SUSTAINABLE DEVELOPMENT OF UN-REFINED FLY ASH IN ECO-FRIENDLY HIGH-VOLUME FLY ASH CONCRETE STRUCTURES

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Degree of Master of Science

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DECLARATION

I declare that this is my own work and this thesis/dissertation 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.

Also, hereby I affirm that the details of this research report were exclusively carried out by me under the supervision of Mr. Guluwita and Dr. Ismail and all the information contained in this research report is certain and accurate to my knowledge.

…… ……..

Signature Date

The above candidate has carried out research for the Masters Dissertation under my supervision.

1……. Date……

Mr.SP.Guluwita

Internal Supervisor)

2……. Date……

Dr. MIMU Ismail

External Supervisor

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ABSTRACT

Sustainable development in concrete industries is reducing the cement consumption in overall the world. Huge amount of carbon dioxide gas is released to the atmosphere during the production time of Portland cement. Carbon Dioxide is the leading contributor for the greenhouse effect and it directs to the global warming of world. In the present situation, most of the developed countries are thinking about these issues and implement severe rules and regulations to limit of the carbon dioxide emissions. So supplementary cementitious materials are required to reduce the consumption of Portland cement for the sustainable development. Fly Ash is one of the most abundant supplementary cementitious materials in worldwide. It is a by-product and waste material in thermal power stations. Disposal of fly ash is one of the major problems in the power stations because it leads to many environmental issues. Utilization of Fly Ash in the concrete industries, assure sustainable development by reducing cement consumption and also reduce the emission of carbon dioxide to the environment. The superior properties of fly ash provide much support to improve the rheological properties of fresh concrete and produce ultimate strength as well as better durability in long term hardened concrete. From the broad view it can be ensured that the usage of High-Volume Fly Ash is an environmentally friendly process and also it will enhance the quality of concrete such as high-performance concrete.

Key words – High Volume Fly Ash, Durability, Sustainable development

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1. INTRODUCTION

1.1 Global Warming and Sustainable Development

Cement material is one of the main commodities in this current world. As per the history of cement, cementing materials have played a huge role. The origin of the hydraulic cement is Greece and Roman. Lime and Volcanic ash are the initial materials which were used to produce ancient cement. In 1824 Joseph Aspdin who was a British stone mason invented the Portland cement by heating the finely ground lime stone and clay in his kitchen and by ground it and by mixed the mixture with water. From the ancient time to till now there are so many different types of cement were introduced and improved by making changes in the cement properties. Day to day the world is facing so many development plans regarding buildings, roads, bridges and other huge constructions. For these all development activities cement is the important raw material. So, the usage of cement is a necessary process. Clinker and Gypsum are the main ingredients for cement manufacturing process. One of the main materials Clinkers is manufactured by the calcinations and cooling processes of the main ingredients such as limestone and clay and the other sub ingredients.

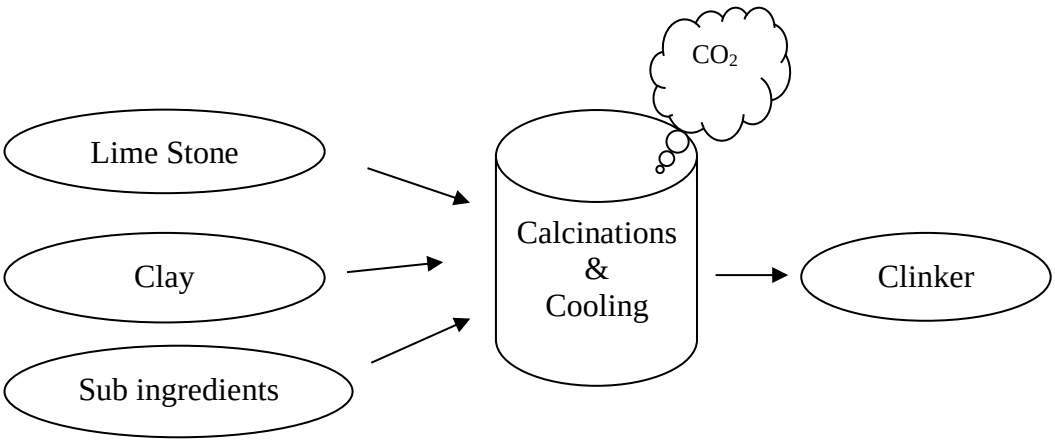

Figure 1: Schematic diagram of Clinker production

Properly Milled and Blended raw commodities such as lime stone, clay and other sub ingredients are passed to the silo and then to the kiln. The temperature arises up to 1450° C in the kiln. During this time decomposition of raw materials and other chemical reactions such as calcinations which means a thermal treatment process in the absence or presence of limited air or oxygen supply take place. When the lime stone ($CaCO_3$) undergoes to the calcinations process it becomes as Calcium oxide (CaO) and also it emits carbon dioxide (CO_2) gas.

$$CaCO_3 \xrightarrow[\text{Thermal Heating}]{} CaO + CO_2 \quad (1)$$

Limestone which is one of the main raw materials in clinker production contains Calcium carbonate as the main chemical component. During the calcinations process it emits carbon dioxide (CO_2) gas in to the environment. Emission of CO_2 gas to the atmosphere is one of major environmental impact and it leads to global warming. Global warming is a severe issue in today's world. It occurs by the long-term rise in the ambient temperature condition of the Earth surface, water sources and atmosphere. Most of the human activities generate greenhouse gases and this leads many environmental issues by the agglomeration of these produced gases in the atmosphere. Increase in sea level, unpleasant weather conditions, amplification of barren plains and desserts are major impacts which are generated by global warming. It can change the stability of the world and the life of all living organisms. The weather patterns are rapidly changing and it affects the survival of living organisms. Not only this, it leads to many natural disasters and movement of many living organisms. The increase quantity of CO_2 expands the acidic condition of seawater.

CO_2 emission is mainly generated by the clinker production and the usage of cement is directly proportional to the production amount of concrete. Possible societal responses to global warming include mitigation by emissions reduction. So, we need to reduce the CO_2 emission levels which are emitted by our cement and concrete industry. Reduction in the usage of cement will reduce the emission of CO_2 by the minimizing the clinker usage in cement manufacturing process.

“Apart from this in Sri Lanka, there are many power stations are running with using various type of raw materials. If we consider about the “Noroaicholai Power Station” which is the sizeable power station in Sri Lanka located in Noroaicholai at Puttalam, on the southern-end of the Kalpitiya, Peninsula. It was estimated that, during this period, approximately 150-200 tons of fly ash were released to the environment a day.” This is also a main environmental issue because the fly ash wastes cannot be dumped in the earth surface at all time. And there is no any recycling process to use this waste fly ash again as a raw material in power station.

If we analyze about this Fly ash which is coming as a waste material from Noroaicholai power station, we can see about the chemical properties and can ensure that it can be used as an additive in cement and concrete industry. “Sustainable development of un-refined fly ash in eco-friendly high-volume fly ash concrete” has the aim of replacing cement by fly ash to act as a better solution for main environmental issues which are related with the cement and concrete industries.

1.2 Potential waste of Coal Power Plant

Fly ash is the byproduct of coal fired power stations collected from the flue gases by mechanical & electro static precipitators. Currently there are many researches are in progress in China, India and in several countries about the environmental challenges and impacts regarding disposal of ash from the coal power plants and all of these explorations is suggesting that this major impact need to be solved and controlled masterly. In Sri Lanka, there are three unit of coal power plant located in Noroaicholai. Each one has the capacity of 300MW power generator with maximum consumption of 750,000 metric tons of coal per year and requirement for all three unit of power station (900MW) are 2,250,000 metric tons per year [1]. Each 300MW power station runs with 2640 tons of coal per day and it releases 180 tons of fly ash and 40 tons of bottom ash per day [1]. This waste material Fly Ash which is coming from the coal power plants is an advantageous and a valuable raw material for both cement and concrete industries. So, if it is considered by both industries, it is confidently expected that enormous quantity of fly ash can be reused and therefore the wastage quantity can be

reduced and also disposal of fly ash can be controlled. Presently 80 percentage of fly ash waste is consumed by cement industries and roof manufactures and the balance 20 percentage of fly ash waste is still dumping in local areas. Certain quantity of cement can be replaced with fly ash in the concrete production. So substantial volume of waste can be utilized.

The utilization of fly ash instead of dumping it in the environment is a favorable outcome for environmental lands and areas and it is advantageous to economic part also. When fly ash is used as a minor raw material in cement or mineral admixture in concrete, it supports to improve the workability, late strength, and it decreases the water demand for better workability and also reduce bleeding issues and evolution of heat. The quantity of fly ash which can be used as a cementitious commodity in concrete depends on several factors. Workability of concrete, water demand, required design strength and relative expenses need to be compared between usage of cement and replacement of fly ash. During the mixture proportion of fly ash for the concrete these main factors must be considered. Generally, the usage of mineral admixtures is familiar in all construction industries due to cheap expenses and low energy and also it is beneficial for the protection of environment and conservation of natural resources. Raw fly ash, rice husk ash, metakaolin; silica fume is some of the mineral admixtures which are generally used. Addition of such mineral admixture materials improves several concrete properties.

Fly ash is the commonly used mineral admixture among all other mineral admixture as it is readily available in many developing countries in huge quantities. According to the SLS ISO 107:2015[2] by Sri Lanka Standards Institute (SLSI) the maximum percentage of fly ash in Ordinary Portland Cement is 5 percent by weight and as per SLS 1247[3] the maximum of fly ash in Blended Hydraulic Cement is 25 percent by weight.

Comparably, Blended Hydraulic Cement with high-volume fly ash which is currently in use gives better late strength and also the strength increase with aging. Emission of CO_2 and other greenhouse gases are reduced by the usage of Blended Cement with this

fly ash waste material. There are many authors studied and published about the chemical and physical properties about the blending materials. Fly ash and Rice husk ash can be directly used as blending materials and also there is no need for requirement of any other activation material. The capacity for better performance of fly ash in concrete industry can be enhanced by many methods such as chemical activation, mechanical activation and thermal activation which are currently in use. Chemical activation process can be done comfortably but thermal activation and physical activation process cannot carry out simply and also more advanced type of machinery items are needed to initiate these activation process.

1.3 Properties of Fly Ash

Predominantly Ash consist spherical particles (1 to 150μm) of alumino-silicate glass containing various proportions of Ca, Fe, Mg & alkali metals. The chemistry and mineralogy of fly ash depend on the composition of the coal and condition with in the boiler. According to the ASTM C618[4] standard, fly ash was divided into two classes based on the type of the coal and the composition of ash.

- Class F : Produce from bituminous coals
  $SiO_2 + Al_2O_3 + Fe_2O_3 > 70\%$
  CaO less than 8%

- Class C : Produce from lignite & sub-bituminous coal
  $SiO_2 + Al_2O_3 + Fe_2O_3 > 50\%$
  CaO typical 8% - 30%

Fly ash commonly consist the pozzolanic properties in the presence of lime or another activator and it will form C-S-H product. Widely class F fly ash is used to produce concrete with the improved durability. The percentage of reactive silica is relatively high in class F fly ash and it is performing as an activator for the reaction with $Ca(OH)_2$ which is produced from cement hydration.

Cement hydration is an early age reaction and calcium hydroxide is the by product in that reaction. Fly ash reacts with this formed calcium hydroxide in the presence of moisture and form calcium silicate hydrate in later age therefore long-term strength will increase.

Fly ash has the capable of 'pozzolanic activity'. This specific ability is explained as it is a measurement process of the reaction rate between the pozzolanic material and $Ca(OH)_2$ in the presence of water or the degree of reaction over time. According to the American Society for Testing and Materials (ASTM, C618[4]) pozzolan is defined as it is a siliceous or siliceous and aluminous material which have very minute amount of cementitious value and it can the ability for the reaction with calcium hydroxide [$Ca(OH)_2$] at ordinary temperature in the presence of moisture and it forms compounds representing cementitious properties by the reaction.

Hydration Reaction

$$2(3CaO.SiO_2) + 11\ H_2O \longrightarrow 3CaO.2SiO_2.8H_2O + 3(CaO.H_2O) \quad (2)$$

(Tricalcium silicate) (Water) (C-S-H) (Calcium hydroxide)

$$2(2CaO.SiO_2) + 9\ H_2O \longrightarrow 3CaO.2SiO_2.8H_2O + CaO.H_2O \quad (3)$$

(Dicalcium silicate) (Water) (C-S-H) (Calcium hydroxide)

Pozzolanic Reaction

$$3\ Ca(OH)_2 + 2\ SiO_2 \longrightarrow 3CaO.2SiO_2.3H_2O \quad (4)$$

$$3\ Ca(OH)_2 + Al_2O_3 + 3\ H_2O \longrightarrow 3CaO.Al_2O_3.6H_2O \quad (5)$$

Mineralogy and the particle characteristic properties of the fly ash are the two main parameters which are determining the reactivity. Particles of fly ash are mostly spherical, solid and glassy. Particular amount of noncombustible carbon is also present this noncombustible carbon quantity depends on the ignition efficiency. Larger particles above 45 microns may be considered as inert materials and they do not take part in the pozzolanic reactions even after one year and also, they will behave like sand. There are many investigations were done and published regarding the reactivity of fly ash, particle size distribution of fly ash and the strength of concrete with the use of fly ash combined cement. Theses research process prominently considered low-calcium fly ashes. As per these, the particles below 45-micron are predominantly responsible for the pozzolanic effect. Particles below 10 to 20µ are mostly important for the enhancement of compressive strength in the concrete. Usage of best and correct quality fly ash helps in reducing the water demand for desired slump. LOI (Loss on Ignition) is one of the main parameters which is calculated from the presence amount of carbon content and it supports in the determination of required water quantity for proper workability of mortar and concretes. If the carbon content percentage is high the water needed for the preparation of cement paste with normal consistency is high. So, Class C fly ash is not preferable because of the high loss on ignition. But the class F fly ash is suitable because of low carbon content.

1.4 Literature review

The usage of fly ash was initiated by Cleveland Electric Illuminating Company and the Detroit Edison Company in 1932 for the treatment of Cd(11) rich effluents studies[5].There was an earliest literature confirmed that the usage of fly ash in concrete was initially studied in 1937 regarding compare the properties between blended fly ash cement concrete and Portland cement concrete[6].The demand of electric power suddenly growth in year of 1950's in the world. Therefore, the power stations were being constructed and along with this, the fly ash studies were advanced and the standards on fly ash cement were slowly constituted [7]. Investigation about the study of materials which could be used in concrete to replace a portion of Portland cement was done by Lamond in 1950-1967. Several studies were published in 1968

regarding utilization of pozzolanic waste materials such as fly ash and slag[8].In 1983, the use of cementitious by products as mineral admixtures for concrete was explained by Mehta[9].The high-volume fly ash was replaced in high strength concrete by using ASTM Class C type fly ash with superplasticizer in 1986[10].In 1987 “fly ash in cement and concrete” was published by Helmuth, R. in Portland Cement Association[11].In 1991, Raju N.K. was highlighted the performance of high-volume fly ash in concrete such as good workability and strength achievement[12].Malhotra & Ramezanianpur was explicated the comparison in properties between various percentage replacement of fly ash in 1994[13].

The guidelines of fly ash testing and monitoring quality control program were given in ASTM C311[14] by American Society for Testing and Materials in 1994.The guidelines of fly ash replacing percentage between 15% to 35% in concrete instead of cement were given in ACI 211[15] in 1996 by American Concrete Institute. The sustainable development was initiated by Metra in 2001. He explained the usage of fly ash and the reduction of carbon dioxide emission during the cement production by reducing cement consumption [16]. In 2002, The high percentage of fly ash replacement (more than 30%) studies was carried out by Malhotra and Mehta [17].

The relationship between carbonation depth and strength of concrete was analyzed for 0%, 50% & 70% fly ash replacement instead of cement in concrete. It was emphasized by Cengiz Duran Attis in 2002[18]. The high-volume fly ash concrete was made by replacing 40%, 50% and 60% of Class F type fly ash and its properties were investigated at both 28 days and 90 days by Rafat Siddique in 2004[19]. The high percentage of fly ash replacement in concrete enhanced the durability at long term. The chloride permeability value become very low and minimizes the risk of corrosion. It was investigated by Ozkan Sengul in 2005[20]. In 2007, Binod Kumar carried out the testing to find out economical fly ash replacement for pavements concrete by using superplasticizer [21]. In 2009, Venkata has emphasized that increase of fly ash percentage considerably reduces the permeability of concrete with the increase of time period [22]. In 2014, T.Ch. Madhavi, L. Swamy Raju& Deepak Mathur were experimentally proved the durability and Strength properties of High-Volume Fly Ash

Concrete. They had pointed out the strength improvement after 28 days and reduction of crack width / with low shrinkage compare with normal Portland concrete [23].
The influence of strength improvement in fly ash blended concrete was explained by microstructure characterization by using X-Ray Diffraction pattern and Scanning Electron Microscope. It was carried out by OzlemCelik in 2008[24]. The X-Ray Diffraction pattern of raw fly ash was characterized by Jianglong in 2012[25]. The compressive strength of hydrated cement- fly ash paste was characterized by using X-Ray Diffraction pattern. This study was carried out by Baoguo M, and Ting Zhang in 2018. They had pointed out the identical phases in fly ash paste [26].

There are possibilities to improve the durability of concrete by incorporating the fly ash with cement. Therefore, strength improvement and durability properties are going to be study by analyzing XRD and SEM images.

1.5 Objectives

The aim of this study is characterizing the concrete structure for the improvement of concrete's durability by adding high percentage of fly ash and utilization of byproduct from coal power plant. Also reduce the usage of ordinary Portland cement which contributes to Global warming by releasing CO_2 gas to the atmosphere. Confers overall ecological and environmental benefits and sustainable development in concrete industry.

2. MATERIALS AND METHODOLOGY

2.1 Materials & Equipment

2.1.1 Materials

Nippon Pro OPC Cement sample (Annex I) and Un-Refined fly ash from coal power plant were taken as the main materials for the test. Crushed metal 20mm complying with BS 812:1992 standard[27] was used as Coarse aggregates (Annex II) , River Sand complying with BS 812:1992 standard[27] Fine aggregates (Annex III), Econex Eska21 complying with ASTM C494[28] as Super plasticizer (Annex IV) and Daratard17 complying with ASTM C494[28] as retarder (Annex V) were used as the sub materials in the concrete trials. Drinkable water was taken and used as mixing agent in making pastes and for other concrete trials. NaOH solution (0.3N), NaCl solution (3.0%) and De-aerated water were prepared as per the standard requirement and used in the Rapid Chloride Penetration Test. Hydrochloric acid (0.1mol/l), EDTA solution (0.03mol/l), Methyl orange indicator and Patton and Reeders indicator were used in the titration process during the Pozzolanicity Test.

2.1.2 Equipment

Polypropylene bag was used in the collection and storage of main materials such as Nippon Pro OPC Cement sample and Un-Refined fly ash. Analytical Balance (RW00-3220-300, Cub Brand) and Platform Balance (Avery Weigh-Tronix ZM201) were used to measure the weight of the testing materials, admixtures, reagents and concrete cubes. Pipette (50.0ml), Burette (50.00ml), Pipette filler and measuring cylinders (500ml and 1000ml) were used to measure the testing solutions and other needed solutions. Polyethylene container and wide stem funnel were taken for the preparation of sample and Oven is used for the conditioning of the Pozzolanicity test. Not only these but also beaker (250ml), Buchner funnel & flask and pH meter were used as the testing equipment in the Pozzolanicity Test.

45-micron sieve was used for the 45-micron residue test. Porcelain crucibles, Furnace and Desiccators were taken as the main tools for the Loss on Ignition Test. Rapid Chloride Penetration test machine was used to measure the permeability of concrete cube. The chemical properties of the Un-refined fly ash were analyzed by using XRF machine (Bruker-S2 ranger). In the determination of the phases of cement and fly ash pastes A-21-Cu Rigaku XRD machine was used. Scanning Electron Microscope was used for the identification of the images of the mineral composition of Un-refined fly ash and the molecules produced from the hydration reaction. Pot mixer, Test molds (150x150x150mm) and Slump cone were used in the concrete trials. And the Compressive strength machine (ELE 3000kN) was used in the measurement of compressive strength of the concrete cubes.

2.2 Methodology

Un- Refined fly ash sample was collected in a polypropylene bag from power plant and it was sealed and kept in the room temperature. Nippon Pro OPC cement sample which tested as per the SLS ISO 29581-1:2011 Part 1[29] test methods and certified according to the SLS ISO 107:2015 [2] Standard Specification Requirements were collected in the polyethylene bags from Tokyo cement factory and those were sealed and kept in the room temperature. Crushed metal 20mm (Coarse aggregates), River sand (Fine aggregates) were collected from Tokyo Cement Concrete Plant and the fineness properties were tested and assured by the sieve analysis test according to the BS 812:1992 standard [27] method and the satisfied materials were kept in SSD condition. Properly checked and assured chemical admixtures with perfect quality such as Super plasticizer (ESKA21) and Retarder (Daratard17) were collected from Chemical supplier and kept in room temperature. Drinkable water was kept in the room temperature for the use of experiment.

2.2.1 45-micron residue Percentage

As per the ASTM C430 test method [30] 1.00g of sample was taken and it was poured into the 45-micron sieve container. Then it was washed in the pressure line (Pressure-10Bar) for 30 seconds. After that it was dried. Then the weight of the dried sample was taken and the result was calculated.

$$45 \text{ microns } (\%) = \frac{\text{Remain sample weight}}{\text{Sample weight}} * 100 \quad (6)$$

2.2.2 LOI (Loss on Ignition) Percentage

According to the SLS 1247:2015[3], SLS ISO 29581-1:2011 Part 1[29] Initially, 1.00g of sample was taken in a porcelain crucible. Then it was ignited for one hour in the Muffle furnace at 950 ºC temperature. After that the crucible with the ignited sample was removed from the furnace and that was kept in the desiccator to get cool. Then the weight was recorded. The constant mass was recorded by heating again and again for 5 minutes. Finally, the loss on ignition was calculated.

$$\text{LOI } (\%) = \frac{\text{Loss in weight}}{\text{Sample weight}} * 100 \quad (7)$$

2.2.3 Pozzolanacity Test

Pozzolanacity test was done as per the BS EN 196-5:2005[31]. 100ml of freshly boiled water was taken into the polyethylene container and it was sealed and placed in the uniform temperature enclosure for 1 hour until equilibrium is reached. Then the container was removed from the temperature enclosure. After that 20.00 ± 0.01 g of sample was poured into it, using a wide stem funnel. Then the container was sealed immediately and it was shaken vigorously in a horizontal rotary motion for about 20 seconds to avoid formation of cement lumps. After that the container was replaced horizontally in the uniform temperature enclosure. After a period of 8 days in the uniform temperature enclosure, the container was removed and the solution was filtered immediately under vacuum through the Buchner funnel into the vacuum flask

using dry double filter paper in less than 30 seconds. Then the vacuum flask was sealed immediately and it was kept for some time to get cool.

2.2.3.1 Determination of the hydroxyl ion concentration.

The vacuum flask was shaken to homogenize the filtrate. Then 50ml of the solution was pipette out into the 250ml beaker. Then 5 drops of methyl orange indicator were added and it was titrated with the 0.1mol/l dilute hydrochloric acid solution until the color changes from yellow to orange. The titrated solution (A) was kept for the determination of calcium oxide concentration test.

$$[OH^-] = \frac{1000 \times 0.1 \times V_3 \times f_2}{50} \quad (8)$$

Where,

V_3 is the volume of 0.1mol/l hydrochloric acid solution used for the titration, in (ml)

f_2 is the factor of 0.1mol/l hydrochloric acid solution.

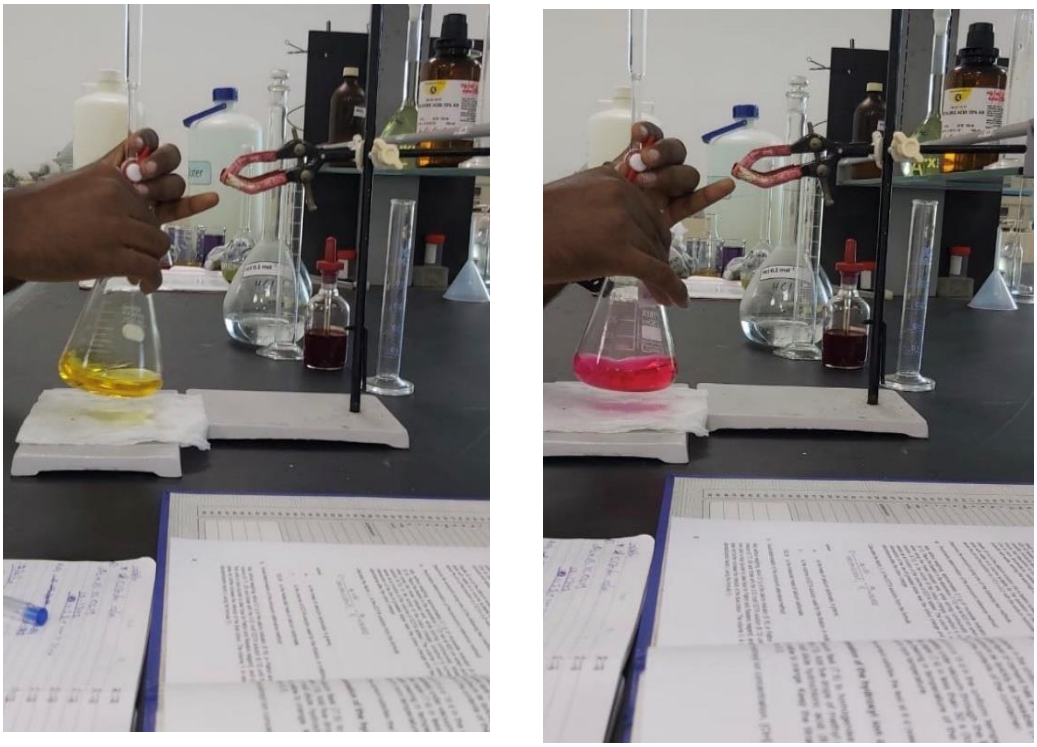

Figure 2: Color change of Methyl Orange

2.2.3.2 Determination of the calcium oxide concentration.

The pH of the titrated solution (A) was adjusted to 12.5 ± 0.2 with sodium hydroxide solution, using pH meter. Then 0.1g of Patton & Reeders indicator was added without weighing. After that the solution was titrated with the 0.03mol/l EDTA solution until the color changes from purple to blue.

$$[CaO]= \frac{1000\times0.03\times V_4\times f_1}{50} \quad (9)$$

Where,

V_4 is the volume of EDTA solution used for the titration, in milliliters;

f_1 is the factor of EDTA solution.

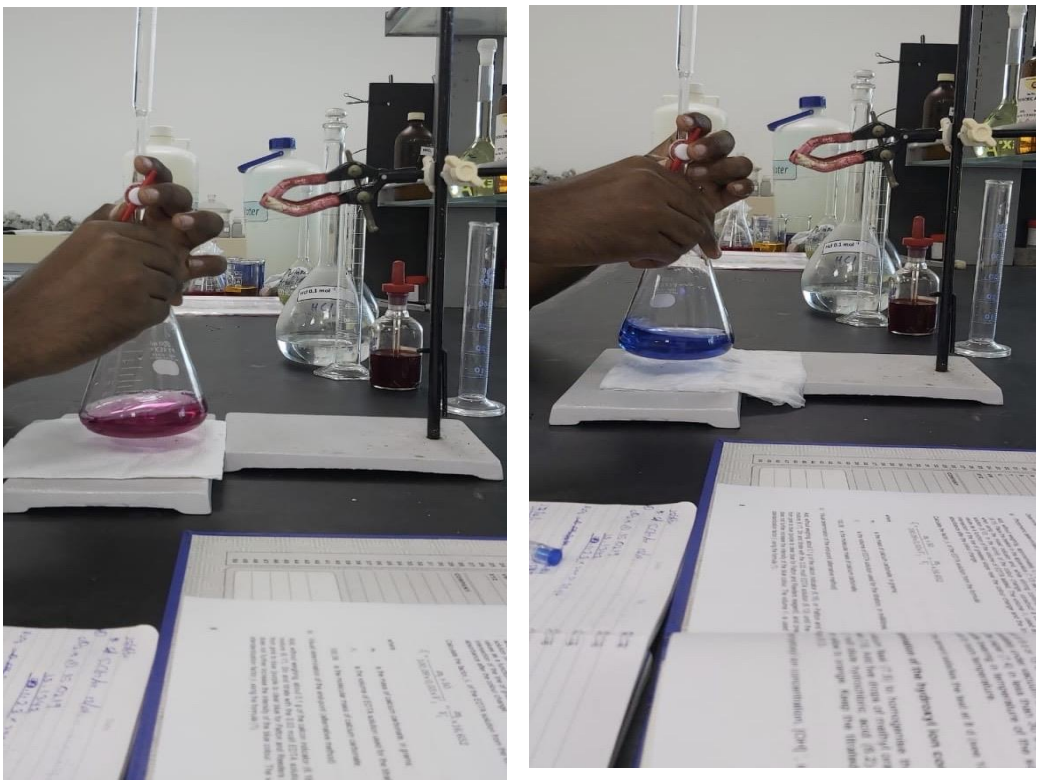

Figure 3: Color change of Patton & Reeders

2.2.4 X-ray Fluorescence Test Methodology (XRF)

Potassium Iodide (0.1000g), Required Fly Ash Sample (2.0000g) and X-ray Flux (8.0000g) were taken. Then they were crushed and mixed properly using Motor and Pestle. After that it was transferred to a Platinum dish and it was kept in the furnace at 1100°C for 3-5 minutes. Then the melted sample was poured into the Platinum mold which was heated using a burner. Then the Bead sample was kept for some time to reach room temperature. Finally, the prepared Bead was placed in the measurement disc and the sample details were fed in the system and it was analyzed using Miniflex XRF machine.

2.2.5 XRD and SEM Characterization

2.2.5.1 Sample Paste Preparation for XRD and SEM Test

Ordinary Portland Cement Sample (372g) and the same sample with the replacement of 60% (223g) of Fly ash were taken. Then they were separately mixed with water and Super plasticizer chemical to make the paste. Then they were placed in the chemical resistance plastic dish for setting. Both plastic dishes with paste samples were kept under perfect curing condition for 28 days and 90 days. After 28 days both OPC cement and fly ash mixed paste samples were taken from the curing cabinet and small piece of OPC cement paste and Fly ash mixed cement paste were removed from it for XRD test and SEM test. Then one part of the sample from both pastes were separately crushed using Motor and Pestle to make the sample with better fineness for XRD test. The same process was done for 90 days sample.

2.2.5.2 X-ray Diffraction Test Methodology (XRD)

The testing samples (OPC sample & Fly ash mixed cement sample) with proper fineness prepared from the paste samples were taken. OPC sample was taken and it was placed in the sample slide properly. Then the sample slide was placed in the sample beam of the Rigaku (A-21-Cu) XRD machine. After that required details were fed in the system and the measurement process was initiated. After finishing the measurement process the measured data was analyzed using PDXL file to get the result values. The same procedure was repeated for the Fly ash mixed cement sample.

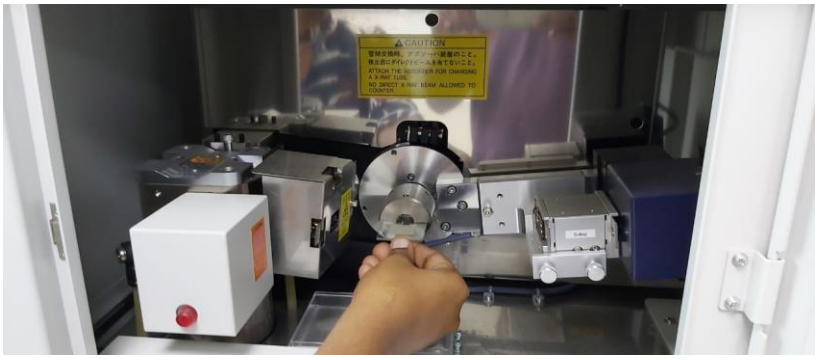

Figure 4: Sampling in XRD

2.2.5.3 Characterization of Scanning Electron Microscope Test

Suitable minute amount of both (OPC sample & Fly ash mixed cement sample) which were removed from the prepared paste were taken accurately. Then OPC paste sample was placed in the sample chamber carefully and the SEM test was initiated in SEM machine (SEM.EVO 18, Carl Zeiss AG, Germany). The emitted secondary electrons were converted into signals. And also, the X-rays and Back scattered electrons were collected by the detectors to produce the final scanned image. The same SEM test procedure was done for fly ash mixed cement paste sample. The final scanned images of both samples were collected from the system.

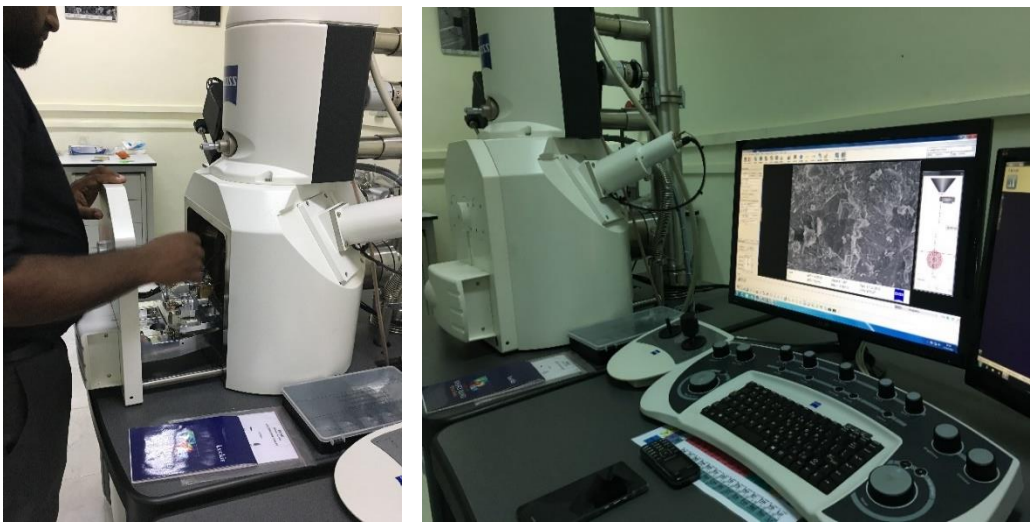

Figure 5: Placing & Characterizing the sample in SEM

2.2.6 Trial mix and molding and demolding of concrete cubes

As per the Table-01 Cement, Sand, Metal, Water and Admixture were weighed and taken according to the control concrete mix design requirements for volume of $0.025m^3$. Then they were placed in the concrete mixer and the concrete mixer was started. Then the initial slump reading value was measured. After that 10% cement material was replaced with the refined fly ash and the water demand was checked and measured to get the same initial slump. Several test trails for different cement samples with the replacement of refined fly ash with 17.74%, 20%, 25%, 30%, 35%, 45% & 60% were carried out and the water demand was measured to satisfy the same initial slump. Then the sample mixtures were casted in the mold and kept under proper temperature and humidity condition for setting. After setting (01 day) demolding was done and the concrete cubes were kept in the curing tank. The concrete cubes were removed from the curing tank and Mortar Compressive Strength Test was carried out and the results were collected by using 3000kN Compression Testing Machine. The Compressive Strength test was done and analyzed for 03 days, 07 days, 28 days, 56 days and 90 days.

Table 01: Control Mix Design

	Cement (kg)	Fly Ash (kg)	Water (kg)	River Sand (kg)	5-20mm Metal (kg)	Retarder D17 (ml)	Super Plasticizer ESKA21 (ml)
$1\ m^3$	372	0	174	841	1090	500	1400
$0.025m^3$	9.3	0	4.35	21.025	27.25	12.5	35

2.2.7 Resist Chloride Ion Penetration Test

The prepared specimen was allowed to surface dry for at least 1 hour. Then the side surface of the specimen was coated properly and it was allowed to cure until it is no longer sticky to the touch. Then the specimen was placed in the vacuum desiccator (both end faces of specimen must be exposed). After that the desiccator was sealed and the vacuum pump was started and it was maintained for 3 hours. Then the separatory funnel tube was immersed into the container with de-aerated water. Then the specimen was covered with de-aerated water by opening the water stopcock

carefully. After that the water stopcock was closed and the vacuum pump was allowed to run for one additional hour. Then the vacuum line stopcock was closed and the pump was turned off. Finally, the vacuum line stopcock was turned to allow air to re-enter desiccator and the specimen was kept under water for 18 ± 2 hours.

The specimen was removed from water after 18 ± 2 hours and the excess water was wiped off. Then the specimen was transferred to a sealed container to maintain the relative humidity in 95% or higher than 95%. After that the specimen was removed from the container and the exposed faces of specimen were covered with rubber. Then the covered specimen was inserted with the two halves of the test cell together to seal. One side of the cell containing the top surface of the specimen was filled with 3.0% NaCl solution. And the other side of the cell was filled with 0.3 N NaOH solution. Then the cell with specimen was attached to the readout apparatus using lead wires and the power supply was turned on. The data was recorded for every 30 min for 6 hours.

$$Q=900(I_0 + 2I_{30} + 2I_{60} + \ldots\ldots\ldots\ldots + 2I_{330} + 2I_{360})$$

Where,

Q- Charge passed (coulombs)

I_0-current immediately after voltage is applied

I_t-current at t min: after voltage is applied

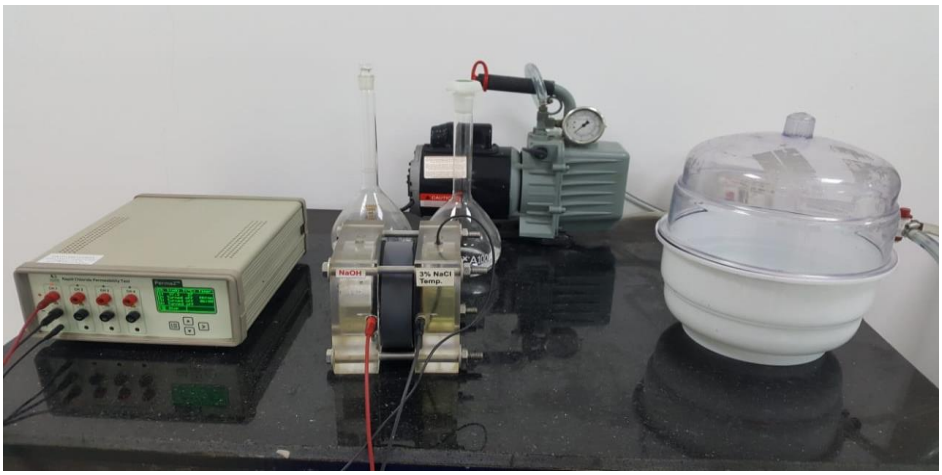

Figure 6: Resist Chloride Penetration test

3 RESULTS AND DISCUSSION

3.1 Fly ash parameters

According to the ASTM C430[31] test method 45-micron residue is 28 percentage. As per the SLS 1247:2015[3], SLS ISO 29581-1:2011 Part 1[32] test method the Loss on Ignition value is 3.5 (% by mass)

Figure 7 indicates the pozzolanic activity. According to BS EN 196-5:2005[33], the calcium ion concentration (mmol/l) and the hydroxyl ion concentration (mmol/l) were calculated. Here fly ash was act as a pozzolanic material and it reacts with the $Ca(OH)_2$ which is coming as a byproduct in the cement hydration. Therefore, during the testing period fly ash reacted with Ca $(OH)_2$, because of this pozzolanic reaction remaining $Ca(OH)_2$ amount is low. The hydroxyl ion concentration is 69.43mmol/l and the calcium ion concentration (expressed as calcium oxide) is 3.74mmol/l. When the test results are plotted, the point is below the curve of calcium ion (expressed as calcium oxide) saturation concentration. Regarding this result it satisfies the test for pozzolanic activity according to BS EN-196-5:2005[33].

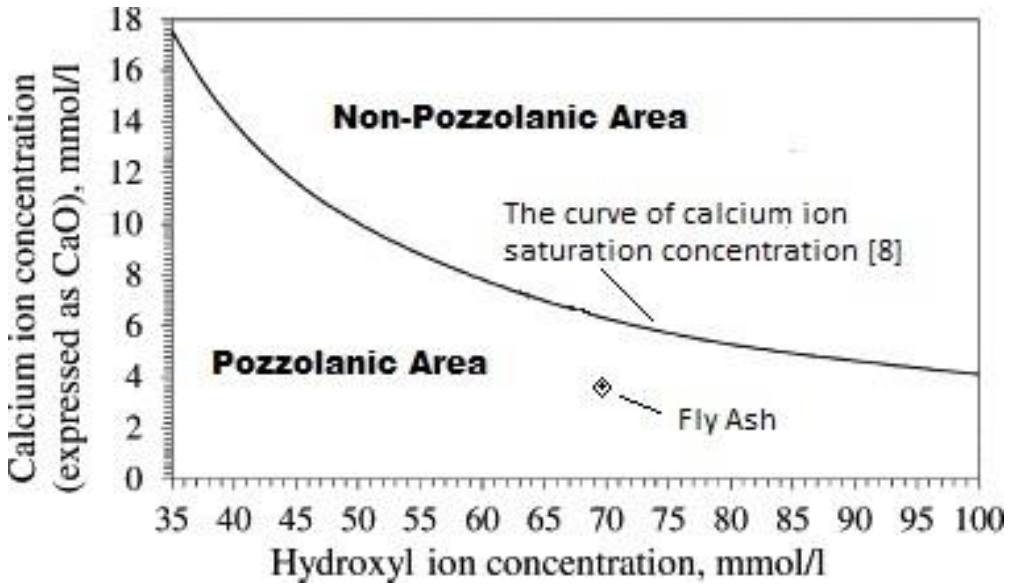

Figure 7: Diagram for assessing pozzolanacity [33]

Table 2 indicates the chemical composition of Raw fly ash. According to the standard ASTM C 618[4]; the total content of sum of $SiO_2 + Al_2O_3 + Fe_2O_3$ is greater than 70% and the Calcium Oxide content is less than 8%, the requirement for reactive calcium oxide shall be deemed to be satisfied. Therefore, the raw fly ash is Class F type fly ash. It was produced from bitumen coal.

Table 02: Chemical Composition of Fly Ash

Parameter	Result
Silica (SiO_2) / % by mass	47.7
Aluminum oxide (Al2O3) / % by mass	28.4
Iron oxide (Fe_2O_3) / % by mass	3.0
Total Calcium Oxide (CaO) * / % by mass	5.2
Magnesium oxide (MgO) / % by mass	0.9
$SiO_2 + Fe_2O_3 + Al_2O_3$ / % by mass	79
Chloride content (Cl^-) / % by mass	<0.01
Total Alkali equivalent as Na_2O/ % by mass	0.7
Sulphate (SO_3) / % by mass	0.6
Reactive Silica (SiO_2) / % by mass	12
Soluble Phosphate (P_2O_5) / mg/kg	1
Loss on Ignition / % by mass	3.5

3.2 X-Ray Diffraction

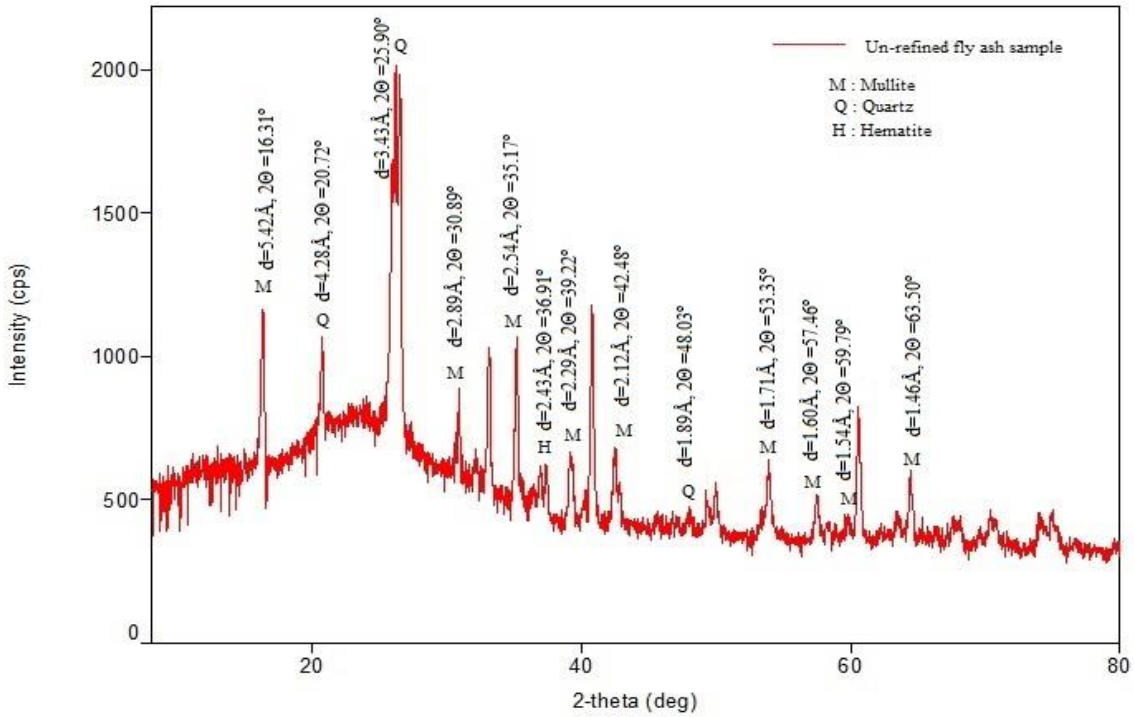

Figure 8: XRD pattern of un-refined fly ash

The raw fly ash sample was subjected to X-ray diffraction. The Figure 8 shows the X-ray diffraction pattern of the raw fly ash. According to the XRD pattern the high peak detects quartz at 25.90 degree of two theta angle with d space of 3.43Å and also most of the peak detect for mullite phase as shown in Figure 8. The small peak of hematite phase detects at 36.91 degree of two theta angle with d space of 2.43Å. This XRD pattern of raw fly ash is relatively same with the reference XRD pattern [34].

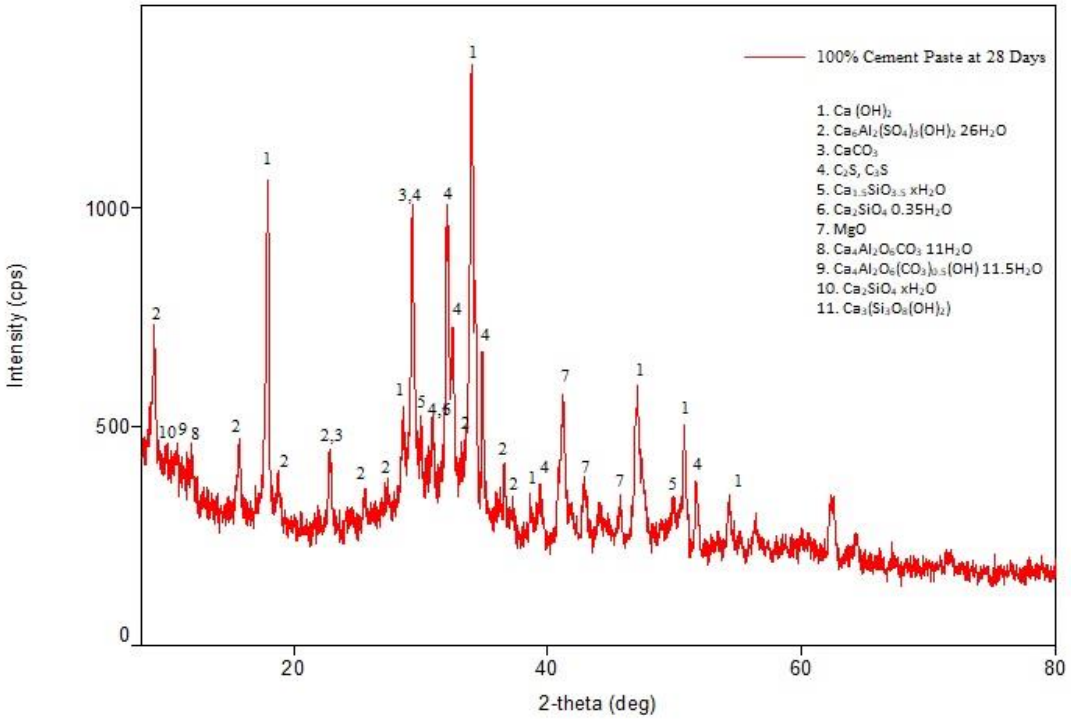

Figure 9: XRD pattern of 100% cement paste at 28 days

The Figure 9 indicates the X-ray diffraction of 100% cement paste after 28 days water curing. The cement sample mostly contain alite & belite peak as well as gypsum before hydration process, and portlantite peak does not observed. (Annex 1) After the hydration process the alite phase transfer as tobomorite phase and initiate the portlandite phase[35]. According to the Figure 9, the high peak value corresponds to portlandite phase because $Ca(OH)_2$ is a large crystalline structure. The peak numbers 5 and 6 correspond to tobomorite phase because the hydrated product has low crystallinity or semi amorphous materials therefore the peak is small and very narrow. The peak number 2 corresponds to ettringite phase. The Figure 9 relatively same with the reference XRD pattern[36].

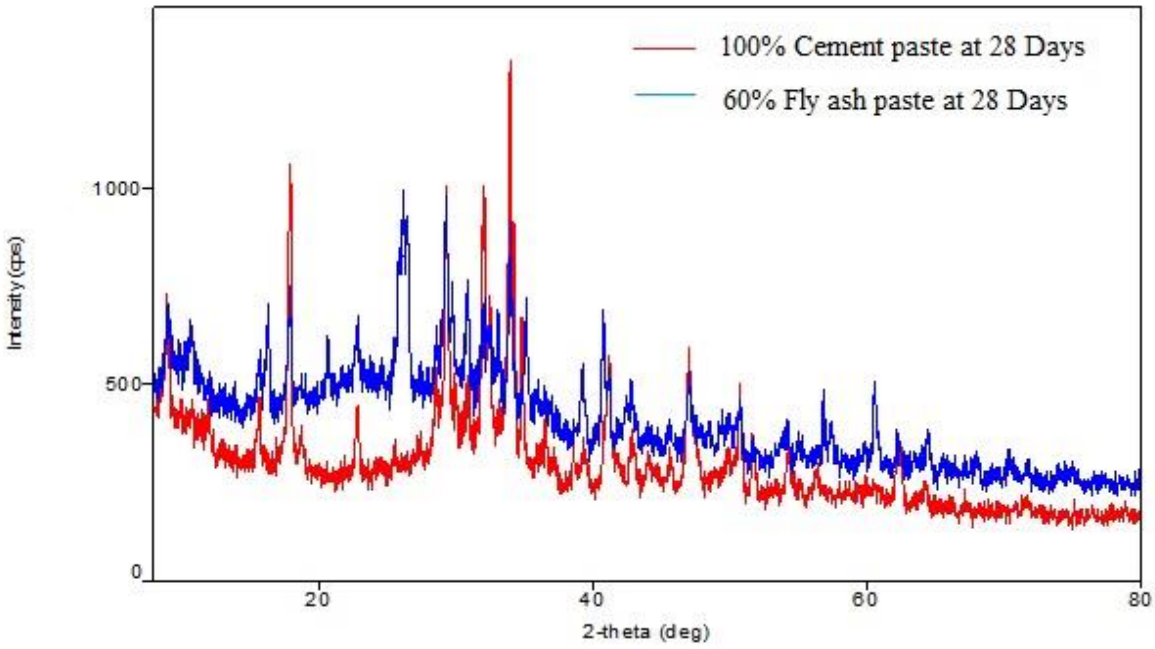

Figure 10: Comparison of XRD pattern between 100% cement paste (Red color) and Cement with 60% fly ash paste (Blue color) at 28 Days

The Figure 10 indicate the comparison of XRD patttern between 100% cement paste and 60% fly ash replaced paste after the 28 days water curing. According to the graph the same peaks are over lapping in both XRD pattern that mean same hydrated products are observed in 60% fly ash paste. There are some specific peaks observed in 60% fly ash paste. It is corresponded to mullite and quartz phase as same in raw fly ash XRD pattern. If compare the portlantite phase in both graph, the peak value of 60% fly ash paste is smaller than 100% cement paste because pozzolanic reaction was started between portlandtite and raw fly ash.

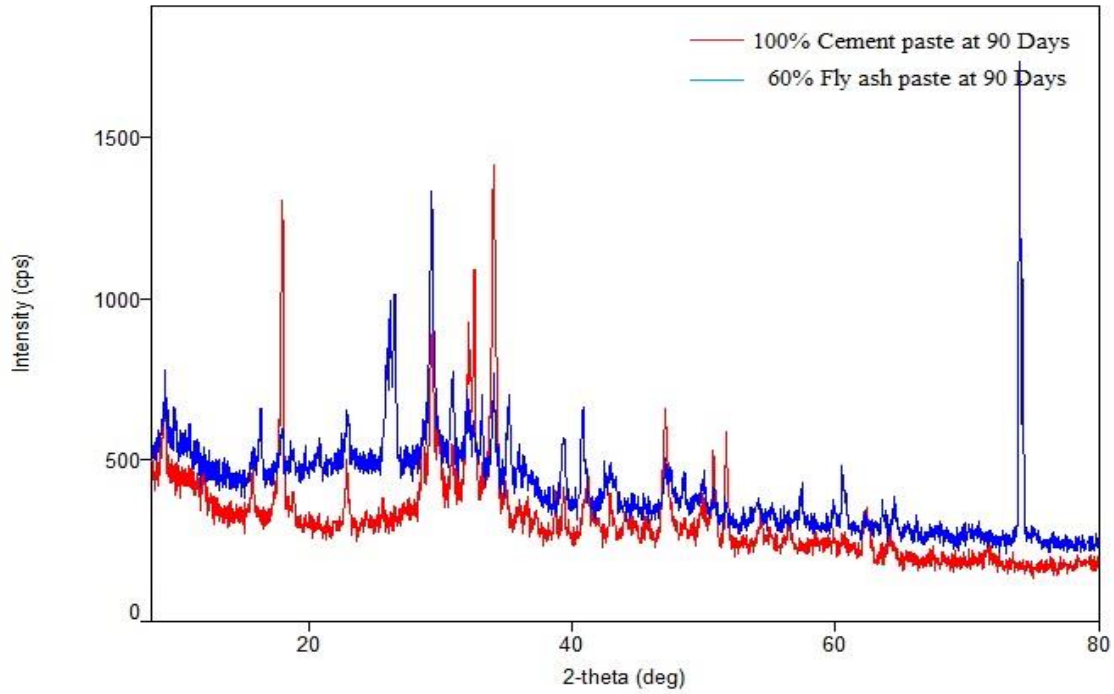

Figure 11: Comparison of XRD pattern between 100% cement paste (Red color) and cement with 60% fly ash paste (Blue color) at 90 Days

The Figure 11 indicate the Comparison of XRD pattern between 100% cement paste and 60% of fly ash replaced paste. According to the figure the portlandite peak value of fly ash paste is very small than cement paste and there are some new peaks can be observed in fly ash paste compare with cement paste therefore fly ash particles also hydrated and produce the hydrate product like Tobermorite.

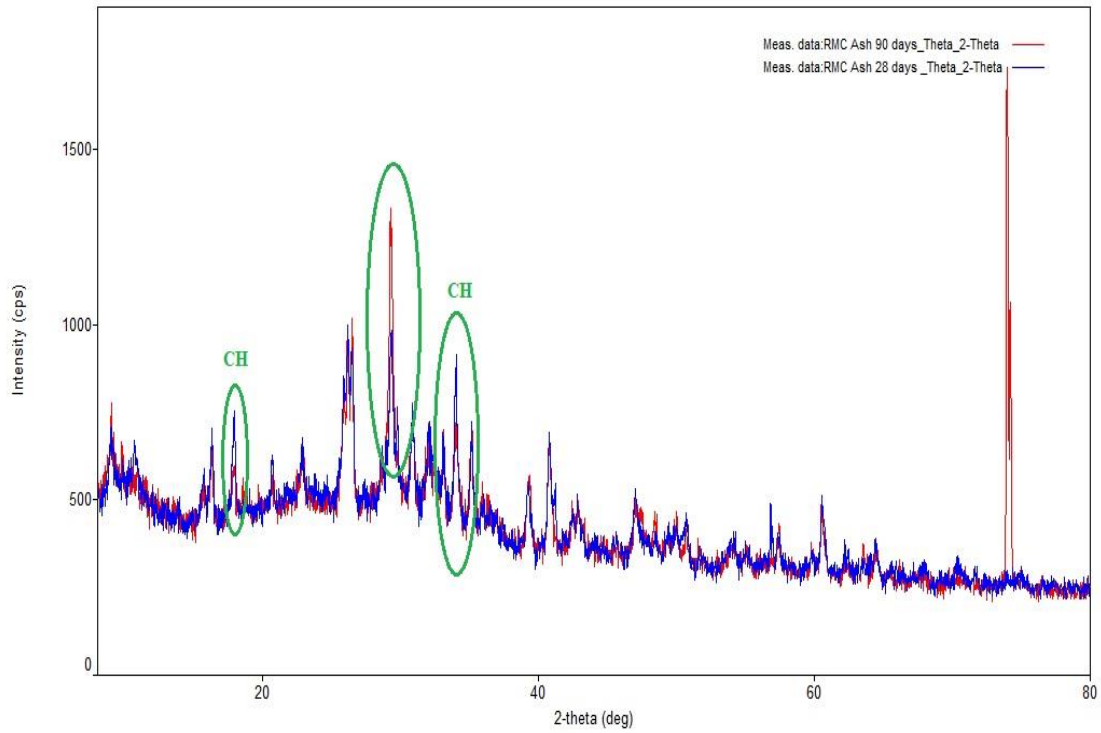

Figure 12: Comparison of XRD pattern between cement with 60% fly ash paste at 28 days and cement with 60% fly ash paste at 90 days

The Figure 12 indicates the comparison between portlandite peak reduction for cement with 60% fly ash paste from 28 days to 90days. Portlandite is a byproduct of cement hydration process which accelerates the pozzolanic reaction. It is clearly proved that the pozzolanic reaction was taken place continuously from 28 days to 90 days because portlandite peak is reducing from 28 days to 90 days.

When the both graphs are compared there is a new high peak value observed in 90 days. This high peak value corresponds to hydrate product of pozzolanic reaction. The same raw fly ash peak values are observed in 90 days because still there are some un reacted fly ash particles are remaining in the cement paste with 60% fly ash paste.

3.3 Scanning Electron Microscope (SEM) Characterization

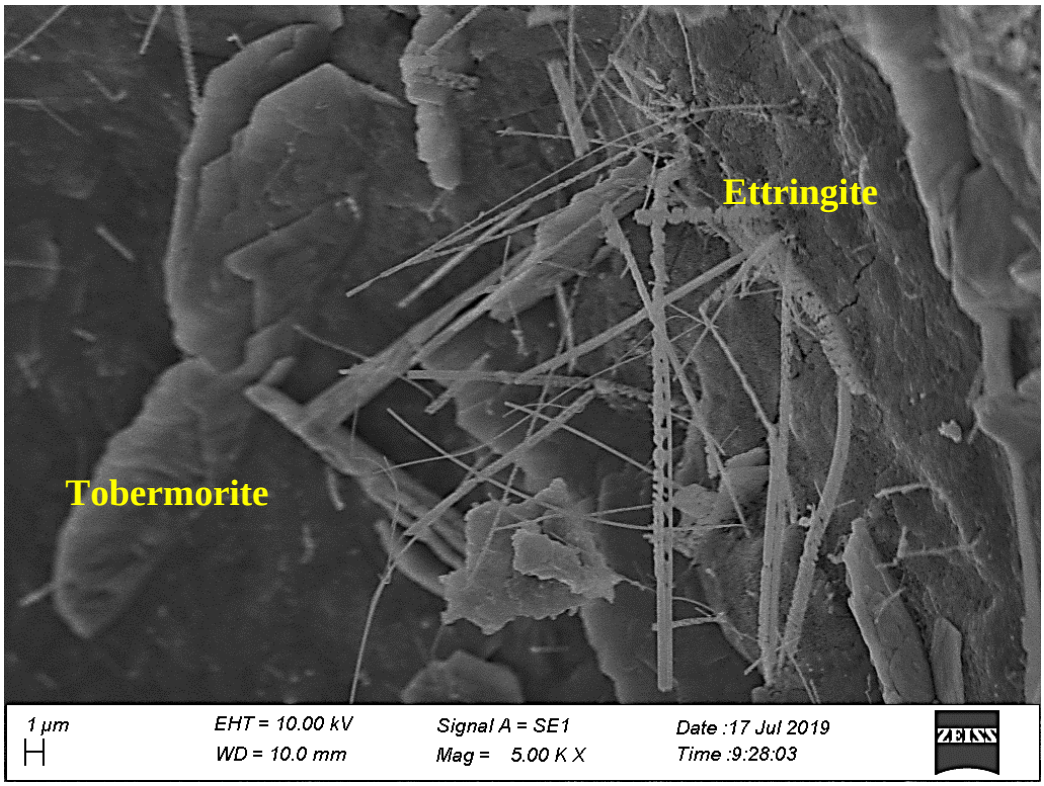

Figure 13: 100% Hydrated Portland Cement sample at 28 days,

The Figure 13 indicates the Scanning microscope image of 100% hydrated cement paste at 28 days. This image was taken at one micrometer level. There are two major phases can be identified. The needles structures are the ettringite at 28 days and that solid structures are the hydrated cement such as Tobermorite structures. There were no any spherical particles observed in the micro structure that mean all the cement particles were reacted and formed Calcium Silicate Hydrate product. Similar SEM studies carried out by Jumate Elena and Manea Daniela Lucia in 2012[35].

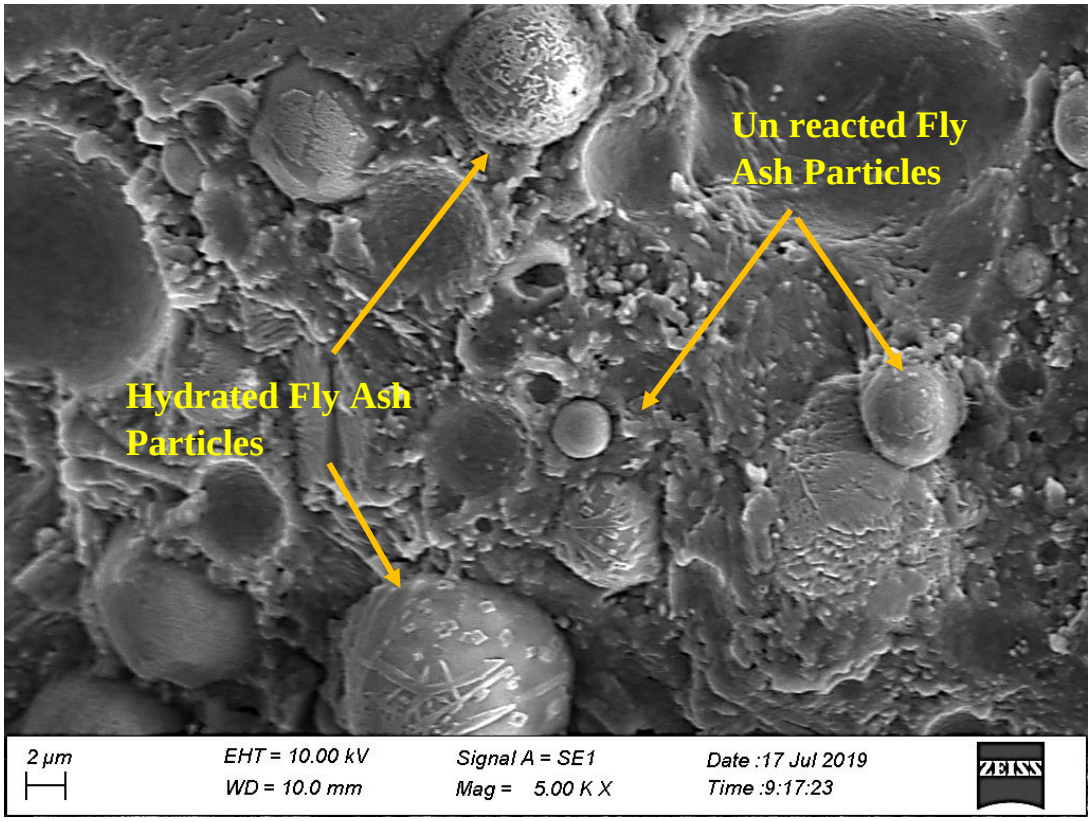

Figure 14: Cement with 60% Fly ash replacement sample at 28 days

The Figure 14 indicates the SEM image of 60% fly ash paste. There can be observed the spherical particles. Pozzolanic reaction was took placed in surface of some spherical particles. Those are the hydrated fly ash particles and some un reacted fly ash particles also shown in Figure 14. Due to the lack of portlandite, excess amount of fly ash particles available in 28 days. These unreacted fly ash particles continuously react with hydration by product and improve the strength of concrete. Similar SEM study carried out by Baoguo M, and Ting Zhang in 2018[28].

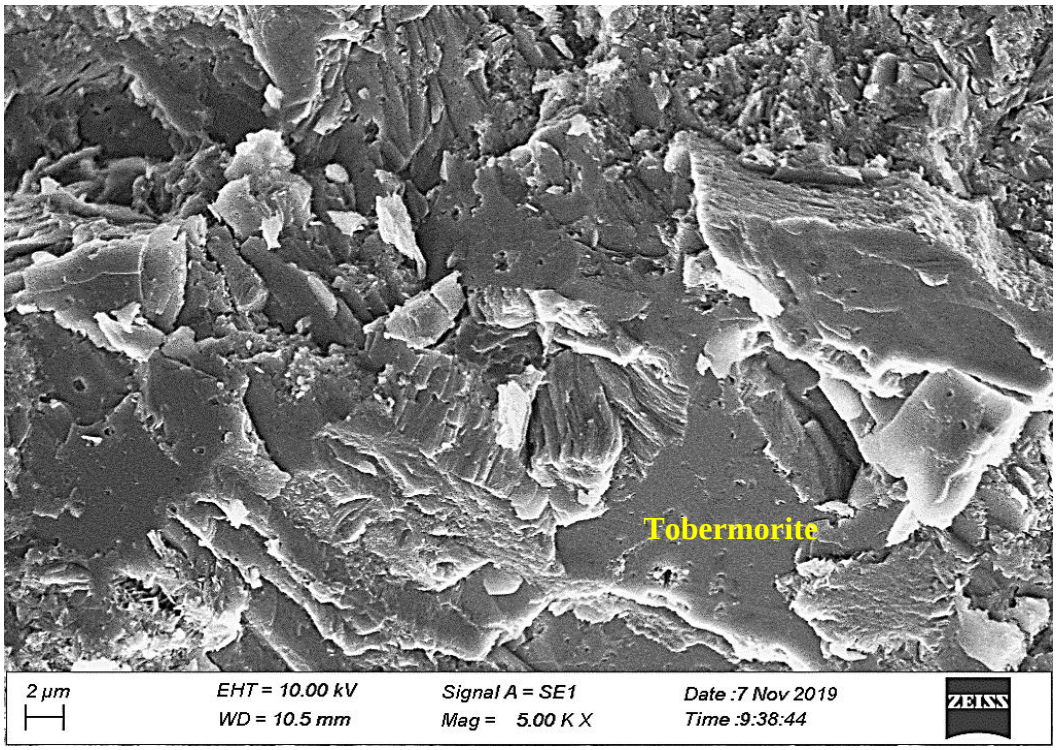

Figure 15: 100% Hydrated Cement paste at 90 days

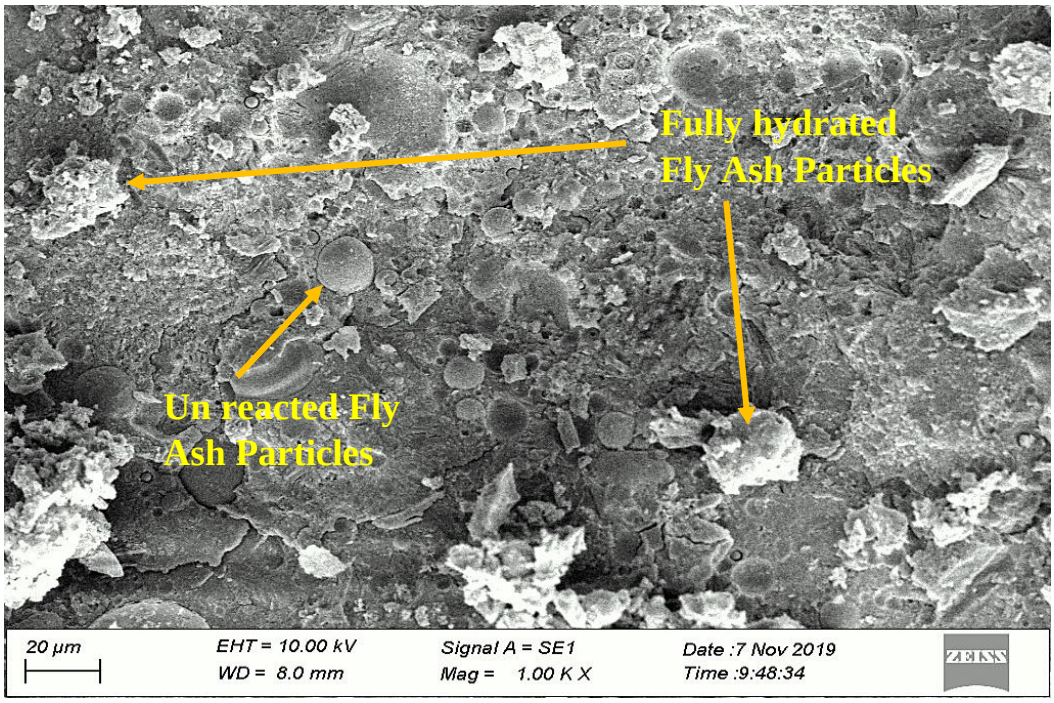

Figure 16: Cement with 60% Fly ash replacement sample at 90 Days

Figure 15 indicates the SEM image of 100% cement paste sample at the age of 90 days. It is similarly same as 28 days structure but the ettringite is not observed and Tobermorite structure is only present. Hydration reaction is completed at this stage therefore no any improvement in strength. The Figure 16 indicates the SEM image of the paste with 60% fly ash replacement at the age of 90 days. Completely hydrated fly ash particles are observed at this stage and still there are some unreacted fly ash particles also available. The strength increases again due to the hydration of fly ash particles after 28 days. When the cement is mixed with the water the hydration reaction will take place. Tricalcium Silicate and Dicalcium Silicate react with water molecules and produce Calcium silicate hydrate (C-S-H) and Calcium hydroxide.

As per the Quantitative XRD analysis of the Ordinary Portland cement (Annex VI) which was taken for the test, nearly 61.4% of Tricalcium Silicate and 18.8% of Dicalcium Silicate are present.

If the calculations were done theoretically, From equation (2) & (3);

The weight of OPC cement which was taken for mix proportion I =149g

So, the weight of Tricalcium Silicate as per the percentage = (61.4×149)/100

= 91.486g

So, the weight of Dicalcium Silicate as per the percentage = (18.8×149)/100

= 28.012g

Moles of Tricalcium Silicate = 91.486g / 228gmol^{-1}

= 0.402mol

Moles of Calcium hydroxide from Tricalcium Silicate = 0.602mol

Moles of Dicalcium Silicate = 28.012g/172gmol^{-1}

= 0.163mol

Moles of Calcium hydroxide from Dicalcium Silicate = 0.081mol

Total moles of Calcium hydroxide coming from the Hydration reaction = 0.602 + 0.081 = 0.683mol

According to the XRD and SEM characterization of 100% cement paste at 28days, certain amount of Calcium silicate hydrate molecules and Calcium hydroxide molecules are present by the hydration reaction and observed. In the Figure 16, SEM

image at 90days certain amount of Fly ash particles are remaining which means the byproduct calcium hydroxide is insufficient for the reaction of the fly ash particles. So, if the calculations were done theoretically as per the fly ash reaction with the byproduct Calcium hydroxide,

According to the table 02; XRF analysis of fly ash consists 47.7% of Silica and 28.4% Aluminum oxide. From equation (4) & (5);
The weight of Fly ash which was taken for mix proportion I = 223g

So, the weight of Silica as per the percentage = (47.7×223)/100
= 106.37g
So, the weight of Aluminum oxide as per the percentage = (28.4×223)/100
= 63.33g
Moles of Silica = 106.37g/60gmol^{-1}
= 1.772mol
Required Moles of Ca $(OH)_2$ for react with Silica = 2.659mol
Moles of Aluminum oxide = 63.33g/102gmol^{-1}
= 0.620mol
Required Moles of Ca $(OH)_2$ for react with Aluminum oxide= 1.86mol
Total moles of Ca $(OH)_2$ requirement for the fly ash reaction = 2.659 + 1.86
= 4.52mol

So, the insufficient moles of Calcium hydroxide = 4.52 – 0.683
= 3.837mol

Therefore, the formed by product Calcium hydroxide is not enough for the reaction with 223g fly ash. Because of this insufficient amount of Calcium hydroxide certain amount of fly ash is remaining in the cement paste at 90days.

3.4. Mix design chart of fly ash replacement

Table 03: Mix design chart for volume of 0.025m^3

Mix Design	A	B	C	D	E	F	G	H	I
ASH REPLACEMENT	0% Fly Ash	10% Fly Ash	17.74% Fly Ash	20% Fly Ash	25% Fly Ash	30% Fly Ash	35% Fly Ash	45% Fly Ash	60% Fly Ash
Grade	G30	G30	G30	G30	G30	G30	G30	G30	G30
Cement (Kg)	9.3	8.37	7.65	7.45	6.975	6.5	6.05	5.125	3.725
Fly Ash (Kg)	0	0.93	1.65	1.85	2.325	2.8	3.25	4.175	5.575
Water (Kg)	4.35	4.25	4.1	4	3.9	3.8	3.8	3.75	3.65
R Sand (Kg)	21.025	21.025	21.025	21.025	21.025	21.025	21.025	21.025	21.025
Metal 20mm (Kg)	27.25	27.25	27.25	27.25	27.25	27.25	27.25	27.25	27.25
Retarder- D17 (ml)	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
Super plasticizer - ESKA21 (ml)	35	35	35	35	35	35	35	35	35
W/C	0.47	0.46	0.44	0.43	0.42	0.41	0.41	0.40	0.39

According to the Table 03 trial mix was carriedout. During the trial mix, 4.35kg of water is required for the control mix design to obtain 135mm of initial slump value as well 0.47 of water-cement ratio. Thereafter, 10% of Cement was replaced with fly ash in mix proportion of 'B'. The mix proportion 'B'contain 10% of fly ash and 90% of cement. Due to the reduction of cement content, the required water content also reduce to obtain same initial slump value of control mix proportion in the presemce of superplasticizer because there are no any reaction occur between fly ash and water in fresh concrete state. Likewise according to the Table 03 the replacement with fly ash goes to 17.74%, 20%, 25%, 30%, 35%, 45% & 60% respectively water content also reduced 4.1kg, 4kg, 3.9kg, 3.8kg, 3.8kg,3.75kg & 3.65kg. Table 04 indicates the mix design chart for 1 cubic meter. The water demand was plotted in Figure 17.

Table 04: Mix design chart for volume of 1m^3

Mix Design	A	B	C	D	E	F	G	H	I
ASH REPLACEMENT	0% Fly Ash	10% Fly Ash	17.74% Fly Ash	20% Fly Ash	25% Fly Ash	30% Fly Ash	35% Fly Ash	45% Fly Ash	60% Fly Ash
Grade	G30	G30	G30	G30	G30	G30	G30	G30	G30
Cement (Kg)	372	334.8	306	298	279	260	242	205	149
Fly Ash (Kg)	0	37.2	66	74	93	112	130	167	223
Water (Kg)	174	170	164	160	156	152	152	150	146
R Sand (Kg)	841	841	841	841	841	841	841	841	841
Metal 20mm (Kg)	1090	1090	1090	1090	1090	1090	1090	1090	1090
Retarder- D17 (ml)	500	500	500	500	500	500	500	500	500
Super plasticizer - ESKA21 (ml)	1400	1400	1400	1400	1400	1400	1400	1400	1400
W/C	0.47	0.46	0.44	0.43	0.42	0.41	0.41	0.40	0.39

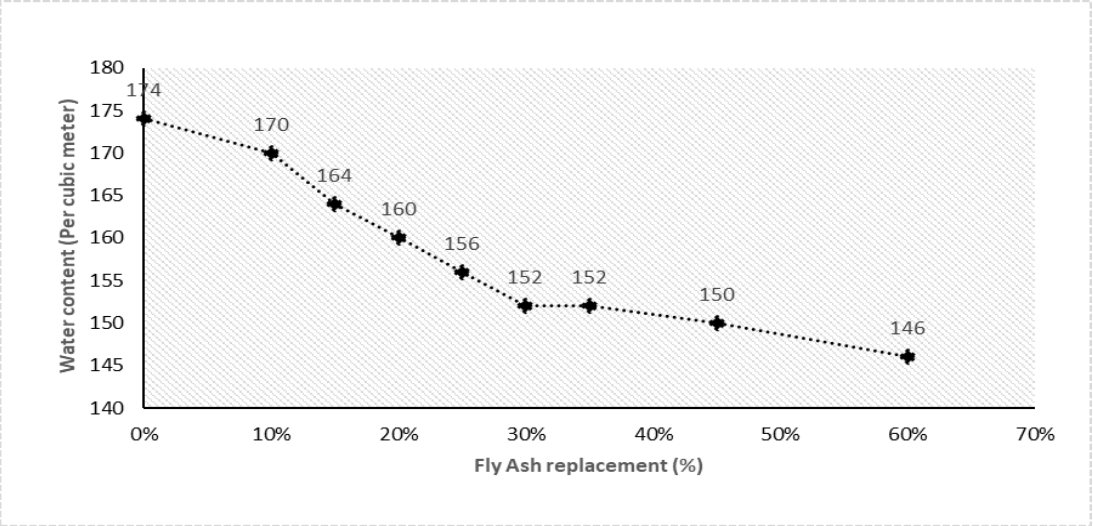

Figure 17: Water content versus fly ash replacement

3.5 Slump retention

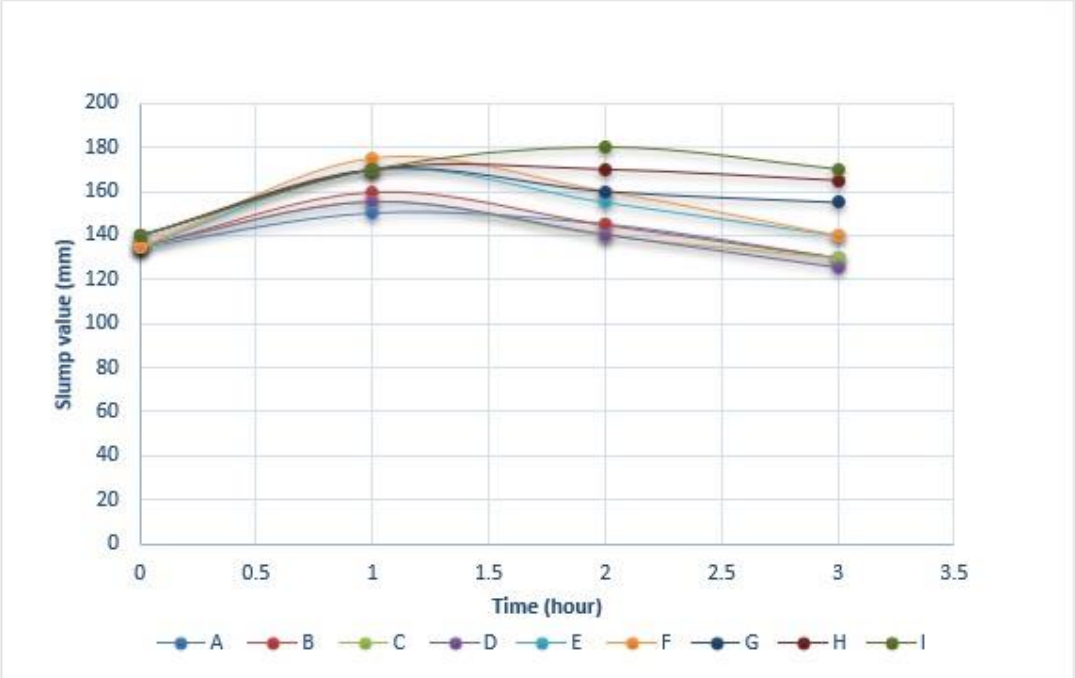

Figure 18: Slump value versus period of time

Figure 18 indicates the slump value versus mix proportions with time period. According to the Figure 18 initial slump value of all the mix design is same as 135±5 mm and the second slump was higher value than initial slump thereafter gradually the slump value was decreased with time. However, in high volume of fly ash replacement has the good slump retention because the blended cement contains less amount of

cement and the initial setting time is extended by 30 to 45minutes this setting delay is improve the slump retention.

3.6 Compressive Strength

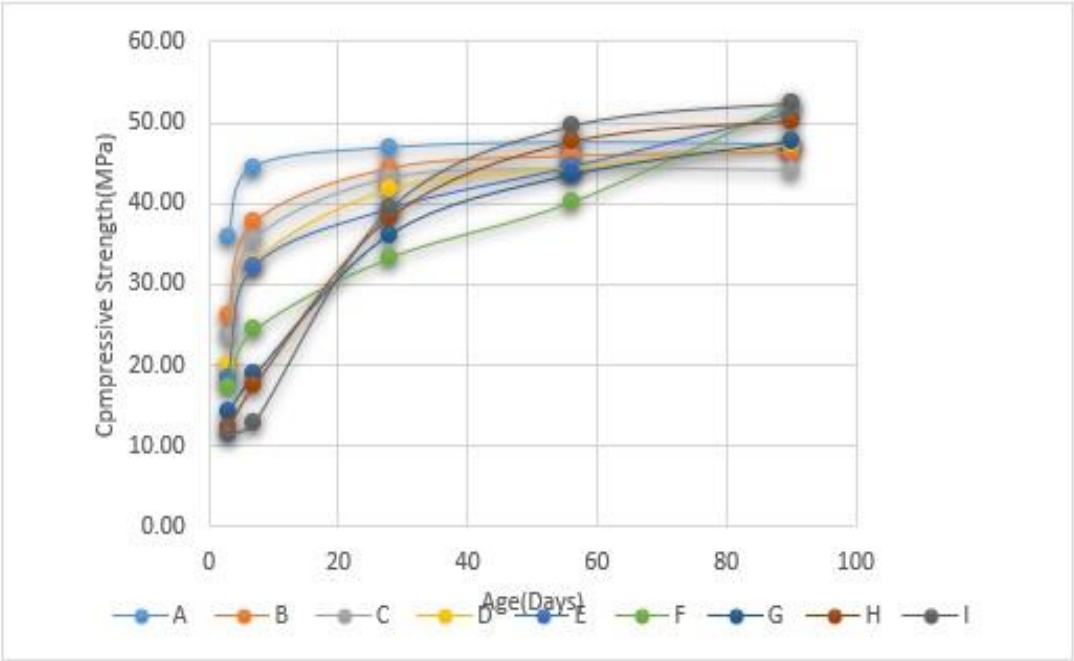

Figure 19: Compressive Strength versus replacement of fly ash percentage

Figure 19 indicates the compressive strength value of each mix proportions against curing period. According to the Figure 19, the control mix design showing higher strength value in early age than other mix designs and after 28 days strength improvement was very low. The early strength was decreased with the amount increase in fly ash percentage, but it showed continuous strength improvement in 90 days. The control mix proportion 'A' has high content of OPC cement particles therefore early age cement hydration was started and formed the Hydration products such as Calcium -Silicate-Hydrate and Calcium hydroxide. Therefore, early age strength was high. After the 28 days hydration reaction was completed therefore no strength improvement obtain from later age in control mix proportion. However, in other mix proportion, amount of OPC cement particles reduced therefore early age hydration products was reduced, in lack of Calcium hydroxide of hydration by product, the fly ash particles were not involved in pozzolanic reaction therefore early age strength was decreased

compare with control mix. In later age the un reacted fly ash particles were reacted with Calcium hydroxide and again formed the Calcium -Silicate-Hydrate. Due to that pozzolanic reaction again strength was increased in later age in 90 days. Increase of fly ash content the later age strength was increased.

3.6 Rapid Chloride Permeability

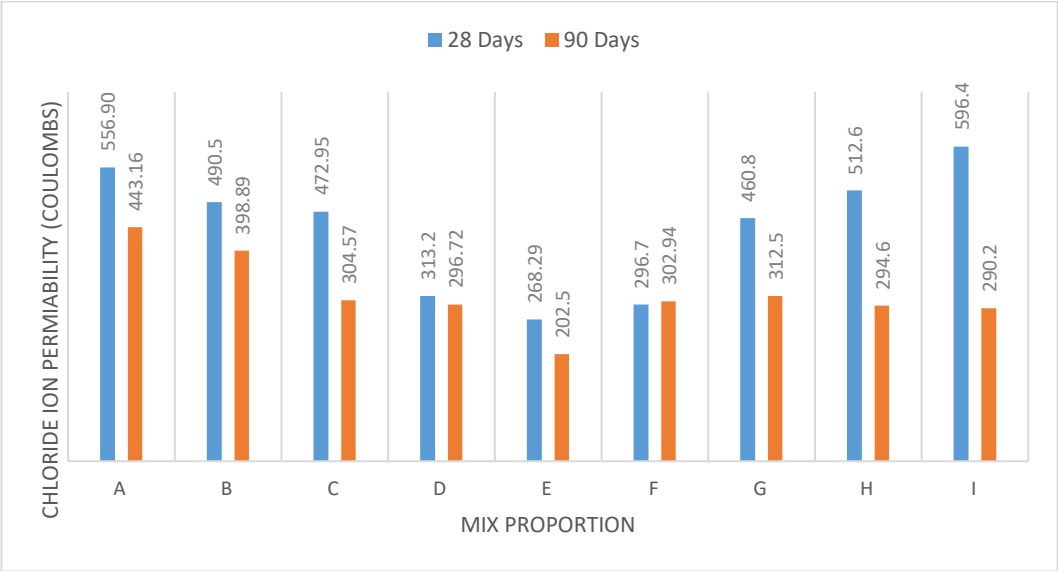

Figure 20: Rapid Chloride Permeability

Figure 20 indicates the chloride ions penetration with the increasing amount of fly ash percentage in mix design. According to the Figure 20 the rapid chloride permeability ion passing values decreased with the increasing of fly ash content up to mix proportion E-25%. Again, value goes to higher in mix proportion F-30%. The hydration products were increased with increasing of fly ash content due to that pozzolanic reaction therefore the porosity of the concrete structure was decreased with increasing of fly ash content in 90days therefore RCP values decreased in 90 days. Compare with 28 days and 90 days the porosity higher in 28 days due to the lack of early age hydration product of calcium hydroxide and the un-reacted excessive fly ash content and it was decreased in 90 days due to that pozzolanic reaction took place in later age. Compare with control sample the 60% replacement of fly ash sample have the lower permeability in 90 days.

4. CONCLUSIONS & RECOMMENDATION

The major byproduct of coal power plant was Class F type fly ash. The fly ash has the pozzolanic properties. It contributes in enhancing long-term compressive strength. The fly ash was activated by calcium hydroxide of cement hydration byproduct. The morphology of fly ash particle was one of major factors in water demand and workability of fresh concrete. The slump retention was improved by this spherical shape of fly ash.

It was confirmed by XRD pattern, the raw fly ash mainly contains quartz and mullite phases. The pozzolanic reaction was taken place in the surface of fly ash particles and it was clearly observed in SEM images.

Low values were observed in Rapid Chloride Permeability test in long term due to the pozzolanic reaction; and hydrated product was formed again and it helped to seal the micro pores in harden concrete and also it reduced the porosity.

Cement can be replaced by fly ash from 30% to 60% in given concrete mix with the support of super plasticizer. Further, there are some unreacted fly ash particles are present in the cement paste with 60% of fly ash replacement at 90 days due to the lack amount of calcium hydroxide from cement hydration. By adding the fly ash activators to the mix, it can enhance the pozzolanic reaction in 90 days.

60% of cement consumption was reduced per one cubic meter concrete and 60% of un-refined fly ash was utilized. From reducing the cement consumption by 60%, the carbon dioxide emission also reduced by 60%.

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Appendix-I

TOKYO CEMENT COMPANY (LANKA) PLC
469 1/1, Galle Road, Colombo 03, Sri Lanka
T: (94 11) 2500466, 2587619, 2592308-9, 2508572
F: (94 11) 2500897, 2508582 E: tokyogm@sltnet.lk
W: www.tokyocement.lk

NIPPON CEMENT
SLS 107

Dear Customer,

We attached test certificate for cement delivered on 15/12/2018.

Report No : B0101/2018

Identification :TCM091218 NIPPON/ Nippon Pro Bulk Cement Sample

Thanks & Regards,

NKThirumal
N.K.Thirumal
Manager QC

Factory:
P.O.Box 2, Cod Bay, China Bay, Trincomalee, Sri Lanka
T: 026-2233291, 026-2233292, 026-2233165, 026-2233166
F: 026-2233293,026-2233163
E: tokyofac@sltnet.lk

Company Registration No: PQ-115

TOKYO CEMENT COMPANY (LANKA) PLC -LABORATORY
P.O.Box No 02, Cod Bay, China Bay, Trincomalee, Sri Lanka.
Tel: (94 26) 2233291, 2233292, 2233165, 2233166
Fax: (94 26) 2233293, 2233163
E-mail: thirumal@tokyocement.lk

SLAB ACCREDITED
ISO/ IEC 17025
TL 044-01

TEST REPORT ON ORDINARY PORTLAND CEMENT

Report No	: B0101/2018
Report genareted on	: 12/12/2018
Sample Received on	: 10/12/2018
Sample Description	: 5 kg Cement in sealed Polythelene bag
Customer Name	: Tokyo Cement Company(Lanka) PLC Delivery Department
Identification / Commodity	:TCM091218NIPPON/ Nippon Pro Bulk Cement Sample
Period of testing	: 10th to 12th December 2018

CHEMICAL TEST RESULTS

CHEMICALCOMPONENTS	Units	TEST RESULTS	MU (±)	SLS 107 - 2015 SPECIFICATIONS	Method
Insoluble Residue	(%)	0.90	0.04	Max : 5.00	SLS ISO 29581-1 : 2011
Loss on Ignition	(%)	2.14	0.49	Max : 5.00	SLS ISO 29581-1 : 2011
Sulphur Tri Oxide (SO_3)	(%)	2.26	0.08	Max : 3.50	SLS ISO 29581-1 : 2011
Choloride (Cl^-)	(%)	0.01	0.001	Max : 0.10	SLS ISO 29581-1 : 2011

PHYSICAL TEST RESULTS

PHYSICAL PROPERTIES	Units	TEST RESULTS	MU (±)	SLS 107 - 2015 SPECIFICATIONS	Method
Specific Surface Area	(cm^2/g)	3330	78		TCLM1 (SLS 107 :Part 2 :2008)
MORTAR COMPRESSIVE STRENGTH	(N/mm^2)				
2 Days		23.9	1.92	Min : 10.0	SLS ISO 679 : 2011
28 Days		under testing	1.94	42.5 - 62.5	SLS ISO 679 : 2011
SETTING TIME					
Standard Consistency	(%)	30.60	_		SLS ISO 9597 : 2011
Initial Setting Time	(h-m)	2:24	0:06	Min : 1 hour	SLS ISO 9597 : 2011
EXPANSION					
Soundness (Le' Chaterlier's Method)	(mm)	1	0.05	Max : 10	SLS ISO 9597 : 2011

Conditions:
This report refers specifically to the test item(s) submitted. Test report shall not be reproduced in total or in part without (Laboratory) written approval from Manager Quality Control.
The Laboratory is not responsible for sampling.

N.K.Thirumal
Manager Quality Control

Appendix - II

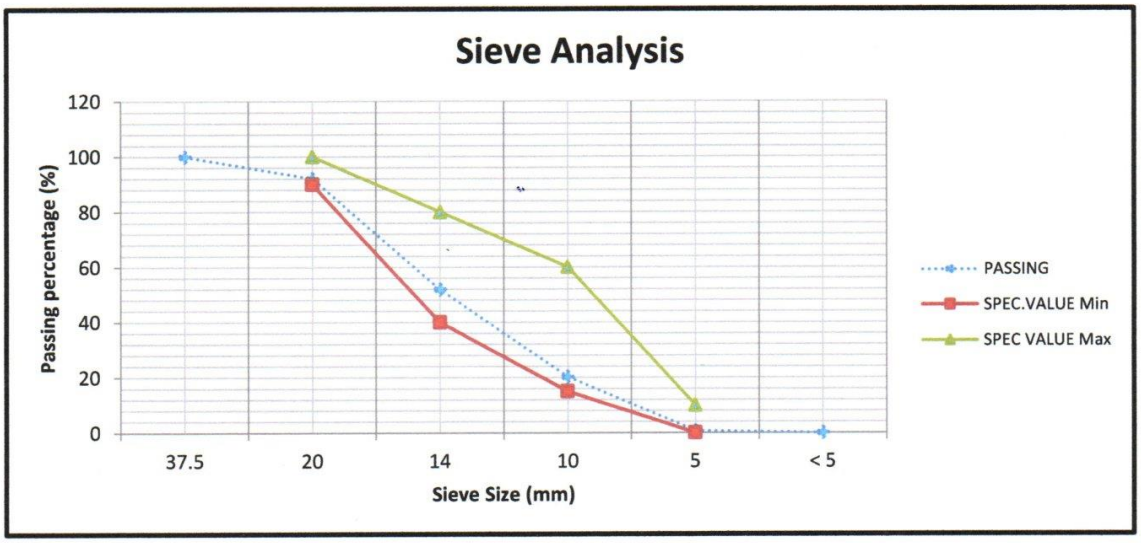
TOKYO SUPERMIX	SUPER MIX Ready-Mixed Concrete Plant Tokyo Supermix (Pvt) Ltd Trincomalee	Document Format FRMC - 02

TEST REPORT - METAL

Supplier :	**Southern Group**	DATE OF SAMPLE:	16.12.2018
Quarry :	**Vilhamvihara**		
TYPE : METAL (Graded Aggregate)		DATE OF TESTING:	16.12.2018
Vehicle No:	**LJ 7389**		

SIEVE NO. MM	WEIGHT OF (RETAINED (g)	% RETAINED	CUM RETAINED	PASSING	BS 882 : 1992 SPEC.VALUE Min	BS 882 : 1992 SPEC VALUE Max
37.5	0	0.00	0	100		
20	158	7.91	7.91	92.09	90	100
14	802	40.14	48.05	51.95	40	80
10	633	31.68	79.73	20.27	15	60
5	390	19.52	99.25	0.75	0	10
< 5	15	0.75	100.00	0.00		

Total weight : 1998.00 g



Comments:.....

.....

.....
Quality Controller

.....
Plant Manager

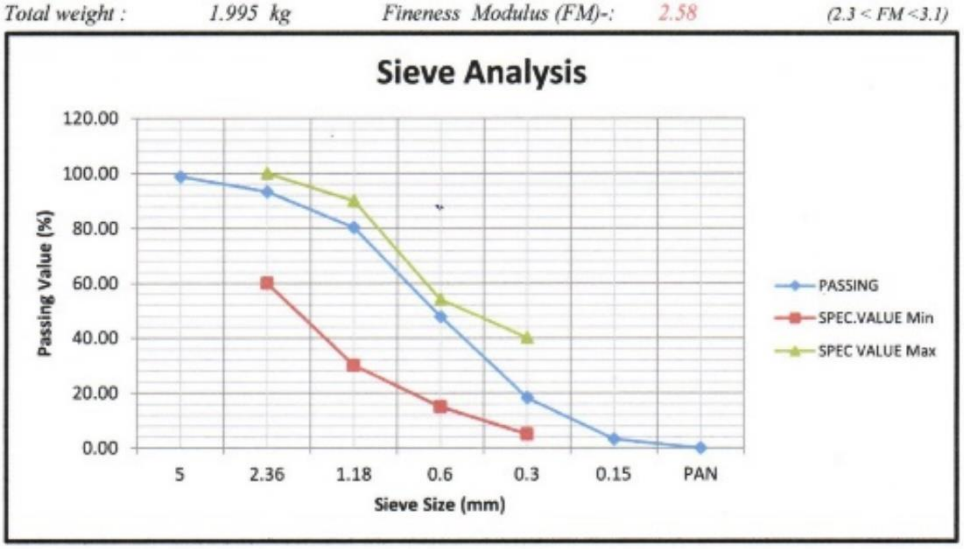
Appendix - III

TOKYO SUPERMIX	SUPER MIX Ready-mixed concrete plant Tokyo Supermix (Pvt) Ltd Trincomalee	Document Format FRMC - 01

TEST REPORT - SAND

Supplier: Stock Pile			DATE OF SAMPLE:		16.12.2018	
TYPE : River Sand			DATE OF TESTING:		16.12.2018	
					BS 882 : 1992	
SIEVE NO. MM	WEIGHT OF (RETAINED (kg)	% RETAINED	CUM RETAINED	PASSING	SPEC.VALUE Min	SPEC VALUE Max
5	0.024	1.20	1.20	98.80		
2.36	0.109	5.46	6.67	93.33	60	100
1.18	0.260	13.03	19.70	80.30	30	90
0.6	0.649	32.53	52.23	47.77	15	54
0.3	0.588	29.47	81.70	18.30	5	40
0.15	0.300	15.04	96.74	3.26		
PAN	0.065	3.26	100.00	0.00		

Total weight : *1.995 kg* *Fineness Modulus (FM)-:* *2.58* *(2.3 < FM <3.1)*



Comments.:.....

.....

.....
Quality Controller

.....
Plant Manager

Appendix- IV

MahaChem
market innovation

Maha Chemicals (Asia) Pte Ltd
61 Tuas West Drive, Singapore 638415
Tel +65 6863 1808
Fax +65 6863 1819
sales@mahachem.com

CERTIFICATE OF ANALYSIS

Product : ECONEX BRAND CONCRETE ADMIXTURE ESKA-21
Lot No. : JKA2118100201
Date : 2018-10-05
Quantity : 12,320 KG

8

Inspection characteristics/ - method		Specification	Result of Analysis
Appearance	VISUAL	Aqueous viscous liquid	Aqueous viscous liquid
Non-volatiles	KS M 0009	59.0 ~ 61.0 (wt.%)	60.0
Specific gravity (25°C)	KS M 0004	1.060 ~ 1.160	1.110
Viscosity (25°C)	KS M ISO 2555	350 ~ 1000 (cPs)	695
pH (25°C)	KS M 0011	3.5 ~7.5	5.21

Conclusion:

We hereby certified that the goods tested and passed the above specifications.

- This is a system generated document, no signature required -

This is property of St. Anthony's Hardware (Pvt) Ltd.

ST. ANTHONY'S HARDWARE (PVT) LTD.
No. 524, Sri Sangaraja Mawatha,
Colombo 10.

Appendix V

gcp applied technologies

Certificate of Analysis

Jurong

26 Tanjong Penjuru
Singapore 609024

COA Number: August 2019 / DTD 17

Date: 22 August 2019

Lot Number: SJT08-0435-01 to 02

Product Name: DARATARD 17
Spec: BS EN 934-2

Date of Manufacture: Aug 2019

Property	Property Local	UOM	Lower Limit	Upper Limit	Result
Appearance: Dark Brown Liquid					Pass
pH (SJ-pH-B-73-1)			8.0	8.0	7.54
Relative Density (SJ-SG-B-33-1)		g/ml	1.220	1.280	1.245
Dry Material Content Level (SJ-TS-B-27-1)		%	47.5	52.5	50.37

Approved by: Chian-Kien Ng

Quality Representative: Chian Kien Ng

This is an electronic approval:

Chian Kien Ng

Water Soluble Chlorids (a), (b), (c), (EN 480-10:2009): 0.53% (Spec: Max 0.65).

Type: Watering-Reducing Initial Set Retarder

This is property of St. Anthony's Hardware (Pvt) Ltd.

29/11/19

ST. ANTHONY'S HARDWARE (PVT) LTD.
No. 524, Sri Sangaraja Mawatha,
Colombo - 10.

Printed By: ckng

Page 1 of 1

Printed On: 22 August 2019

INDUSTRIAL TECHNOLOGY INSTITUTE (ITI)

P. O. Box, 787, 363, Bauddhaloka Mawatha, Colombo 7, Sri Lanka.
Telephone: 0094 011 2379800 Fax: 0094 011 2379850
120/4 A, Vidya Mawatha, Colombo 7, Sri Lanka.
Telephone: 0094 011 2379800 Fax: 0094 011 2379950

TEST REPORT

Report No. SS 1809834

Report to :

St. Anthonys Hardware (Pvt) Ltd.
No:524, Sri sangaraja Mawatha,
Colombo 10..

Issued By :

Materials Laboratory,
Industrial Technology Institute,
363, Bauddhaloka Mawatha,
Colombo 07.

2018-07-06

ST. ANTHONY'S HARDWARE (PVT) LTD
No. 524, Sri Sangaraja Mawatha
Colombo - 10.

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LITIGATION: All costs associated with litigation or dispute for oral or written testimony or preparation of same or for any other purpose related to work provided by the ITI shall be paid by the customer. Such costs include, but are not limited to hourly charges, travel and accommodation, mileage, counsel, legal fees and all other expenses associated with the said litigation and dispute.

CHANGE OF CONDITIONS: ITI may at its sole discretion add to or amend the conditions of this report at the time of issue of the report and such additions or amendments shall be binding on the customer.

ST. ANTHONY'S HARDWARE (PVT) LTD
No. 524, Sri Sangaraja Mawatha,
Colombo - 10.

... Continuation Sheet

TEST REPORT

Report No. SS 1809834

Customer : St. Anthonys Hardware (Pvt) Ltd, No:524, Sri sangaraja Mawatha, Colombo 10..	**Test Item :** Admixture **Service Required :** Customer's letter dated 2018-06-11
Description : One (01) test item.	**Identification of Test Item :** Test item was labelled as: Product – DARATARD 17 **Date of Receipt of Test Item :** 2018-07-03
Test Dates : 2018-07-05	

TEST RESULTS:

Test / Unit	Test Method	Sample	Requirements BSEN 934-2: 2001
1. Relative density at 27 °C	BSEN 934 -2 : 2001	1.24	D± 0.03 if D>1.10 D± 0.02 if D≤1.10 Where D is manufacture's stated value
2. pH at 20 °C		7	Manufacturer's Stated value ± 1 or within manufacture's stated range

Authorized Signatory
C.N. Vitharana
Research Engineer
Materials Laboratory
2018-07-06
-/lp

P.A.R.S. Kumarage
Assistant Research Technologist

Page 03 of 03 pages

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23/11/18

ST. ANTHONY'S HARDWARE (PVT) LTD.
No. 524, Sri Sangaraja Mawatha,
Colombo - 10.

Appendix - VI

Quantitative Analysis Results (WPPF)

General information

Analysis date	2019/01/12 12:56:01		
Sample name	RMC Nippon Pro 091218	Measurement date	2019/01/12 10:53:00
File name	RMC Nippon Pro 091218 _Theta_2-Theta.asc	Operator	
Comment			

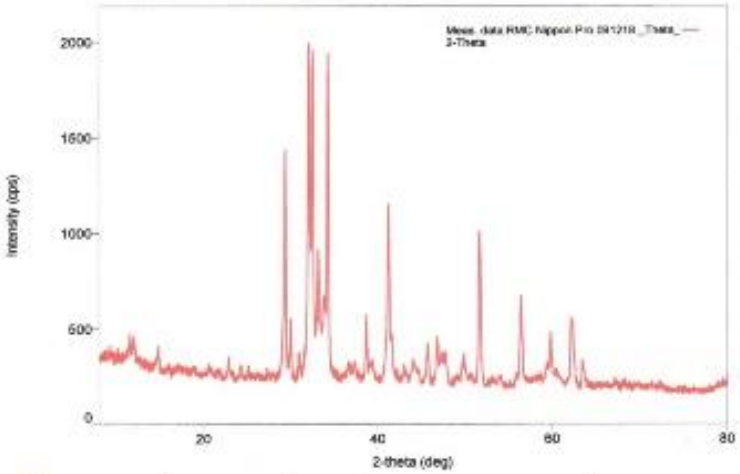
Qualitative analysis results

Phase name	Formula	Figure of merit	Phase reg. detail	DB card number
0107_C3S-Mono.M3	Ca3 (Si O4) O	0.605	User	7
0209_C2S-Mono.B_J	Ca2 (Si O4)	1.286	User	17
0305_C3A-Cubic_JC	Ca9 (Al2 O6)3	1.100	User	25
0306_C3A-Ortho._JC	Ca3.13 Na0.87	1.215	User	26
0403_C4AF-Ortho._J	Ca2 Fe Al O5	1.260	User	29
1101_Portlandite	Ca (O H)2	3.001	User	41
0601_W2.0(Gypsum)	Ca (S O4) (H2 O)2	1.372	User	32
0703_W0.50(Bassani	Ca (S O4) (H2 O)0.5	1.558	User	36

Weight ratio

	Phase name	Content(%)
-	0107_C3S-Mono.M3_JCA	61.4(4)
-	0209_C2S-Mono.B_JCA	18.8(5)
-	0305_C3A-Cubic_JCA	5.69(18)
-	0306_C3A-Ortho._JCA	3.49(19)
-	0403_C4AF-Ortho._JCA	8.29(15)
-	1101_Portlandite	0.44(8)
-	0601_W2.0(Gypsum)	1.88(19)
-	0703_W0.50(Bassanite)	0.00(16)

Measurement profile



This sample was tested at Tokyo Cement Company (Lanka) PLC - Laboratory by using Rigaku XRD machine (miniFlex 600 A-21-Cu)

NUThinmal 17/01/2019.

MANAGER
QUALITY CONTROL
TOKYO CEMENT CO. (LANKA) LTD.