INVESTIGATION OF THE SUITABILITY OF SINTERED FLY ASH AND RESERVOIR SEDIMENT MATERIALS AS A FINE AGGREGATE REPLACEMENT MATERIAL

T. Tharshigan

198059J

Degree of Master of Science

Department of Civil Engineering

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Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering

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DECLARATION

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Prof. W.K. Mampearachchi.

ABSTRACT

Fly ash is produced as a byproduct from Lakvijaya coal power plant, Sri Lanka. The daily production of fly ash at Lakvijaya power plant is 950 – 1000 tons. Around 40% of fly ash is consumed by cement manufacturers, balance of fly ash is stored without any means of disposal inside the plant. This research study discusses about development of fine aggregate replacement material using sintered coal fly ash with internal curing characteristics. A series of samples were prepared with various composition of fly ash and reservoir sediment material and sintered from 800^0C to 1300^0C temperatures in the interval of 100^0C for 30 minutes of sintering time the sintered fly ash was crushed to prepare fine aggregates. Reservoir sediment material was used as a binder material and it improved green strength of solidified fly ash. TGA – DSC and XRF analysis were used to investigate the thermal and chemical properties of raw materials, respectively. Microstructure of produced fly ash aggregate was observed using SEM photographs. Water absorption, water desorption and relative density of fine aggregate were measured. Water absorption and relative density of aggregates were in the range of 21 – 40%, 1.2 – 1.55, respectively. The aggregate with 80% of fly ash and 20% of reservoir sediment material which was heated at 1100^0C had 21.4% water absorption and 74.12% water desorption was selected as suitable replacement material instead of natural river sand. Relative density of selected fly ash aggregate was recorded as 1.46. Concrete was prepared using wetted fly ash aggregate by replacing 17.7% of natural river sand and the concrete was not subjected to external curing. Concrete with wetted fly ash aggregate gained lower strength at early stage then it gained more strength at 28 day than that of conventional concrete. Fly ash aggregate supplied internally stored water for hydration reaction of cement after finishing the free water presence inside the concrete and gave internal curing behavior to the concrete, therefore concrete with fly ash aggregate gained more strength than conventional concrete without external curing.

Keywords - coal fly ash, reservoir sediment material, sintering, fine aggregate, water desorption, internal curing concrete.

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Finally, I am grateful to the technical officer and laboratory assistants of Advance bitumen testing laboratory, construction material testing laboratory, analytical laboratory and heat treatment laboratory for providing me with the laboratory facilities and to their kind support to successfully conduct the research project.

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LIST OF ABBREVIATION

XRF – X - ray fluorescence

CFA – Coal fly ash

FAFA – Fly ash fine aggregate

RSM – Reservoir sediment material

ICC – Internal curing concrete

ECC – External curing concrete

NCC- No curing concrete

SSD – Saturated surface dry

SEM- Scanning electron microscope

TGA -Thermo gravimetric analysis

DSC- Differential Scanning Calorimeter

IRH- Internal Relative Humidity

1. CHAPTER 01- INTRODUCTION

1.1 Background

Concrete is one of the most used materials for the construction on the earth today. It is a mixture of cement, water, fine aggregate, coarse aggregate. River sand is widely used as a fine aggregate. River sand is formed by the weathering of rock. The Formation of river sand is a natural process and production of river sand from rocks takes a long time. Therefore, the quantity of available river sand is inadequate to cater the demand. Figure 1.1 shows the sand mining is being done in Maha Oya. Figure 1.2 shows erosion that has been taken place near the riverbank of Maha Oya. Erosion near the riverbank is a result of the dredging sand from the river bed. Environmental authorities are currently acting to reduce the dredging of river sand from the riverbed. If there is a limit on the use of natural river sand, other types of fine aggregates should be introduced instead of natural river sand.

Figure 1. 1 Sand mining in Maha Oya

Figure 1. 2 Eroded river bank of Maha Oya

With the development of the construction industry, Sri Lanka experiences a shortage of natural fine aggregate. Some alternative materials, such as washed sea sand, crushed sand, mining sand and manufactured sand are currently used as fine aggregate in construction industry. In sea sand the presence of chloride ion is high and it has shell particles. Therefore, sea sand affects the long-term durability of concrete structures. In mining sand, the presence of clay particle is high, and it also causes environmental impacts like collapse in land areas. Mining sand affects the strength development of concrete. Manufactured sand is produced by crushing of granite stones. It has a high percentage of fines (particle size less than 75 μm) and presence of impurities is high. The angular shape of particles adversely affects the concrete's workability.

Fly ash is a by-product of a coal-fired power plant in Lakvijaya. Lakvijaya coal-fired power plant currently meets 50% of the daily electricity demand of Sri Lanka. Ceylon Electricity Board predicts that about 84% of the power generation will be from coal-fired power plant in 2021 [1]. A portion of fly ash is collected by cement manufacturers, and the balance fly ash is stored within the plant in the district of Puttalam without any means of disposal. The monsoon wind from the Indian Ocean blows fly ash to the adjacent areas of the power plant and fly ash gets deposited on crops and houses as this power plant is located near the Indian Ocean.

Figure 1. 3 shows the crops are covered with fly ash that blows from the coal power plant. Interaction of fly ash with air and contamination of fly ash with groundwater during the rainy season create environmental and health issues in the surrounding areas of the power plant. The adverse environmental impacts are air pollution, biodiversity loss, soil contamination, groundwater pollution, reduce ecological and hydrological connectivity, surface water pollution and aesthetic degradation. Certain health hazards due to the exposure of ash contaminated air are discomfort in the eyes, asthma, breathing diseases, coughs and other environmental related diseases. So, the development of fine aggregate replacement material using treated coal fly ash will provide solutions for the fly ash disposal issue from the power plant and give an alternative material to the natural river sand in the construction industry.

Figure 1. 3 Fly ash covers the crops

Sri Lanka is in the dry zone, so it faces drought for a long period in a year. Adequate amount of water is needed to be stored for paddy cultivation. There are many irrigation reservoirs situated across the island. Due to the poor maintenance, most of the reservoirs are filled with sediment material. Potential liability of reservoir would be affected by sedimentation. Proper dredging process is required to maintain the optimum capacity of reservoir. Since reservoir sediment material has a high amount of clay content, it could not be used as filling material in construction work. While storing the sediment material near the reservoir after dredged, which washes out and returns to the reservoir again during the rainy season.

The research presented in this thesis focuses on developing of fine aggregate as an alternative material in the concrete industry with internal curing properties using sintered fly ash and reservoir sediment material.

1.2 objective

Objectives of this research study are,

- To manufacture an alternative product for fine aggregate using fly ash produced in the coal power plant.
- To verify the suitability of the product in the production of concrete.

1.3 Scope of the research

In this experimental study, an inceptive literature survey was carried out to identify the important parameters related to the production of fly ash aggregates. Thermal, physical and chemical behavior of fly ash and reservoir sediment material were investigated. Fly ash aggregates were developed using sintered fly ash with reservoir sediment material. Water absorption, water desorption, relative density, microstructure of developed fine aggregates were analyzed to select the suitable mixing composition of fly ash and reservoir sediment material and sintering temperature. Finally, concrete samples were prepared with the replacement of developed fine aggregate instead of natural river sand and carried out a comparative study with conventional concrete.

1.4 The arrangement of thesis

Report comprises of five chapters. Chapter 01 presents background, objectives and scope of the research.

Chapter 02 includes literature review of the study. This chapter discusses properties of fly ash and reservoir sediment material, production methods of fly ash aggregate, properties of the artificial aggregate, internal curing concrete, properties of internal curing concrete aggregate.

The Chapter 03 presents the methodology of this study and the Chapter 04 contains the experimental results and discussion.

Chapter 05 contains the conclusions and recommendation for future studies.

2. CHAPTER 02 – LITERATURE REVIEW

2.1 General

This chapter discusses the properties of fly ash, aggregate production methods, properties of developed fine aggregates, and internal curing concrete. It is important to note, that most of the studies were performed using various raw materials and for various types of aggregate.

2.2 Fly Ash

Fly ash is a byproduct produced from the combustion of coal in a coal power plant. During the combustion process of coal fly ash, two types of materials are produced such as fly ash and bottom ash. The production process of fly ash is shown in Figure 2.1. A part of the residue that is mixed into particles is the bottom ash. The fly ash is the component of the ash that exits from the boiler entrained in the combustion gas. Fly ash is then accumulated on either mechanical collectors or electrostatic precipitators.

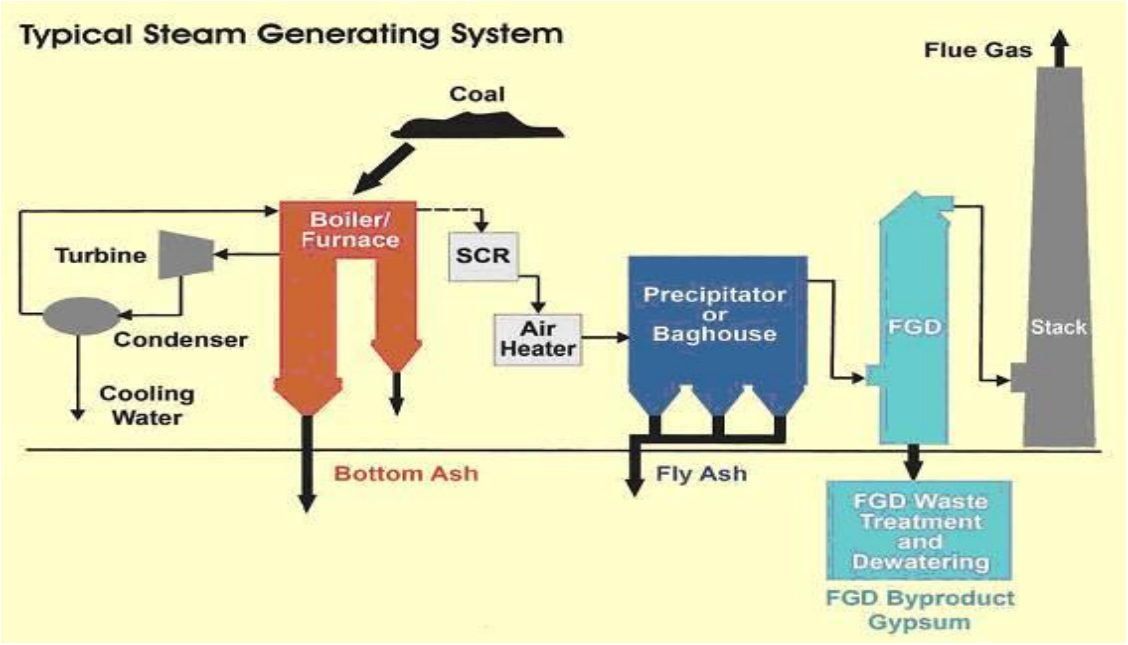

Figure 2. 1 Production of fly ash from coal power plant

There are two types of fly ash such as class C and class F. The type of fly ash is categorized according to the raw coal. Class F is derived from coal of the bituminous type and lignite type coal produces fly ash of the class C type. Class of fly ash is graded based on its chemical composition. The typical Class C and Class F fly ash chemical composition according to ASTM C618 as given in Table 1.1 The Loss on Ignition (LOI) value of fly ash class F has a higher than that of class C. Class F fly ash contains a higher amount of unburned carbon [2]

Table 2. 1 Typical composition of class C and Class F fly ash

Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	LOI
Class F	20-60	5-35	10-40	1-12	0-15
Class C	15-45	20-25	4-15	15-40	0-5

2.2.1 Disposal of fly ash

Fly ash contains poisonous chemicals and heavy metals and has tiny particles. Coal is the main resource for generating electricity in fired power plants around the world. In the world, millions of tons of fly ash are produced annually as waste material, while a limited quantity is beneficially used in the cement industry to manufacture blended cement. The remaining fly ash is used for landfilling purposes and stored without any means of disposal. For example, coal-fired power plants in Yugoslavia generated 5000 kt of fly ash per year, while only 20 kt of fly ash was used in the cement industry to make paving blocks and ready mixed concrete [3]. Fifteen countries of European Union produced approximately 44 million tons of fly ash in 2003, however 48% of that fly ash was used beneficially for landfilling purposes. United States has generated 70.8 million tons of fly ash in 2004, only 40% of fly ash was used. The remaining liberated fly ash was used for landfilling purposes [2]. About 80 million tons of fly ash is generated annually in India, with most of the fly ash produced in India endure being class F. For the manufacture of blended cement, just 10-15% of fly ash is beneficially used [4]. As India's fly ash is class F, the percentage of fly ash used for manufacturing blended cement is not significant. Fly ash stabilization is commonly used for improving soil properties of land filling materials. This could cause long-term environmental effects. The poisonous compounds and heavy metals present in fly ash contaminate the groundwater resources during rainy season. Contaminated water will be one of the consequences of human threat. The demand of energy is increasing day by day across the world with economic development. Increase in fly ash production tends to reduce landfilling sites. Many countries are spending vast sum of money on fly ash disposal than on its production. Most of the countries are searching out sustainable ways on disposal of fly ash from coal power plant.

2.3 Preparation of aggregate using coal fly ash

There are considerable experimental studies to investigate the possibility of using fly ash as replacement material for the aggregate with some treatment process. In these studies, treated fly ash is used to replace both fine aggregate as well as coarse aggregate. Fly ash particles should be agglomerated to use as aggregate. Bijen [5] have analyzed some methods to harden the agglomerated fly ash in manufacturing of artificial lightweight aggregate using coal fly ash. They are sintering, cold bonding and autoclaving. Above methods are mainly focusing on hardening of the fly ash. Production of fly ash aggregate follows the same methods which are used in the production of fired clay bricks and also the building materials.

Flow chart, which is shown in Figure 2.2 describes the procedure to manufacture aggregate using fly ash. Universally, aggregate prepared from coal fly ash is used as lightweight aggregate. Pelletization of fly ash is an important step in manufacturing of coarse aggregate, so fly ash particles should bind properly in order to increase the green strength of fly ash pellets. Prepared fly ash pellets should have proper strength otherwise, prepared pellets might get damaged while transferring to the hardening process. In the production of fine aggregate, fly ash is compacted as plates and hardened using any suitable hardening method. Hardened plates are crushed into fine sizes to produce fine aggregate.

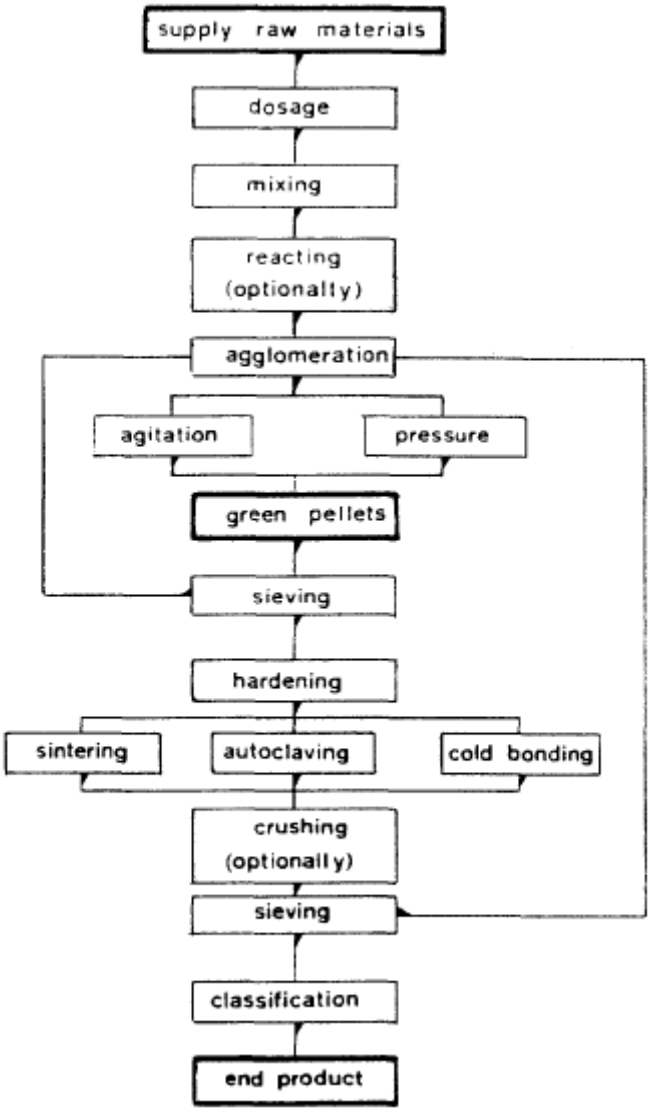

Figure 2. 2 Procedure for manufacturing of artificial fine aggregate using coal fly ash [5]

2.3.1 Selection of suitable hardening process

Bijen [5] have discussed some hardening process to manufacture fly ash fine aggregates, such as sintering, autoclaving and cold bonding.

Sintering is a thermal treatment for bonding particles into a coherent, predominantly solid structure via mass transport events that often occur on the atomic scale [6]. The purpose of this sintering is to fuse the coal fly ash particle at the point of mutual contact. Two types of sintering process are used in the development of sintered fly ash aggregate, they are rapid sintering and slow sintering [7]. Slow sintering means green samples are placed into the furnace initially and the temperature is increased at a constant rate until it reaches the required sintering temperature.

Sintering temperature is maintained for a period of soaking time. The sintered sample are allowed to cool at a constant rate until they reach room temperature. Rapid heating means, placing the green samples into the furnace after the furnace has reached the sintering temperature. Samples are maintained for a period of soaking time and then they are removed from the furnace and sintered samples are allowed to cool to room temperature under normal atmosphere. Figure 2.3 shows the phase change in particles during sintering. The paste was prepared by mixing powder material in addition with water. The prepared paste was pressurized to agglomerate the particles. At last pressurized paste was sintered to high temperature. Particles were fused together as shown in the Figure 2.3 (D). Generally, fly ash is sintered at a temperature greater than 900^0C [8]. In sintering process, fly ash particles are bonded together by material bridge bonding [5]. Figure 2.4 demonstrates the production method of sintered fly ash aggregate. Figure 2.5 depicts a graphical diagram of sintering strand.

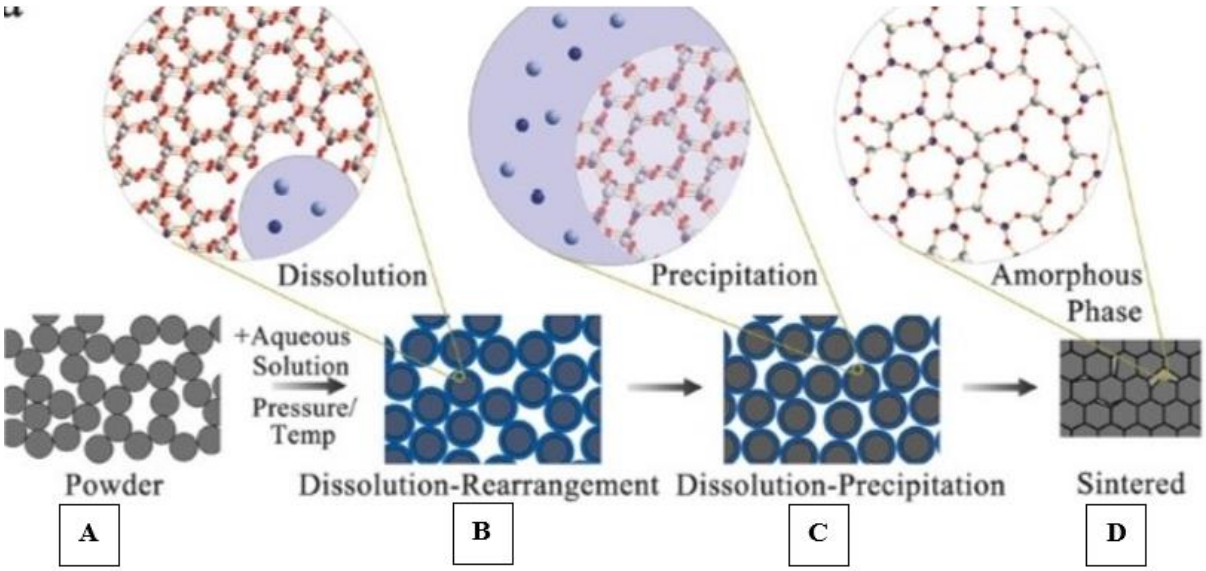

Figure 2. 3 Sintering of particles

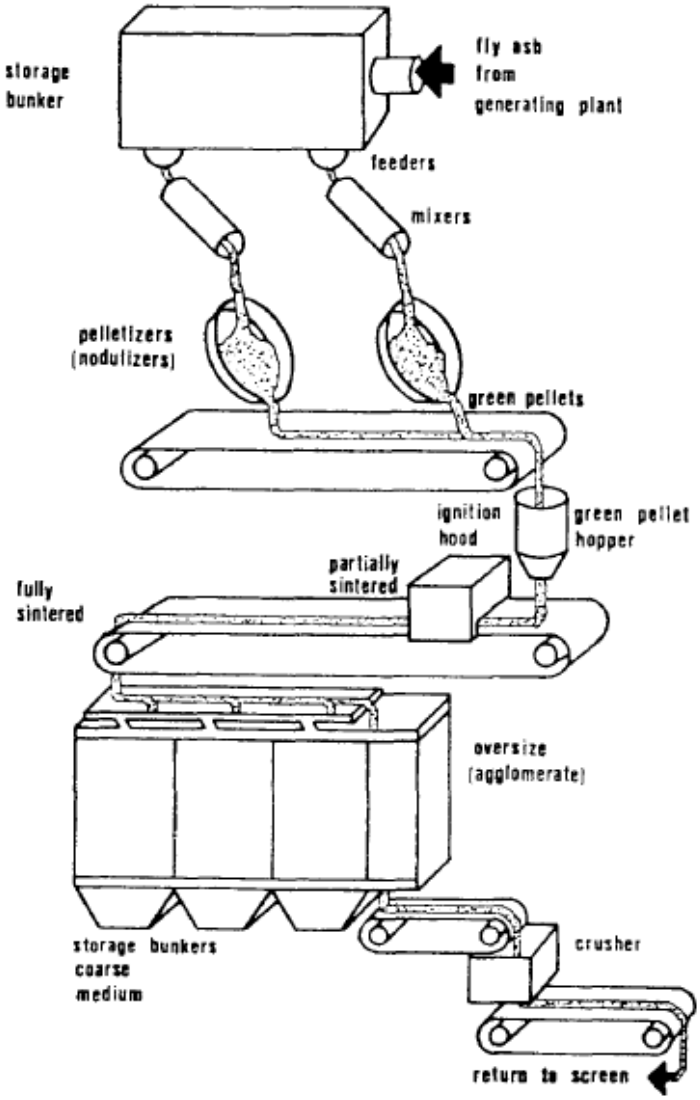

Figure 2. 4 Arrangement for sintering of coal fly ash aggregate [5]

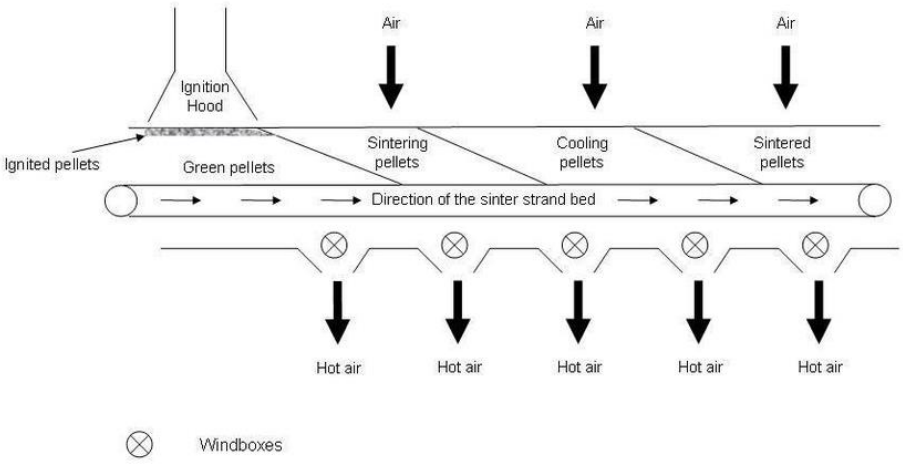

Figure 2. 5 Sintering strand [30]

Bonding between fly ash particles is achieved by the chemical reaction of Portland cement or lime with coal fly ash assorted with water in the autoclaving process. This type of process is carried out at temperature ranging from 100^0C to 250^0C. Addition of gypsum with fly ash enhances the properties of developed fly ash aggregate using autoclaving method. Quartz sand is added in this process to improve the particle size distribution of developed fine aggregate. Lime reacts with fly ash, sand, and water and forms calcium silicate hydride (CSH) during the autoclaving process. In contrast to the CSH phase in cement is hardened at room temperature. These hydrates are typically crystalline for fly ash, but these hydrates are less well crystallized than for the quartz sand. The degree of crystallinity of fly ash depends on temperature and autoclaving process time.

In the cold bonding process, two particles are bound together without the use of heat. In the cold bonding process, calcium hydroxide ($Ca(OH)_2$) available from Portland cement reacts at normal temperature with fly ash to form a water-resistant bonding material which is used to bind fly ash particles employed by matrix bonding. Further, the reaction between water resistant bonding material and fly ash forms a matrix. The key sources of calcium hydroxide are lime, Portland cement, and calcium sulphate. Alkaline compounds have a beneficial impact on the strength of produced fly ash aggregate. In this process, the temperature is maintained less than 100^0C. The hardness of fly ash aggregate developed using cold bonding methods is weaker than that of aggregates developed using sintering and autoclaving methods.

Selection of suitable hardening methods especially, mentioned above depends on the chemical composition of coal fly ash. Sintering is a suitable method for the fly ash with high carbon content while autoclaving and cold bonding are suitable methods for fly ash with low carbon content.

2.3.2 Effect of sintering of coal fly ash

Carbon and ammonia present in fly ash affect the marketability of fly ash [8]. Since fly ash has unburnt carbon, coal fly ash could not be used as a replace material in construction industry. Unburned carbon present in fly ash could reduce air entrainment in concrete which leads to the reduction of workability of concrete. Ammonia present in fly ash could create ammonia emission from concrete. Sintering of fly ash helps to remove the unburnt carbon and ammonia present in fly ash [8]. Sintering tends to change the colour and phase minerology of fly ash.

The degree of sintering of coal fly ash depends on the heating temperature, soaking time, chemical composition, and particle size of raw fly ash [3], [2]. Milling of fly ash affect the characteristics of the sintered product. Milled coal fly ash has low water absorption, low porosity after sintering, because surface area of the fly ash particle increases by milling process. Wet milling is used to wash or leach the fly ash and to remove soluble unwanted compounds like alkali metal salts [3]. Sintering of fly ash decreases the amount of gehlenite, anhydrite, glassy phase, and quartz present in fly ash and induce the formation of mullite, hematite, cristobalite and anorthite. Formation of mullite ($3Al_2O_3.2SiO_2$) is the main factor for increasing the strength of fly ash after sintering [8]. Chemical composition of raw material influences the bloating ability of them while sintering. Raw material should have the following chemical composition that falls under the range of SiO_2 48 - 70%, Al_2O_3 8 - 25% and Fe_2O_3 4.6 - 31% to have self-bloating ability while sintering [9].

Density and water absorption of sintered product can be used to measure the sintering efficiency of fly ash [2]. Density of fly ash aggregate increases with sintering temperature and soaking time. At lower temperature particles exist individually. Individual particles combine together while necks form between these particles with increasing temperature. Therefore, sintered fly ash product has higher density and lower water absorption compared with green fly ash samples. Formation of black coring may be observed in sintered fly ash product. The black core is created due to the absence of adequate air to burnout the combustible substances present in green fly ash samples. The size of the black core depends on factors, such as sample location in the furnace, the direction of air flow, the temperature of sintering, and the method of sintering. Sintered fly ash has a distinct colour change from raw fly ash which depends on the sintering temperature, soaking time, and location of sample in the furnace [2].

The thermal behavior of raw material is an important factor in the selection of sintering temperature. The differential scanning calorimetry and thermo gravimetric analysis (DSC-TGA) are used to analyze the thermal behavior of raw materials. The behavior of DSC-TGA plots illustrates a various physical-chemical process that takes place in raw material with heating temperature. TGA plot implies the mass change and the DSC plot implies the heat flow in raw material while heating. Endothermic and exothermic peaks in the DSC plot without mass change indicate the melting and crystallization process respectively. Endothermic and exothermic peaks in the DSC plot with mass loss indicate evaporation and decomposition process respectively [10].

2.3.3 Importance of binder in sintering fly ash.

Fly ash particles exist as dust and possess very low plastic character. They gain plastic character after adding some amount of water to make paste, but after drying, the fly ash particles will lose its plasticity. The development of sintered fly ash aggregate is adversely impacted by the above property transformation of fly ash. Dried solidified fly ash can split thus return to its dust stage while shifting to the ignition hood. Therefore, in the process of production of aggregate certain binders are required to enhance the green strength of solidified fly ash. In pelletizing process of fly ash, binders play an important role on improving the green strength as well as dry strength of pellets, increasing the malleability property of the fly ash, modifying the chemical composition and improving the microstructure of the developed fly ash aggregate. In general, bentonite, lime, cement and some organic substances such as sulfate liquor, tars, corn syrup, borax pentahydrate and alkali substances are used to synthesize sintered fly ash aggregate in aggregate industry [11], [2], [12]. Binder type and dosage are the important parameters for the selection of binders for sintered fly ash aggregate development. Ramamurthy et al. [13] have studied the effect of the binders that results on the properties of sintered fly ash coarse aggregate. In this study, bentonite was used as a binder and 20 % of bentonite improved ten percent fine value as well as decreased the water absorption of the developed fly ash coarse aggregate.

2.4 Reservoir sediment material

Reservoir sediment material is one of the waste materials available in the country which is dredged from the reservoir. Irrigation reservoirs are situated around Sri Lanka to irrigate paddy fields in the dry zone of the country. In ancient times, reservoirs were constructed in the dry zone to overcome the effect of drought as the dry zone of the country experiences a long period of drought over the year. Currently, most of the irrigation reservoirs could not meet its optimal capacity due to sedimentation in reservoir. Soil erosion in catchment areas is the main reason for sedimentation in reservoir. So, proper dredging process is required periodically to maintain the optimum capacity of reservoir.

2.4.1 Availability of reservoir sediment material in Sri Lanka

A research study has been done by Dharmasena [14] to determine the amount of sedimentation in irrigation reservoirs in Sri Lanka. For this purpose, he has selected Marikaragama and Paindikulama tanks located in Anuradhapura district. He has determined the amount of sedimentation, the rate of sedimentation and the life index of the above tanks. Dharmasena

[14] has stated that Sedimentation in the above tanks covered about 23 to 35% of its total storage. Sedimentation in tanks decreases its storage capacity, that intends to reduce the area for cultivation in dry zone. Rate of sedimentation of Paindikulama tank was stated as 6000 m^3/km^2/year in the time period between 1984 and 1990 and, the rate of sedimentation of Marikaragama tank was stated as 3170 m^3/km^2/year in the period between 1986 and 1990. Tank life index means the time taken to fill the total capacity of tank compared to the present rate of sedimentation. The tank life index of *Marikaragama* and *Paindikulama* tanks was stated as 35 and 150 years respectively. Particle distribution of sediment collected from the above tanks indicates that most part of the sediment materials are clay particles.

2.4.2 Disposal of reservoir sediment material

Some research studies were conducted in Sri Lanka to verify the suitability of reservoir sediment material to use as a filling material in road construction. Nawagamuwa et al. [15] have done an experimental study to verify the suitability of deposit from the irrigation reservoir in Angunakolapelessa, Hambantota district to use it in the embankment construction. Sediment material contains a higher percentage of silt and clay. Dredged material which is stored nearby the reservoirs causes the formation of sedimentation in tanks during rainy seasons, because of the sediment material that washes out and returns to the water bodies. So, it is necessary to dispose the dredged material away from the catchment area. Nawagamuwa et al. examined the properties of sediment materials to use as an alternative material in embankment construction. According to the proctor compaction test result, reservoir sediment material has low maximum dry density and high optimum moisture content, therefore sediment material cannot be recommended for embankment construction. Finally, they recommended that packed sediment material can be used as erosion barrier.

Artificial lightweight aggregates are produced using sintered reservoir sediment materials. Tang et al. [10] have done an experimental study to investigate the properties of sintered lightweight aggregate using sediment material dredged from the Shihmen reservoir in Taiwan. The reservoir sediment material has a higher amount of organic compound. These organic compounds burnout and form cavities in aggregate due to the emerging gases during sintering of sediment material. Formed cavities help to lose the weight of aggregate. Figure 2.6 shows the SEM view of sintered lightweight aggregate using reservoir sediment material. There are plenty of voids in the sintered lightweight aggregate. Dredged sediment material has essential compounds that facilitate the bloating and calcining process in sintering kiln. Sediment

lightweight aggregate was utilized as coarse aggregate in this study. The use of dredged sediment material to develop lightweight aggregate gives technical, environmental as well as social benefits.

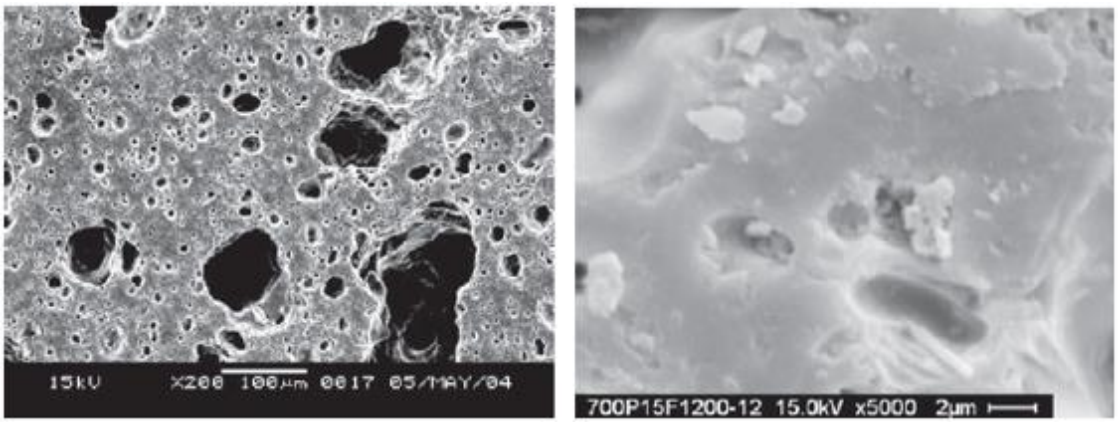

Figure 2. 6 SEM view of the sintered light weight aggregate [10]

Hwang et al. [16] have done an experimental study to develop and investigate the properties of lightweight aggregate using municipal solid waste incinerator fly ash with reservoir sediment material. According to the experimental result, lightweight aggregates can be developed by mixing 30% of municipal solid waste incinerator fly ash and 70% of reservoir sediment material. The use of reservoir sediment material helps to minimize the amount of fly ash and the presence of heavy metal in developed light weight aggregate.

2.5 Curing of concrete

After pouring concrete, it is necessary to supply free water to the concrete structure to enhance the hydration reaction. A significant volume of water contained in concrete is lost due to sunlight and heat generated by the hydration reaction of cement. The supply of water to concrete is called curing. In general, two types of curing methods are used to enhance the hydration reaction in the construction industry. They are external (conventional) curing and internal curing.

External curing is the process where water is sprayed to the surface of concrete structure after casting. The amount of water penetrated into concrete is restricted in this process. Thus, results to cease the hydration reaction of cement so, that a certain depth of concrete gets hardened, External curing process cannot supply extra water to the interior of the concrete structure to maintain the moisture level. Therefore, efficiency of hydration reaction decreases beyond the several millimeters depth from the surface of concrete structure due to insufficient amount of water [17]. This will affect the strength gaining of concrete and ends up with shrinkage cracks.

2.5.1 Internal curing concrete

Internal curing method is subjected by supplying water to concrete using pre-wetted aggregate or by using internal sealing method for the purpose of hydration reaction in concrete. The American Concrete Institute (ACI) defined internal curing as "supplying water throughout a freshly placed cementitious mixture using reservoirs, via pre-wetted lightweight aggregates, that readily release water as needed for hydration or to replace moisture lost through evaporation or self-desiccation". Figure 2.7 illustrates the difference between internal curing and external curing methods. For the motive of internal curing, pre-wetted aggregates are added into concrete while mixing. Initially, free water present in concrete is used for hydration reaction of cement. After the reduction of free water present in concrete, water which is absorbed by the pre-wetted aggregate is supplied for the hydration reaction of cement. Therefore, water is available for the hydration reaction of un-hydrated cement in concrete. Pre-wetted aggregates which are in the form of fine aggregate are uniformly distributed in concrete is shown in Figure 2.7. Commonly Bentonite clay, superabsorbent polymers, pumice, perlite, expanded shales, expanded slates, expanded clays are used as internal curing aggregates in the world. Internal sealing is a technique which is used to prevent water loss from the concrete surface using special curing agents in concrete mixture. Dhir et al. [18] have done an experimental study to investigated the feasibility of developing the self-curing concrete by adding some chemicals. Some of the chemicals helped to reduce water loss from the concrete structure that improved the degree of hydration of cement as well as aided to improvise the strength gaining of concrete.

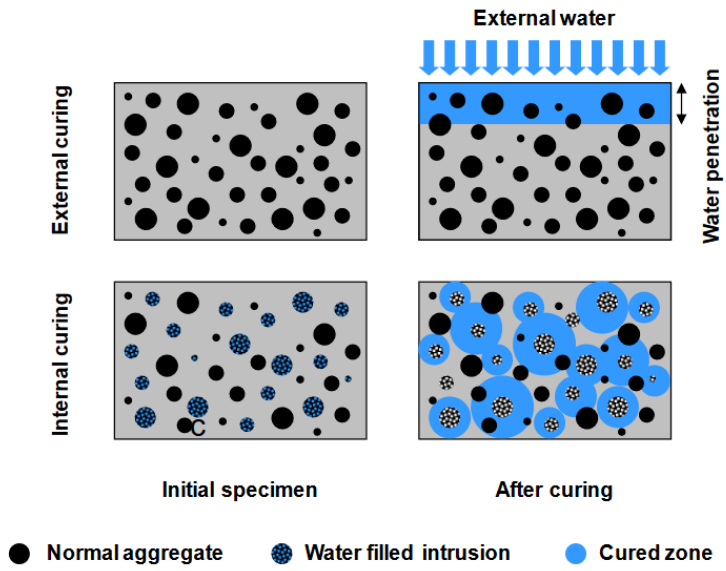

Figure 2. 7 Difference between internal curing and external curing [17]

2.5.2 Characteristics of internal curing aggregate

Efficiency of internal curing method depends on water absorption, water desorption microstructure [19], [20] ,spatial distribution [21] of internal curing aggregate in concrete. The internal curing aggregate should have the ability to absorb water. Holm et al. [22] has reported that the water absorption of the internal curing aggregate should be between 5% and 25% of the dry weight of the aggregate. Castro et al. [21] observed typical 24-hour water absorption values of expanded slates, expanded shales and expanded clays that vary between 6% - 12%, 10% - 20% & 15% - 31% respectively. Internal curing concrete aggregate should have the ability to release the absorbed water after lowering the humidity inside the concrete which is called as desorption of pre-wetted aggregate.

Internal curing aggregates should have open pores to store free water and these pores should be interconnected. Interconnected pores help in the flow of stored water from aggregate to concrete. Jensen et al. [19] have stated that each pore size of aggregate should be greater than 100 nm, to store internal curing water. Water which is stored in tiny pores cannot be released by the surface tension effect. Water which is stored in pores less than 100 nm is not useful for the internal curing of concrete. Aggregates with larger porosity have high degree of water absorption rate. Isolated pores present in aggregate do not take part in the water absorption process [23].

The distribution of pre-wetted aggregate is also an important thing in internal curing concrete. The spatial distribution of pre-wetted aggregates improves the efficiency of internal curing concrete. Fine aggregates are more favorable than coarse aggregates to use as an internal curing aggregate because fine aggregates strengthen the spatial distribution of water reservoirs in internal curing concrete.

2.5.3 Use of pre-wetted aggregates in internal curing concrete

Pores present in lightweight aggregates and artificial sintered aggregates have the ability to store water. Pre-wetted lightweight aggregates and sintered aggregates act as internal water reservoir in internal curing concrete. Bandara et al. [23] has developed sintered red clay chips as an internal curing agent and used pre-wetted sintered clay chips to improve the properties of internal curing concrete. A suitable sintering temperature was selected by analysing the water absorption, water desorption and the pore distribution of sintered clay chips heated at various temperatures to prepare sintered red clay aggregates with the internal curing characteristics. Red clay chips which were sintered at 900^0C, were selected as a fine aggregate replacement

material with internal curing characteristics instead of natural river sand in concrete. Pre-wetted sintered clay chips were used as internal water reservoir in internal curing concrete. 14.60%, 16.00% and 17.20% of natural river sand were replaced by prewetted sintered clay chips in grade 25, grade 30 and grade 35 concrete mixtures respectively. Workability and the water-cement ratio of internal curing concrete were studied in order to develop a high strength internal curing concrete. It was developed by reducing the water-cement ratio of internal curing concrete ICC. The slump value of ICC was higher than that of conventional concrete (external curing concrete), but both of these concrete mixtures had approximately equal compressive strength at 28 days. Internal curing concrete with higher compressive strength was achieved by slightly lowering the water-cement ratio than that of internal curing concrete and external curing concrete with designed water-cement ratio while maintaining the same workability as well as the same cement content.

Shen et al. [24] has done an experimental study to investigate the influence of pre-wetted lightweight aggregate (LWA) on the properties and cracking potential of internal curing concrete by replacing the normal weight coarse aggregate (10%, 30% & 50% of the total volume of coarse aggregate were replaced by pre-wetted LWA). Increasing the amount of pre-wetted LWA give rise to the increasing temperature in concrete, because degree of hydration reaction increases with increasing amount of pre-wetted LWA. Autogenous shrinkage, tensile stress rate and cracking stress decreases with increasing amount of pre-wetted LWA. Therefore, pre-wetted LWA are useful to reduce the cracks formation in mass concrete. Microstructure of cementitious paste become denser and stronger with the increasing amount of pre-wetted LWA. Internal cured water increases the tensile strength of concrete and provides the ability to resist the creep in concrete by improving the hydration reaction of cement. Cracking potential of internal curing concrete decreases with increasing amount of pre-wetted LWA through decreasing the ratio of cracking stress to tensile strength.

While increasing the amount of pre-wetted aggregate in concrete, the internal relative humidity (IRH) of internal curing concrete increases at 28 days of casting as well as the decreasing rate of IRH of internal curing concrete decreases. Reduction in IRH induces crack formation in high performance concrete. Use of pre-wetted aggregate improves the cracking resistance of concrete [25]. Use of pre-wetted LWA as a replacement material instead of natural river sand helps to reduce plastic shrinkage cracks and settlements in concrete structure [26]. Pre-wetted aggregates have the ability to supply water for hydration reaction of cement. Thereby this results in strength gaining of concrete that cannot be limited by the moisture loss from the

concrete structure in addition the amount of un-hydrated cement will be reduced in concrete [27].

2.6 Determination of saturated surface dry weight of fine aggregate

Water absorption and water desorption of aggregate are essential parameters which affect the efficiency of internal curing concrete. In assessing the water absorption and water desorption of internal curing concrete aggregate, calculation of the saturated surface dry (SSD) weight of the aggregate is a significant step. In general, the sand cone method and paper towel method are used to caculate the saturated surface dry weight [21]. The selection of the effective method for SSD weight determination depends on the characteristics of the surface of the aggregate.

The research protocol for the paper towel method to achieve saturated surface dry fine aggregate was explained by the Department of Transportation, New York State [21]. Some amount of fine aggregates is taken and then soaked in water for 24 hours then finally aggregates were removed from water. Soaked aggregate is spread over the paper towel and the paper towel picks up the moisture that exists on the surface of the aggregate, then this step is repeated by changing the paper towel until no moisture is picked by the paper towel to achieve saturated surface dry aggregate. The paper towel method is the most suitable method for determining the SSD weight of the crushed aggregate.

The sand cone method is another method that is used to determine the saturated surface dry weight of the fine aggregate. Aggregates are soaked in water for 24 hours and water is decanted from the aggregate. Moisture present in the surface of the soaked aggregate is removed using a drier. The metal conical mold is filled into three layers with dried aggregate and each layer is tamped 25 times, then the metal cone is slowly lifted. The condition of the aggregate is decided based on the remaining shape of aggregate pile after the removal of cone. If aggregate pile remains in conical shape, it notifies that some amount of moisture is still present in the surface of aggregate. If the fine aggregate slumps slightly without free moisture on the sample, it specifies that aggregate has achieved saturated surface dry stage. If aggregate pile collapses from the conical shape it shows that aggregates are over dried. This type of method is most suitable for granular aggregate. Although the aggregate has achieved the state of saturated surface dry, but crushed aggregate may remain in conical shape due to the interlocking between crushed aggregate.

2.7 Water desorption of fine aggregate

Water desorption is one of the important parameters for internal curing aggregate. Water desorption capacity means the percentage of absorbed water released from saturated surface dry aggregate. Water desorption is affected by the relative humidity of the environment and the type of aggregate. According to ASTM C1761, water desorption capacity of the internal curing aggregate should be determined at 94% of humidity. Saturated solution of salt can be used to maintain the specific humidity value in a chamber. Paul et al. [28] reported that saturated solution of KNO_3 and K_2SO_4 are used to maintain 93% and 97% of humidity at 23^0C, respectively.

Initially, saturated surface dry aggregate should be taken using sand cone method or paper towel method. Chamber is arranged in a way to maintain the specific humidity with saturated solution of salt. Saturated surface dried aggregate is placed into the chamber as shown in Figure 2.8 and weigh the aggregate for every 4 hours in the first day and continue to weigh the measurement in a proper time interval for 28 days. Then place the aggregates into an oven after 28 days to get dry weight of fine aggregates. So, the water desorption capacity can be calculated from the weight measurements obtained as a percentage of absorbed water.

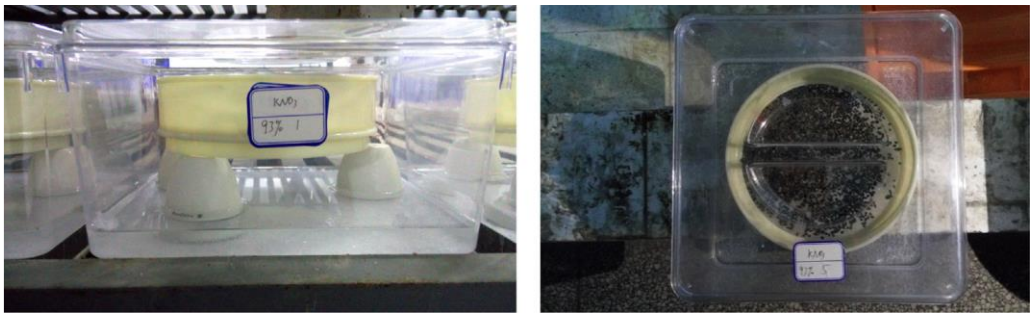

Figure 2. 8 Arrangement for the water desorption test

2.8 Summary

According to the previous studies, aggregates which were prepared by pelletizing the fly ash were used as a coarse aggregate in concrete industry. Sintering, cold bonding and autoclaving methods were used to agglomerate fly ash particles. Selection of the agglomerating process depends on the characteristics of raw fly ash. Sintering is the suitable method for fly ash with high carbon content. Sintering process not only helps for agglomerating the fly ash but also on the removal of unburnt carbon from fly ash. Binder takes an important role in the production of fly ash aggregate to enhance the green strength of solidified fly ash. Artificial binders and

natural materials which possess plastic character can be used to improve green strength of solidified fly ash. Reservoir sediment material is one of the easily available waste materials and which have high plastic characteristics.

Curing is an important process to improve the strength gaining of concrete after casting. Internal and external curing can be done for concrete. Internal curing is more efficient than the external curing because, internal curing mitigates shrinkage cracks and improves hydration reaction of cement. Internal curing can be subjected to concrete using pre-wetted aggregate or internal sealing method. The success of internal curing depends on water absorption, water desorption and microstructure of pre-wetted aggregate.

3. CHAPTER 03 - METHODOLOGY

3.1 General

Research methodology is included in this chapter. Overview of this research methodology is demonstrated in Figure 3.1. Laboratory experiments were carried out to identify the proper mixing composition of fly ash and reservoir sediment material and the sintering temperature. Laboratory furnace was used for this purpose. A commercial furnace from Lanka Refractories in Paduka was used for sintering to produce fine aggregate with the identified mixing composition and sintering temperature for concrete mix design using fly ash aggregate.

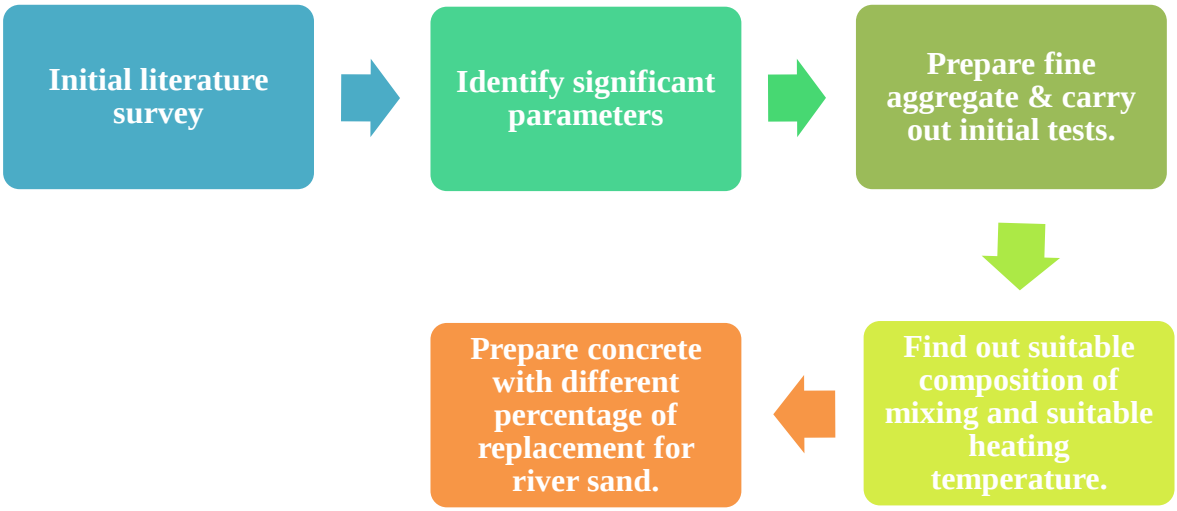

Figure 3. 1 Overview of research methodology

In order to develop the basic concepts of this study and to evaluate the research gap, the previous studies applicable to this research were investigated. Literature review of this study is given in chapter 2. Identified significance parameters of this research study are divided into three sections, (1) raw materials, (2) fly ash aggregate and (3) concrete. Identified parameters are listed in Figure 3.2.

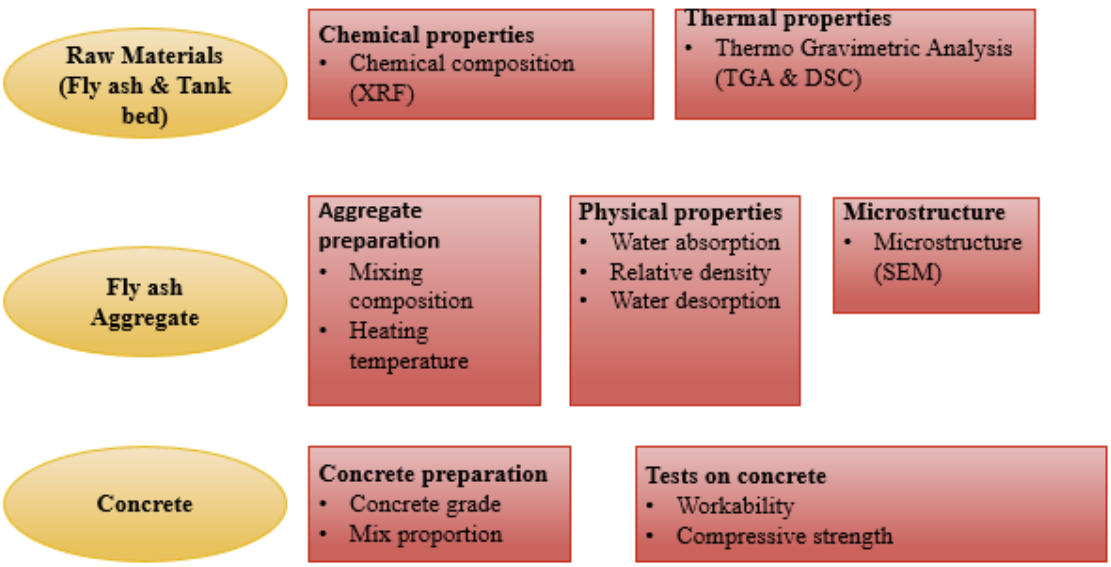

Figure 3. 2 Identified significance parameters regarding the research study

3.2 Raw Material

Fly ash which is readily available as a waste material from the coal power plant was used as a primary raw material in this study and reservoir sediment material was used to strengthen the plastic properties of fly ash in this study. Reservoir sediment material is one of the waste materials that is dredged from irrigational reservoirs found in several parts of the country. Figure 3.3 shows the raw materials which were used in this research study. Thermal and chemical properties of raw material were analyzed. The DSC – TGA method was utilized to analyze the thermal behavior of fly ash and reservoir sediment material. A small amount of raw material was heated using SDT Q600 V20.9 instrument at a temperature range from 0^0C to 1400^0C and heated at a rate of 10^0C per minute under nitrogen atmosphere. Nitrogen gas was passed through the instrument at a rate of 100 ml per minute. The ceramic sample handlers and crucibles were used in the sample preparation. The XRF method was used to analyze the chemical properties of coal fly ash and reservoir sediment material. The amount of heavy metal present in coal fly ash and the percentage of oxides present in the coal fly ash and reservoir sediment material were determined using the X - ray fluorescence method.

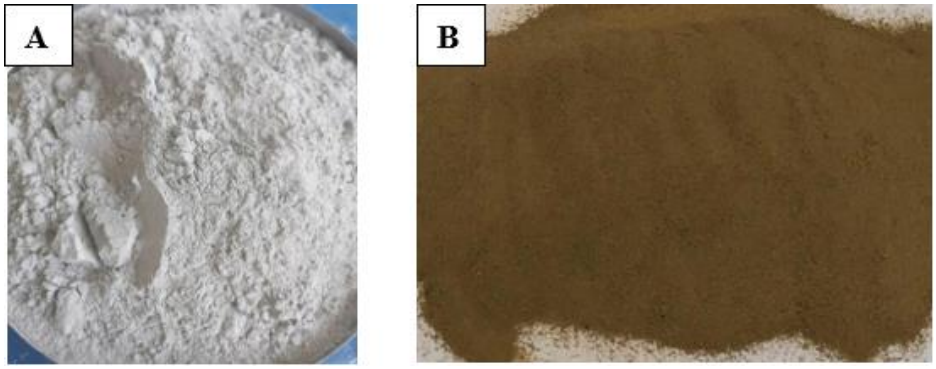

Figure 3. 3 Raw Materials - (A) Fly ash (B) Reservoir sediment material

3.3 Development of fly ash aggregate in laboratory scale

Fly ash aggregates were developed in laboratory scale to find out suitable mixing composition and the sintering temperature. Coal fly ash was collected from Lakvijaya coal power plant, Nooraichcholai, Puttalam. Fly ash which was collected from Lakvijaya power plant was like a fine powdered particle and which was used without any initial treatment (milling or sieving). Reservoir sediment material was also used in this study, which was dredged from an irrigational reservoir located in Kurunagale district. The dredged sediment material was in a very wet condition. It was allowed to dry under the sunlight. Dried reservoir sediment material was milled using a ball mill to get fine particles. Milled sediment material was sieved through a 0.6 mm sieve.

Fly ash and reservoir sediment material were mixed together in various compositions and pastes were prepared by adding water. Fly ash was replaced by reservoir sediment material at 0%,10%, 20%, 30%, and 40% in the sample preparation. To spread the humidity uniformly within the mass formation, the prepared paste was left for 1- 1.5 hours. 14 mm diameter cylindrical fly ash sticks as shown in Figure 3.4, were prepared using a laboratory piston press (Figure 3.5) and were cut into small sticks using tightened wire.

Figure 3. 4 Cylindrical fly ash sticks

Figure 3. 5 Piston press

Cylindrical sticks were prepared with five selected compositions. Prepared cylindrical sticks were pre-heated at 100^0C using a laboratory oven to eliminate the moisture present in the fly ash sticks. The presence of moisture in fly ash sticks may cause an explosion during sintering in the furnace. Therefore, it is important to dry the cylindrical stick at or above 100^0C before placing them in the laboratory kiln. Pre-heated fly ash sticks were sintered using a laboratory kiln. To find the suitable sintering temperature, sticks were sintered at various temperatures starting from 800^0C to 1200^0C in an interval of 100^0C for 30 minutes of soaking time. Figure 3.6 shows the process of sintering cylindrical sticks using a laboratory kiln. Sintered cylindrical sticks were crushed manually into a size of less than 4.75 mm to produce fly ash fine aggregates.

Figure 3. 6 Sintering of fly ash sticks in laboratory kiln

3.4 Investigate the properties of fly ash aggregate

3.4.1 Microstructure analysis of fly ash aggregate

A cross-section of the crushed aggregate was obtained, and the porous structure of aggregates was investigated using a Scanning electron microscope – model "Zeiss Evo 18". Initially, the surface of the crushed sample was cleaned properly, as it is essential to remove debris and dust from the surface. The sputter coater which is shown in Figure 3.8 was used to coat the samples to upgrade the conduction of fine aggregates. Coated samples were then inserted into the SEM machine. Scanning electron microscope captures the image of the sample by scanning the sample with a high energy beam of the electron. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography. The surface topography of the sample will give the information about the pore distribution of the developed fly ash aggregate. Figure 3.7 shows an arrangement of samples to insert into the scanning electron microscope.

Figure 3. 7 Arrangement of sample for SEM analysis

Figure 3. 8 Sputter coater

3.4.2 Water absorption test

Water absorption test for the produced fine aggregates was performed in compliance with ASTM C1761/1761M. Particles passing through 4.75 mm sieve and retained on 0.6mm sieve were selected to measure the water absorption capacity. Selected samples were soaked in water for 24 hours. Soaked fine aggregates were removed from the water bath and saturated surface dry (SSD) aggregates were obtained using the paper towel method and then they were weighed. Later on, SSD samples were placed in the oven to get dry weight and then it was weighed. Equation 3.1 as specified in ASTM C1761/1761M was used to measure the water absorption capacity of developed fly ash fine aggregates.

$$\textbf{Water absorption capacity} = [(M_{SSD} - M_{OD}) / M_{OD}] * 100 \quad \text{Equation 3.1}$$

Here,

M_{SSD} = Saturated surface dry mass of aggregate (g)

M_{OD} = Oven dry mass of aggregate (g)

3.4.3 Relative density of fly ash aggregate

The relative density of developed fly ash fine aggregates was determined according to ASTM C1761/1761M. Developed fine aggregate which were soaked in water for 72 hours then it was transferred into pycnometer. Pycnometer with wetted fly ash fine aggregate was filled with water and weighed. Afterwards, the SSD condition of fine aggregate was achieved using paper towel method. Saturated samples were finally dried using oven and then weighed. The relative density of fine aggregate was calculated according to Equation 3.2 as specified in ASTM C1761/1761M standard. Relative density of fine aggregates with different compositions of fly ash and reservoir sediment material at different sintering temperatures were measured.

$$G_{OD} = M_{OD} / (M_{SSD} + M_{PW} - M_{PS}) \quad \text{Equation 3.2}$$

Here,

G_{OD} - Relative density (oven dry) of aggregate (unit less)

M_{OD} – Oven dry mass of aggregate (g)

M_{SSD} – Saturated surface dry mass of aggregate (g)

M_{PW} – Mass of pycnometer with water (g)

M_{PS} – Mass of pycnometer with aggregate and water (g)

3.4.4 Water desorption of developed fine aggregate

The water desorption of developed fine aggregate was measured according to the ASTM C1761/1761M standard. An experimental set up as shown in Figure 3.9 was developed to measure the desorption capacity of produced fly ash fine aggregate. According to ASTM C1761/1761M water desorption should be measured in an environment with 94% of humidity and 25^0C temperature. Saturated Potassium nitrate (KNO_3) solution was placed inside the chamber as shown in Figure 3.9 (A) to maintain 94% of humidity inside the chamber. Fine aggregates were soaked in water for 72 hours. The saturated surface dry condition was attained using the paper towel method. Saturated surface dried aggregates were placed into the setup and weighed at various time intervals. After 28 days, aggregates were dried using the oven to achieve the oven-dried condition and then weighed. Water desorption capacity was calculated according to Equation 3.3 as specified in ASTM C1761/1761M standard.

$$\textbf{Water desorption capacity (\%)} = [(M_{SD} - M_{INS}) / (M_{SSD} - M_{OD})] * 100 \quad \text{Equation 3.3}$$

Here,

M_{INS} – Mass of aggregate in each time interval (g)

M_{OD} - Oven dry mass of aggregate (g)

M_{SSD} - Saturated surface dry mass of aggregate (g)

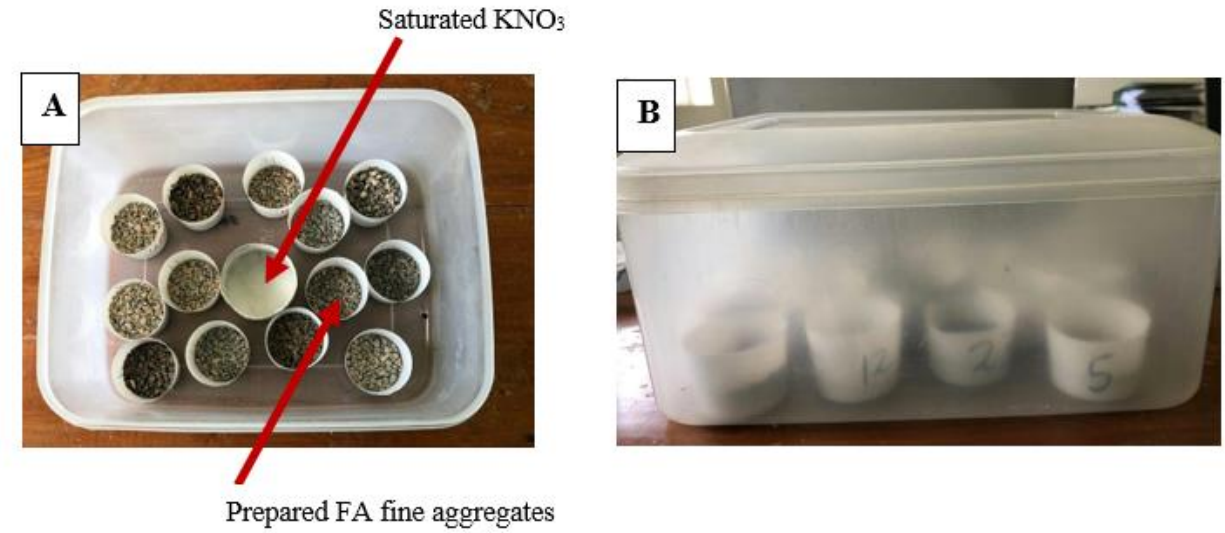

Figure 3. 9 Experimental set up to measure water desorption capacity of prepared fly ash aggregates

3.5 Production of fly ash aggregate at large scale

The blending composition of coal fly ash and reservoir sediment material and the suitable sintering temperature were identified based on the result of the water absorption test, the relative density test, and the water desorption test of developed fly ash fine aggregate which were mixed in various compositions and heated at different sintering temperatures. Coal fly ash and reservoir sediment material were mixed with the identified composition. Then the paste was prepared by mixing with water. The prepared paste was covered by a polythene bag for 1–1.5 hours for the humidity to spread uniformly in mass formation. Pugmill which is shown in Figure 3.10 was used to covert the paste into rollers. Rollers were cut into small plates of 14 mm thickness. Figure 3.11 shows the prepared thin plates. Subsequently, the plates were allowed to dry and then pre-heated at 100^0C to remove the extra moisture present inside the fly ash plates. Pre-heated plates were transferred into the industrial kiln and sintered at the identified temperature for 30 minutes. Sintered plates were left outside and cooled to reach room temperature. Figure 3.12 shows the sintered fly ash plates using the industrial kiln. The sintered plates were crushed manually to make fly ash fine aggregates for the concrete preparation. Figure 3.13 shows the prepared fly ash fine aggregates. Plates were crushed manually without a suitable crusher for the amount to be prepared. Industrial crushers can be used for the preparation of large quantities of materials.

Figure 3. 10 Pugmill

Figure 3. 11 Prepared thin plates for sintering

Figure 3. 12 Sintered fly ash plates

Figure 3. 13 Prepared fly ash fine aggregates

3.6 Mix design calculation

In this study, two types of composition were used to prepare concrete. For type 1 concrete mixture, mix design was prepared for grade 30 concrete according to the BS 1881-116: 1983 standard. Then in type 2 concrete mixture, natural river sand was replaced by the developed fly ash fine aggregate. The amount of fly ash aggregate to replace the natural river sand was calculated according to Equation 3.4 as specified in ASTM C1761.

$$Cf*CS*\alpha max=S*\Phi*M_{Agg} \qquad \text{Equation 3.4}$$

Here,

M_{Agg} = mass of (dry) fine aggregate needed per unit volume of concrete (kg/m^3).

Cf = cement factor (content) for concrete mixture (kg/m^3)

CS = chemical shrinkage of cement

αmax = maximum expected degree of hydration of cement

S = degree of saturation of aggregate

ϕ = absorption of aggregate (kg water/kg dry aggregate)

The equation 3.4 can be used to calculate the replacement amount of aggregate with water desorption rate more than 85 %, but aggregate with the water desorption lower than 85%, the equation 3.5 can be used to calculate the amount of aggregate to replace the natural river sand in concrete. Equation 3.5 is called as Castro modified equation [29].

$$Cf*CS*\alpha max = S*\Phi*\psi*M_{Agg} \quad \text{Equation 3.5}$$

Here, ψ = Desorption of aggregate

Here CS is considered as 0.07 for ordinary Portland cement. Further, $\propto_{max}$ is considered as 1 for the concrete mix. Degree of saturation can be considered as 1, water absorption value is 0.214 and desorption value is 0.74.

Table 3.4 shows the summary of the mix design calculation for two types of the concrete mixture. In type 2 concrete mixture, the developed fine aggregate was used as an internal curing aggregate. Fly ash aggregates have a high-water absorption capacity, therefore pre-wetted aggregate acts as a water reservoir inside the concrete. Dried fly ash fine aggregates were soaked in water for 24 hours and then the wetted aggregates were made to spread on the paper towel to get saturated surface dry aggregate as shown in Figure 3.14. Saturated surface dried aggregates were used to partially replace the natural river sand in concrete.

Table 3. 1 Summary of mixed design calculation

Material	Type 1 (Conventional mix)	Type 2 (FAFA)
Cement (kgm^{-3})	410	410
Coarse aggregate (kgm^{-3})	1060	1060
River sand (kgm^{-3})	770	770 - M_{Agg}
Fly ash fine aggregate (kgm^{-3}, dry)	-	M_{Agg}
Water (kgm^{-3})	205	205

Figure 3. 14 Aggregate spread on paper towel to achieve saturated surface dry condition

According to the mix design calculation mentioned in Table 3.1 two different concrete mixtures were prepared. Type 1 mixture was prepared as control samples using normal fine aggregate. Type 2 mixture was prepared with pre-wetted fly ash fine aggregate (part of the natural river sand was replaced by pre-wetted FAFA). Concrete Cubes (150mm×150mm×150mm) were casted according to the test criteria for the compressive strength test from each mixture. The casted cubes were kept in the molds for 24 hours as shown in Figure 3.15. Metal molds were removed after 24 hours of casting.

Figure 3. 15 Casted concrete cubes

Two different types of curing methods were used for the control mixture (Type 1) with natural river sand. Half of the concrete cubes were soaked in water as shown in Figure 3.16 for the purpose of external curing of concrete (ECC) and the other set of concrete cubes were left outside without any curing process as shown in Figure 3.17 which is referred to as no curing concrete (NCC). Concrete cubes with pre-wetted fly ash aggregate were left without curing which is called as internal curing concrete (ICC).

Figure 3. 16 External curing of concrete

Figure 3. 17 Cubes are left outside for no curing purposes

3.7 Test on concrete

The concrete slump was measured for each type of concrete mixture. The slump test was carried out for each type of concrete mixture as shown in Figure 3.18.

Figure 3. 18 Slump test

The compressive strength of concrete was measured at the age of 7, 14 and 28 days. Figure 3.19 shows the compressive strength test apparatus.

Figure 3. 19 Compressive strength test apparatus for concrete

4. CHAPTER 04 – EXPERIMENTAL RESULTS AND DISCUSSION

4.1 General

The salient findings of this research are included in this chapter. This chapter includes the chemical and physical properties of fly ash and reservoir sediment material, the microstructure of developed fine aggregates, the physical properties of developed fine aggregates (water absorption, water desorption, relative density) and the experimental result on concrete prepared with fly ash fine aggregate and natural river sand.

4.2 Chemical composition of raw material

Table 4.1 provides the chemical composition of coal fly ash (CFA) and reservoir sediment material (RSM). The amount of heavy metals present in coal fly ash is shown in Table 4.2. According to the chemical composition of fly ash, it contains 81.84% of SiO_2 + Al_2O_3 + Fe_2O_3. Therefore, the fly ash available from lakvijaya power plant can be categorized into class F according to ASTM C168. According to chemical composition of fly ash and reservoir sediment material, they do not have the ability to expand while heating. Because the amount of SiO_2, Al_2O_3 and Fe_2O_3 present in the above materials are not in the required range of oxides to have the bloating ability.

Table 4. 1 Chemical composition of coal fly ash and reservoir sediment material

Oxides	Fly Ash (FA) (%)	Reservoir Sediment Material (RSM) (%)
SiO_2	46.89	33.07
Al_2O_3	33.07	31.38
Fe_2O_3	3.28	6.90
MgO	1.56	1.12
CaO	7.56	1.29
TiO_2	1.79	1.91
Na_2O	0.23	0.11
LOI	5.60	24.17

Table 4. 2 Heavy metals present in coal fly ash

Heavy metals	Hg	Cr	Cu	Pb	Zn	Ni	U
mg/ kg	0.35	191	77	76	57	73	33

4.3 Thermal behavior of raw materials

Figure 4.1 and Figure 4.2 show the changes in the thermal behavior of coal fly ash & reservoir sediment material with temperature respectively. The following decisions can be confirmed from TGA – DSC plot of coal fly ash; chemically bonded water molecules evaporate at 548.87^{0}C, decomposition of fly ash occurs at 652.24^{0}C and then fly ash melts at 988.37^{0}C. Similarly, from TGA - DSC plot of reservoir sediment material (RSM), physically & chemically bonded water evaporate at 61.50^{0}C & 485.76^{0}C respectively, chemical decomposition occurs at 325.67^{0}C, crystallization occurs at 939.54^{0}C and RSM melts at 1032.45^{0}C.

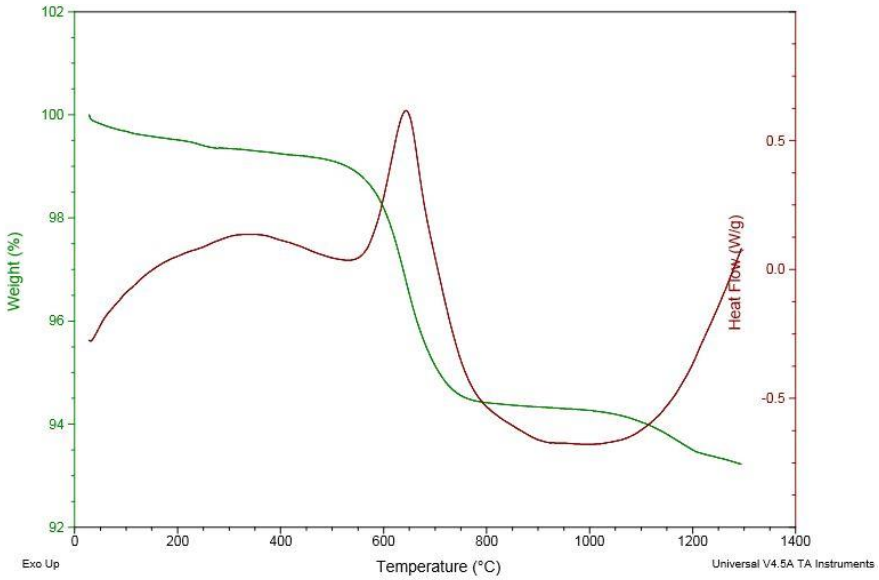

Figure 4. 1 TGA - DSC plot for fly ash

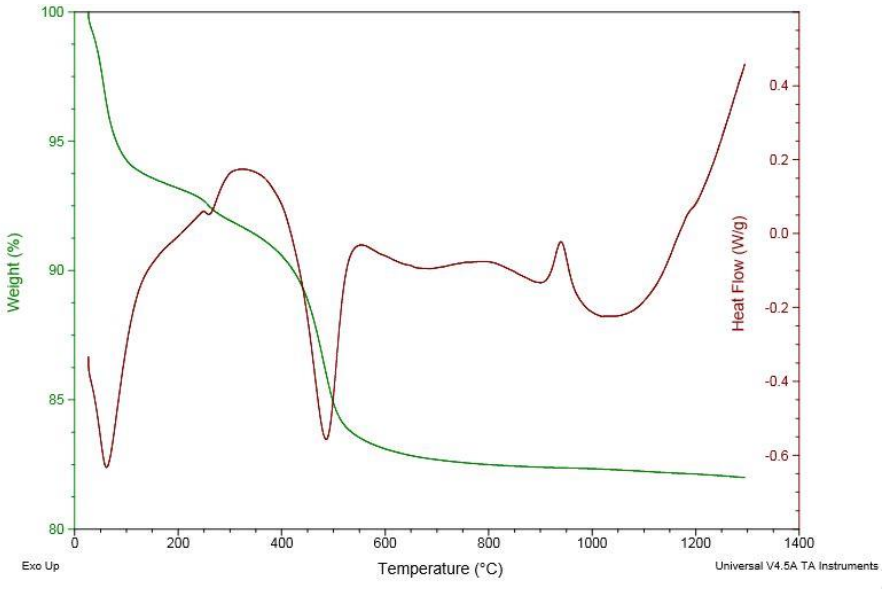

Figure 4. 2 TGA - DSC plot for reservoir sediment material

4.4 Fly ash fine aggregates

Fly ash and reservoir sediment material were mixed in various compositions and sintered at various temperatures with 30 minutes of soaking time. Sintered solid samples were crushed into small particles to obtain fine aggregate for the replacement of sand in concrete. Colour changes of the sample were observed with sintered temperatures. Figure 4.3 shows the colour variation of sintered cylindrical samples made up of various compositions of coal fly ash and reservoir sediment material. Sintering temperature of the samples are indicated in Figure 4.3. Figure 4.4 shows the prepared fly ash fine aggregates. Sintering temperature of each aggregates are indicated in figure 4.4.

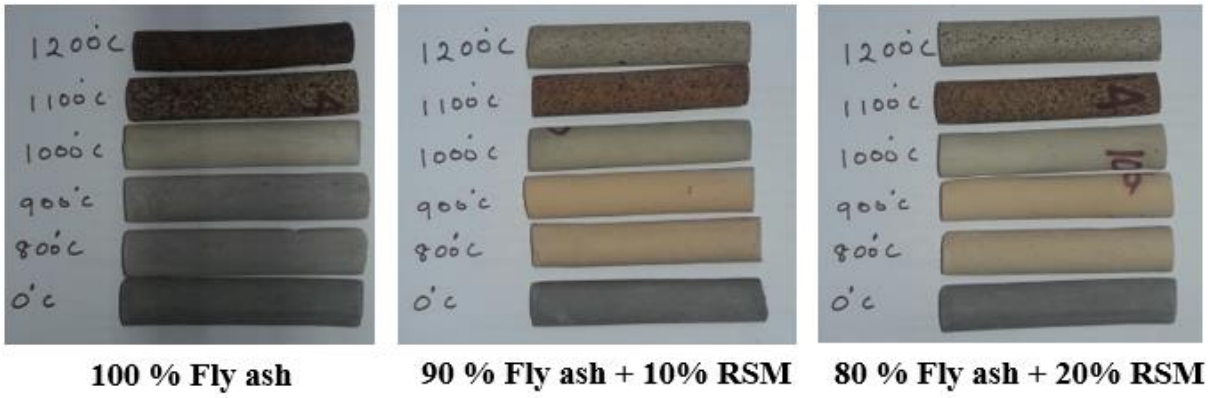

Figure 4. 3 Colour variation of sintered cylindrical samples

Figure 4. 4 Prepared fly ash fine aggregates

4.5 Experimental results of developed fly ash aggregates

4.5.1 Microstructure of developed fine aggregates

Figure 4.5 shows the SEM photographs of the fractured surface of prepared aggregates, sintered at temperatures from 800^0C to 1200^0C at an interval of 100^0C. The SEM photographs shown below reveals the different stages of combining fly ash particles while sintering. Due to the poor sintering of fly ash particles at lower temperatures, Figure 4.5 (A-C) depicts that fly ash particles present in fly ash fine aggregate with 100% of fly ash appear in a spherical shape and show an independent nature. While increasing the sintering temperature, fly ash particles combine together to form pores and the surface becomes smooth. Gases are evolved when the burning of burnable substances present in raw materials while sintering. Gases evolved are trapped inside the aggregate. This causes the creation of pores in aggregate while sintering. Isolated pores can be observed in fine aggregates as shown in Figure 4.5 (D & E), in which aggregates were prepared with 100% of fly ash and sintered at 1100^0C & 1200^0C respectively. When the sintering temperature exceeds the melting point of the raw materials, it starts to melt and fill the pores between particles. Therefore, isolated pores are formed as shown in Figure 4.5 (D & E).

Particles in fly ash fine aggregates sintered at lower temperatures lose their spherical shape and independent nature even at 800^0C with the addition of reservoir sediment material as shown in Figure 4.5 (F & K). This indicates that the addition of reservoir sediment material improves the binding ability of particles. Figure 4.5 (G-J and L-O) shows, that the formation of pores starts at 900^0C due to the addition of reservoir sediment material in fly ash and the size of pores increases while increasing the sintering temperature. This is because the addition of reservoir sediment material increases the emission of gases during increasing the sintering temperature. Loss on ignition of reservoir material was recorded as 24.17% in mass. Pores present in aggregates which were prepared with fly ash and reservoir sediment material, sintered at 1200^0C are larger than that of aggregates which were sintered at lower temperatures.

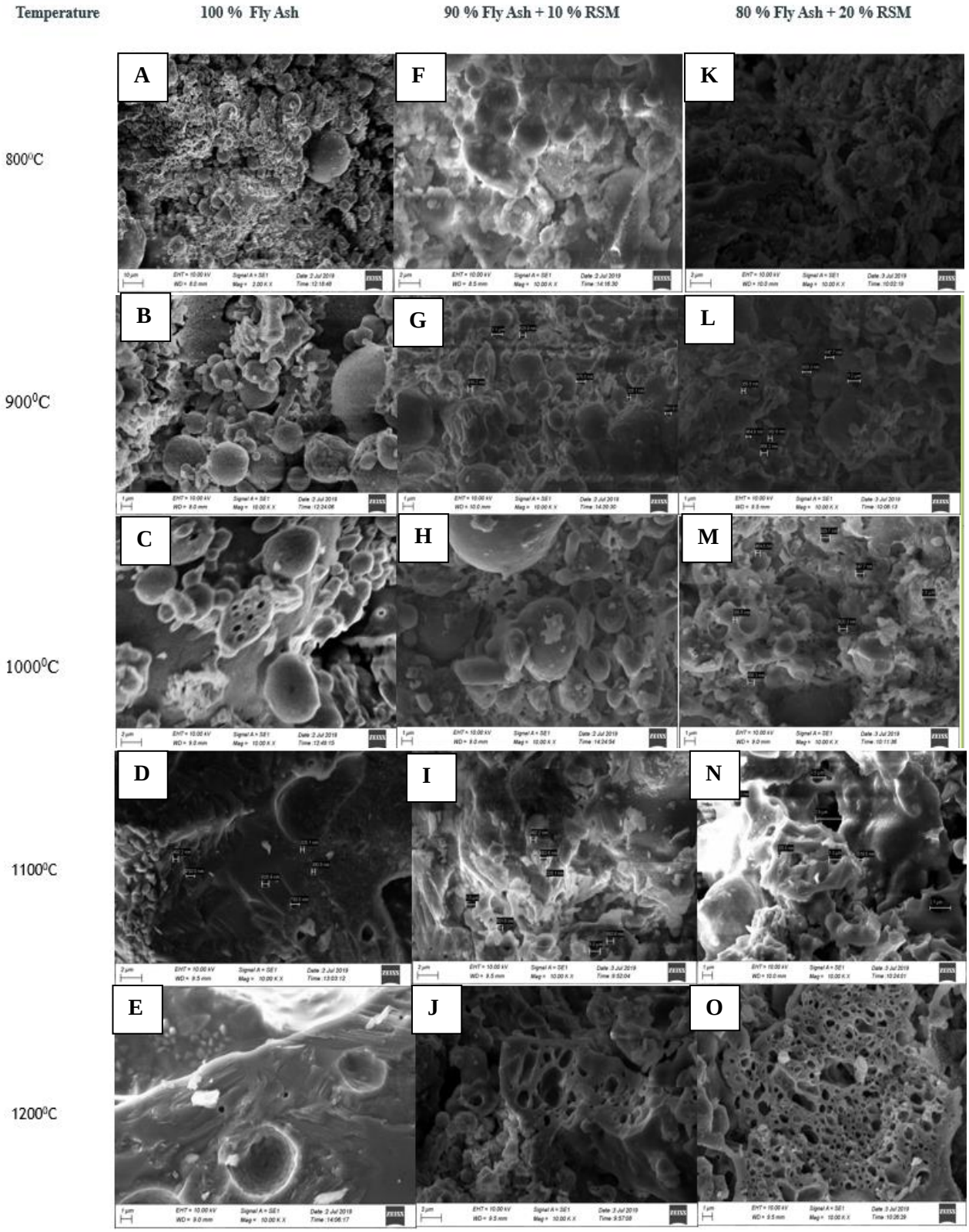

Figure 4. 5 SEM view of crushed fly ash fine aggregate

4.5.2 Water absorption capacity of developed fine aggregate

Figure 4.6 shows the behavior of water absorption capacity of the developed fine aggregates with sintering temperatures concerning their mixing composition of fly ash (FA) and reservoir sediment material (RSM). Fine aggregate with 100% of fly ash has higher water absorption capacity than other aggregates. While increasing the amount of RSM content water absorption of fly ash fine aggregates decreases. Water absorption of fine aggregates with 100% of fly ash is high at lower temperature and it decreases with the sintering temperature. Fine aggregate with 100% of fly ash and sintered at 1200^0C has the lowest water absorption capacity. Water absorption of fly ash fine aggregate with 10% & 20% of RSM gradually decreases with sintering temperature, but there is a sudden reduction in water absorption at 1100^0C, then the water absorption increases again at 1200^0C. It is observed that fly ash and reservoir sediment particles are started to fuse at the point of mutual contact at 1000^0C in SEM photographs and large pores are formed in aggregate with fly ash and RSM at 1200^0C due to the emission of gases by burning of substances present in reservoir sediment materials. A higher number of open pores can be observed in fly ash aggregates with reservoir sediment material heated at 12000C in SEM photographs. Water absorption of fly ash fine aggregate with 30 & 40% of RSM gradually decreases with temperature. The addition of reservoir sediment material in fly ash fine aggregates reduces the water absorption of fly ash fine aggregates.

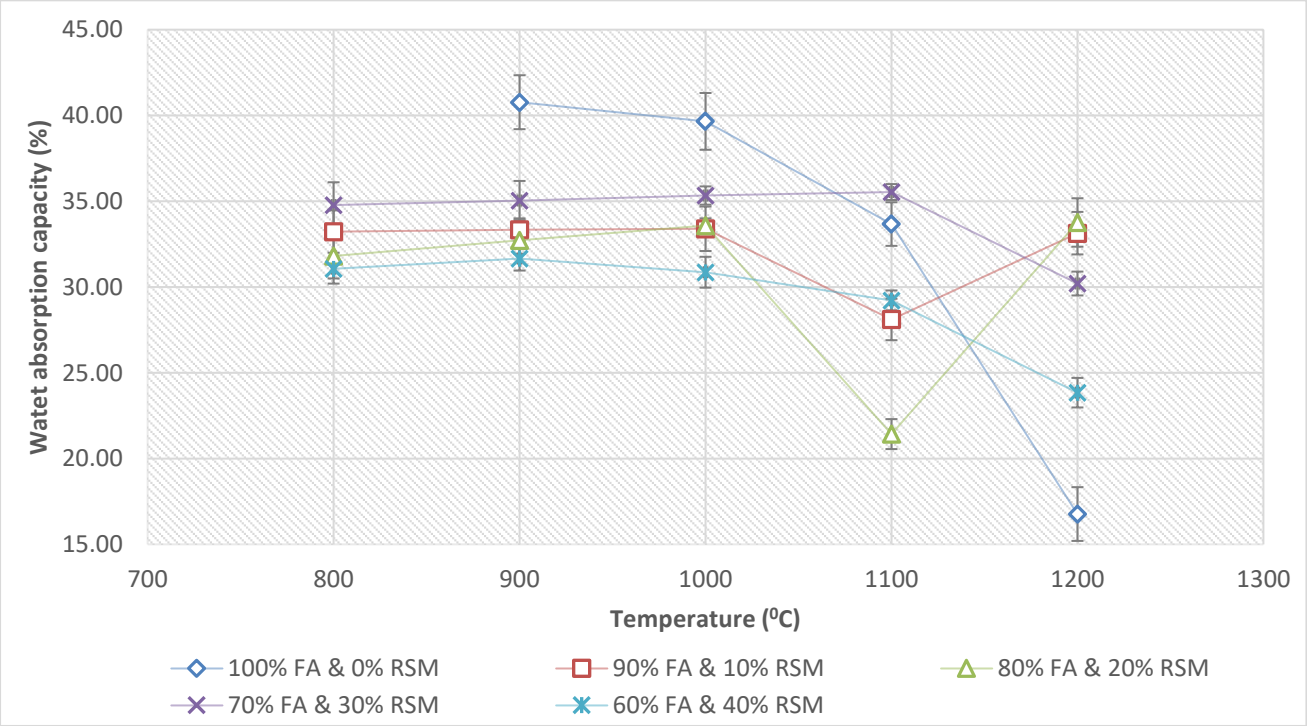

Figure 4. 6 Water absorption capacity of prepared fly ash fine aggregate

4.5.3 Water desorption capacity of developed fine aggregate

The behavior of the water desorption capacity of developed fly ash fine aggregates with the sintering temperature concerning their mixing composition of fly ash and reservoir sediment material is shown in Figure 4.7.

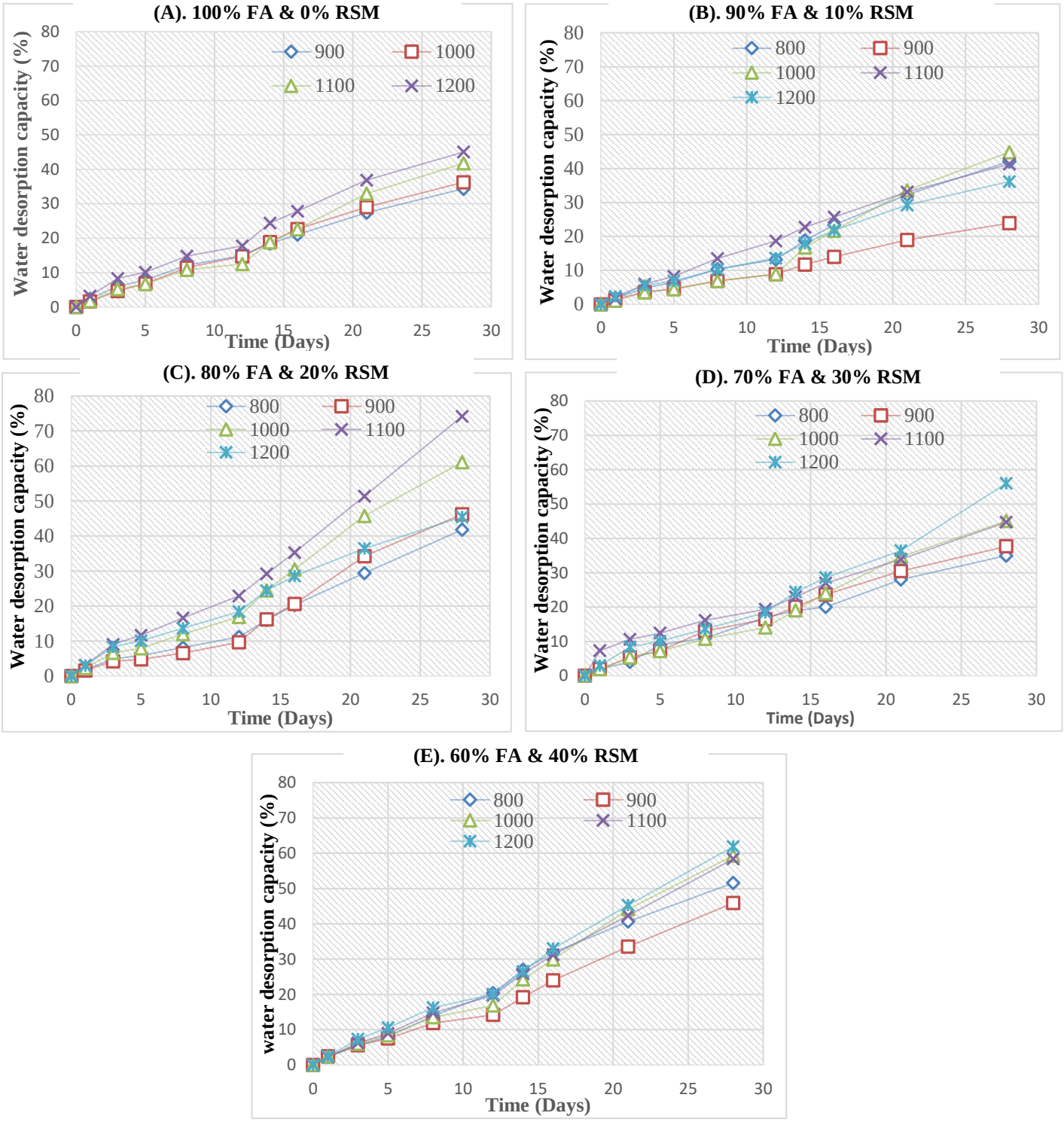

Figure 4. 7 Water desorption capacity of fly ash fine aggregates

Most of the fly ash aggregates released less than 70% of absorbed water at 94% relative humidity. Aggregates with 20% of RSM heated at 1100^{0}C released 74.13% of absorbed water at 94% relative humidity as shown in Figure 4.7 (C). Fly ash fine aggregates with 0% of RSM and 10% of RSM have lower water desorption capacity than other fine aggregates as shown in Figure 4.7 (A & B). The addition of reservoir sediment material in fly ash increases the water desorption capacity of fly ash fine aggregates.

4.5.4 Relative density of developed fine aggregate

Relative density is a key parameter for the selection of fine aggregate in concrete. Low-density aggregates have very low strength and lightweight properties. The behavior of relative density of developed fly ash fine aggregate with different sintering temperatures concerning their mixing composition is shown in Figure 4.8. Fine aggregate with 100% fly ash has the lowest relative density and the relative density of fine aggregate increases with the addition of reservoir sediment material with fly ash. The aggregate with 100% fly ash heated at 1200^{0}C has 1.53 relative density. Fly ash fine aggregate with 60% of fly ash and 40 % of reservoir sediment material sintered at 1200^{0}C achieved the maximum relative density of 1.55.

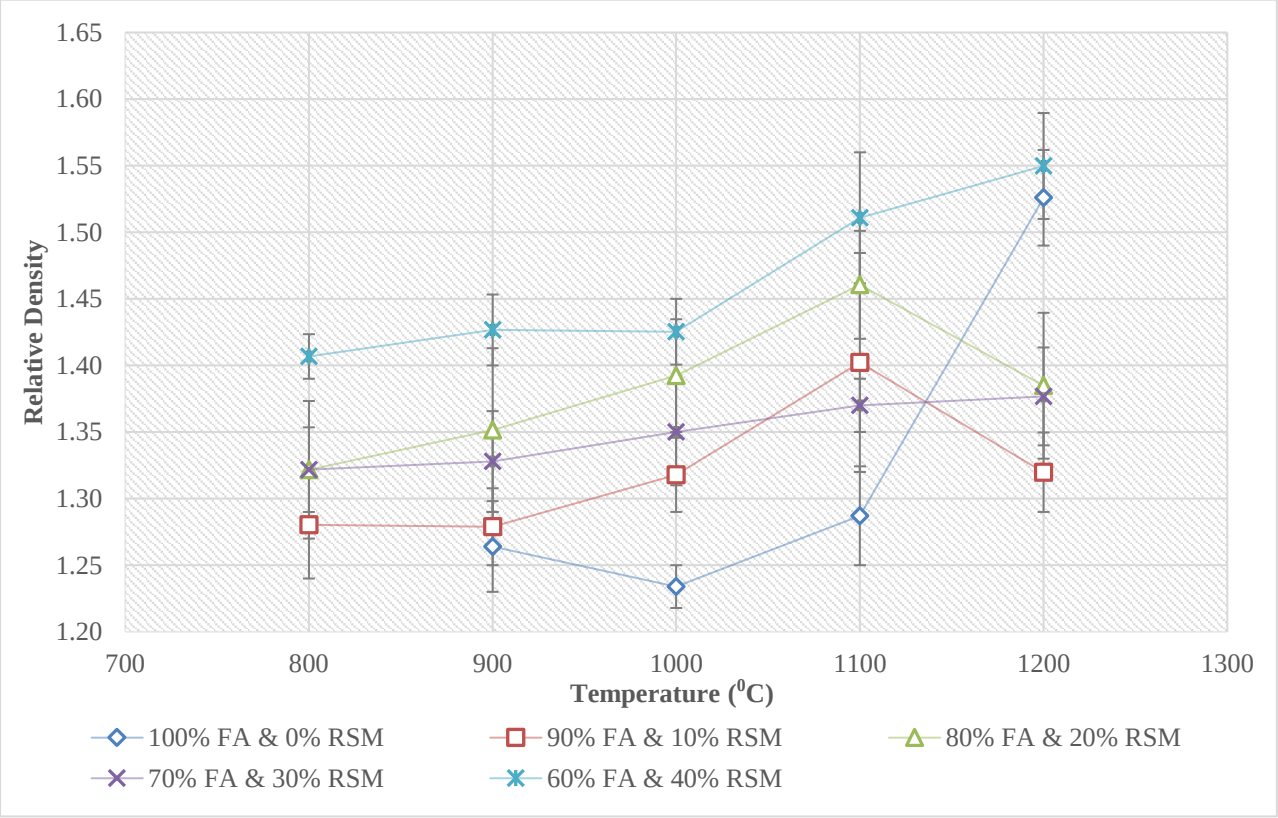

Figure 4. 8 Relative density of prepared fly ash fine aggregate

4.6 Experimental results of concrete

Workability and compressive strength are the essential design parameters that are used to verify the properties of concrete. The workability of concrete was measured using the slump value. The slump value of Conventional concrete was 140 mm as well as the slump value of concrete with developed fly ash fine aggregate (Internal curing concrete) was 160 mm. The wetted aggregate has been used in internal curing concrete mixture therefore which has a high slump value compared to the conventional concrete mixture.

Compressive strength is an important parameter for concrete which is used in the load bearing structure. Figure 4.9 shows that the compressive strength of no curing concrete (NCC), external curing concrete (ECC) and internal curing concrete (ICC) how does the changes take place with time. ECC achieved the highest early-age strength (7 days and 14 days) compared with NCC and ICC. ICC achieved the highest strength which was slightly higher than that of ECC concrete at 28 days. The NCC achieved the lowest strength at 28 days compared with other concrete samples because there was a lack of water for the hydration reaction of cement in no curing concrete. At early-age, ICC concrete achieved lower strength than that of ECC but at 28 days compressive strength of ICC exceeded the compressive strength of ECC because the water stored in wetted fly ash aggregate was released and which helped in the hydration reaction of cement. Water absorbed by fly ash fine aggregate induces the hydration reaction of cement in ICC and it improves the strength gaining of internal curing concrete.

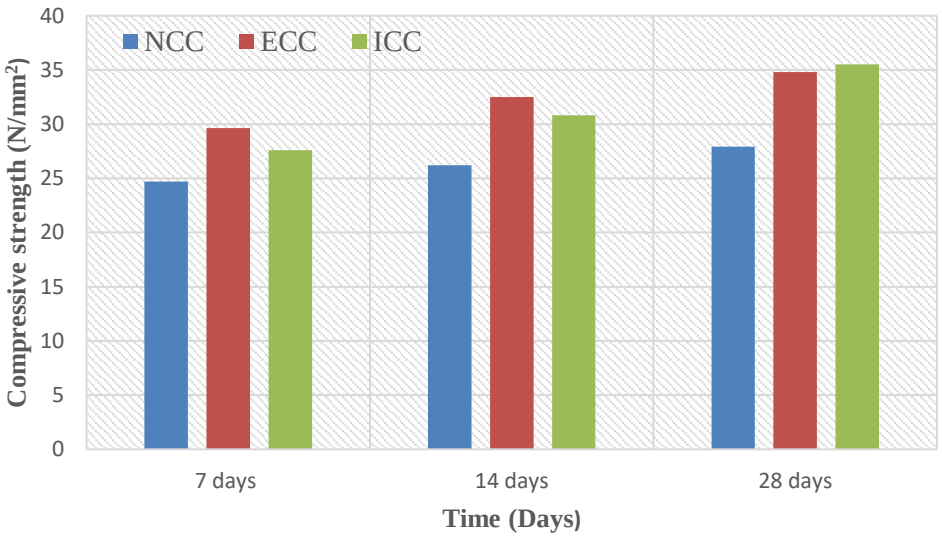

Figure 4. 9 Compressive strength of concrete

5. CHAPTER 5- CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The foremost objective of this study was to manufacture an alternative product for fine aggregate using coal fly ash. Coal fly ash was collected from Lakvijaya coal power plant situated in Norochcholai. Fly ash is one of the waste products from the coal power plant. Since fly ash particles do not have plastic nature, reservoir sediment material was added as a binding agent to enhance the green strength of solidified fly ash. Since the fly ash contains high carbon content, sintering method was selected to develop fly ash aggregate for the purpose of hardening of agglomerated fly ash particles.

Initially, the chemical composition and thermal behavior of fly ash and reservoir sediment material were investigated using XRF analysis and TGA-DSC analysis respectively. Series of fly ash fine aggregates were prepared with various compositions of coal fly ash and reservoir sediment material at various sintering temperatures to identify the proper mixing composition and the suitable sintering temperature. Laboratory experimental studies have been done to investigate the water absorption capacity, water desorption capacity, relative density and microstructure of the developed fly ash fine aggregates. Based on the results of the above experiments, a mixture of 80% coal fly ash 20% reservoir material has been selected as the best mixing composition and 1100^0C has been selected as the sintering temperature to develop fly ash fine aggregate. The water absorption value and desorption rate aggregate with 80% of coal fly ash and 20 % of reservoir sediment material sintered at 1000^0C was 34 % and 60 % respectively as well as aggregate sintered at 1100^0C was 21.4 % and 74 %. Fly ash with reservoir sediment material can be sintered in the range of 1000^0C to 1100^0C because melting temperature of fly ash is 988.37 ^{0}C. Sintering temperature of coal fly ash should exceed the melting temperature to strength the particles in aggregates. The fly ash fine aggregates prepared by mixing of 80% coal fly ash and 20% reservoir material and heated at 1100^0C have lower water absorption than other fly ash aggregates as well as have the highest water desorption capacity. The developed fly ash fine aggregate was lighter than naturally available river sand. Since, the developed fly ash aggregate has higher water absorption and has considerable high-water desorption capacity, it can be used as an internal water reservoir inside the concrete.

Second objective of this research was to verify the suitability of developed fly ash fine aggregate in the production of concrete. Mix design has been done for grade 30 concrete

according to BS 1881-116:1983 standard. Required amount of fly ash fine aggregate was calculated according to ASTM C1761 standard to prepare internal curing concrete. Natural river sand was replaced by wetted fly ash aggregate in mass to internal curing concrete. The workability and compressive strength of no curing concrete, external cutting concrete and internal curing concrete were analyzed. ICC had higher slump value than conventional concrete. ICC achieved lower strength at early age (7 days) but ICC achieved higher strength than that of ECC at 28 days. The compressive strength results of ECC & ICC imply that fly ash aggregate can be used as a fine aggregate replacement material instead of natural river sand and as an internal curing reservoir inside the concrete to supply water for internal curing purposes. Here nearly 18 percentage of river sand has been replaced by developed Fly Ash fine aggregate. The amount of replacement has been identified as per ASTM 1761 equation. Moreover, Here the intention of this replacement is providing the internal curing water reservoir in concrete. While increasing the amount of FAFA to replace naturally available river sand in concrete, it may affect the durability of the concrete. Therefore, durability and mechanical properties should be checked with different percentages of this aggregate to analyze the excess replacement, and the optimum replacement amount should be identified. In the preparation of concrete fine particles passing through the 150 micrometers have been removes to avoid the material loss during the soaking period. While increasing the amount of FAFA to replace the natural river sand, it would affect the gradation of fine aggregate in concrete as well as packing density and durability properties of concrete.

5.2 Recommendation

In this experimental study, suitability of fly ash aggregate was investigated with grade 30 concrete and no admixtures were used. Further studies must be done for high grade concrete. At present admixtures are used to improve some properties of concrete in ready mixed plants. So, a comprehensive study should be performed to investigate the properties of concrete with fly ash fine aggregate and commonly available admixtures.

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