ECO-FRIENDLY UTILIZATION OF RICE HUSK ASH AND BAGASSE ASH BLEND AS PARTIAL SAND REPLACEMENT IN SELF-COMPACTING CONCRETE

MS STRUCTURES THESIS DISSERTATION

BY

Muhammad Hamza Hasnain

MS-2016-00000170994

SUPERVISOR

Dr. Ather Ali

National Institute of Civil Engineering (NICE)
School of Civil and Environmental Engineering (SCEE)
National University of Science & Technology (NUST), Islamabad, Pakistan

2020

This is to certify that Thesis titled

ECO-FRIENDLY UTILIZATION OF RICE HUSK ASH AND BAGASSE ASH BLEND AS PARTIAL SAND REPLACEMENT IN SELF-COMPACTING CONCRETE

Submitted by

Muhammad Hamza Hasnain

Fall 2016-MS Structural Engineering
00000170994

Has been accepted towards the partial fulfillment

of

The requirements for award of

degree of

Master of Science in Structural Engineering

Thesis Supervisor

Dr. Ather Ali

Assistant Professor

Department of Structural Engineering

NUST Institute of Civil Engineering (NICE)

National University of Sciences and Technology (NUST)

Islamabad Pakistan

THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS thesis written by **Mr. Muhammad Hamza Hasnain**, Registration No. **00000170994**, of MS Structural Engineering **2016** Batch (NICE) has been vetted by undersigned, found completed in all respects as per NUST Statutes/Regulations, is free of plagiarism, errors, and mistakes and is accepted as partial fulfilment for award of MS degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have been incorporated in the said thesis.

Signature: ___________________________

Name of Supervisor: **Dr. Ather Ali**

Date: _______________________________

Signature: ____________________________

Head of Department: **Dr. Rao Arsalan Khushnood**

Date: _______________________________

Signature: ____________________________

Dean: **Dr. S. Muhammad Jamil**

Date: ________________________________

DEDICATED

TO

HOLY PROPHET (SAW)

AND

MY LOVING PARENTS

WHO GAVE ME A LOT OF INSPIRATION

&

COURAGE

ACKNOWLEDGEMENTS

“**In the name of Allah, the most beneficent the most merciful**”

I am extremely grateful to my supervisor Dr. Ather Ali and H.O.D Dr. Rao Arsalan Khushnood for providing me an opportunity and enabling me to take a deep insight into structural sciences as a specialized subject. Their able guidance and encouragement steered me to think beyond visible facts to bring more useful and applicable conclusions from the work in hand. Their pleasant and friendly conduct facilitated me to discuss my view point on the subject in detail and addressed my queries to my entire satisfaction.

It is worth to mention here that completion of this research work was only possible due to the co-operation of my committed and supportive colleagues. Besides my supervisor and committee members, I would also like to thank my friends especially Engr. Saeed Zafar and Engr. Usman Javed for supporting me throughout my research work.

I appreciate the support provided to me by my family as this research work would not have been completed without their prayers and whole-hearted encouragement and support.

ABSTRACT

Self-compacting concrete (SCC) is largely used construction material worldwide, uplifting the demand of river sand along all of its constituents due to the recent construction boom. Rice husk ash (RHA) and Bagasse ash (BA) are the biomass waste of the abundantly produced crops in Pakistan, which causes several cardiovascular diseases to humans and poses threats to degrade air quality as well. Therefore, this research aims to study the effect of environmental friendly substitution of river sand with blended waste ashes of RHA and BA on microstructural, fresh, physicomechanical and sulfate resistance of SCC. The results of microstructural characterization revealed that the adsorptive natured siliceous micro-sized particles contribute toward higher water demand in SCC. The microstructural investigation of SCC mixes containing blended ashes of RHA and BA was conducted by Scanning Electron Microscopy (SEM) to find the hydration phases. Based on their calcium to silica (Ca/Si) ratios determined from Energy Dispersive X-ray Spectroscopy (EDX), the results shows the formation of secondary Calcium Silicate Hydrate (CSH) gel. The rheological properties including slump flow, J-ring, L-box, V-funnel, and air content tests were conducted in the fresh state to study its flow ability, passing ability, filling ability. The results of rheological properties revealed that the fluidity of SCC mixes reduced due to porous nature of incorporated ashes, whereas the viscosity of the mixes improved upon the incorporation of blended ashes. The physicomechanical properties include water absorption, hardened density, compressive strength, and split tensile strength. The physicomechanical properties revealed that the 20% collective replacement of incorporated waste ashes produced structural lightweight concrete with the compressive strength and hardened density values of 20MPa and 1816 Kg/m^3, respectively. Conclusively, the ecofriendly utilization of blended ashes of RHA and BA improved the viscosity, physicomechanical properties and sulfate resistance of SCC.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

1.1. General

Concrete is a composite material obtained by mixing binder, water, aggregates and chemical or mineral admixtures. It is universally used as construction material and over the years concrete has become best suited material for construction because of its economy, durability and ability to cast into any shape. The process of concreting involves heavy compaction by skilled labor. Inability to compact the concrete or lack of skill of labor may reduce the quality of concrete and harm its durability. The best available option free from quality of construction work and to achieve durable structure is the use of self-compacting concrete.

1.1.1. Self-Compacting Concrete

Self-compacting concrete (SCC) as defined by ACI 237R – 07 as "a highly flow able, non-segregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation". The time required for SCC concreting is incredibly reduced as compared to normal concrete. One disadvantage of SCC is the increased cost as compared to normal concrete but for larger projects like multi-story buildings, roads, dams etc. SCC is presently used because of its obvious advantage and is described as a milestone in the modern concrete technology. There are a lot of site conditions and working limitations in construction industry that makes self-compacting concrete a better substitute to conventional high slump concrete, most general are cost effectiveness or efficiency of concrete. SSC has also gained popularity in recent years because of its incorporation of secondary raw materials.

Due to large scale urbanization concrete has become 21st century most consumed material all around the globe. The material is important because of its good strength, ability to form any shape, durability and economy. It's been 100 years since the industrialization began, and where this industrialization improved the living standards of human beings and provided other great benefits to benefits, it also caused harm to our planet and its climate and ecology.

Because of these issues most important and great threat humanity is now facing is climate change Natural resources depletion, fragile economies, and sustainability. Conserving energy as planet's natural resources are depleting, a much needed revolution for constructing green buildings which should be economical and sustainable are the major point of interest in present time all over the globe.

To cope up with these issues numerous researches are going on for the alternatives which can be adopt to minimize the damage being caused to environment. Sand being the 2nd most used material in the world at the moment tried and replaced by different materials such as agricultural waste materials which includes corn cob ash, wheat straw, RHA and BA. As the disposal of agricultural waste ashes is also a problem, they also cause environmental issues and health diseases, also there needs to be a proper dumping procedure and sites. So it is beneficial to use agro waste ashes in concrete which can impart or enhanced the physical, chemical properties of concrete.

1.2. Problem Statement

With the fast growing construction industry due to large scale urbanization, sand becomes the 2nd most widely used natural material all around the globe which in results causing depletion of natural sand reservoirs and sand mining also damaging our eco system. There is a need of looking for alternatives which can replace the sand, lot of experimentation is carried all over the world on different materials. Pakistan is blessed with fertile land and produces huge amount of Rice and sugarcane, their waste also known as Rice Husk Ash and Bagasse Ash are left behind which needs proper disposal otherwise they are hazardous to our nature and also to human life. These ashes carry pozollanic properties and also have the filler effects so they can be used as sand replacement.

1.3. Research Methodology

The methodology of the study is given in detail as follows:

a. Characterization of rice husk ash and bagasse ash.
b. Selection of Mix design.
c. Study the density, water absorption, and compressive strength for each formulation.
d. To have an insight into the response of RHA and BA formulations in comparison to the control mix study microstructural properties.
e. Performing fresh tests on all formulations.

f. Study the response of all formulations against Acid attack.

1.4. Objectives

Objectives of this study are as follows:

a. Characterization of Ashes.
b. To determine the effect of blend of BA and RHA on fresh properties of SCC.
c. To determine the effect of blend of BA and RHA on mechanical and durability properties of SCC.
d. To investigate the effect of blend of BA and RHA on microstructural properties of SCC.

1.5. Scope of research

Scope of research is limited to the study of effects of RHA and BA blend as sand replacement on fresh and hardened properties of SCC and having an insight to the effects on microstructure of SCC.

CHAPTER 2: LITERATURE REVIEW

2.1. Development History

Development of Self compacting Cementicious systems (SCCS) originated in 1980's in Japan. In mid-1980's Japanese construction industry was facing some serious challenges related to durability and serviceability requirements of the concrete structures. To make durable concrete structures proper vibration of concrete is required to place it at placements where heavy and overcrowded reinforcement is present. These places include heavily reinforced columns, deep foundations, tunnel linings, piers of bridge etc. Skilled labour is needed to compact the concrete and to place it in such highly reinforced zones. But Japanese construction industry faced a severe challenge of shortage of skilled labour force capable of operating mechanical devices to place and compact concrete [1]. Lack of uniform compaction resulted in differential compaction and hence loss in durability. Thus, there was an immediate need for a type of concrete that would not require human efforts for its compaction and placement.

This whole scenario led to the development of self-compacting concrete and Professor Hajime Okamura was the first to give concept about it in 1986. Later on, in 1988 the first sample was developed by Professor Ozawa at university of Tokyo [2]. Professor Okamura studied its properties in detail and named it "High Performance Concrete" but Professor Aticin had already used this term for concrete with low water to cement ratio and high durability [3]. So then Okamura adopted "Self-compacting high performance concrete" for this type of concrete [2]. Through invention of self-compacting concrete, the need for skilled labour was considerably reduced and concrete could be placed at any area without the need of any mechanical device. By early 1990, Japan became successful in implementing this type of concrete in tis construction industry that didn't require any manual vibration; instead it flowed under its own weight. This new technology presented economic and environmental benefits over traditional methods of placement of concrete. SCC provided better travel rates of concrete placement, smooth and easy flow of concrete around heavy and dense reinforcement.

2.1.1 Advantages of SCC

SCC is a unique product; it offers a large number of advantages.

- SCC flows under its own weight. Thus, placing the concrete has become affordable due to the elimination of manual vibrators. Now, concrete can be easily placed in areas of heavy reinforcement.
- Self-compacting concrete possesses better qualities as compared to conventional or normal concrete and its use in construction industry improves productivity and working conditions.
- As use of SCC removes compaction, this evades the internal segregation between materials which results in weak transition zones between mortar and aggregate and color of concrete in enhanced [4] . Moreover, increased strength and high durability can be achieved.
- Self-compacting concrete also helps to reduce the noise pollution by removing the use of mechanical vibrators. It has also eliminated the health related problems of workers such as “white fingers” and “deafness” which used to arise due the use of vibrating equipment [4].
- SCC gives a uniform and homogeneous mix in the hardened state as mechanical vibrator has not been applied on it. Additionally, effects of bad workmanship are greatly reduced.
- SCC gives high quality surface finish. Its good flow produces smooth surfaces and minimizes the need for additional finish like plaster.
- The formwork doesn’t need to be tighter due to the enhanced cohesiveness of SCC as compared to the conventional vibration requiring concrete.

With large scale urbanization at a very high pace the material largely in use is concrete. It’s because of high strength, durability, economics and also it can be cast into whatever shape one can think of. One of the main constituent of concrete is sand which is a natural material formed due to erosion of rocks, time spanning up to thousands of years [5]. River sand is favored for development since it requires less handling and has preferred quality over different sources. In any case, it comes at a gigantic expense to the stream and those living around it. Over the top sand mining can affect the river bed, power the stream to change course, erode banks and lead to flooding. It likewise wrecks the natural surroundings of water life and miniaturized scale living beings. It is evident from history that sand is being used as aggregate for civil construction purposes since ancient times [6]. After water, sand is now second most consumed natural resource on earth [7]. And also UNEP states that not only sand and gravel are second most used raw material in world but alarming fact is that their great use has also exceeds their renewal rate [7]. Different researches have been made to use different waste materials as replacement of natural aggregates [8].

2.2. Effects of Sand Mining on Rivers and Surroundings

Nature has blessed mankind with rivers which are the most important life supporting systems. The main source of sand is mining it from the river. But due to the rapid growth of construction industry and increased demand of sand, the rate of river sand mining has increased many times and this in result causing many problems to environment, river beds, embankments, and also causing great danger to rivers ecosystems.

The areas draining the Vembanad lake in southwest of India are developing and becoming urbanized industrial zones. For which the demand of sand aggregate is very much high and due to this reason there is an immense sand mining from the seven rivers which drained the Vembanad Lake. As a result of which riverbed is getting lowered and also causing danger to biological and physical environments of these seven river systems [9]. It is necessary to have smooth transport of sediments in rivers throughout its length to avoid bed erosion, lowering of bed, weakening of embankments. Because if the sediments transportation gets interrupted due to dams or mining of aggregate then the flow will become sediments starved and will start eroding beds, embankments [10]. Degraded streams results in loss of productivity of fisheries, its bio diversities and aesthetics of that area. Channels widening is also result of reduction in sediments and it will be continued until the equilibrium between incoming and transported sediments is re-established. In stream sand mining also creates deep pits in the channel resulting in the lowering of ground water table. Excess of sand mining also causes the undermining of bridge piers and exposing other underground infrastructure which also includes pipelines. In Selangor river, Malaysia the water quality at immediate downstream of river proved to be much polluted. This was due to sand mining which causes small sediments to be suspended in water [11]. Excessive sand mining in Yangtze river and Poyang river results in banning of dredging in both rivers in 2001 and 2008 respectively due to effects of bed weakening and threats caused to the bio life and ecosystems of the rivers [12].

The demand of sand aggregate has increased many folds with passage of time and in result production goes very high. The leading producers of sand all over the world are graphically presented below in time period of 2010-2015.

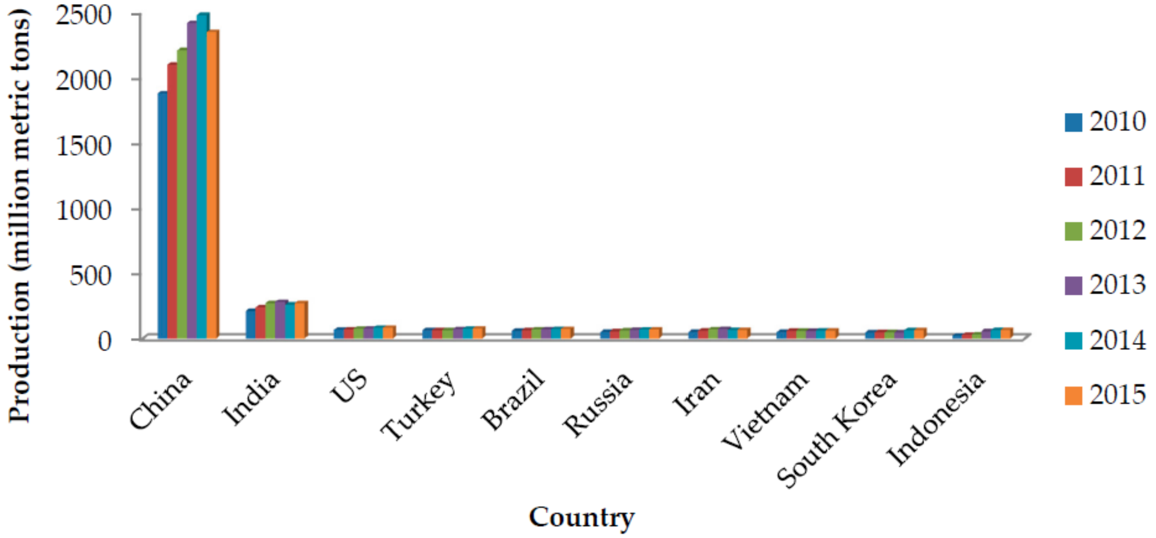

Fig. 2. 1: Leading Producers of Sand and Gravel countries from 2010 to 2015 (million metric tons) [13].

The evil impacts of sand mining on natural life are not kept to sandbanks, yet in addition incorporate subsurface environments. At the point when sand is mined from stream beds, it makes turbidity in the water. The human and machines unsettling influence instigated by such processes can have negative effect on underwater life. The turbidity can make a hindrance that keeps daylight from entering the water, which is unsafe to corals that need daylight. Fishes also gets in danger because of an absence of nourishment and oxygen in the turbid waters. In this way, the whole aquatic system may collapse because of sand mining. The fishery industries that are subject to such waters will likewise endure incredible financial misfortunes.

Sandbanks go about as obstructions to flooding. At the point when sand mining expels such boundaries, regions close to the stream become progressively inclined to flooding. As a result communities living in surrounding areas are threatened by flooding. The other biological, physical and chemical parameters which includes low pH value ranging between 2-3, brown or reddish color of water, high concentration of ions of destructive metals, high conduction of electricity in water, and low dissolved oxygen (DO) are the indicators which proves the quality degradation and amount of pollution of water due to sand mining [14].

2.3. Climate Change Effect on Rivers Sediments

The major threat to the world in this present time is climate change. As it is affecting our lives, economies, nature and above all its going to get worse in near future if we don't pay consideration to legitimate threats.

It's because of climate change that some regions are facing worst ever heat waves among and latest example of that is Australian forests which are facing wildfires. Then there are regions which are facing cold temperatures after so many years. And then there are anomalies like arctic ice is melting, and rivers all over the globe are rerouting and reorganizing their course affecting the habitat life in their surrounding and causing floods and droughts. Rivers also getting narrower. It is reported that global temperature may rise between 1.4 degrees to 5.88 degrees Celsius and it is also reported that Himalayan glaciers are retreating at rate of 10-60 meters per year due to high temperature and climate change [15].

River Indus is the main largest river in Pakistan getting water from Himalayas and has five major tributaries in Pakistan named Jhelum, Chenab, Sutlej, Beas and Ravi. As glaciers are retreating this means these rivers will be getting narrower and time may came they become dry. And also rivers are the main source of natural sand which they carry with their flow. And as from the given facts that climate change causing rerouting of river and narrowing of streams, so there is much need of looking for other alternatives to sand for the use in construction industry and other purposes. As Pakistan is among the world's top most affected country from climate change [16] so we need to take remedial measures and try to rely less and less on these resources and look for alternatives.

2.4. Sugarcane Bagasse Ash and Rice Husk Ash as replacement of Sand

One of the widely grown crops in almost 110 countries of the world with production of 1500 million tons is Sugarcane [17]. Pakistan is situated in the region of South Asia with a covered are of 796,095 km2 and is the 6th largest nation in the world. Its 62% population more or less rely on agriculture, Pakistan is the 5th largest producer of Sugar cane and 11th largest producer of Rice in the World [18].

2.4.1. Bagasse Ash (BA)

Sugarcane today plays an important role in the global economy. Sugar and alcohol are produced by it. Countries are earning impressive profits through the imports of these two products. Production process of sugar and alcohol through sugarcane produces bagasse as a waste, which is then burnt as a fuel to stoke boilers that generate steam for electricity production. The final product of this burning is residual sugarcane bagasse ash (SBA), which is normally used as fertilizer in sugarcane plantations. The total production of sugarcane worldwide is over 1500 million tons [19].

BA is tested as cementitious replacement in different parts of the world. Results shows that bagasse ash certainly magnifies different properties of the mortar and concrete. These properties included high packing density, compressive strength and water tightness, but these advantages were only achieved if bagasse was used at certain replacement percentages and small size. The high quantity of silica content in the bagasse ash was considered to be special reason for high strength and all other improvements in the quality of concrete.

With the 2nd largest cash crop of Pakistan, Sugarcane is being cultivated on 0.966 million hectares results in contribution of around 3.6 % of GDP. Sugarcane at the moment accounts 4.8% of total cropped area and adds 11% value to the total crops. The sugar industry has an important role in the national economy of our country [20].Pakistan produces 73.4 million tons of sugar cane in year 2017, growing at a rate of 3.79% per annum. From 1968 to 2017 growth of sugarcane increases from 18.7 million tons to 73.4 million tons Fig. 2. 2.

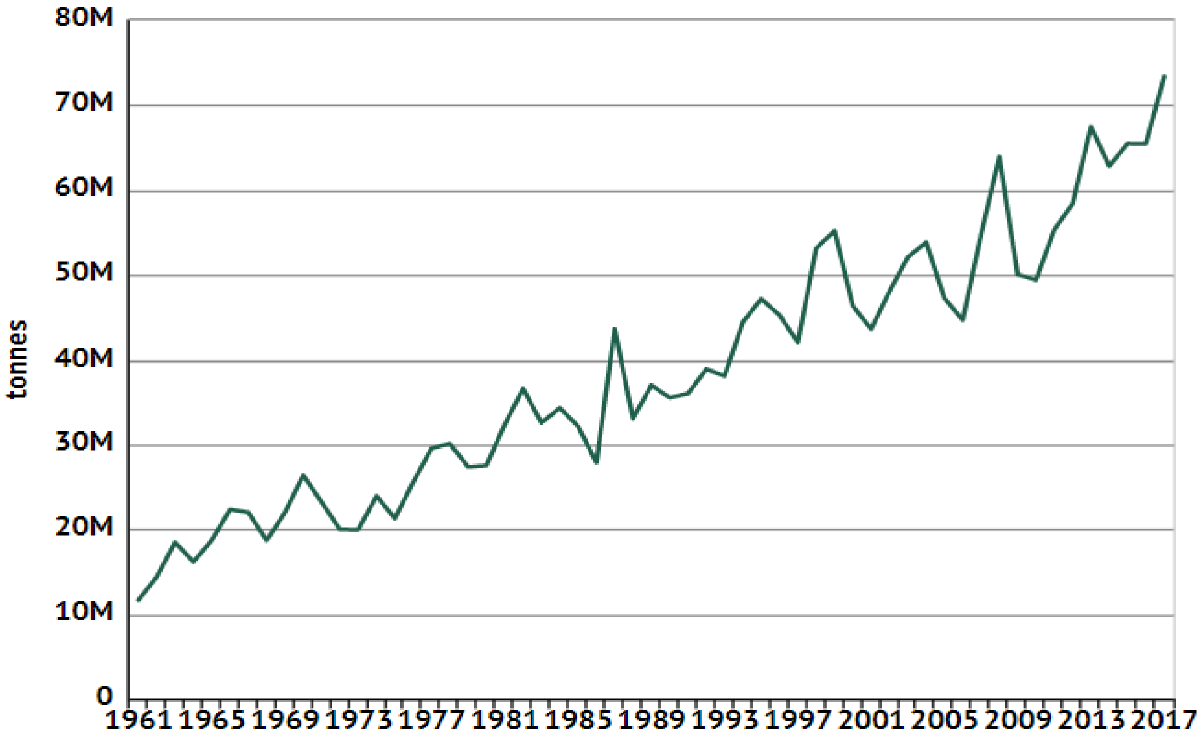

Fig. 2. 2: Sugarcane production of Pakistan 1961-2017 [Source: knoema]

The production process of sugarcane generates bagasse as waste material which later used as a fuel to stoke boilers which then generates steam for power generation purposes. The residual after burning of bagasse is known as Sugarcane Bagasse Ash (SBA) which is an inert material having no pozollanic reactivity or hydraulic property and can be used as replacement of sand [21]. SCBA is also experimented as mineral additives and can also be used as supplementary Cementicious material which means upon mixing with cement it changes into pozollanic material giving both strength and filling ability to concrete. The enhanced properties of concrete after adding SCBA in the material is due to both pozollanic property and packing effect of fine sized particles [22]. At elevated temperatures and partial combustion of ash in the reactivity of compromises because of the presence of large percentage of carbon content and crystalline silica [23]. Because of the physical properties of SCBA its particle size, fineness modulus, bulk density it can also be called as fine aggregate and can be used as replacement of natural sand, as it possess inert property and has the filling ability [21]. In literature it is observed that replacement of SCBA with 10%-20% with fine aggregates in concrete can improve the compressive and other mechanical properties of the concrete [17, 22, 24]. Also it is stated that due to fine sizes of SCBA the chemical degradation of concrete reduces due to increased packing density and less porosity. Also rate of hydration reaction in concrete enhances when blended with SCBA particles due to its pozollanic nature [24].

2.4.2. Rice Husk Ash (RHA)

Vital crops such as Cotton, Rice, Maize, Wheat and Sugarcane contributes 23.60% value in agricultural sector which accounts for 4.45% of the GDP of Pakistan. Out of this Rice contributes 3.1% to value of agricultural sector and 0.6% to the GDP of Pakistan, it stand as second prime exportable crop after wheat. The production of rice reaches all-time high in the history of Pakistan in the year 2017-2018 with 7.4 million tons of Rice which was cultivated on 2,899 thousand hectares. The production of rice from1960-2020 is shown in the Fig. 2. 3.

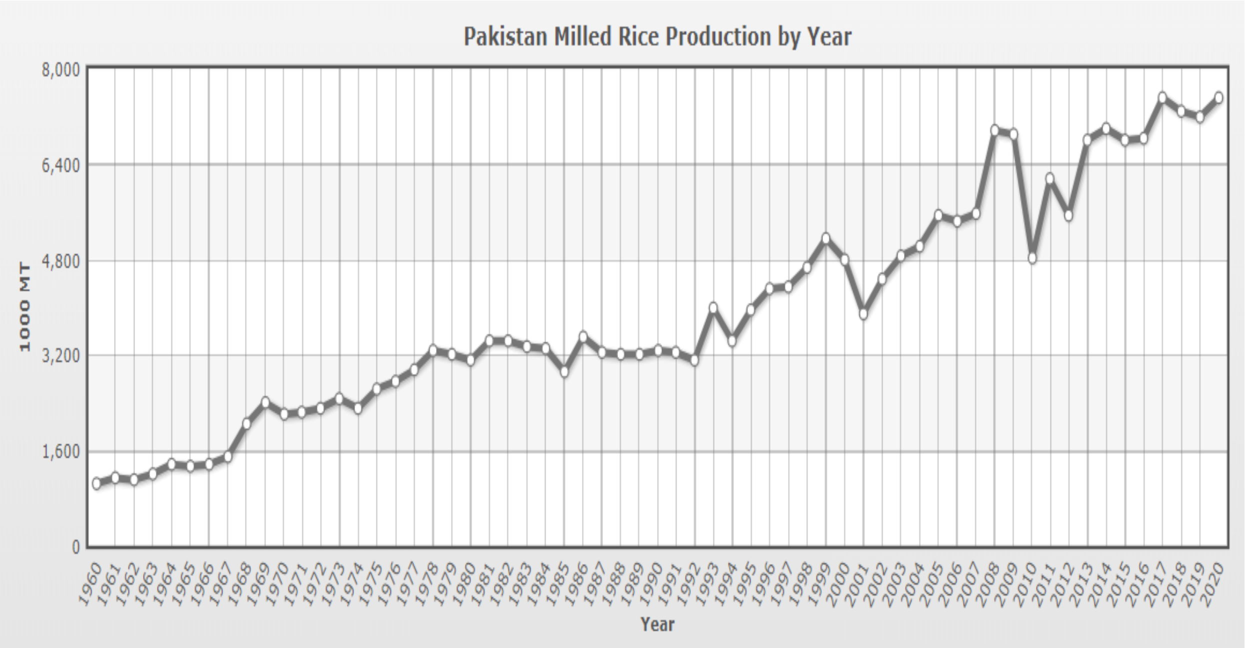

Fig. 2. 3: Production of Rice from 1960-2020 years in Pakistan [Source: Pakistan Milled Rice Production]

Rice Husks are the tough protective coverings around the rice grains which gets separated during milling process from the rice grains. Rice husk is freely available agricultural waste material in all countries which are producing rice. Rice husk is used for different purposes in different parts of the world such as local fuel and for parboiling paddy in rice mills. Under controlled burning conditions, volatile organic matter such as cellulose gets consumed and the left over is mainly consist of amorphous silica. This silica is the main constituent of RHA and is highly reactive which in results contributes in the pozollanic property of the Rice Husk Ash. RHA can be used for different purposes which includes as pozollan in construction industry, as filler material because of its fine size [25] and also as an additive. RHA have higher water demand because of its porous microscopic structure. Incorporating RHA in concrete as replacement of sand reduces the unit weight of concrete [26]. It was observed in literature that rice husk ash contributes in enhancing the mechanical properties of concrete when used in range between 10%-20% as replacement of cement, while increased amount of RHA causes sudden decline in mechanical properties such as compressive and flexural properties of the concrete [27, 28].

2.5. Characterization of Ashes

The micro and macro-structural characterization of ashes were performed to investigate their intrinsic properties. Microstructural characterization including SEM/EDX, XRD, and XRF analysis was conducted to examine the morphology, crystallographic phases, and chemical oxide composition of both RHA and BA. Macrostructural characterization includes the specific gravity, water absorption, and sieve analysis was performed to predict its behavior in SCC.

The micro-morphological features along chemical composition (EDX analysis) of BA and RHA depicted in SEM micrographs as shown in Fig 2.5, 2.6 and 2.7, 2.8 respectively. The SEM micrographs of BA depicted that its particles have agglomerated, tubular, prismatic, needle, spherical and irregular shape with the presence of porous and fibrous particles with the particles sizes of BA particles ranges between 2 µm to 250 µm which are similar to the morphology reported in the literature [29]. The EDX analysis of BA showed the presence of a higher amount of silica and a fewer fraction of unburnt organic particles. The published study [30] on the effect of particle shape of BA on its pozzolanic activity revealed that the irregular shaped particles are silica-rich. The morphological features of BA presented in this research are similar to those reported in the literature [23, 30-32]. The micro morphological features of RHA revealed irregular, flaky, platelets, and tubular-shaped particles with the particle sizes ranged between 0.25 µm to 100 µm. The particles ranged in microns and the sub-micron dimension had a high tendency to form agglomerates. The similar particle shape of irregular, tubular, flaky, and platelets of RHA was reported in the literature [33-35]. The EDX analysis of RHA indicated that the amorphous silica particles having flaky plate-like and tubular morphologies improved the reactivity and attribute the amorphous nature to the RHA which is also evident in literature [35]. XRD was conducted to study the crystallographic nature of RHA and BA using the X-ray diffractometer model JDX-3532

JEOL, the diffraction peaks were recorded between 2θ scan value of 5° and 80°. The diffraction pattern was used to identify the chemical phases present in mineral ashes by using "MATCH Phase Identification v3.1" software. The diffraction pattern of RHA and BA is shown in fig 2.9. The diffraction peaks of both RHA and BA was identified as crystobalite and quartz at 2θ values of 22.03° (4.03 Å), 29.42° (3.03 Å), and 20.84° (4.26 Å), 26.63° (3.34 Å), 39.45° (2.28 Å), 40.25° (2.23 Å), 50.13° (1.81 Å), 68.20° (1.37 Å) respectively. Both ashes contain a high concentration of silica in the form of quartz and crystobalite, which can be observed as the intensity of phase diffraction peaks are proportional to the concentration of component producing it, and peak phase intensity difference symbolizes difference in its concentration [36, 37]. Oxide composition of BA and RHA contains the cumulative sum of silica, alumina, and iron oxides values of 91.29, and 89.79% respectively satisfying the chemical requirement of pozzolan as per ASTM standard C618. The gradation properties of coarse aggregate and sand comply with the ASTM specification C 33 which was performed as per ASTM standard C136. The average particle size of sand and maximum size of coarse aggregate was observed as 0.61 and 20 mm respectively, whereas the average grain size of RHA and BA was observed as 0.15 and 0.17 mm respectively. The literature [38, 39] suggested that material finer than 75µm accounts for significant increase in water demand. The water absorption, specific gravity and density of coarse and fine aggregate were determined as per ASTM C-127 and ASTM C-128 respectively. The physical properties of RHA, BA, fine and coarse aggregate are presented in Table 2.1, while the particle size distribution curve of fine aggregates is shown in fig 2.4. The water absorption and specific gravity values for coarse and fine aggregate are 0.89, 2.67 and 1.73, 2.62 respectively, For RHA and BA the values of water absorption and specific gravity was determined as 14.78, 1.63% and 16.51, 1.44 respectively. Alongside the incorporated ultrafine silica rich waste ashes would contribute as a filler might also show chemical reactivity in cement paste matrix upon its incorporation in SCC.

Table 2. 1: Physical properties of sand, coarse aggregates RHA and BA

Materials	D_{50} (mm)	Water Absorption	Specific Gravity
Sand	0.61	1.73	2.62
Coarse Aggregates	-	0.89	2.67
RHA	0.15	14.78	1.63

BA	0.17	16.51	1.44

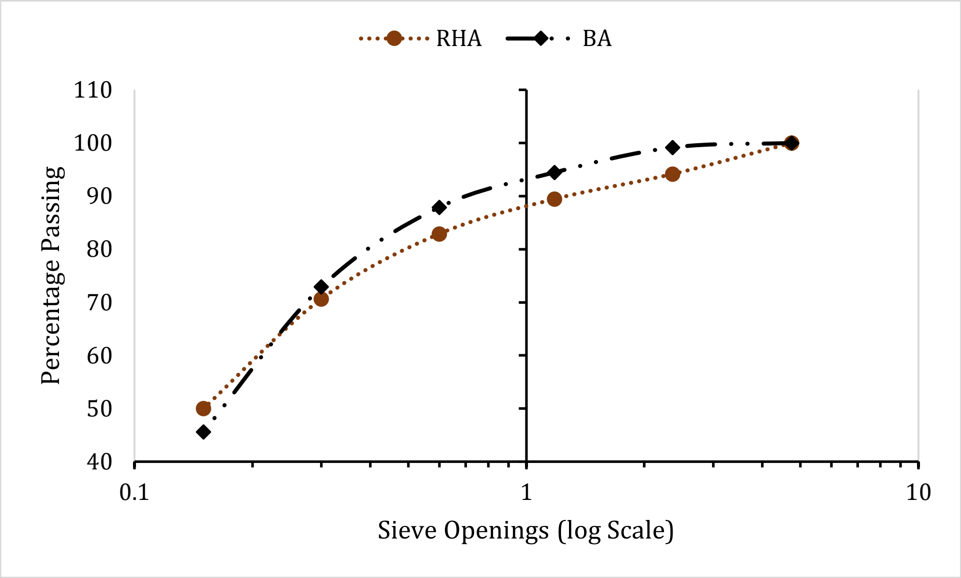

Fig. 2. 4: Particle gradation curves for RHA and BA

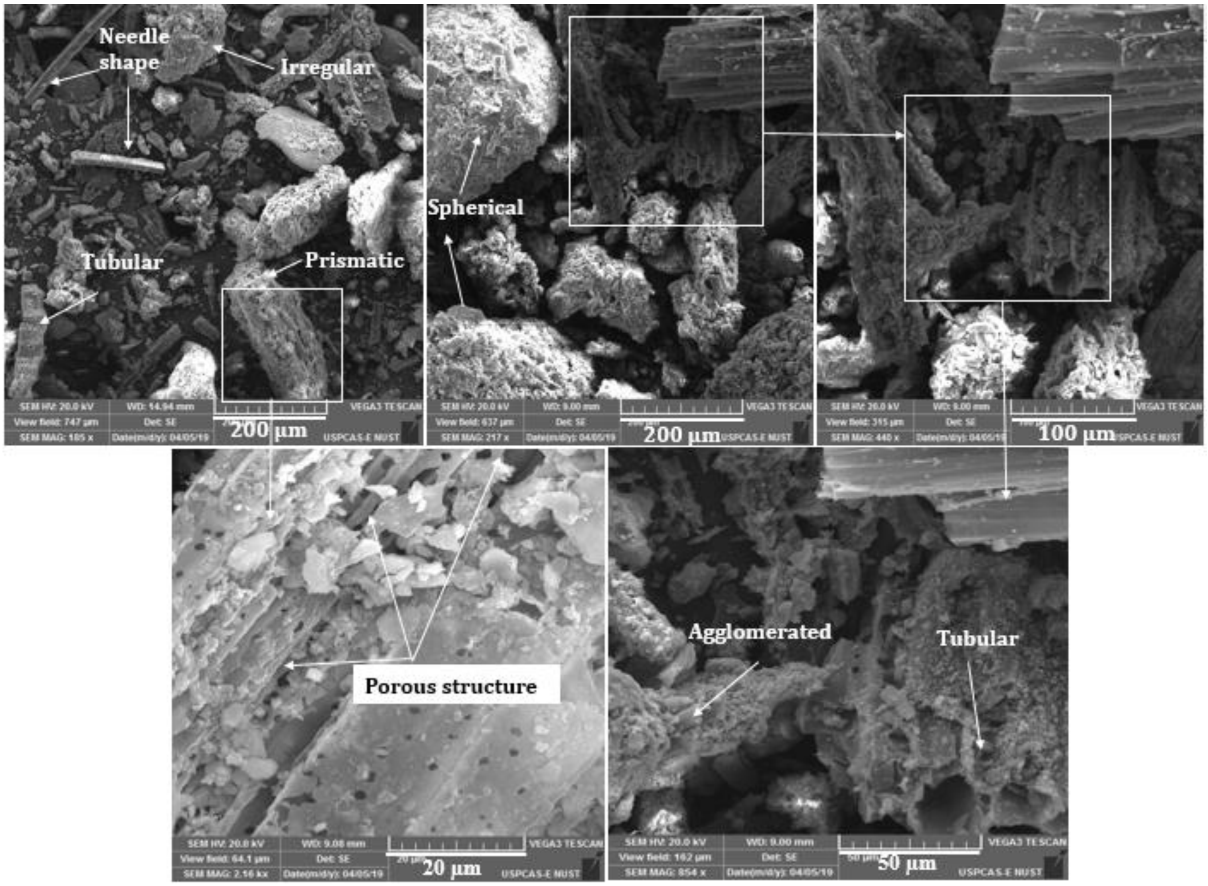

Fig. 2. 5: Scanning electron micrographs of BA at different magnifications

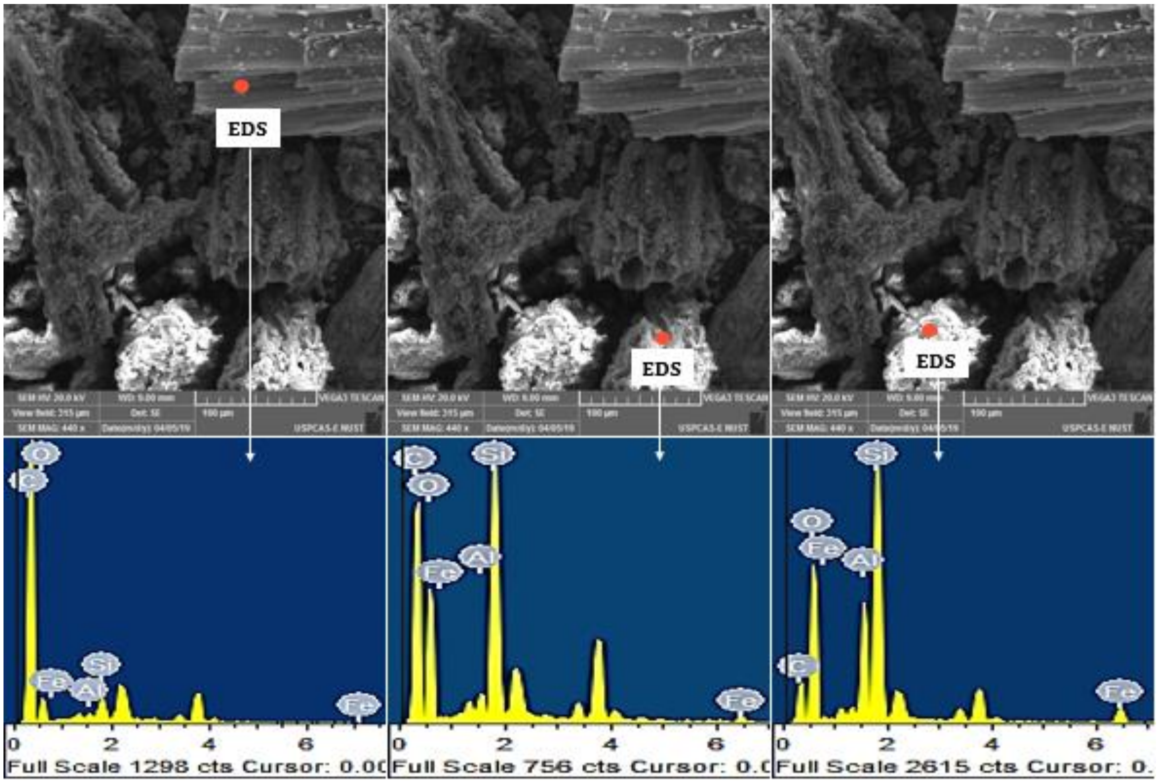

Fig. 2. 6: Energy dispersive x-ray spectroscopic micrographs of BA

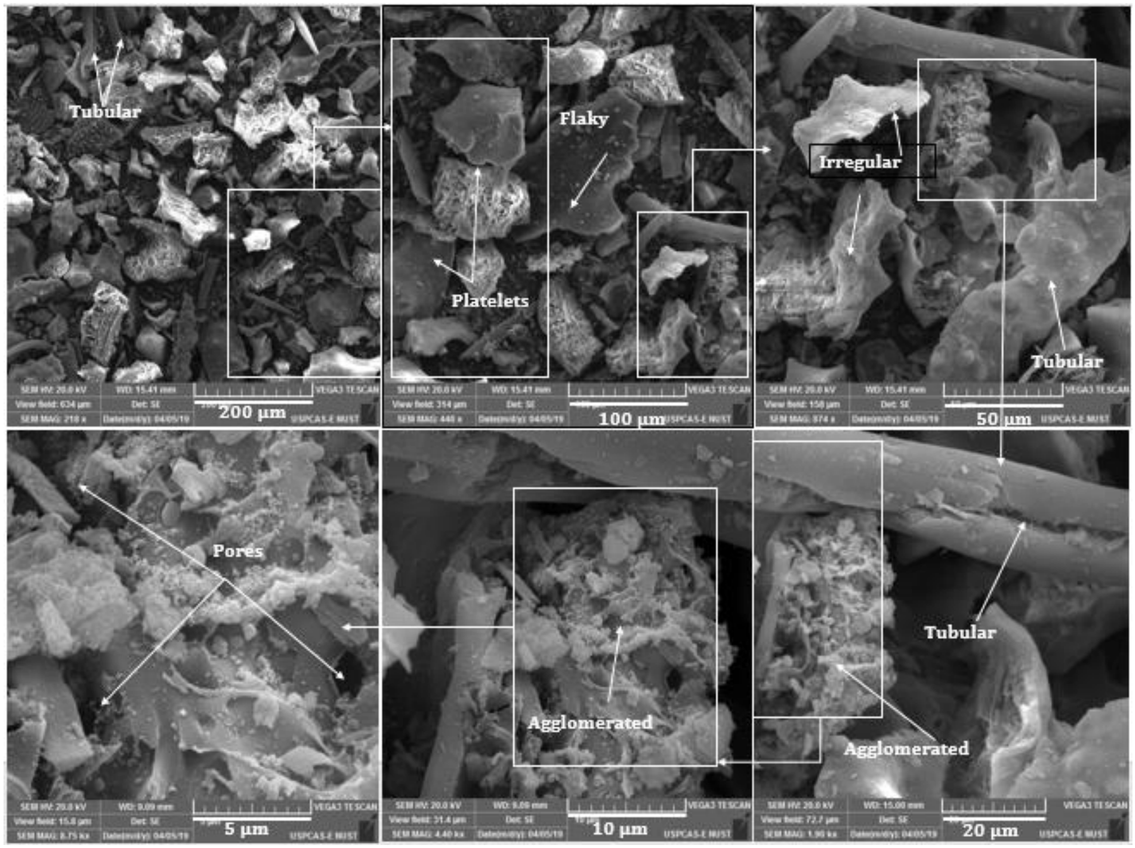

Fig. 2. 7: Scanning electron micrographs of RHA at different magnifications

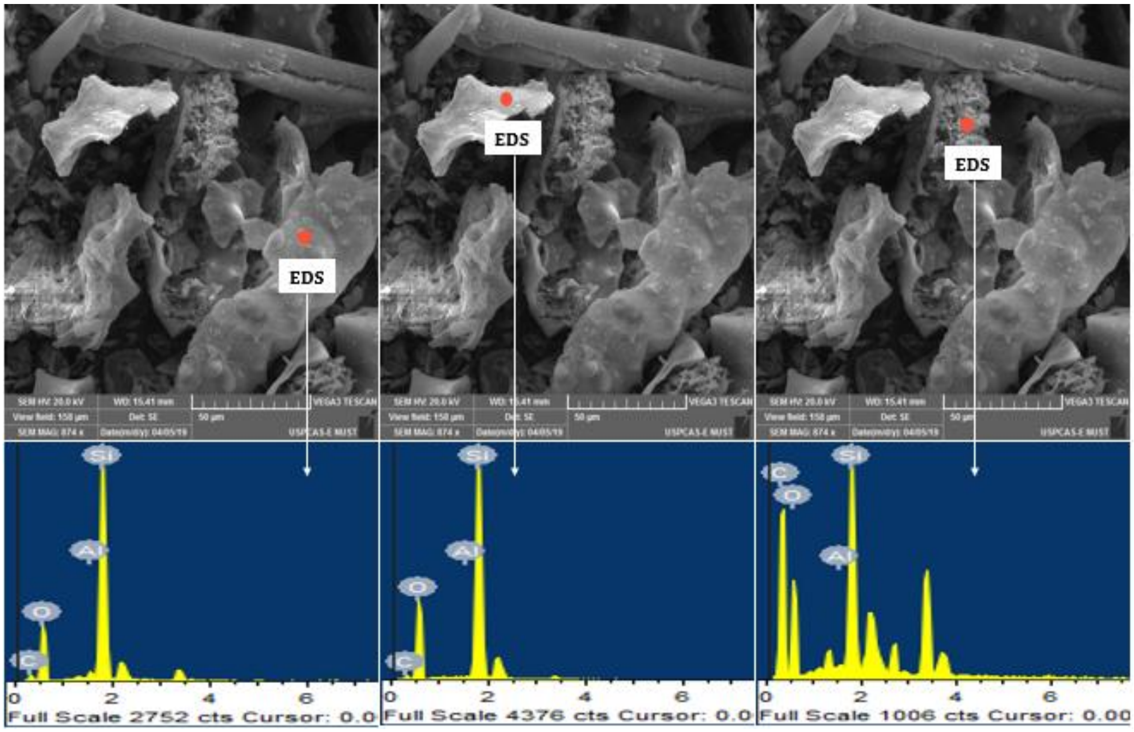

Fig. 2. 8: Energy dispersive x-ray spectroscopic micrographs of RHA

Table 2. 2: Oxide composition of BA and RHA

Oxide Composition	**SiO_2**	**Fe_2O_3**	**Al_2O_3**	**CaO**	**Na_2O**	**K_2O**	**MgO**	**MnO**	**LOI**
BA	74.34	3.4	5.55	2.15	0.12	1.46	0.67	0.89	11.42
RHA	80.2	3.2	2.39	1.51	0.34	1.8	0.59	0.67	9.30

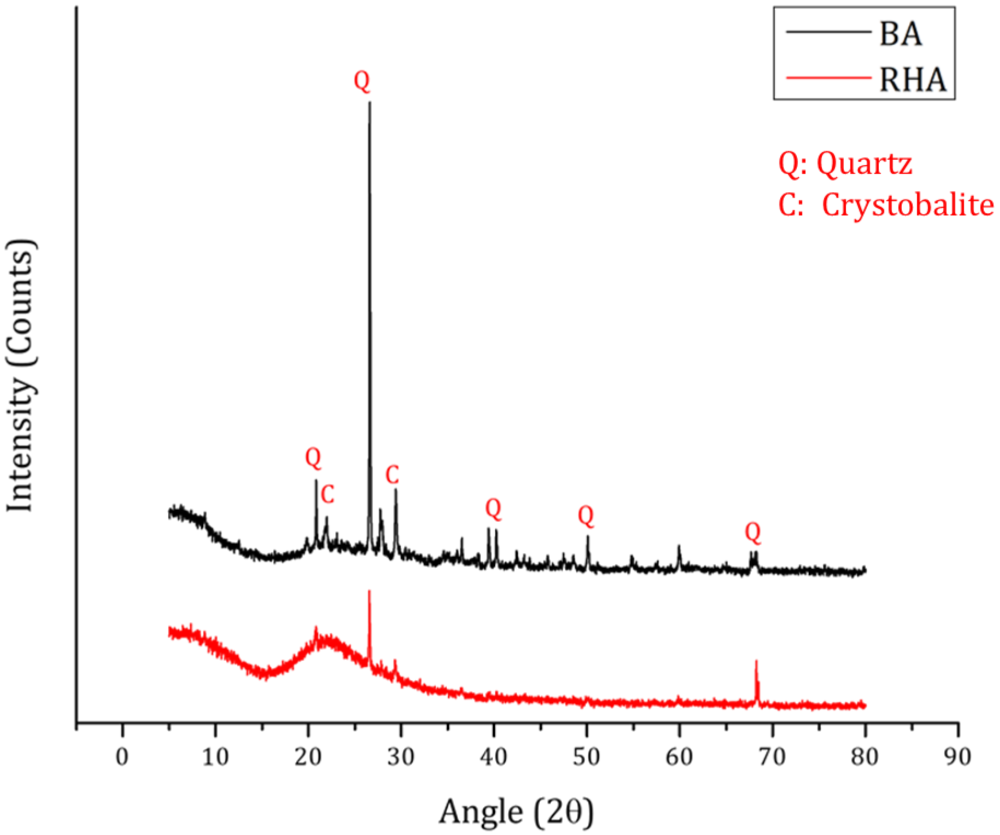

Fig. 2. 9: XRD pattern of RHA and BA

2.6. Super Plasticizers (SP)

The high water reducing admixtures generally known as super-plasticizers are artificially prepared water soluble organic substances that are used to significantly decrease the amount of water needed to achieve a certain consistency of concrete which means higher compressive strength and higher workability. Super-plasticizers can be used to serve following purposes:

1- To reduce the water content, this would result in increased strength, better permeability and higher durability
2- It acts as cement dispersant for the same water content to increase consistency and workability.

Super-plasticizers use was started in Japan and Germany during 1960 and 1970 respectively. The chemical composition of super plasticizers is different from that of normal plasticizers. Using Super-plasticizers can reduce water up to 30% percent without any reduction in workability as compared to normal plasticizers which can only reduce water up to 15%. Super-plasticizers are generally used for the production of high flowing, self-levelling and self-compacting concrete. In American literature, they are termed as High Range Water Reducers (HRWR). Use of Super-Plasticizer has allowed water cement ratio as low as 0.25 or in some cases even lower than that and yet they are able to make concrete of around 120 N/mm2 strength or more [40]. Super-Plasticizers are considered to be the important part of high performance concrete. They are not only used to lower the water demand but also regulate the open time and setting time. Their basic structure resembles a “comb type” molecule. The Poly-carboxylate group forms the main trunk or major chain of the molecule while the polyether groups are connected to poly-carboxylate trunk by chemical bonding. These polyether groups are also knows as “side chains” or “grafts”. Their name suggests a likely connection between poly-carboxylate and ether groups. There are basically three types of “grafts” or “side chains” which are ether, ester and amide. Ester is common group among them. Super-plasticizers are responsible for lowering the porosity of Cementicious systems in hardened state [41].

2.6.1. Mechanism of Super Plasticizers

Now-a-days super-plasticizers are used at large scale in concrete industry. Two major super-plasticizers that are being used are polynaphthalene Sulphonate and polymelamine Sulphonate formaldehyde condensates. These are polymers and both follow the same dispersing mechanism. The main polymers chains (Sulphonate groups -SO3 -) get themselves absorbed onto the surface of cement particles; as a result of it cement particles get negative charge on them. Therefore, electrostatic repulsion takes place between the cement particles and they start repelling each other. These repulsion forces between the cement particles offset the inter-particle attractive forces. Poly-carboxylate superplasticizers increase dispersion because of their better performance in dispersing cement particles. They easily disperse cement particles even at smaller dosages and maintain the concrete slump without prolonging setting times of concrete [41]. Electrostatic repulsion plays an important role in the dispersion mechanism of super-plasticizers.

CHAPTER 3: EXPERIMENTAL PROGRAM

3.1. General

Complete testing was performed in accordance with the standards under controlled conditions in laboratory with controlled temperature and humidity. The required quantity of materials i.e. cement, rice husk ash, bagasse ash, super plasticizer were stored in a plastic container along with air tight caps so that no external factor can effect on the homogeneity or efficiency of stored materials.

3.2. Materials used

3.2.1. Cement

Ordinary Portland cement (Type-I) in accordance with ASTM C150 was used in entire experimentation and testing of research program. D50 of OPC with Grade-53 was 19.54 microns [42]. XRF analysis of cement was carried out to fine out its chemical composition.

Table 3. 1: Oxide composition of Ordinary Portland cement

Sample Name	Cement
SiO_2	19.19
TiO2	0.29
Al2O3	5.07
Fe2O3	3.28
MnO	0.04
MgO	2.12
CaO	65.0
Na2O	0.66
K2O	0.51
LOI	3.84

3.2.2. Fine Aggregate

Natural sand was brought from lawrencepur and was used in complete experimentation and testing procedures. The sieve Analysis of natural sand was carried as per guidelines of ASTM C136. The D_{50} size of aggregate was 0.61mm.

3.2.3. Coarse Aggregate

As coarse aggregates in constitutes 35-70% of total volume of concrete. They have an impact on all properties of self-compacting concrete from strength to segregation resistance to flow ability and passing ability of the mix. Margallla crush was used as natural coarse aggregate in complete research program.

Fig. 3. 1: natural coarse aggregate

3.2.4. Super Plasticizer

Sikament NN super plasticizer was used in the experimentation, manufactured by Sika Pakistan. It is a liquid super plasticizer in accordance with ASTM C494 Type / BS EN 934-2. Its chemical base is Naphthalene Formaldehyde Sulphonate. The dosage recommended by Sika for this super plasticizer is in the range of 0.5-3.0% by weight of cement. But it’s also necessary to perform trial mixes for the accurate dosage which may vary depending upon the weather, temperature, site conditions, material used and best engineering judgment.

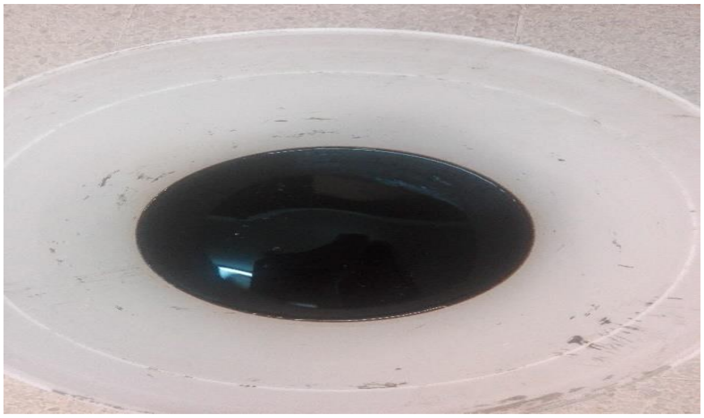

Fig. 3. 2: Sikament NN

Table 3. 2: Characteristics of Super Plasticizer

Admixture	Sikament® NN
Color	Dark brown liquid
Density	1.2 ± 0.02kg/l
Ph (23 ± 2 °C)	8 ± 1
Chloride content %	< 0.1% (EN 934-2)

3.2.4.1. Uses and Advantages

Following are the advantages and uses of Sikament® NN super plasticizer to be used in Self Compacting Concrete:

- Concrete having strong fluidity
- Workability greatly enhanced
- Concrete for long transportation, delayed placing or high temperatures
- Placing ability improved greatly and fill in the confined reinforcements
- Increased slump value
- Reduced water demand up to 25%

3.2.5. Mixing Water

In the experimentation ordinary tap water was used and as the samples were made in the month of March the temperature range was between 16-24 °C.

3.3. Casting of Samples

SCC was cast in cubes molds of 150x150x150 mm^3 size to measure the compressive strength, density, and water absorption. While concrete cylinders were made for the testing of split tensile. After demolding the samples at 24 ± 1 hrs. The temperature and relative humidity for the mixing and casting samples were 23±4°C and 90% respectively which comply with the ASTM C 511 [43]. They were water cured at room temperature up to the specified age of testing.

Table 3. 3: Specimens sizes and standard test methods for assessing various properties

Sr. No.	Test Name	Standard Designation	No. of Specimens	Specimen Size (mm)	Specimen Type
01	Compressive Strength	BS EN 12390-3	03	150 x 150 x 150	Cube
02	Split Tensile	ASTM C496	03	150ϕx 300	Cylinder
03	Sulfate Resistance	ASTM C267	03	150 x 150 x 150	Cube
04	Hardened Density	ASTM C642	03	150 x 150 x 150	Cube
05	Water Absorption	ASTM C642	03	150 x 150 x 150	Cube

3.4. Concrete Mix Proportions

The CM mix was designed for M25 and the cumulative blend of RHA and BA as a partial sand replacement was performed by an absolute weight method which is shown in Table 1. The partial substitution of sand with the blend containing an equal amount of 0, 10, 20, and 30% RHA and BA by weight was incorporated in SCC. The amount of cement and coarse aggregates were kept constant while the water to cement ratio and superplasticizer content was kept as 0.40 and 1.7% by weight of water.

Samples	Cement (Kg/m³)	SP (Percent of binder)	Sand (Kg/m³)	Coarse aggregates (Kg/m³)	BA (Kg/m³)	RHA (Kg/m³)	W/C ratio
CM	350	1.7	823.41	1026	0	0	0.40
B05R05	350	1.7	741.07	1026	41.17	41.17	0.40
B10R10	350	1.7	658.73	1026	82.34	82.34	0.40
B15R15	350	1.7	576.38	1026	123.51	123.51	0.40

Table 3. 4: Percentage weight of SCC constituents

3.5. Mixing Regime

Preparation of SCC requires dedicated work and proper mixing sequence and time duration. High performance pan mixture was used for mixing of SCC.

All the materials were filled in high performance pan mixture at once. Cement at first followed by Sand, RHA, BA and cement for efficient mixing. The mixing regime for the preparation of SCC of all four formulations is as follows.

Table 3. 5: Mixing Regime

Time	Mixing Regime
1 minute	Dry mixing of constituents at 180 rpm (slow rate).
2 minutes	Add 80% of water in the dry constituents and mix again at 180 rpm (Slow Mixing).
3 minutes	Add SP in remaining 20% water; mix again thoroughly at 360 rpm (Fast Mixing).

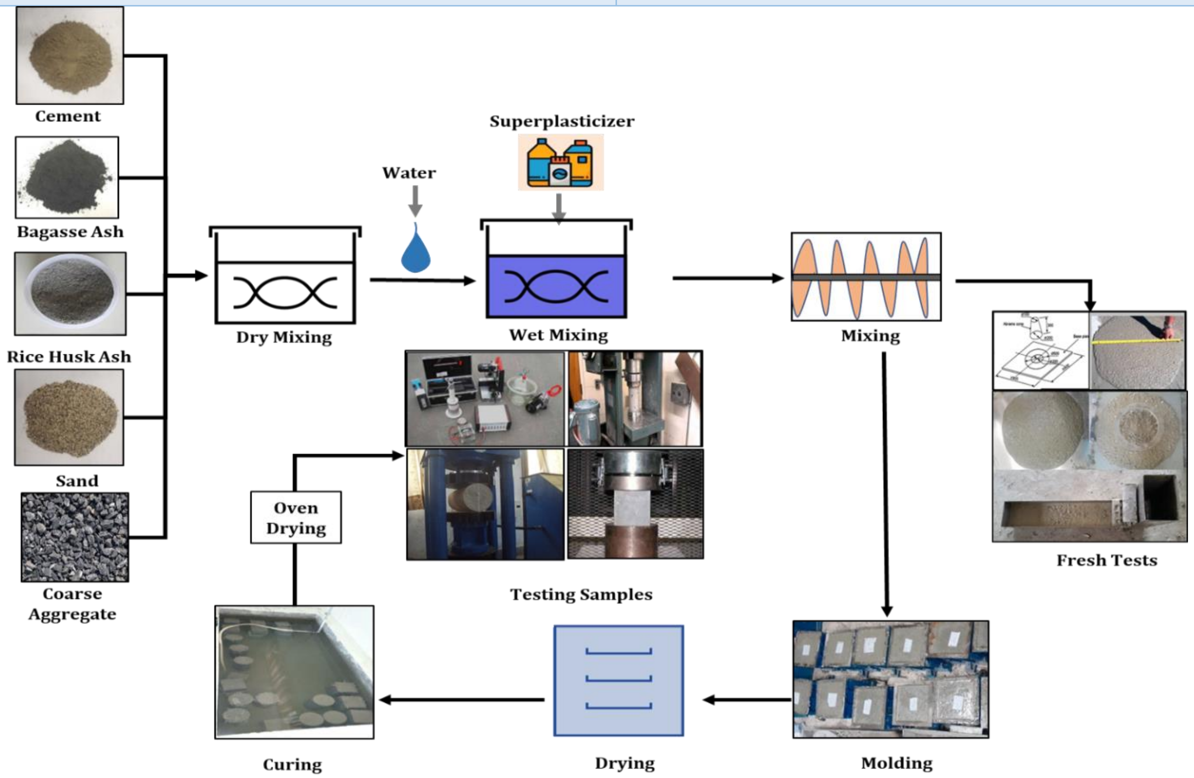

Fig. 3. 3: Schematic flow for preparation of SCC samples

3.6. Test Procedures

All tests were performed in accordance with the provided guidelines of EFNARC 2005 [44].

3.6.1. Slump Flow Test

The purpose of slump flow test is to determine the filling ability of SCC. It is used to determine the flow time and total flow spread of SCC. The amount of SP and W/C plays a significant role in investigating the flow properties of self-compacting concrete. According to ASTM C1611 slump flow test can be performed either with narrow end down or narrow end of slump cone. In this experimentation narrow end down option was opted.

After mixing the SCC in high performance pan mixture the cone from inside and baseplate was wetted using sponge and towel and then concrete was poured in the in the cone which is placed in the center of diameter 200mm without external compaction. The cone is lifted perpendicularly to the base plate and the concrete is allowed to flow freely without having any obstruction in its way. The stopwatch started the moment cone left the contact with baseplate and time was noted when flow reaches 500mm diameter also called as T50. When the concrete seizes to flow, the diameter of concrete is measured at two places in orthogonal direction and their mean value is the called as slump flow value.

The SCC spread must be checked visually to look for segregation r bleeding if there is any particularly at the edges.

+

Fig. 3. 4: Slump flow

3.6.2. L-Box Test

L-Box test is performed to determine the passing ability of SCC through reinforcement. After passing thorough gaps of reinforcement bars and flowing within the limits, the concrete's attained height is measured. The passing ability of SCC can be determined thorough this attained height.

In the experiment the bars having diameter of 12mm were used, L-Box was placed on hard surface. Firstly closing the sliding gate and then filling the vertical portion of L-Box to the full with SCC without and external compaction. And later concrete was allowed to set for 1 minute. Then started the stop watch the moment sliding gate was completely opened and measured the time at distances 200mm, 400mm and 600mm in the horizontal portion. Then, measuring the heights H1 and H2 after the concrete flow stopped.

Fig. 3. 5: L-box Test

3.6.3. J-Ring Flow Tests

J-ring test is performed to determine the passing ability of SCC. This test is performed as per guidelines of ASTM C1621. It's a ring of bars, slump cone is placed in its center. The rest of testing procedure is same as for slump flow test. And after lifting the cone the T50 spread is measured by help of stop watch and J-ring flow is measured at two different places in orthogonal directions. The mean value of both diameters is the J-ring flow value. Later, the Blocking value is determined which shows the effect of blocking.

Fig. 3. 6: J-ring flow

3.6.4. Air Content of Fresh SCC

The air content of freshly mixed SCC is measured as per guidelines of ASTM C231. The container of known volume is filled with SCC and then pressure lid is placed on the container and then air content is measured from measuring gauge.

Fig. 3. 7: Air content test

3.6.5. V-Funnel Test

This test is performed to determine the flow ability of SCC. It gives the time length required by the concrete to fall due to the gravitational pull from a small opening in the apparatus.

To perform this experiment, V-funnel is set vertically on a flat and stable ground, with the top opening horizontally positioned. Sponge or towel can be used to moist the internal surface of the funnel. Bucket is placed at the end of the funnel on ground to collect the concrete which going to fall from the funnel and shut the opening at the bottom of the funnel. Then Fill completely the funnel with SCC freshly prepared without doing any tamping. After a rest of 10 ± 2 seconds, open the gate from the bottom of the funnel. Noted the time from releasing the gate till viewing the very first light from below opening. The time measured hence referred as V-funnel flow time, and stated to the closest 0.1 second.

3.7. Acceptance criteria for SCC

Acceptance criteria defined by EFNARC 2005 for SCC is as follows [44]:

Table 3. 6: Acceptance criteria for fresh properties of SCC

Test Method	Units	Allowable Range	
		Minimum	**Maximum**
Slump flow	Mm	650	800
T_{50}cm Slump flow	sec	2	5
L-box	H2/H1	0.8	1.0
V-Funnel	sec	6	12
J-ring	(H1-H2) mm	0	10

3.8. Microscopic properties

3.8.1. Scanning Electron Microscopy

To investigate the particle size, shape and morphology of RHA and BA and also to study the hydration products and microstructure of SCC formulations, scanning electron microscopy was carried. Broken pieces of SCC mixes were collected and oven dried at 100±5 °C for 24 h to stop the hydration process and make the samples free from moisture. Then samples were broken into required size and attached to carbon tape on studs to get clear and clearer images. Then gold coating was done using sputter coater. SEM analysis was performed using model "TESCAN VEGA3".

3.8.2. Energy Dispersive X-Ray (EDX) Analysis

The EDX spot analysis was also performed on each of the three specimens considered for SEM using the model “TESCAN VEGA3” to study the chemical composition.

3.8.3. X-Ray Fluorescence (XRF)

Chemical analysis of cement and secondary raw materials is done using X-ray fluorescence (XRF). XRF is an experimental technique in which emission of characteristic X-rays from a material takes place. XRF gives the complete chemical analysis of a sample giving the quantities of all the chemical compounds or elements present in a sample.

3.9. Resistance to Acid Attack

For determining the resistance to acid attack, cubes of 150x150x150 mm^3 samples of each formulation were casted. The samples were immersed in 5% solution of sulfuric acid for 28 days till the age of 56 days starting from 28 days age. After 28 days samples were again dried in oven for 24 hours. Percentage loss was determined from these recorded weights and strength. The test was performed to check the durability of SCC samples of different mixes.

3.10. Strength Evaluation

3.10.1. Compression test for SCC

The cubes of 150x150x150 mm^3 were tested for compressive strength after being taken out from curing tank and were oven dried. The cubes were tested at three different ages (7, 28, and 56).

3.10.2. Split Tensile strength test

SCC was casted in cylindrical molds for the testing of split tensile strength test. Samples were cured for (7, 28, 56) days and were then tested after removing them from curing tanks and drying them.

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Fresh properties test on SCC

4.1.1. Slump flow test

The result of slump flow along with the slump flow time (T50) values for all SCC mix formulations is shown in Fig 4.1. The slump flow values of SCC containing RHA and BA as sand replacement were opted to range between 650-800 mm table 3.6 at constant water cement ratio and superplasticizer content values of 0.40 and 1.7% respectively which comply with the EFNARC guidelines [44], whereas the slump flow time increased from 2.77 to 4.93 s till highest replacement level as shown in Annexure A. There is a decreasing and increasing trend of slump flow and slump flow time values respectively at constant water to cement ratio depicting the loss of flow due to the adsorptive nature of incorporated ashes which attributed the higher viscosity to the SCC mixes. Moreover, the presence of unburnt organic particles depicted by loss of ignition values in Table 4 attributed to incorporated ashes which causes the increase in superplasticizer and water demand of the SCC mixes, conversely the slump flow decreased at constant superplasticizer content and water to cement ratio. The ashes are highly porous which was revealed in SEM analysis, the higher porosity of the ashes induces the higher water demand. Chopra and Divya [45] reported that incorporating 10-20% of RHA in SCC, results in decrease of slump flow value from 700 to 600mm. Similarly Sua-iam and Makul [46] reported the slump flow time (T_{50cm}) values of SCC increased upon the incorporation of BA in SCC that ranged between 4 to 6 s. Therefore, the incremental values of BA and RHA addition cause increasing viscosity and decreasing flow values.

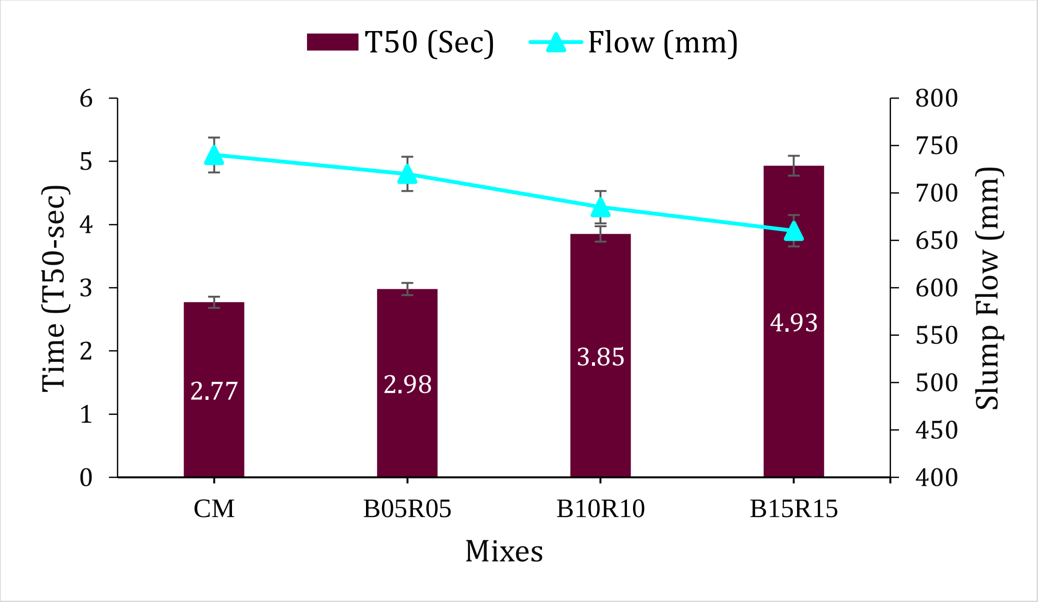

Fig. 4. 1: Slump Flow and T50 (sec) Values

4.1.2. J-Ring test

The rheological characteristics such as the passing ability and viscosity of SCC formulations was evaluated using the J-ring test. When the slump cone is lifted the SCC tends to flow through the network of reinforcements and the J-ring slump flow is recorded which is shown in Fig. 4. 2. The difference between the flow values of slump flow and J-ring slump flow was used in the blocking assessment as shown in Annexure A. No visible to minimal blocking can be termed if the flow differences exist between 0-25 mm, 25-50 mm difference corresponds to the minimal to noticeable blocking, whereas the difference above 50 mm is classified as noticeable to extreme blocking. The minimal blocking was observed for the B15R15 SCC mix as the difference observed was 25 mm, whereas all other mix formulations remained within the first blockage range. Additionally, the difference between J-ring values at center and periphery of the flow is indicated by (h_1-h_2) values, which was observed within the prescribed EFNARC criteria table 3.6. Similarly, Sua-iam and Makul [46] reported that no extreme blocking of SCC until the mix formulations contain 40% BA as a fine aggregate replacement was used. Moreover, the passing ability of the SCC mixes can also be evaluated by taking the difference in the height of SCC at the center and circumferential point on the J-ring slump flow. The standard range of difference for evaluating passing ability exists between 0-10, therefore the difference of all the tested mix formulations lies within the standard limits except B15R15 mix which depicts the good passing ability of SCC mixes. Similarly, Rahman et. al. [47] reported the passing ability of SCC mixes containing RHA as a supplementary cementitious material complying with the EFNARC guidelines [48]. Generally, the SCC mixes containing the mixture of BA and RHA depicted the adequate passing ability.

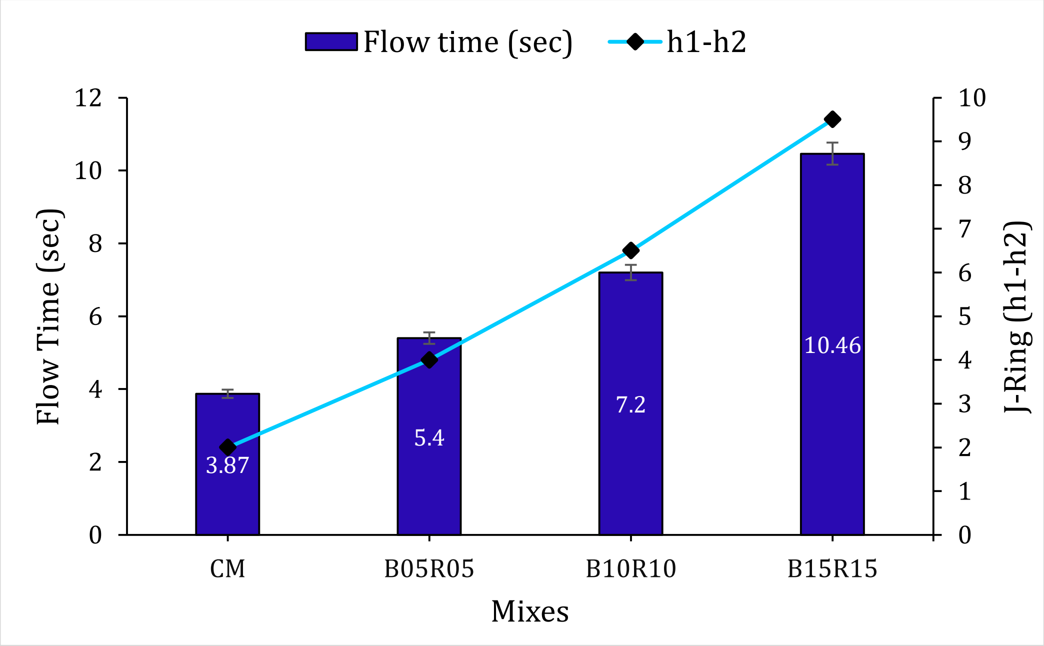

Fig. 4. 2: J-Ring value of all samples

4.1.3. L-Box test

The passing ability and filling ability of SCC mix formulations are measured using the L-box test, the results are shown in Fig. 4. 3. The results of the H_2/H_1 values of different mix formulations revealed the decrease in the L-box ratio from 0.99 to 0.82 for minimal to maximum replacement of ashes respectively, therefore the L-box ratio existed within the prescribed limits (0.8-1.0) of EFNARC guidelines [44], which are shown in Annexure A. The increasing trend of loss in filling and passing ability of the SCC mixes by incorporation of RHA and BA increases the demand of the water and superplasticizer attributed to the adsorptive nature of incorporated ashes. The incorporation of ashes in SCC increased the viscosity of formulations due to the adsorptive nature of ashes. Similarly, the published literature has reported that the addition of waste ashes resulted the L-box ratios within 0.8 to 1.0. The results of RHA added SCC reported that 35% inclusion of RHA produced blocking ratio of 0.86 [49], Kannan and Ganesan [50] reported that H_2/H_1 ratio ranged between 0.9 to 0.6 from 0 to 25% of cement replacement. Therefore, the passing ability of the mix formulations is fulfilling EFNARC criteria.

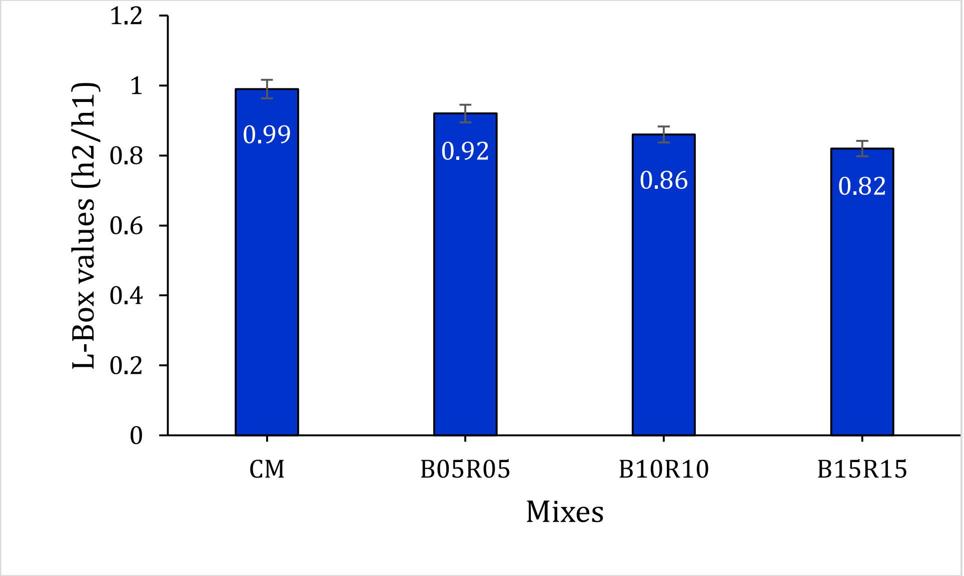

Fig. 4. 3: L-box test values of all samples

4.1.4. V-Funnel Test

The flow ability and stability of SCC were assessed by the V-funnel test [51]. According to EFNARC [48] guidelines, the values of V-Funnel flow time must exist between 6-12 s. This test corresponds to both internal and external friction which is due to cohesive forces among SCC constituents and adhesive forces between SCC and funnel. The resistive frictional forces among the SCC constituents are dominant in the narrower section of the V-funnel [52]. The incorporation ashes increase the frictional forces between paste and aggregate phases attributed to their higher surface area. Therefore, the increasing values of V-funnel flow by the replacement of ashes ranged between 6.77 to 11.88 s depicting the higher viscosity of SCC upon the incorporation of ashes due to the higher surface area, adsorptive, irregular and abrasive nature of ashes, thus increased the V-funnel flow time. The results in Fig. 4. 4, comply with that reported in the literature [49, 50, 53-55]. Sua-iam and Makul [46] revealed that when BA is incorporated with 10% in SCC, the value of V-funnel flow time remain between 8-12s but as the amount of BA increases, the V-funnel flow time does not fulfill the EFNARC criteria. Pai et. al. [49] reported V-funnel time of 9 s when 35%

RHA was added in SCC, Kannan and Ganesan [50] revealed that RHA incorporation reduced the V-funnel flow values increased from 4 to 8 s from 0 to 30% of RHA. The reduced V-funnel flow values attributed to the irregular shape, abrasive, high surface area and adsorptive nature of RHA. Therefore, flow ability decreases with the replacement level of ashes and flow of all mix formulations exist within the standard values.

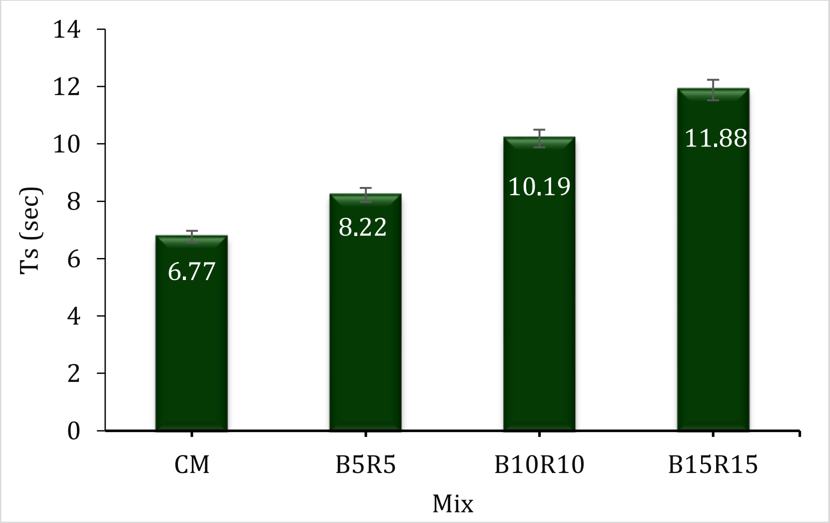

Fig. 4. 4: V-funnel flow time of all samples

4.1.5. Air Content

Air content corresponds to the percentage of air voids in SCC the results of which are shown in Fig. 4. 5. The air content values in SCC increased from 1.7% to 3.5% from CM to B15R15 respectively. The percentage increase of air content from CM to B05R05, B05R05 to B10R10, and B10R10 to B15R15 23.52, 23.81, and 34.61% respectively. There is a higher increase in air content between B10R10 and B15R15 than between other formulations despite the similar step size. The increase in air content upon the incorporation of ashes is due to higher surface area and porous nature of ashes. Hossain and Elsayed [56] also reported that with increase in amount of RHA ash from 10% to 20%, the air content tends to increase from 2.1 to 3.2%. Therefore, the incorporation of RHA and BA as sand replacement induces air into the cement paste matrix due to higher surface area and adsorptive nature of ashes.

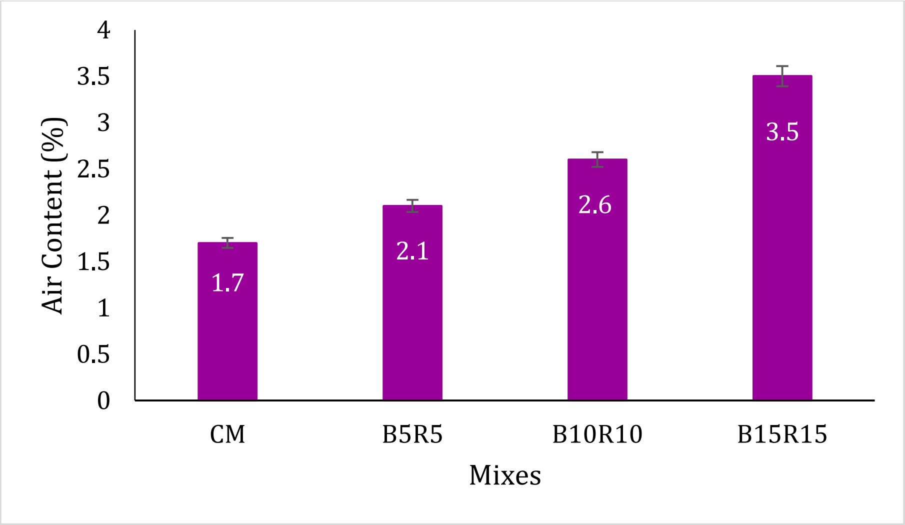

Fig. 4. 5: Air content percentage in all samples

4.2. SEM Analysis

The micro-forensic analysis of SCC samples containing BA and RHA is presented in Fig. 4. 6, and Fig. 4. 7, for CM (a, b), B05R05 (c, d) and B15R15 (e, f). The SEM images showed the surface morphology mainly emphasizing the pores structures and distribution of hydration products in the cement paste matrix. The SEM images revealed the presence of wider pores sizes ranging between 50-300 µm and 10-200 µm in CM and B15R15 mixes respectively. The microstructure of the B05R05 mix is densified due to micro-pore refinement by physical filler effect and pozzolanic activity, which was attributed to the presence of micro-sized incorporated particles and chemical reactivity of blended ashes respectively [57-60]. Furthermore, SEM images of B05R05 (c, d) revealed a more densified microstructure due to pore refinement through micro-pore filling and uniform distribution of C-S-H of improved morphology as compared to CM (a, b) and B15R15 (e, f) which indicate the optimum pozzolanic activity suspected in the mentioned formulation, which is also evident in literature [35, 57, 58]. This improved microstructure might enhance the mechanical and durability properties of concrete. Moreover, the SEM images illustrated the formation of C-S-H phases which exhibit several morphologies resulting in a densified microstructure. These phase morphologies might include closely packed grains, fibers, flaky, honeycombs, and featureless materials with dense structure at the microscopic level, however, it exhibits foiled morphology at the nanometer level [61]. The hydration phases were identified using the calcium to silica (Ca/Si) ratios approach through EDX analysis in accordance with the ‘Lea’s chemistry of cement' [61] which is presented in Table 4.1 and Fig. 4. 8. The Ca/Si ratio plays a vital role in the development of varying morphologies of CSH at a micro-scale. The amorphous, dense and featureless hydration products for B05R05 mix identified when Ca/Si ratio reaches the value of 1.5 [61]. The morphology of CSH may change from loose to densely packed grains morphologies with increasing Ca/Si ratios [62]. At low calcium silica Ca/Si ratio the CSH morphology exists in the branch-like structure, whereas, at a high Ca/Si ratio the isolated CSH has agglomerated and densely packed microstructure [62]. Furthermore, published literature has reported the Ca/Si ratio of the CSH phase in mature hydration phases might exist from 1.4 to 2.0 [63] and 1.2 to 2.0 [64]. According to the literature [62], mineral admixtures also significantly influence the CSH morphologies with varying values of Ca/Si ratio. The incorporation of pozzolan such as fly ash, silica fume and natural pozzolan, containing reactive silica stimulates the formation of hydration products [65-68]. The Ca/Si ratio of the cement pastes containing fly ash, rice husk ash, and other reactive and siliceous minerals were reported as 1.45, below 1.3 and 1.5 respectively [66, 68, 69]. The RHA has the capability to react rapidly as compared to other pozzolans such as fly ash and it consumes the CH produced by C_3S at a very fast rate as reported by literature [66]. The microstructure of the B05R05 mix is significantly improved due to micro-pore refinement in the interfacial transition zone by filling effect as well as chemical enhancement attributed to the pozzolanic activity. Therefore, the densification of microstructure occurred due to physical filler effect and pozzolanic activity.

Table 4. 1: Ca/Si and Ca/(Si+Al) of concrete specimens

Elements Ratio	**Percentage Atomic Weight**		
	CM	B05R05	B15R15
Ca/Si ratio	1.22	1.41	0.94
Ca/(Si+Al)	1.26	0.92	1.10

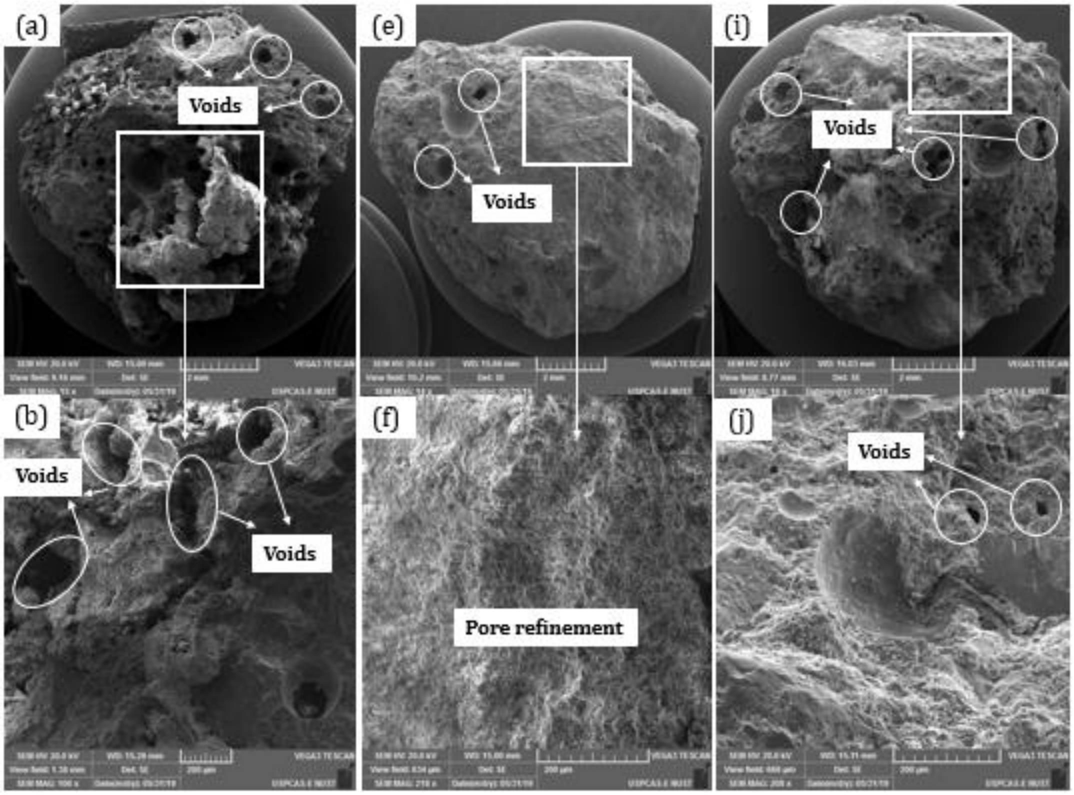

Fig. 4. 6: Macro-pores in SEM micrographs of CM (a, b), B05R05 (c, d), and B15R15 (e, f) mixes

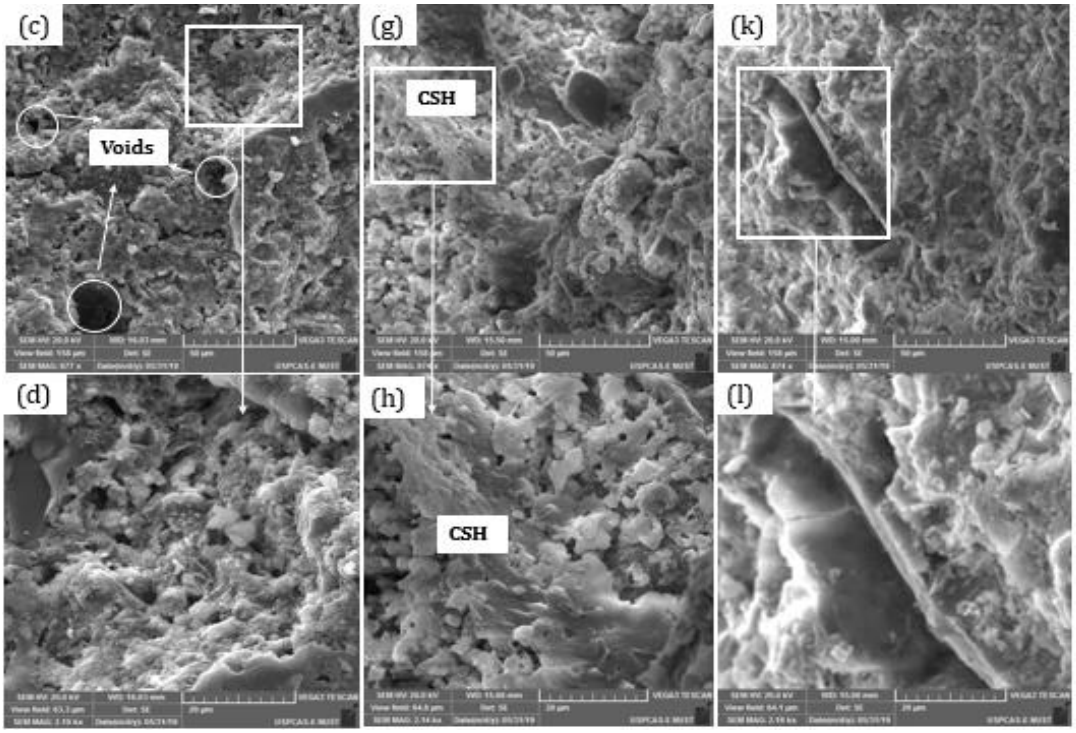

Fig. 4. 7: SEM images of concrete samples, CM (a, b, c, d), B5R5 (e, f, g, h), B15R15 (i, j, k, l)

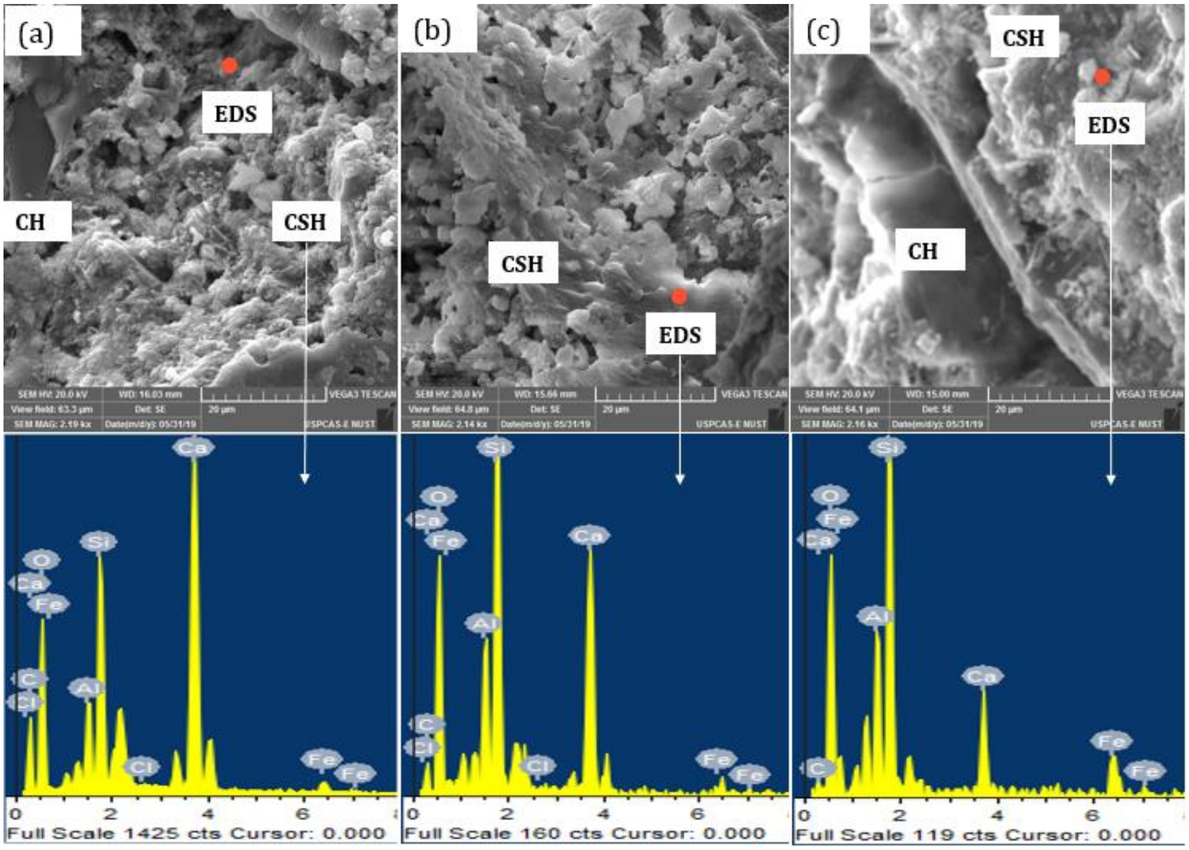

Fig. 4. 8: Chemical composition of hydration phases of CM (a), B05R05 (b), and B15R15 (c) mix samples by EDX analysis

4.3. Hardened Density and Water Absorption:

Hardened density is an important parameter for the concrete which corresponds to its physico-mechanical, microstructural, and durability properties. The values of hardened density and water absorption of all mixes are shown in Fig. 4. 9. The hardened density values of SCC mixes decreased with the increase in the incorporation of RHA and BA, therefore the increase in water absorption of mixes also occurred. The values of the hardened density of SCC mixes are 2129, 1993, 1816, and 1717 Kg/m^3 respectively. The percentage decrease in hardened density of SCC mixes is 6.39, 8.88, and 5.45% from CM to B05R05, B05R05 to B10R10, and B10R10 to B15R15 respectively. The water absorption for CM, B05R05, B10R10, and B15R15 SCC mixes are 2.51, 3.73, 4.62, and 5.72% respectively. The values of hardened density decreased with the increasing values of water absorption as shown in Fig. 4. 10. The hardened density results indicated that both B10R10 and B15R15 classified as lightweight concrete [70, 71]. Normally, the higher density concrete possesses superior mechanical strength, denser microstructure, and better durability resistance toward external degrading agents [72]. According to Barbhuiya [51], when the SCC mixes contain a constant amount of cement content and a varied amount of fine aggregates then the hardened density is a function of the specific weight of incorporated ashes, thus the hardened density of SCC formulations containing RHA and BA appeared to decrease due to a significantly lower specific weight of the incorporated ashes comparative to that of sand. The investigation on micromorphological features revealed that added ashes contain various particle shapes with porous nature as discussed in section 2.6. The porous morphology of the incorporated ashes observed in SEM analysis which endorsed the results of hardened density and water absorption of the SCC mixes. Several studies are reported incorporating the agricultural waste ashes including RHA and limestone powder [73], RHA [52], BA [46], and coal bottom ash [74] as partial replacement of sand in SCC. Sua-iam and Makul [73] utilized the high volume of RHA and limestone powder as a filler, the results showed that the density of the SCC mixes decreased for RHA incorporation which is attributed to the specific weight of the added minerals. Another published study [52] concluded that the incorporated. Sua-iam and Makul [46] concluded the decrease in hardened density upon the incorporation of BA. R. Siddique [74] also revealed the higher water absorption of coal bottom ash due to the porous nature of ash. The replacement of blended RHA and BA as sand replacement reduces the density and increases water absorption as it is the function of a specific weight. Hence, hardened density and water absorption decreased and increased respectively upon the incorporation of a combination of BA and RHA.

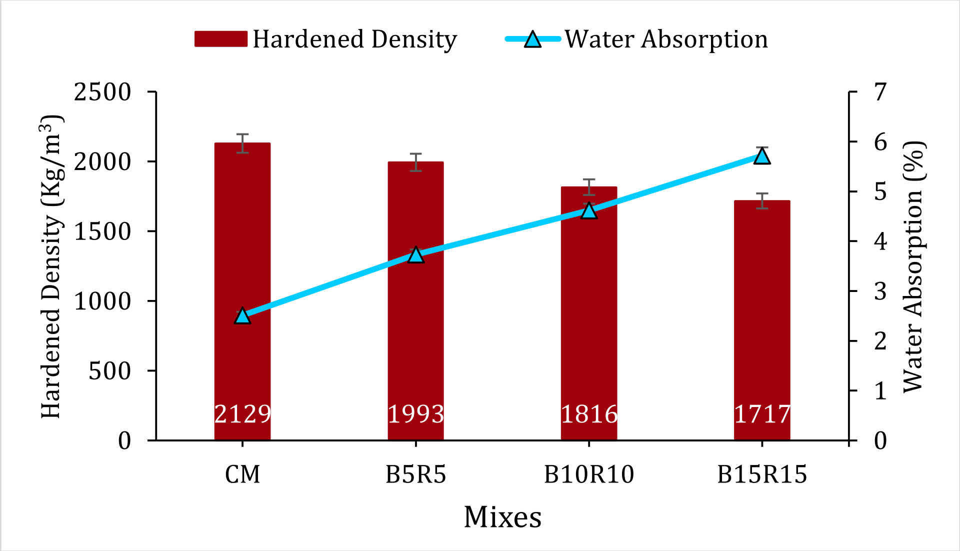

Fig. 4. 9: Hardened density and water absorption of mixes

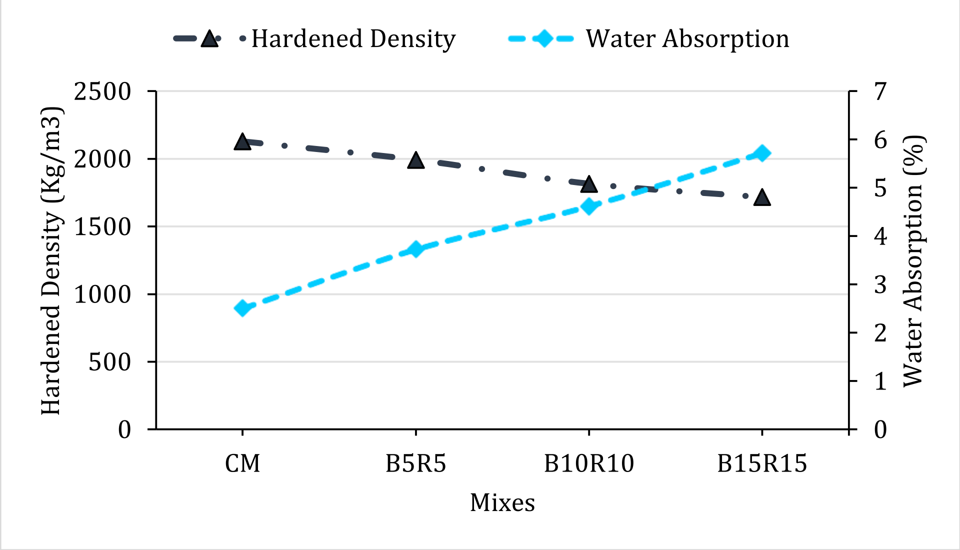

Fig. 4. 10: Relationship between Hardened density and Water Absorption values

4.4. Compressive Strength

Compressive strength is the structural property that depicts the load-carrying capacity of the SCC in compression. The compressive strength values in Fig. 4. 11, of CM, B05R05, B10R10, and B15R15 was determined as 23.07, 21.31, 16.35, 12.27 MPa at 7 days, 26.64, 26.08, 20.08, 15.22 at 28 days 29.84, 32.16, 24.41, 19.24 MPa at 56 days of curing age. Compressive strength values of SCC mixes decreased with the incorporation of blended ashes and increased with the increasing values of curing ages which are attributed to the pozzolanic activity of ashes. The maximum compressive strength value of 32.16 MPa at 56 days was achieved for B05R05 mix with the optimum level of suspected pozzolanic activity, however, the compressive strength values decreased upon further incorporation of ash due to its fragile and porous nature in comparison with sand. The percentage of strength development between 7 and 56 days for CM, B05R05, B10R10, and B15R15 is 29.34, 50.91, 49.29, and 56.80% respectively. The values of hardened density and compressive strength are 1816 Kg/m^3 and 20.08 MPa for B10R10 mix, which classifies B10R10 mix as structural lightweight concrete [70, 71]. Whereas, the maximum values of strength development were recorded for B05R05 due to the formation of secondary CSH gel as a result of a pozzolanic activity (EDX analysis) and pore refinement by physical filler effect as discussed earlier in section 4.2. Various published studies used coal bottom ash, RHA, BA used as sand replacement in SCC and investigated the physico-mechanical properties including compressive strength. The compressive strength of coal bottom ash increased with the curing age and decreased with the ash incorporation [74]. Sua-iam and Makul [46] incorporated BA as filler in SCC mixes, the results depicted that 20% replacement of BA increased the compressive strength from 35 to 49 MPa between 28 and 90 days of curing age indicating higher pozzolanic activity. Furthermore, the incorporation of RHA as a partial replacement of cement in concrete had resulted an increase in strength of 3.78% at 10% replacement and reduction in strength was observed at incorporation level of 15% and 25%[75]. Likewise, Siddique [76] assessed the effect of utilizing fly ash as substitution of sand in which the compressive strength improved along with replacement and curing ages. Singh and Siddique [77] performed tests on the mechanical and micromorphological levels on SCC by substituting iron slag as a replacement of sand, the result indicated that 20% replacement of iron slag produces higher compressive strength at higher curing age due to filling effect and formation of calcium silicate hydrate. Moreover, the incorporation of BA in SCC contributes toward the strength gain due to the pozzolanic reaction [46]. Therefore, the compressive strength development of SCC mixes is attributed to the densification of concrete microstructure due to pozzolanic activity.

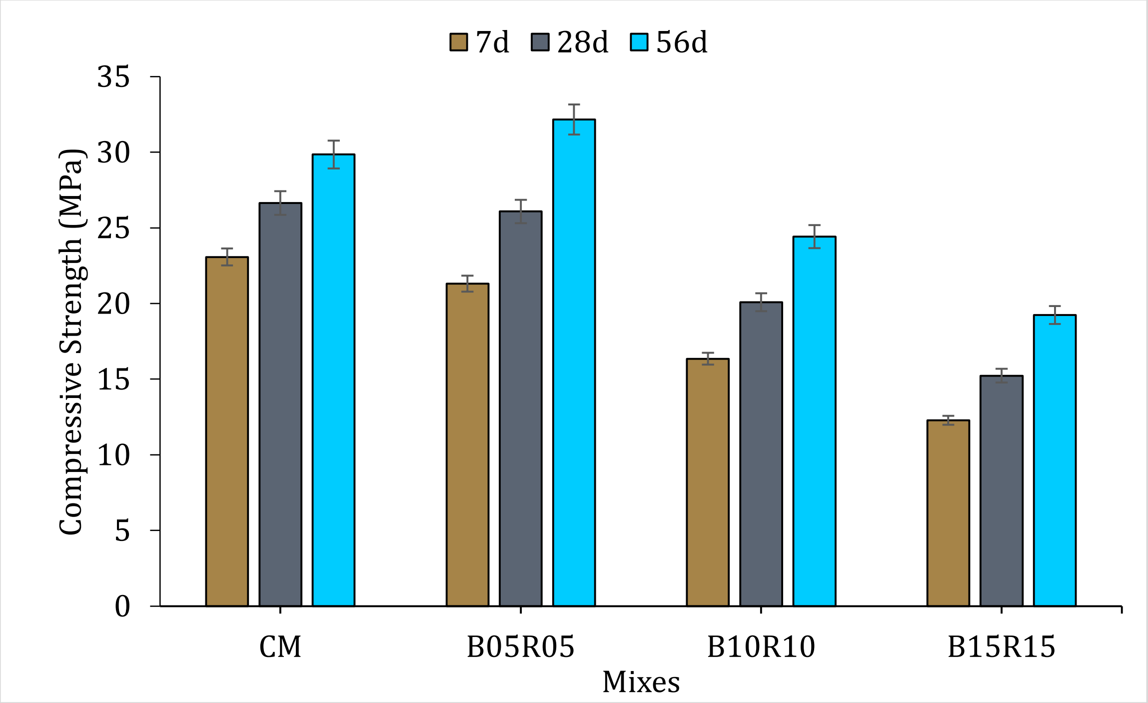

Fig. 4. 11: Compressive strength of all samples at different ages

4.5. Sulfate Resistance test

Sulfate resistance of SCC mixes in terms of weight loss and strength loss is shown in Fig. 4. 12, which was due to the deleterious action of sulfuric acid. The strength loss and weight loss values of the CM, B05R05, B10R10, and B15R15 are 14.24, 11.84, 14.49, 18.71 and 3.1, 2.9, 2.2, 1.8% respectively. The minimum and maximum strength loss values of 11.84 and 18.71% was observed for B05R05 and B15R15 mix respectively. B05R05 mix offered maximum sulfate resistance toward weathering due to corrosion as this mix formulation resulted in the highest performance in terms of mechanical strength. The weight loss and strength loss occurred due to the expansive natured delayed Ettringite formation which disintegrates concrete by spalling and cracking for further penetration of acid in the cement paste matrix [78]. The higher replacement of blended ashes showed the poor sulfate resistance due to the presence of higher alumina (Al_2O_3) content which subsequently formed calcium sulfoaluminate (delayed Ettringite) at exposure to sulfuric acid [50]. The ingress of sulfuric acid causes the formation of gypsum by reacting it with calcium hydroxide [79]. The highest sulfate resistance was observed which was due to the densification of microstructure by filler effect and formation of secondary CSH gel (section 4.2). The filler effect is caused by the ultrafine sized particles of incorporated RHA and BA, which reduced the permeability and dense packing, and restricted the acid penetration into the pores which is also evident in literature [28]. Similarly, several published studies investigated the acid resistance of SCC containing pozzolan. Kannan and Ganesan [50] revealed that the minimum weight loss of the SCC mix containing 30% RHA showed improved sulfate resistance in terms of weight loss. Said et. al. [80] reported the improved sulfate resistance in terms of weight loss of the 30% fly ash added SCC due to the formation of pozzolanic hydrates. Therefore, the indication of higher sulfate resistance was resulted due to the optimum level of replacement of blended ashes which further degrade the sulfate resistance due to the presence of higher alumina. Therefore, the optimum level of sulfate resistance was observed for B05R05 mix due to the maximum densification of the cement paste matrix.

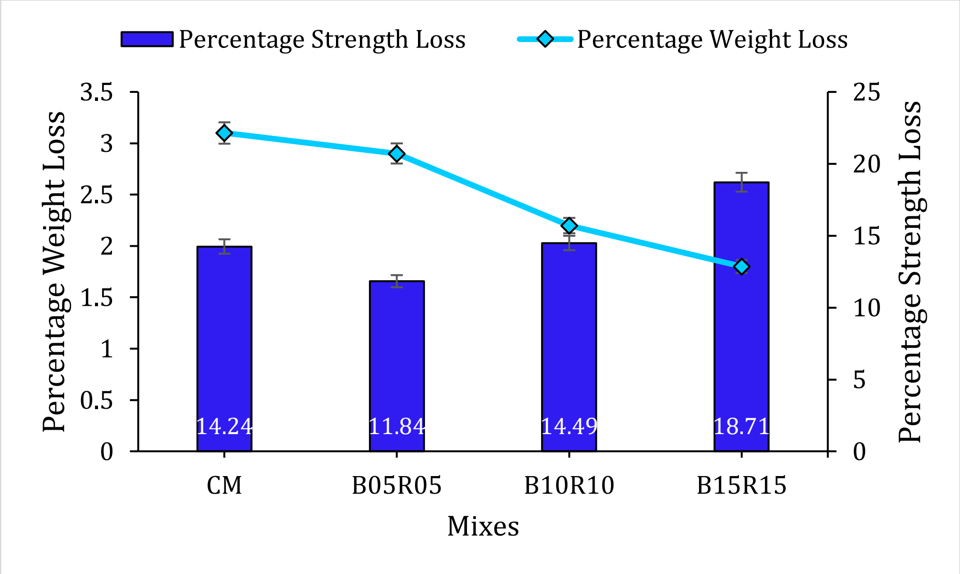

Fig. 4. 12: Strength loss and weight loss of the mixes

4.6. Split Tensile Strength

The results of the split tensile strength of all SCC mixes are shown in Fig. 4. 13. The results indicated the increase of tensile strength at increasing curing ages and decreased upon the incorporation of the mixture of ashes in SCC. The split tensile strength values for CM, B05R05, B10R10, and B15R15 were determined as 2.09, 1.86, 1.46, and 1.29 MPa at 7 days, 2.70, 2.71, 2.13, 1.69 MPa at 28 days, 3.04, 3.14, 2.43, and 1.95 MPa at 56 days respectively. The percentage increase of split tensile strength between 7 and 56 days of the mix formulations are indicative of the strength development between the mentioned ages. Therefore, the percentage strength development of split tensile strength for CM, B05R05, B10R10, and B15R15 between 7 and 56 days of curing age is 45.45, 68.82, 66.43, 51.16% respectively. Therefore, the highest values of strength development rate depict the formation of pozzolanic hydrates which are endorsed by the SEM/EDX analysis of mixes. Both compressive and split tensile strength proportionate with each other, thus the exponential regression relation between the mentioned properties is shown in Fig. 4. 14, with the regression coefficient (R) value of 0.91 which depicts the good relationship between data points and regression curve. The equation of the regression curve as mentioned in figure 20, is $C.S = 6.86e^{0.5033\,(T.S)}$. The split tensile strength of RHA based concrete was reported as 1.85 MPa at 5% incorporation for 150 days curing while at 28 days curing the reduction in strength was observed [81]. Moreover, Noor-ul-Amin [82] studied the impact of bagasse ash on strength properties of concrete and reported an increase in split tensile strength up to 20% incorporation level which was then decreased at 25% and 30% addition. Similarly, Siddique [74] also investigated the split tensile strength of SCC containing coal bottom ash as a sand replacement, the results shows that the split tensile strength of the SCC mixes decreased upon addition of the ash and increased upon increasing curing age. Therefore, at early curing ages the strength development is not so significant due to the incorporation of mixed ashes, however, the strength replenished at higher curing ages is indicative of the pozzolanic potential of the ashes.

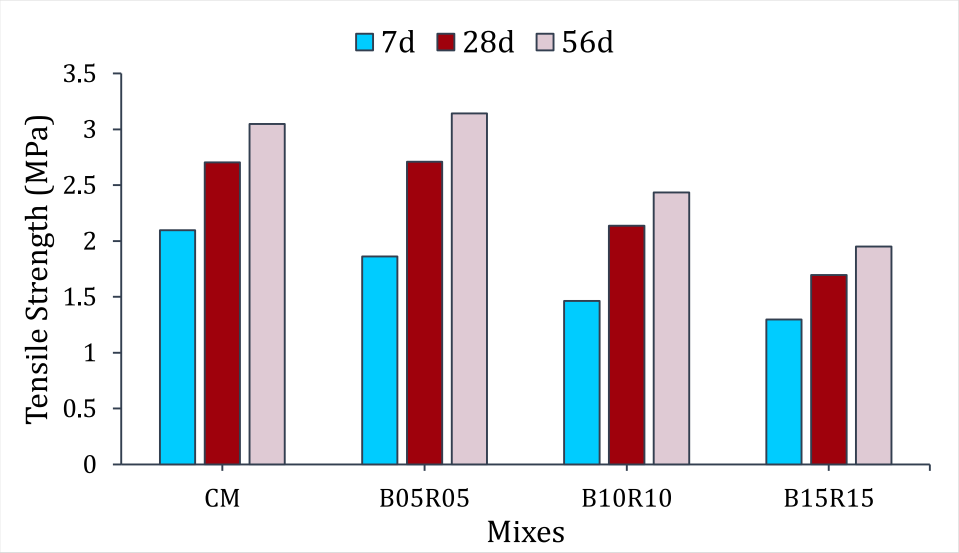

Fig. 4. 13: Split Tensile Strength values of all samples

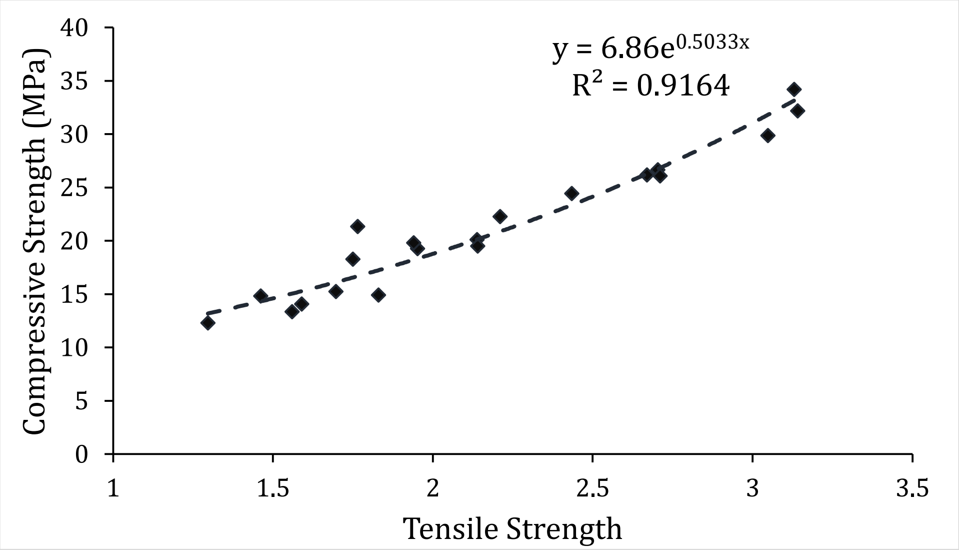

Fig. 4. 14: Tensile and Compressive strength values comparison

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Incorporation of RHA and BA blend as sand replacement in SCC concrete has eco-friendly aspects that include reduction of disposal issue of the mentioned ashes and beneficial impacts on microstructural, physicomechanical and durability properties of SCC by physical effects (micro-filling, clogging) and chemical contribution through the enhanced microstructure of concrete mix due to the pozzolanic reaction. The summarized conclusions of this research are shown below:

1. The characterization results of the RHA and BA revealed that adsorptive and porous natured ashes have a lower specific weight, their massive incorporation might influence the rheological, hardened and durability properties of SCC.
2. The microstructural investigation of SCC mixes containing RHA and BA as sand replacement has shown the formation of a densified microstructure by physical filler effect and formation of secondary CSH gel due to pozzolanic reaction.
3. The fresh properties of the ashes incorporated SCC reduced the flow of the mixes upon incorporation level, thus the demand of water and superplasticizer content increased. However, the replacement of the blended ashes enhance the viscosity of the mixes, therefore it is suggested to investigate the properties of SCC containing RHA and BA as viscosity modifying agent for future research.
4. The hardened density of the mixes reduced at replacement level, whereas the compressive strength increased at higher curing ages due to the chemical reactivity of the ashes. The result indicated that the 20% replacement of RHA and BA classified it as lightweight structural concrete with the compressive strength and density values of 20MPa and 1816 Kg/m^3. Therefore, it can be used in several structural configurations.
5. The sulfate resistance of the SCC mixes improved for B05R05 mix attributed to the densification of cement paste matrix due to filling effect by ultra-fine added ash particles and pozzolanic reaction.

REFERENCES

[1] H. Okamura, M. Ouchi, Self-compacting concrete, Journal of advanced concrete technology 1(1) (2003) 5-15.

[2] A.M. Neville, Properties of concrete, Longman London1995.

[3] R. Gagne, M. Pigeon, Deicer salt scaling resistance of high-performance concrete, Special Publication 122 (1990) 29-44.

[4] T. RILEM, 174 SCC.(2000). Self compacting concrete State-of-the-art report of RILEM technical committe 174-SCC. Skarendahl A, Petersson O, editors, RILEM Publications SARL, France. RILEM Publications SARL, Bagneux, France.

[5] E. John, The impacts of sand mining in Kallada river (Pathanapuram Taluk), Kerala, J. Basic Appl. Biol 3 (2009) 108-113.

[6] D. Padmalal, K. Maya, Sand mining: environmental impacts and selected case studies, Springer2014.

[7] P. Peduzzi, Sand, rarer than one thinks, Environmental Development 11 (2014) 208-218.

[8] M.C. Limbachiya, Bulk engineering and durability properties of washed glass sand concrete, Construction and Building Materials 23(2) (2009) 1078-1083.

[9] D. Padmalal, K. Maya, S. Sreebha, R. Sreeja, Environmental effects of river sand mining: a case from the river catchments of Vembanad lake, Southwest coast of India, Environmental geology 54(4) (2008) 879-889.

[10] G.M. Kondolf, PROFILE: hungry water: effects of dams and gravel mining on river channels, Environmental management 21(4) (1997) 533-551.

[11] M.A. Ashraf, M.J. Maah, I. Yusoff, A. Wajid, K. Mahmood, Sand mining effects, causes and concerns: A case study from Bestari Jaya, Selangor, Peninsular Malaysia, Scientific Research and Essays 6(6) (2011) 1216-1231.

[12] J. de Leeuw, D. Shankman, G. Wu, W.F. de Boer, J. Burnham, Q. He, H. Yesou, J. Xiao, Strategic assessment of the magnitude and impacts of sand mining in Poyang Lake, China, Regional Environmental Change 10(2) (2010) 95-102.

[13] M. Gavriletea, Environmental impacts of sand exploitation. Analysis of sand market, Sustainability 9(7) (2017) 1118.

[14] M.N. Saviour, Environmental impact of soil and sand mining: a review, International Journal of Science, Environment and Technology 1(3) (2012) 125-134.

[15] S.R. Bajracharya, P.K. Mool, B.R. Shrestha, Global climate change and melting of Himalayan glaciers, Melting glaciers and rising sea levels: Impacts and implications (2008) 28-46.

[16] E.H. Allison, A.L. Perry, M.C. Badjeck, W. Neil Adger, K. Brown, D. Conway, A.S. Halls, G.M. Pilling, J.D. Reynolds, N.L. Andrew, Vulnerability of national economies to the impacts of climate change on fisheries, Fish and fisheries 10(2) (2009) 173-196.

[17] P.O. Modani, M. Vyawahare, Utilization of bagasse ash as a partial replacement of fine aggregate in concrete, Procedia Engineering 51 (2013) 25-29.

[18] S. Butt, I. Hartmann, V. Lenz, Bioenergy potential and consumption in Pakistan, Biomass and bioenergy 58 (2013) 379-389.

[19] A. Goyal, A. Anwar, H. Kunio, O. Hidehiko, Properties of sugarcane bagasse ash and Its Potential as Cement-Pozzolana Binder, Twelfth International Colloquium on Structural and Geotechnical Engineering, 2007, pp. 10-12.

[20] M.A. Qureshi, S. Afghan, Sugarcane cultivation in Pakistan, Sugar Book Pub. Pakistan Society of Sugar Technologist (2005).

[21] A. Sales, S.A. Lima, Use of Brazilian sugarcane bagasse ash in concrete as sand replacement, Waste Management 30(6) (2010) 1114-1122.

[22] G. Cordeiro, R. Toledo Filho, L. Tavares, E. Fairbairn, Pozzolanic activity and filler effect of sugar cane bagasse ash in Portland cement and lime mortars, Cement and Concrete Composites 30(5) (2008) 410-418.

[23] G.C. Cordeiro, R.D. Toledo Filho, L.M. Tavares, E.d.M.R. Fairbairn, Ultrafine grinding of sugar cane bagasse ash for application as pozzolanic admixture in concrete, Cement and concrete research 39(2) (2009) 110-115.

[24] N. Singh, V. Singh, S. Rai, Hydration of bagasse ash-blended portland cement, Cement and Concrete Research 30(9) (2000) 1485-1488.

[25] R. Rum, Z. Jaini, K. Boon, S. Khairaddin, N. Rahman, Foamed concrete containing rice husk ash as sand replacement: an experimental study on compressive strength, Materials Science and Engineering Conference Series, 2017, p. 012012.

[26] K. Kunchariyakun, S. Asavapisit, K. Sombatsompop, Properties of autoclaved aerated concrete incorporating rice husk ash as partial replacement for fine aggregate, Cement and Concrete Composites 55 (2015) 11-16.

[27] S. Samantaray, K. Panda, M. Mishra, Rice Husk Ash as Fine Aggregate Sustainable Material for Strength Enhancement of Conventional and Self Compacting Concrete, Key Engineering Materials, Trans Tech Publ, 2016, pp. 94-103.

[28] A. Joshaghani, M.A. Moeini, Evaluating the Effects of Sugarcane-Bagasse Ash and Rice-Husk Ash on the Mechanical and Durability Properties of Mortar, Journal of Materials in Civil Engineering 30(7) (2018) 04018144.

[29] J. Torres Agredo, R. Mejía de Gutiérrez, C. Escandón Giraldo, L. González Salcedo, Characterization of sugar cane bagasse ash as supplementary material for Portland cement, Ingeniería e Investigación 34(1) (2014) 5-10.

[30] A. Bahurudeen, M. Santhanam, Influence of different processing methods on the pozzolanic performance of sugarcane bagasse ash, Cement and Concrete Composites 56 (2015) 32-45.

[31] J. Payá, J. Monzó, M.V. Borrachero, L. Díaz-Pinzón, L.M. Ordonez, Sugar-cane bagasse ash (SCBA): studies on its properties for reusing in concrete production, Journal of Chemical Technology & Biotechnology: International Research in Process, Environmental & Clean Technology 77(3) (2002) 321-325.

[32] V.S. Batra, S. Urbonaite, G. Svensson, Characterization of unburned carbon in bagasse fly ash, Fuel 87(13-14) (2008) 2972-2976.

[33] V.M. Sreekumar, R.M. Pillai, B.C. Pai, M. Chakraborty, Microstructural development in Al/MgAl2O4 in situ metal matrix composite using value-added silica sources, Science and technology of advanced materials 9(1) (2008) 015004.

[34] N. Yalcin, V. Sevinc, Studies on silica obtained from rice husk, Ceramics international 27(2) (2001) 219-224.

[35] Y. Abiodun, A. Jimoh, Microstructural characterisation, physical and chemical properties of rice husk ash as viable Pozzolan in building material: a case study of some Nigerian grown rice varieties, Nigerian Journal of Technology 37(1) (2018) 71-77.

[36] P.E. Stutzxnan, L. Centeno, Compositional Analysis of Beneficiated Fly Ashes, in: U.S.D.O. COMMERCE (Ed.) Building and Fire Research Laboratoy, Gaithersberg, 1995.

[37] U.K. Javed, Rao Arsalan Memon, Shazim Ali Jalal, Fazal E Zafar, Muhammad Saeed Sustainable incorporation of lime-bentonite clay composite for production of ecofriendly bricks, Journal of Cleaner Production (2020) 121469.

[38] L. Zongjin, Advanced concrete technology, John Wiley2011.

[39] S.A.J. Memon, Usman Khushnood, Rao Arsalan, Eco-friendly utilization of corncob ash as partial replacement of sand in concrete, J Construction Building Materials 195 (2019) 165-177.

[40] N. Pamnami, P.D. Patel, A. Verma, J. Pitroda, Comparison and Optimization of Dosage of Different Super-Plasticizers for Self Compacted Concrete Using Marsh Cone, International Journal of Engineering and Innovative Technology 2(8) (2013).

[41] G. Xua, J. Beaudoin, Effect of polycarboxylate superplasticizer on contribution of interfacial transition zone to electrical conductivity of Portland cement mortars, Materials Journal 97(4) (2000) 418-424.

[42] S.A. Rizwan, S. Mustafa, W. Ahmed, MITIGATION OF EARLY AGE SHRINKAGE IN SELF-CONSOLIDATING PASTE SYSTEMS USING SUPERABSORBENT POLYMERS.

[43] A. C511, Standard specification for mixing rooms, moist cabinets, moist rooms, and water storage tanks used in the testing of hydraulic cements and concretes, 2013.

[44] C. BIBM, E. ERMCO, EFNARC (2005) The European guidelines for self-compacting concrete, Specification, Production and Use.

[45] D. Chopra, R. Siddique, Strength, permeability and microstructure of self-compacting concrete containing rice husk ash, Biosystems engineering 130 (2015) 72-80.

[46] G. Sua-Iam, N. Makul, Use of increasing amounts of bagasse ash waste to produce self-compacting concrete by adding limestone powder waste, Journal of Cleaner Production 57 (2013) 308-319.

[47] M.E. Rahman, A.S. Muntohar, V. Pakrashi, B. Nagaratnam, D. Sujan, Self compacting concrete from uncontrolled burning of rice husk and blended fine aggregate, Materials & Design 55 (2014) 410-415.

[48] S.J.L. EFNARC, UK: Association House, Guidelines for self-compacting concrete, 32 (2002) 34.

[49] B. Pai, M. Nandy, A. Krishnamoorthy, P. Sarkar, P.J.A.J.o.E.R. George, Comparative study of self compacting concrete mixes containing fly ash and rice husk ash, 3(3) (2014) 150-154.

[50] V. Kannan, K.J.C. Ganesan, B. Materials, Chloride and chemical resistance of self compacting concrete containing rice husk ash and metakaolin, 51 (2014) 225-234.

[51] S. Barbhuiya, Effects of fly ash and dolomite powder on the properties of self-compacting concrete, J Construction

Building Materials 25(8) (2011) 3301-3305.

[52] G. Sua-iam, N.J.J.o.c.p. Makul, Utilization of high volumes of unprocessed lignite-coal fly ash and rice husk ash in self-consolidating concrete, 78 (2014) 184-194.

[53] M. Safiuddin, J. West, K.J.C. Soudki, B. Materials, Properties of freshly mixed self-consolidating concretes incorporating rice husk ash as a supplementary cementing material, 30 (2012) 833-842.

[54] S.A. Rizwan, High-performance mortars and concrete using secondary raw materials, (2006).

[55] S.A. Rizwan, T.A.J.A.m.j. Bier, Self-consolidating mortars using various secondary raw materials, 106(1) (2009) 25.

[56] Z. Hossain, A. Elsayed, Use of Rice Hull Ash (RHA) as a Sustainable Source of Construction Material, (2018).

[57] A.A.E. Hussein, N. Shafiq, M.F. Nuruddin, F.A. Memon, Compressive strength and microstructure of sugar cane bagasse ash concrete, Research Journal of Applied Sciences, Engineering and Technology 7(12) (2014) 2569-2577.

[58] M.A. Maldonado-García, U.I. Hernández-Toledo, P. Montes-García, P.L. Valdez-Tamez, The influence of untreated sugarcane bagasse ash on the microstructural and mechanical properties of mortars, Materiales de Construcción 68(329) (2018) 148.

[59] S.-H. Jung, V. Saraswathy, S. Karthick, P. Kathirvel, S.-J. Kwon, Microstructure characteristics of fly ash concrete with rice husk ash and lime stone powder, International Journal of Concrete Structures and Materials 12(1) (2018) 1-9.

[60] V. Vishwakarma, D. Ramachandran, N. Anbarasan, A.M. Rabel, Studies of rice husk ash nanoparticles on the mechanical and microstructural properties of the concrete, Materials Today: Proceedings 3(6) (2016) 1999-2007.

[61] P. Hewlett, M. Liska, Lea's chemistry of cement and concrete, Butterworth-Heinemann2019.

[62] D. Hou, H. Ma, Z. Li, Morphology of calcium silicate hydrate (CSH) gel: a molecular dynamic study, Advances in Cement Research 27(3) (2015) 135-146.

[63] I. Sims, APPLICATION OF STANDARD TESTING PROCEDURES FOR ALKALI-REACTIVITY. PART I, Concrete 15(10) (1981).

[64] C. Rogers, Petrographic examination of aggregate and concrete in Ontario, (1989).

[65] V.M. Malhotra, Fly ash, silica fume, slag & other mineral by-products in concrete, American Concrete Institute, 1983.

[66] M. Khan, K. Mohan, H.F. Taylor, Pastes of tricalcium silicate with rice husk ash, Cement and Concrete Research 15(1) (1985) 89-92.

[67] A. Harrisson, N. Winter, H.F. Taylor, Microstructure and microchemistry of slag cement pastes, MRS Online Proceedings Library Archive 86 (1986).

[68] H. Taylor, Nanostructure of C□ S□ H: Current status, Advanced cement based materials 1(1) (1993) 38-46.

[69] Z.-Q. Wu, J. Young, The hydration of tricalcium silicate in the presence of colloidal silica, Journal of materials science 19(11) (1984) 3477-3486.

[70] A. C330, Standard Specification for Lightweight Aggregates for Structural Concrete, 2017.

[71] D.J. Akers, R.D. Gruber, B.W. Ramme, M.J. Boyle, J.G. Grygar, S.K. Rowe, T.W. Bremner, E.S. Kluckowski, S.R. Sheetz, R.G.J.A.R.-A.C.I. Burg, Michigan, Guide for Structural Lightweight-Aggregate Concrete, 2003.

[72] Y.J. Kim, Y.W. Choi, M.J.C. Lachemi, B. Materials, Characteristics of self-consolidating concrete using two types of lightweight coarse aggregates, 24(1) (2010) 11-16.

[73] G. Sua-Iam, N.J.C. Makul, B. Materials, Utilization of limestone powder to improve the properties of self-compacting concrete incorporating high volumes of untreated rice husk ash as fine aggregate, 38 (2013) 455-464.

[74] R. Siddique, Compressive strength, water absorption, sorptivity, abrasion resistance and permeability of self-compacting concrete containing coal bottom ash, Construction and Building Materials 47 (2013) 1444-1450.

[75] M.E. Ephraim, G.A. Akeke, J.O. Ukpata, Compressive strength of concrete with rice husk ash as partial replacement of ordinary Portland cement, Scholarly Journal of Engineering Research 1(2) (2012) 32-36.

[76] R. Siddique, Effect of fine aggregate replacement with Class F fly ash on the mechanical properties of concrete, Cement and Concrete Research 33(4) (2003) 539-547.

[77] G. Singh, R. Siddique, Strength properties and micro-structural analysis of self-compacting concrete made with iron slag as partial replacement of fine aggregates, Construction and Building Materials 127 (2016) 144-152.

[78] P. Mehta, P.J.N.Y.U. Monteiro, M: Concrete Microestructure, properties, and Materials, Third Edit, (2006) 644.

[79] K. Kawai, S. Yamaji, T. Shinmi, Concrete deterioration caused by sulfuric acid attack, International Conference on Durability of Building Materials and Components, 2005, p. 17e20.

[80] I. Said, B. Khan, O. Inderyas, M.A. Rahman, S.J.I.J.o.C.E. Ahmed, Technology, Utilization of Rice Husk Ash as a Pozzolan in Self-Compacting Concrete, 8(1) (2017) 98-108.

[81] L.O. Ettu, O.M. Ibearugbulem, C.S. Ezenkwa, D.A. Amatobi, E. Onyezewe, Split Tensile Strengths of Concrete Incorporating Rice Husk Ash and SawDust Ash.

[82] N.-u. Amin, Use of bagasse ash in concrete and its impact on the strength and chloride resistivity, Journal of materials in civil engineering 23(5) (2011) 717-720.

ANNEXURES

Annex A

MIX	SP (%)	w/c	Slump Flow		L-Box Test (mm)			J-Ring Test (mm)		V-Funnel Test (Sec)	
			$T_{50\ cm}$ (Sec)	Flow (mm)	h1	h2	h2/h1	Diameter	Blocking Assessment	To	Ts
CM	1.7	0.4	2.77	740	61	60	0.99	730	No	6.22	6.77
B05R05	1.7	0.4	2.98	720	63	58	0.92	708	No	6.98	8.22
B10R10	1.7	0.4	3.85	685	65	56	0.86	670	No	8.64	10.19
B15R15	1.7	0.4	4.93	660	66	54	0.82	635	Minimal	9.46	11.88

Table-A: Fresh Properties of Self Compacting Concrete