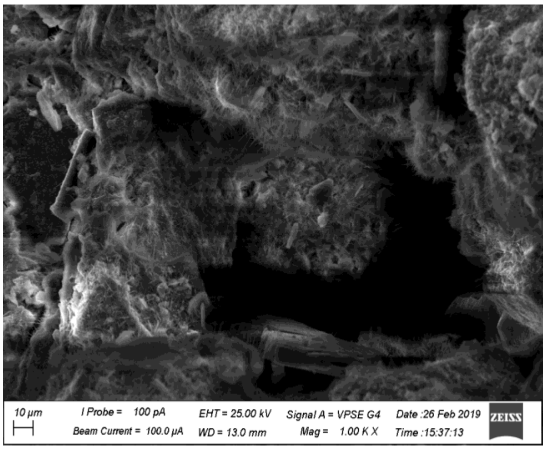


(b)

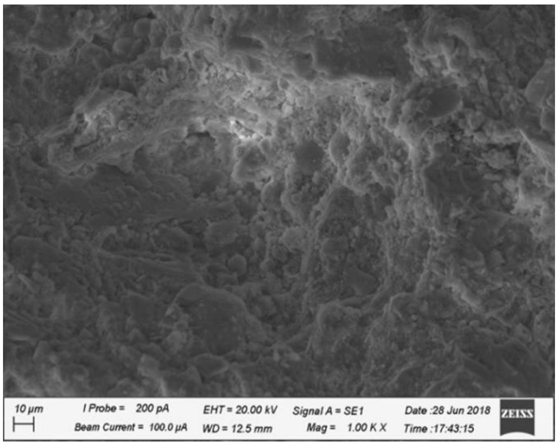
Figure 4.22: SEM comparison between Cement filling OPC sample and Fly ash filling OPC sample

In Figure 4.22, cement filling OPC sample (a) is in 2.50KX magnification and Fly ash filling OPC sample (b) is in 2.50Kx magnification. Fly ash filling sample has a more uniform filling structure than the cement filling sample according to the same magnification as the images of SEM.

4.2.7 Comparison between SEM images of PLC samples with filling cement and filling fly ash



(a)



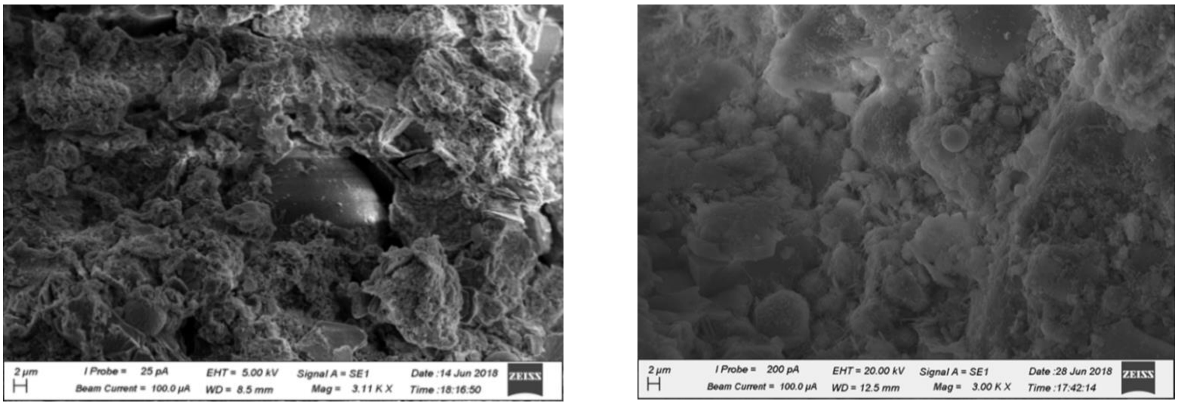
(b)

Figure 4.23: SEM comparison between cement filling PLC and fly ash filling PLC sample.

Same magnifications of SEM images are used for comparison of fly ash filing PLC sample and cement filling PLC sample. Images are shown in Figure 4.23.In Figure 4.23, cement filling PLC sample (a) is in 1.00KX magnification and fly ash filling PLC sample (b) is in 1.00KX magnification. Fly ash filing sample has a more uniform filling structure than the cement filling sample judging in accordance the images of SEM with the same magnification.

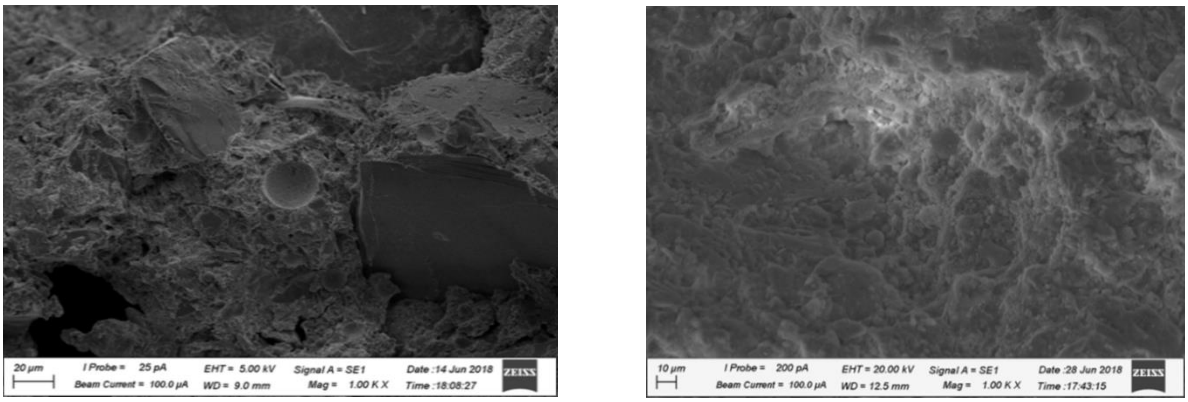
4.2.8 SEM image comparison between OPC fly ash filling sample and PLC fly ash filling sample.

Same magnifications of SEM images are used for the comparison of Fly ash filling OPC sample and fly ash filling PLC sample. (Shown Figure 4.24 and Figure 4.25).In Figure 4.24, fly ash filling OPC sample (a) is depicted in 3.11KX magnification and fly ash filling PLC (b) is depicted in 3.00KX magnification. There is a better packing structure in PLC fly ash filling sample than OPC fly filling sample. In Figure 4.25, fly ash filling OPC sample (a) is in 1.00KX magnification and fly ash filling PLC (b) is in 1.00KX magnification. According to Figure 4.25, there is a better packing structure in the PLC fly ash filling sample than OPC fly filling sample. According to the literature survey, more different particle size mixture give better packing than less different particle size mixture. In PLC fly ash mixture has two types of fine material for filling which are Fly ash & Calcium Carbonate. It leads to an increase compressive strength of ICBP.



(a) (b)

Figure 4.24: SEM comparison between Fly ash filling OPC sample & Fly ash filling PLC sample.



(a) (b)

Figure 4.25: SEM comparison between Fly ash filling OPC sample & Fly ash filling PLC sample

CHAPTER 05. DISCUSSION AND CONCLUSIONS

Improvement of aggregate packing model of interlocking concrete block pavement mixture using fly ash was studied in this research. In Sri Lanka, Norocholai coal power station generates a large amount of fly ash per day as a byproduct. It had been considered as waste and an environmental hazard while its use had been limited. Within this research, fly ash was utilized to improve the aggregate packing model of ICBP. Moreover, the use of interlock concrete block paver is becoming increasingly popular. Due to the optimization of the packing model mix design, it has fewer amounts of voids which need to be filled by cement. It decreases the amount of cement required for filling and increases the cement for bonding. However, reducing the content of cement is needed to achieve the required strength of ICBP. This will help reduce production cost of ICBP and the adverse environment impacts due to manufacturing of cement.

Before the use of fly ash in ICBP mixture, it is very important to check whether it is suitable to be used in the concrete mixture as a filling material and whether it has an environmental hazard. Due to that, chemical properties and physical properties of fly ash were tested according to international standards. According to chemical results of fly ash, it can be categorized as Class F fly ash. Class F fly ash is a pozzolanic type fly ash. Consequently an activator is needed to get cementations properties. However, in Sri Lanka the coal power station that generates fly ash has a less amount of reactive silica than the requirement mentioned in standards. According to S.K.Antiohos and S.Tsimas (2006), less reactive silica reduces the pozzolonic potential of fly ash. Thus, it is conclusive that Sri Lanka’s coal power station generated fly ash has less pozzolonic potential. Due to that reason, it is a good option to use this fly ash for filling purposes in the concrete mixture rather than as a binder. Further, fly ash was also tested for radio activity. Radioactivity of the fly ash sample was found to be below the desirable level. In addition to that, heavy metal analysis (Leaching test) was done for fly ash. According to test results, the content of toxic materials such as Arsenic, Chromium, Cadmium, Mercury and Lead that leaked were not detected. The raw materials of ICBP were tested according to the ICTAD procedure while the requirements and the finished product of ICBP were tested for compressive strength, SEM and water absorption. SEM observation was extremely helpful to identify the filling effect of fly ash in the mixture of ICBP. It is a strong evidence to demonstrate how the compressive strength increases due to the packing effect of fly ash.

According to Compressive strength results and SEM observation, conclusions can be derived as follows,

1. According to test results of OPC samples, 22% & 21% of cement can be replaced with fly ash for respectively grade 15 & 20 of mix design.

2. According to test results of PLC samples, 26% & 21% of cement can be replaced with fly ash for respectively grade 15 & 20 of mix design.

3. Therefore, optimization of the concrete components, especially the aggregates, is a satisfactory option to improve mechanical properties, lower the binder content, reduce material costs, and minimize environmental impacts associated with concrete production.

4. Different cements have different filling materials added by the manufacturer. These filling materials also need be considered in the mix design procedure. Over filling can reduce strength. Further research is a requirement in that area.

5. According to SEM results, at these ages (7 days, 14 days & 28 days) fly ash is in its original shape (Spherical). Due to that, fly ash acts as a filling material in mixture.

6. According to the comparisons between fly ash filling OPC sample & fly ash filling PLC sample, packing density is improved by different types of fine filling material with different sizes of particle size distribution than a single type of fine filling material with particle size distribution.

In accordance with the conclusion of this research, it is an extremely good solution to use fly ash as filling material in the packing optimization in ICBP mixture. The use of fly ash in ICBP helps to minimize the negative environmental impact which is generated from fly ash. However, micro structural behavior of the ICBP mixture and filling of micro voids in mixture need to be researched in advance to identify its behavior and how to further develop the properties of the ICBP mixture.

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APPENDICES

Appendix A

Packing model mix design calculation for ICBP

Combined aggregate proportion of

Quarry dust (M-sand): Natural sand: Coarse aggregate =63:27:60

Total packing density of mixture =0.774

Voids content of mixture =1-0.774 = 0.226

Volume of aggregates =0.774 cm^3

Total solid volume of aggregates = 0.63/2.62 +0.27/2.37+0.6/2.76 = 0.572 cm^3

Weight of Quarry dust = (0.774/0.572)x 0.63x1000 = 852.48 kg/m^3

Weight of Natural sand = (0.774/0.572)x 0.27x1000 = 365.35 kg/m^3

Weight of coarse aggregate = (0.774/0.572)x 0.60x1000 = 811.89 kg/m^3

Weight of Cement for void filling = 71.75 kg/m^3

Weight of Fly ash for void filling = 111.33 kg/m^3

Cement for bonding

Excess cement were added for bonding purpose

For G7 - 100 Kg/m^3 of cement,G15-200 Kg/m^3 ,G16- 250 Kg/m^3 & G20-270 Kg/m^3

After that calculation done for 12 ICBP. (9 blocks for compressive strength &3 blocks for water absorption test).

Volume of one ICBP =2.1748 $x10^6$ mm^3

Volume of 12 ICBP =2.6098 $x10^7$ mm^3

Weight of Quarry dust for 12 ICBP = 22.25 kg

Weight of Natural sand for 12 ICBP = 9.53 kg

Weight of coarse aggregate for 12 ICBP = 21.19 kg

Weight of Cement for void filling for 12 ICBP = 1.87 kg

Weight of Fly ash for void filling for 12 ICBP = 2.91 kg

Weight of binding cement for 12 ICBP= $100 x 2.6098 \times 10^{-2}$ = 26.1 kg

Weight of binding cement for 12 ICBP= $200 x 2.6098 \times 10^{-2}$ = 5.22 kg

Weight of binding cement for 12 ICBP= $250 x 2.6098 \times 10^{-2}$ = 6.52 kg

Weight of binding cement for 12 ICBP= $270 x 2.6098 \times 10^{-2}$ = 7.05 kg

Appendix B

Physical & chemical test report of fly ash

TEST RESULTS :

1. Physical Results

Test/ Unit	Test Method	Results	Specification given in BS EN 450 - 1 : 2012
Fineness / % by mass	In House Method	24	Category N :Shall not exceed 40 % and it shall not vary by more than ± 10 percentage points from the declared value Category S : Shall not exceed 12 %
Particle Density / kg/m^3	BS EN 450 -1:2012	2224	Shall not deviate by more than 200 kg/m^3 from value declared by producer
Soundness / mm		1	Shall not be greater than 10 mm
Initial Setting Time/ minutes - Fly Ash + Cement - Cement		 160 90	Shall not be more than twise of the initial setting time of a 100% (by mass) test cement paste
Water Requirement / %		97	Category N: Requirement does not apply Category S : Shall not be greater than 95% of that for the test cement alone

TEST RESULTS :

2. Chemical Results

Test/ Unit	Test Method	Results	Specification given in BS EN 450 - 1 : 2012
Loss on Ignition / % by mass	BS EN 450 -1:2012	3.7	Shall not be greater than 5.0
Silica (SiO_2) / % by mass		45.0	Sum of the content shall not be less than 70
Aluminum Oxide (Al_2O_3) / % by mass		31.8	
Iron Oxide (Fe_2O_3)/ % by mass		4.4	
Magnesium Oxide (MgO) / % by mass		1.1	Shall not be greater than 4.0
Total Calcium Oxide (CaO) */ % by mass		9.0	--
Chloride content (Cl^-) / % by mass		< 0.01	Shall not be greater than 0.10
Total Alkali equivalent as Na_2O/ % by mass		0.4	Shall not exceed 5.0
Sulphate (SO_3) / % by mass		0.5	Shall not be greater than 3.0
Reactive Silica / % by mass		11	Shall not be less than 25
Soluble P_2O_5 / mg/kg		**	

Note : * If the total content of Calcium Oxide does not exceed 10.0% by mass, the requirement for reactive calcium oxide shall be deemed to be satisfied.

** Soluble P_2O_5 of the given sample can not be determined.

Appendix C

Radio activity & TCLP heavy metal analysis test results for Fly ash

SRI LANKA ATOMIC ENERGY BOARD
Nuclear Analytical Service
Life Science Division
No: 60/460, Baseline Road,
Orugodawatte, Wellampitiya.

ilac-MRA SLAB ACCREDITED ISO/IEC: 17025 TL 012-01

Tel: 011-2533427-8, 2533449
Fax: 011-2533448

E-mail : officialmail@aeb.gov.lk
Web : www.aeb.gov.lk

AEB/ LLC / AR/02

Report No.HPGe/31-32/17

Invoice No : 3299

RESULTS OF ANALYSIS OF RADIOACTIVITY

SAMPLE TYPE	RADIO NUCLIDE ANALYSIS IN ASH SAMPLES
CLIENT	NATIONAL ENGINEERING RESEARCH AND DEVELOPMENT CENTER OF SRI LANKA INDUSTRIAL ESTATE, EKALA, JA ELA.

Your Ref.	Our Ref.	Analytical Date	Radio Nuclide	Activity (Bq/Kg)	MDA
FLY ASH	HPGe-31/17	2017/11/22	Cs-137	ND	2.0
			K-40	199.8 ± 20.9	
			Pb-210	202.0 ± 28.2	
			Ra-226	195.9 ± 18.8	
			Th-232	227.5 ± 26.2	
			U-235	24.7 ± 2.7	
BOTTOM ASH	HPGe-32/17	2017/11/21	Cs-137	ND	2.0
			K-40	189.5 ± 21.4	
			Pb-210	44.6 ± 6.9	
			Ra-226	149.6 ± 16.2	
			Th-232	168.4 ± 20.6	
			U-235	19.7 ± 2.3	

Note:
i.) Method of Analysis : Gamma Spectrometry with HPGe (High Purity Germanium Detector)
ii.) The results are only **valid** for the sample analyzed.
iii.) Sampling was carried out by the Customer.
iv.) Results are produced to the Analytical Date
v.) Receiving Date: **2017.10.17** vi.) Analytical Period : **2017.11.21-22**

Approved By .... Tested By ....
(Director/SSO/Life Science Division) (SO/TA)

Date : **2017.11.23** M.C. Shirani Seneviratne
Director
Life Sciences Division
Sri Lanka Atomic Energy Board

The results relate only to the item tested and the test report should not be reproduced except in full, without written approval of the laboratory

9

BUREAU VERITAS

TEST REPORT

Report No: (7417)255-0122A(SL) Nov 06, 2017

TEST RESULTS

TCLP Heavy Metal Analysis

Parameters	Test Results	LOQ	Requirement	Unit	Method
Arsenic (As)	ND	0.04	5	mg/L	USEPA Method 1311-- TCLP with ICP-MS
Chromium (Cr)	ND	0.04	5		
Cadmium (Cd)	ND	0.04	1		
Copper (Cu)	ND	0.06	Not Given		
Lead (Pb)	ND	0.04	5		
Manganese (Mn)	ND	0.04	Not Given		
Zinc (Zn)	98.2	-	Not Given		
Thallium (Tl)	ND	0.04	Not Given		
Selenium (Se)	ND	0.04	1		
Nickel (Ni)	ND	0.04	Not Given		
Mercury (Hg)	ND	0.007	0.2		
Barium(Ba)	ND	0.04	100		
Iron(Fe)	20.6	-	Not Given		
Silver(Ag)	ND	0.04	5		

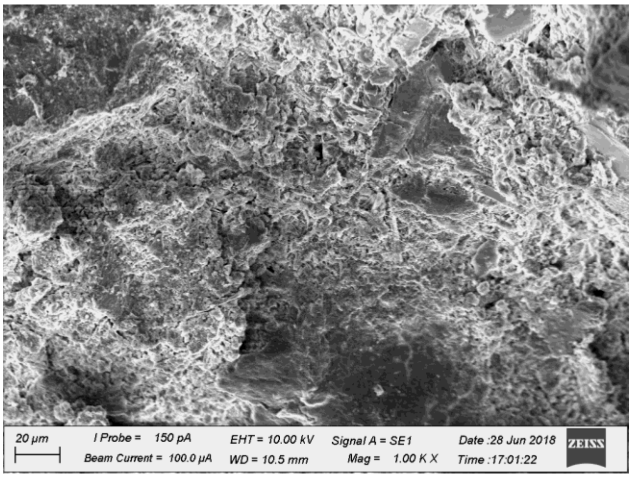
Parameters	Test Results	LOQ	Requirement	Unit	Method
Sulfite content (SO^{2-}_3)	65.6	1.0	Not Given	mg/kg	AOAC 980.02
Sulfate content (SO^{2-}_4)	81.5	1.0	Not Given	mg/kg	
Hexavalent Chromium (VI)	ND	0.4	Not Given	mg/kg	CPSD-AN-00597-MTHD
pH of 10 % (w/v) solution	10.8	-	Not Given	-	-

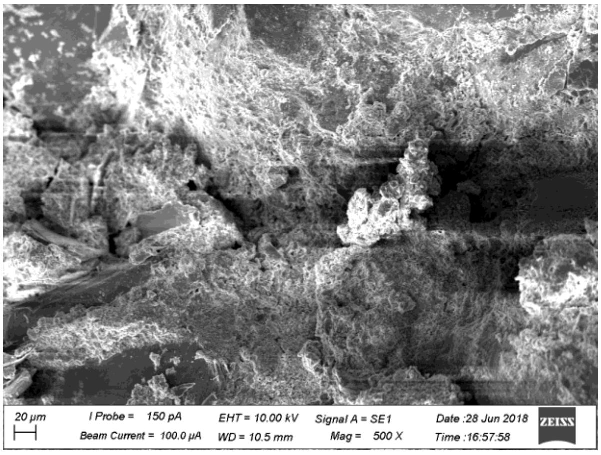
Note:
ND – Not Detected
mg/L – milligrams per Litter
TCLP-Toxicity Characteristics Leaching Procedure
ICP-MS - Inductively Coupled Plasma - Mass Spectrometry
USEPA- United States Environmental Protection Agency
LOQ- Limit of Quantification

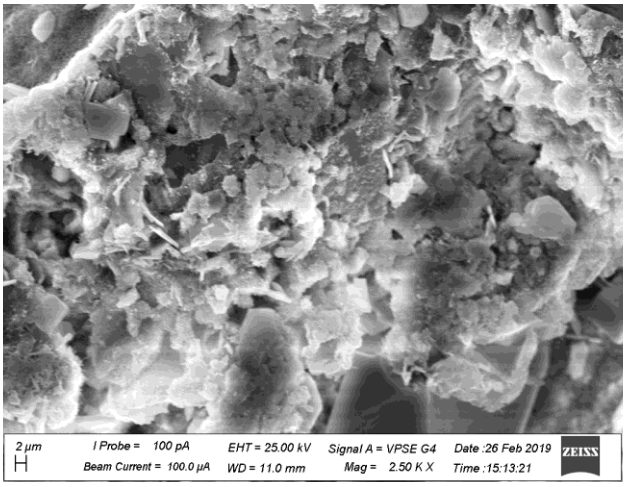
Appendix D

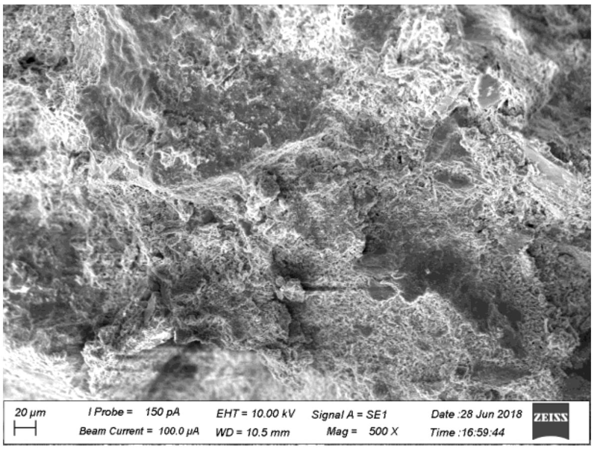
SEM test results of ICBP samples

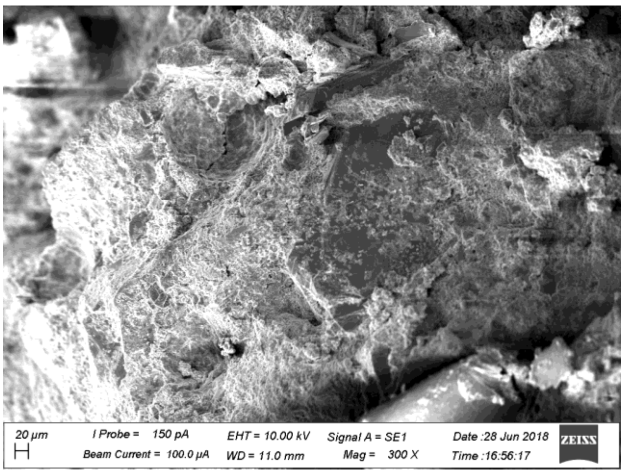
OPC cement filling ICBP samples

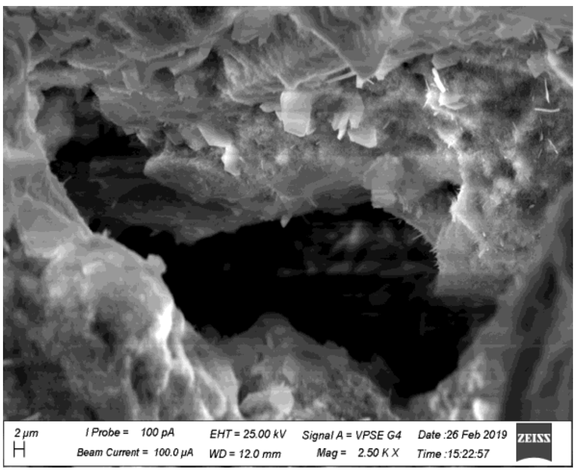


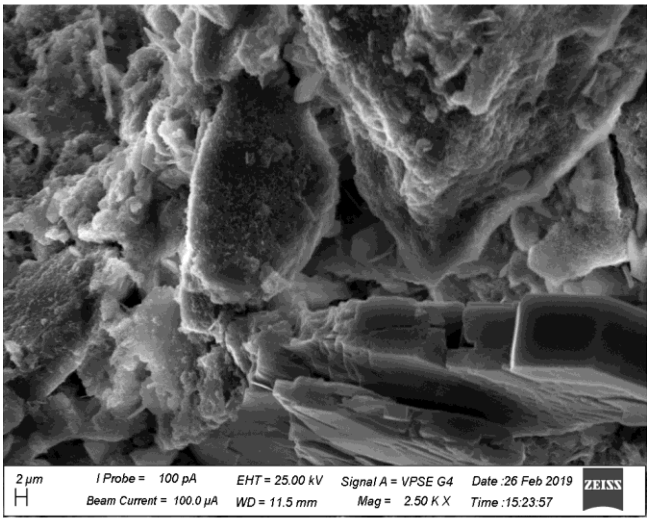


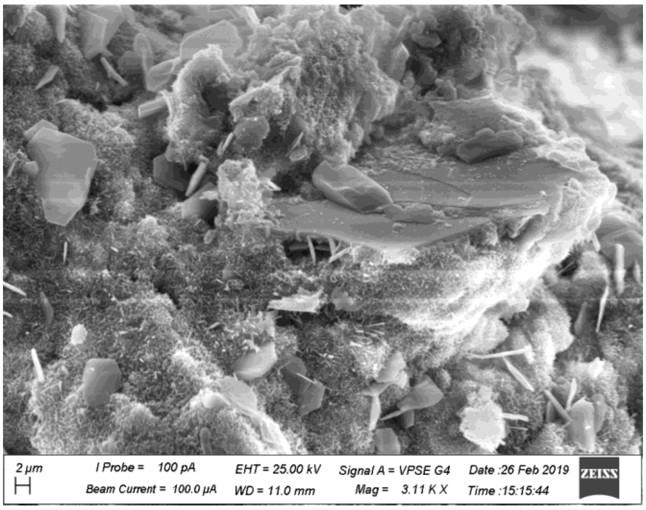


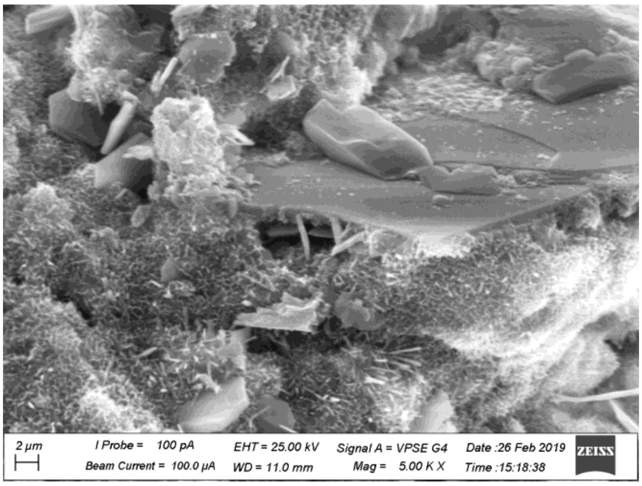


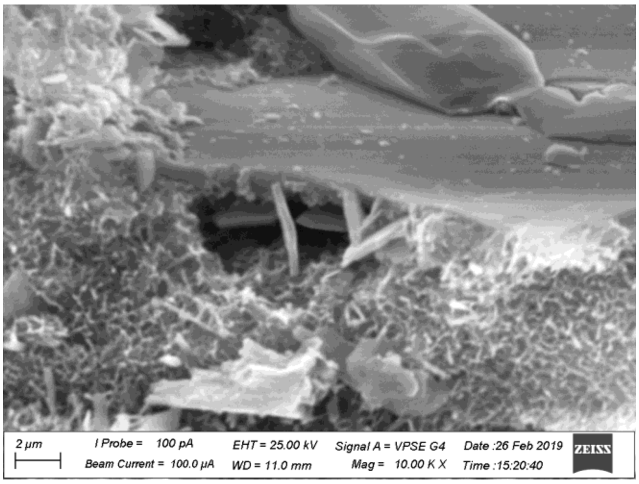




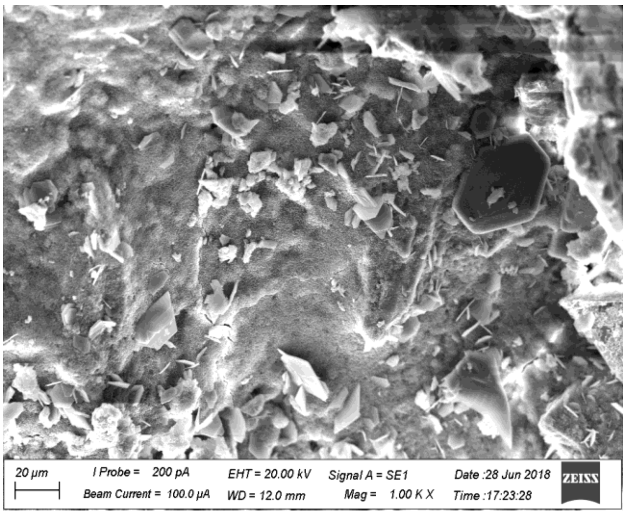


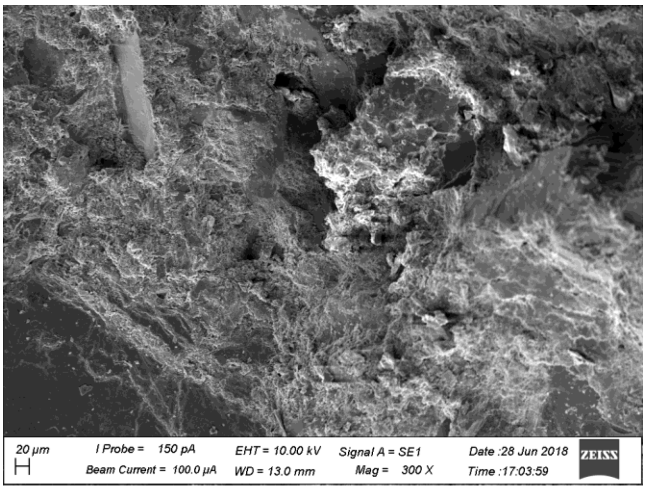


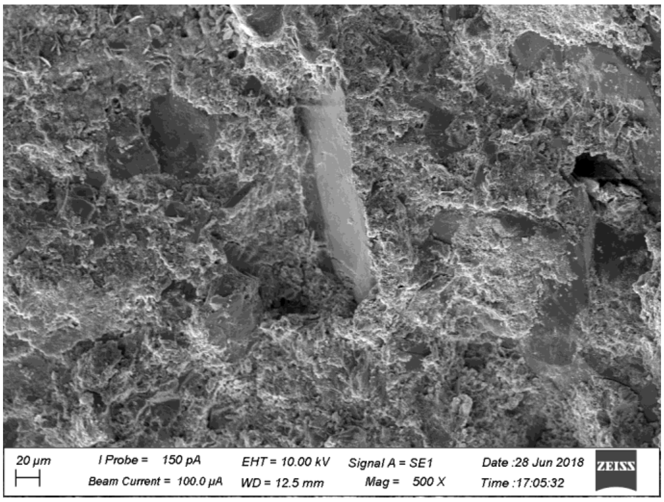




PLC cement filling ICBP sample



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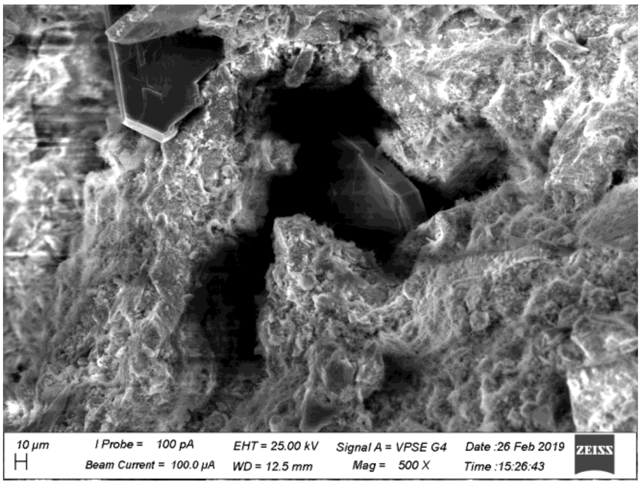
Time :17:05:32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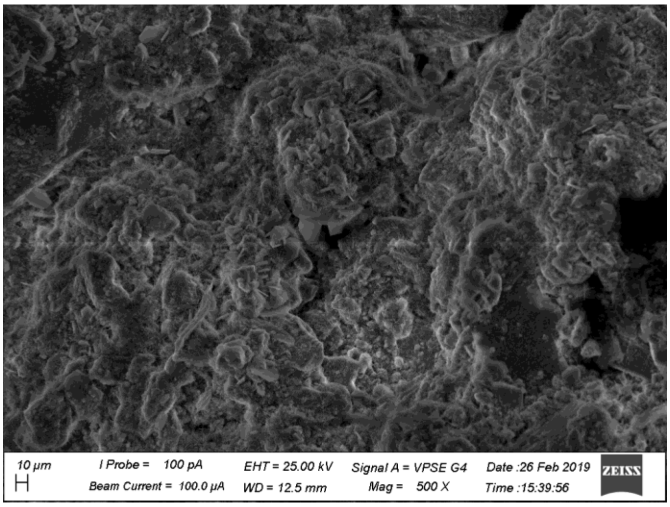
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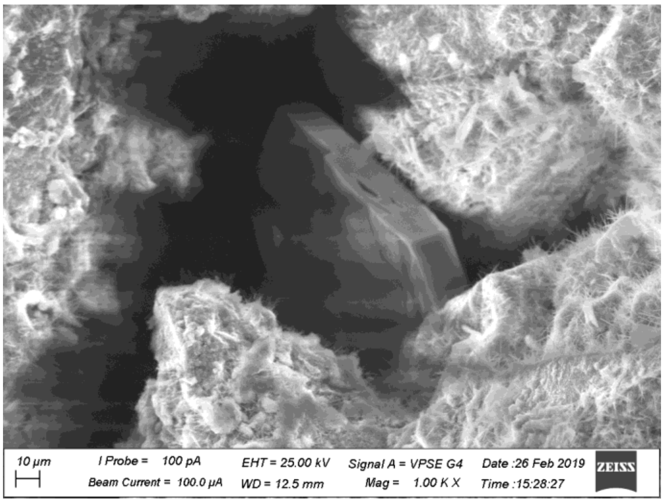
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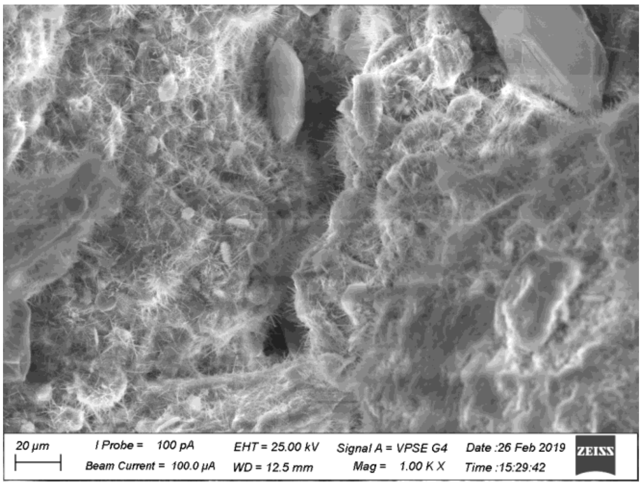
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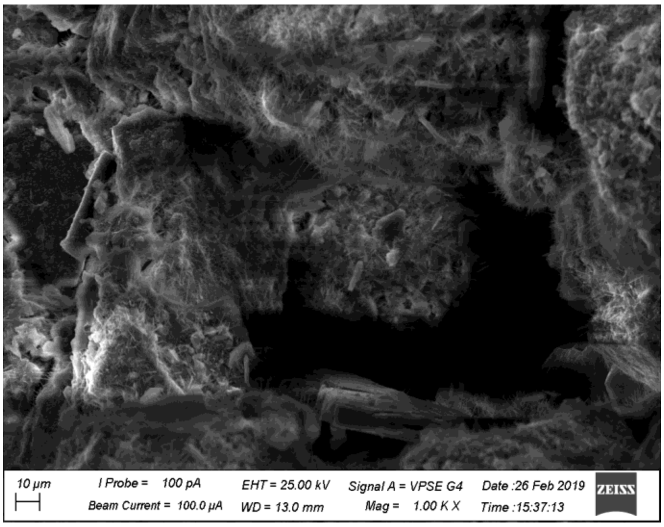
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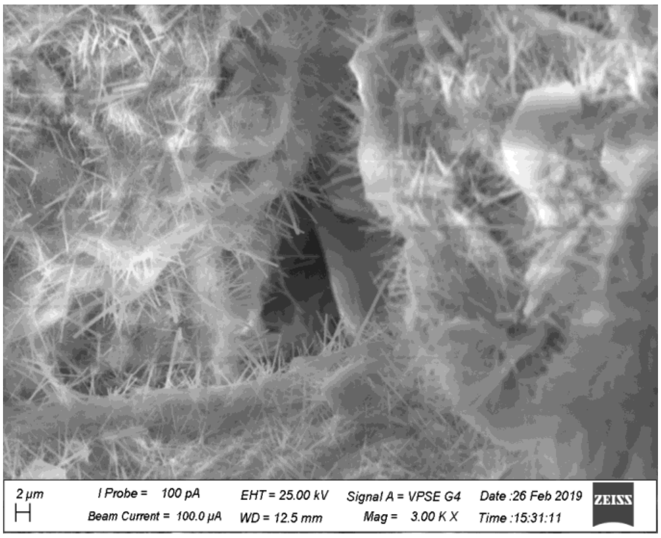
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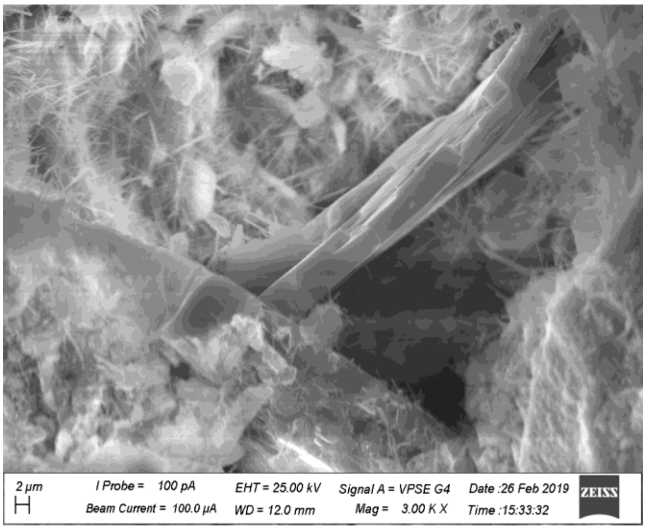
ZEISS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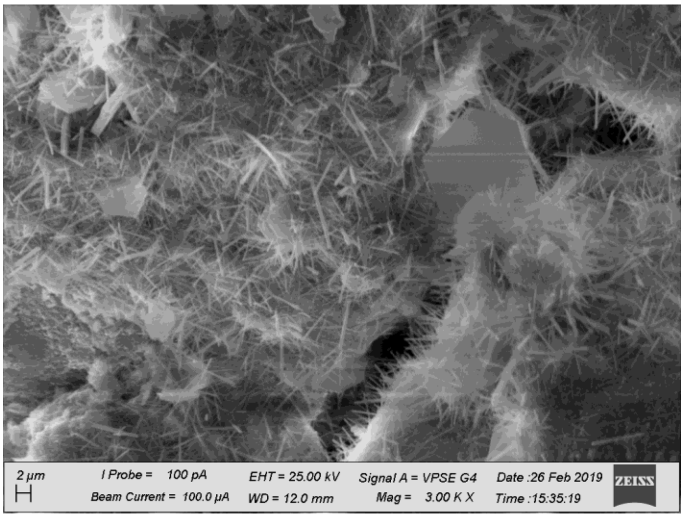
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EHT = 25.00 kV
WD = 12.0 mm
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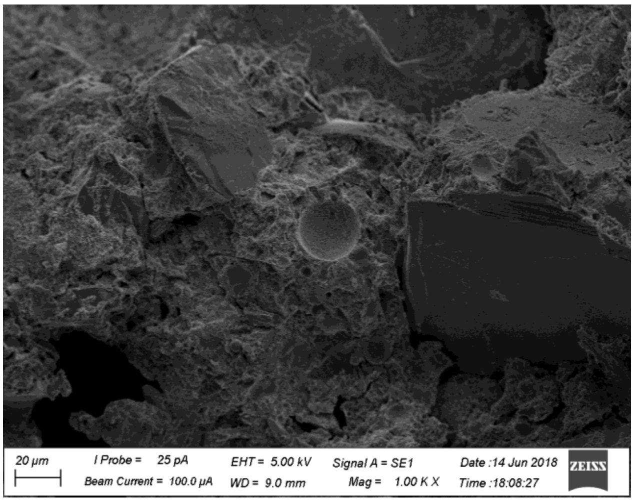
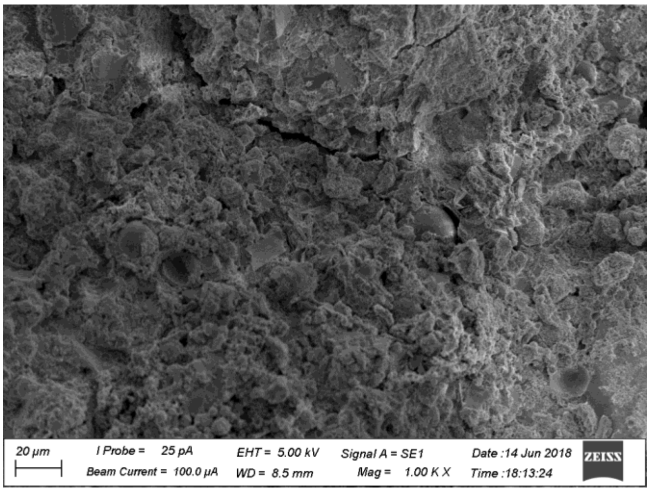
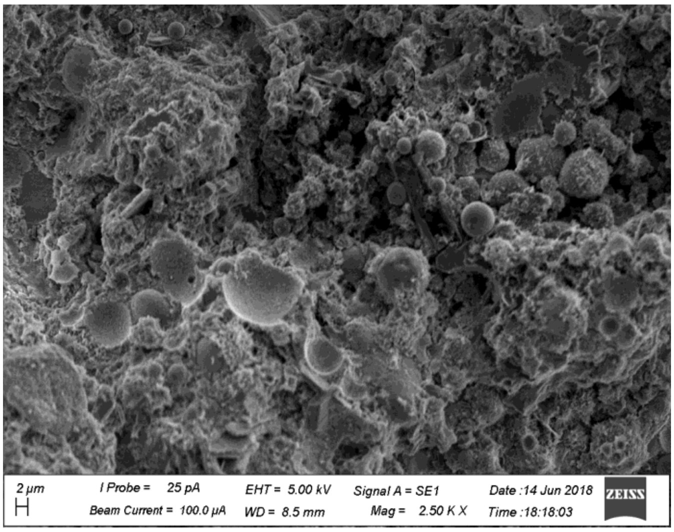
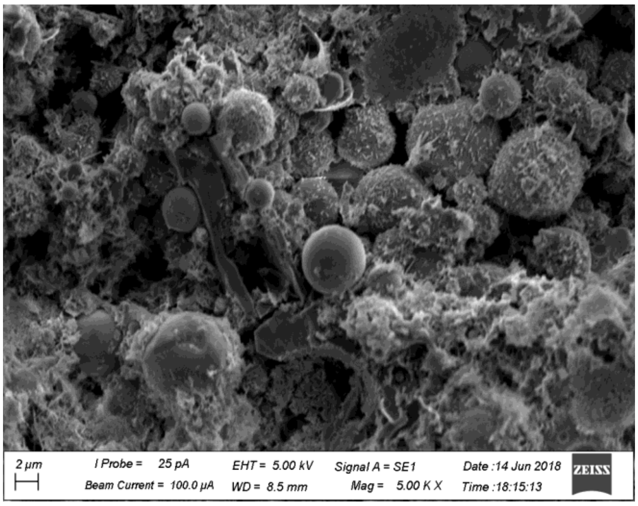
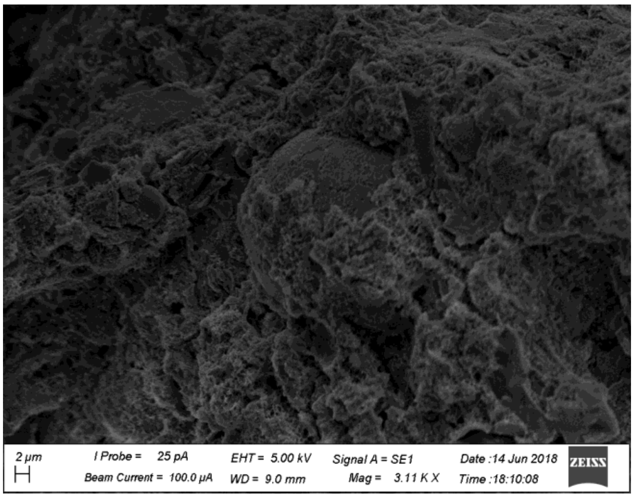
OPC fly ash filling ICBP samples

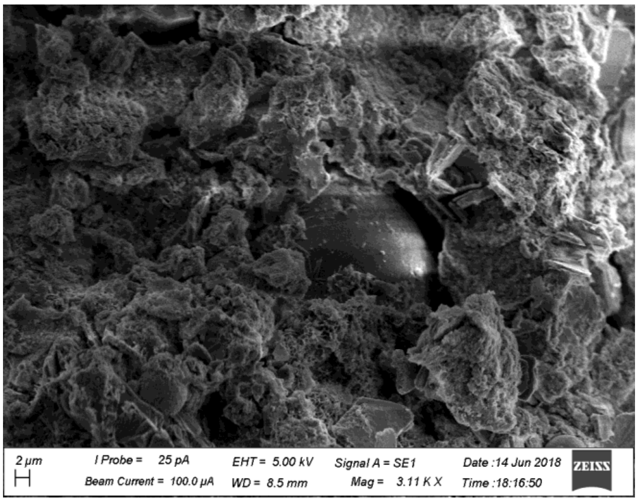


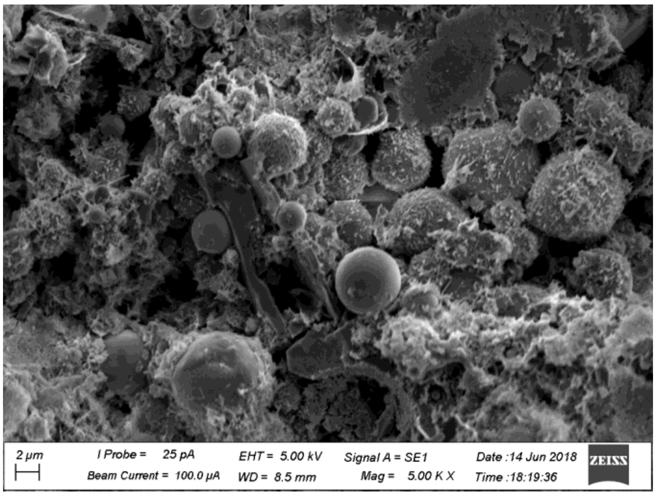


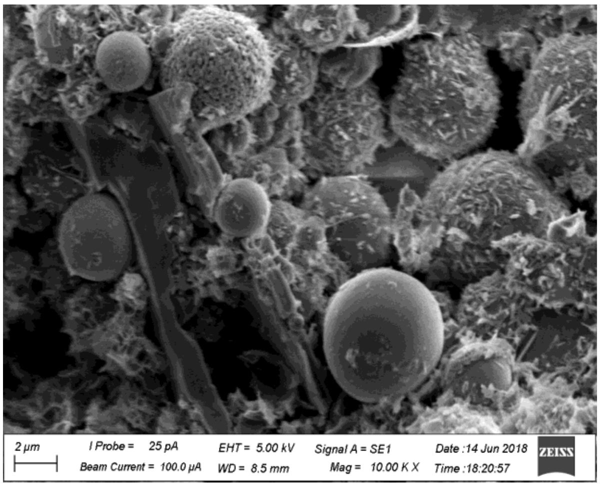




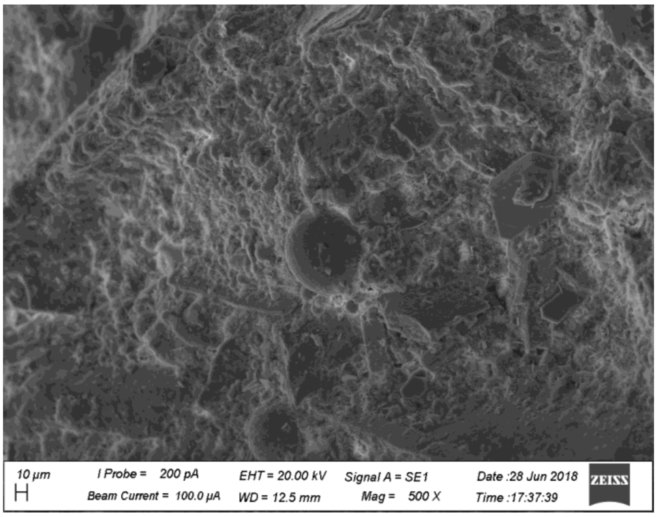


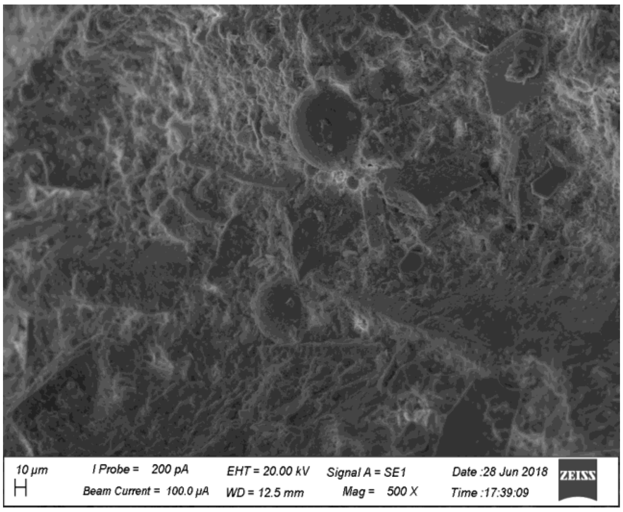


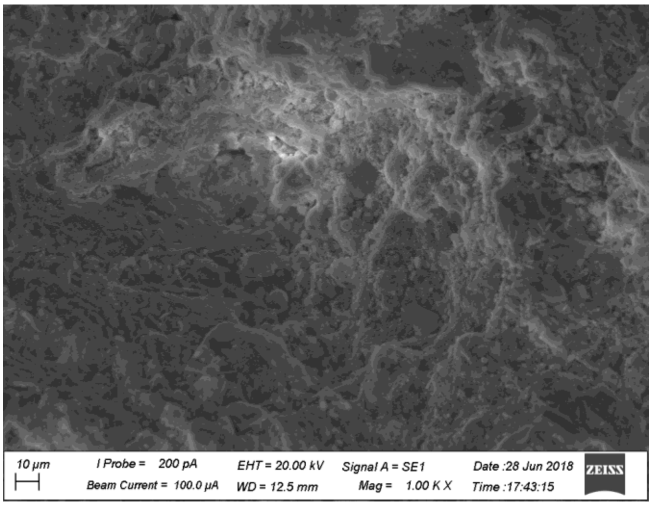




PLC fly ash filling ICBP sample






10 µm
I Probe = 200 pA
Beam Current = 100.0 µA
EHT = 20.00 kV
WD = 12.5 mm
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Mag = 1.00 K X
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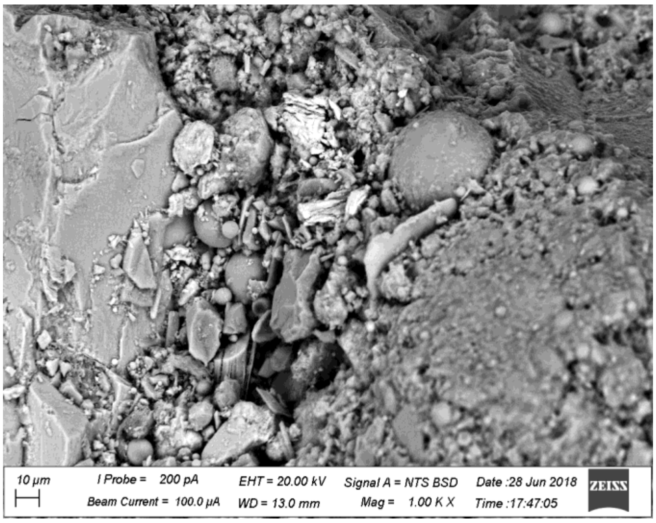
Time :17:43:15
ZEISS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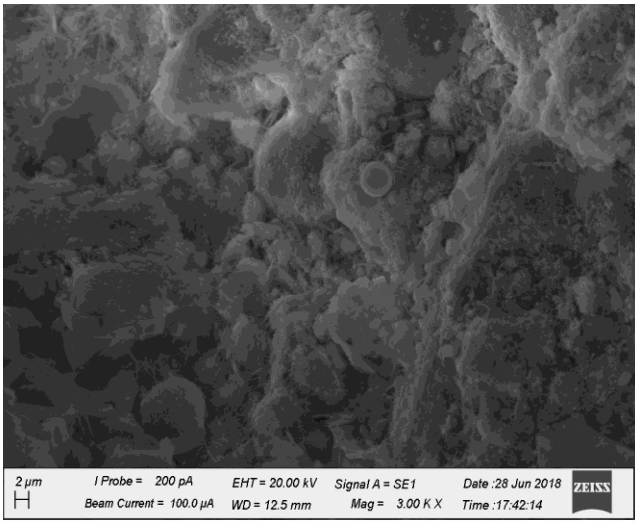
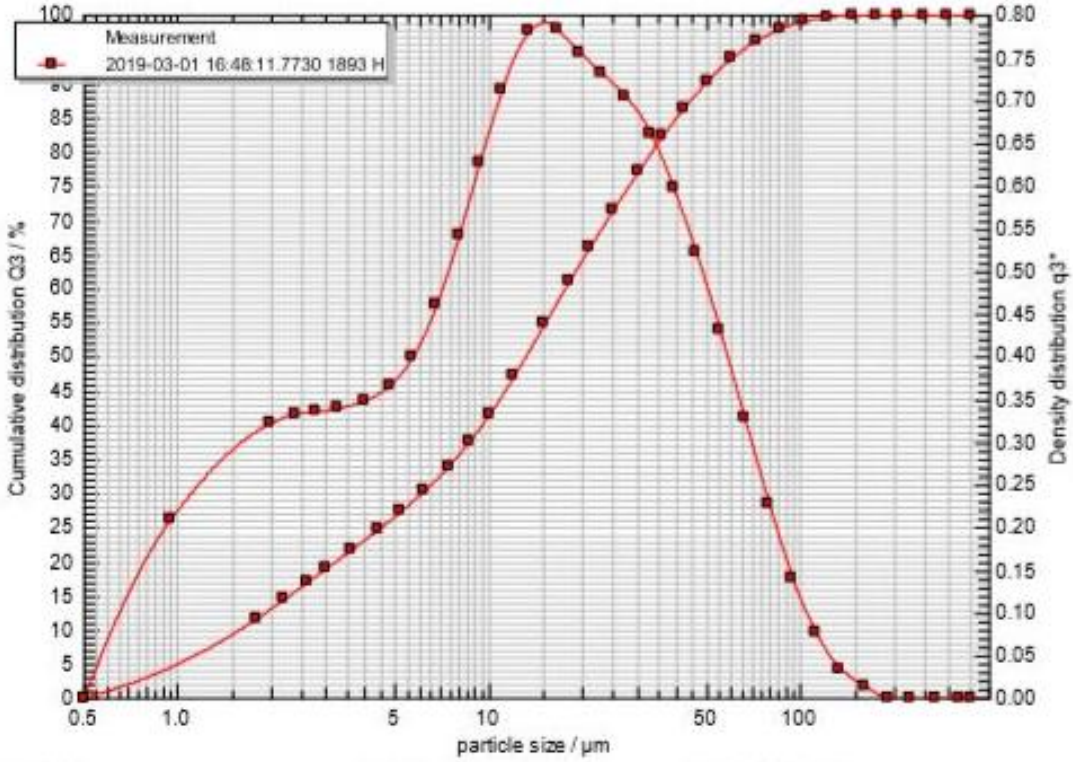

2 µm
I Probe = 200 pA
Beam Current = 100.0 µA
EHT = 20.00 kV
WD = 12.5 mm
Signal A = SE1
Mag = 3.00 K X
Date :28 Jun 2018
Time :17:42:14
ZEISS

Appendix E

Particle size analysis report of OPC, PLC &Fly ash

Particle size analysis for OPC

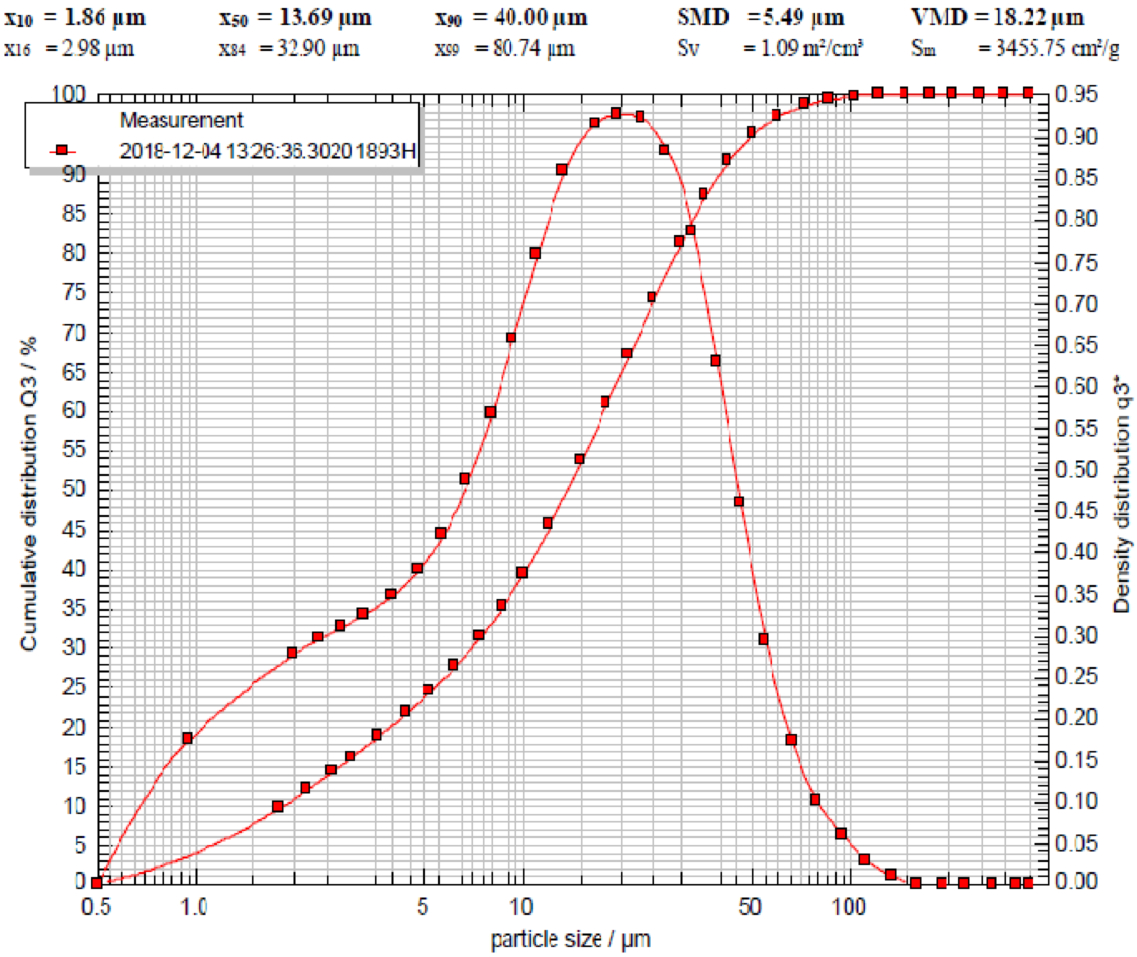
x_{10} = 1.62 µm	x_{50} = 13.13 µm	x_{90} = 49.45 µm	SMD = 5.01 µm	VMD = 20.39 µm
x_{16} = 2.46 µm	x_{84} = 38.53 µm	x_{99} = 101.17 µm	S_V = 1.20 m²/cm³	S_m = 3790.10 cm²/g



Microne	Value	Specification (%)
3 - 30	58.17	50 - 70
> 50	9.	< 25
Passing 3 Microns	18.92	< 25
42 Micron Residue %	13.69 %	< 25
45 Micron Residue%	12.20 %	
75 Micron Residue%	3.36 %	
90 Micron Residue%	1.72 %	
100% value	174.00 µm	

Particle size analysis for PLC

(A) SAMPLE -Cement



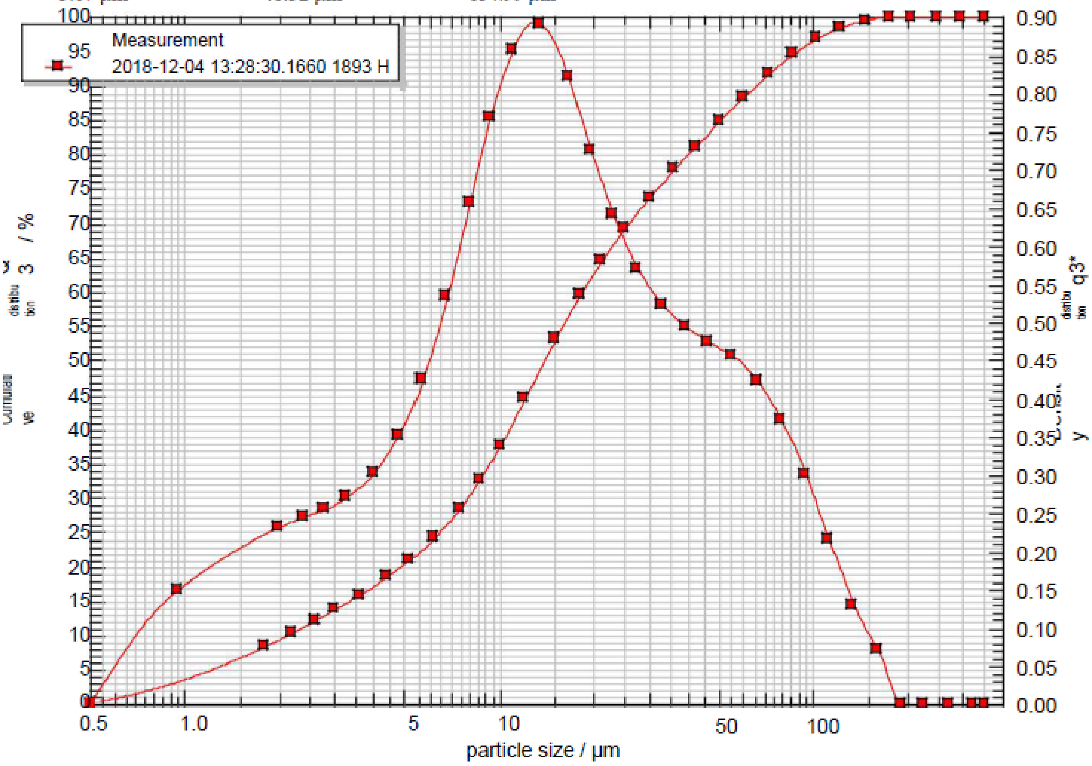
Microne	Value	
Specification (%)		
3 - 30	64.92	50 - 70
> 50	5.14	
< 25		
Passing 3 Microns	16.08	
< 25		
42 Micron Residue %	8.60 %	
< 25		
45 Micron Residue%	7.31 %	
75 Micron Residue%	1.31 %	
90 Micron Residue%	0.60 %	
100% value	146.00 µm	

Particle size analysis for Fly ash

(B) SAMPLE – Fly ash

x_{10} = 2.14 µm **x_{50} = 13.95 µm** **x_{90} = 65.89 µm** **SMD = 6.12 µm** **VMD = 25.00 µm**

x_{16} = 3.67 µm x_{84} = 48.32 µm x_{99} = 134.99 µm Sv = 0.98 m²/cm³ Sm = 3103.54 cm²/g



Microne Specification (%)	Value	
3 - 30	60.10	50 - 70
> 50	15.25	
< 25		
Passing 3 Microns	13.63	
< 25		
42 Micron Residue %	18.84 %	
< 25		
45 Micron Residue%	17.49 %	
75 Micron Residue%	7.68 %	
90 Micron Residue%	4.88 %	
100% value	174.00 µm	