

PROPERTIES OF CONCRETE INCORPORATING BAGASSE ASH

*A Thesis Submitted in Fulfilment of the
Requirement for the Award of Degree of*

MASTER OF ENGINEERING IN STRUCTURAL ENGINEERING

Submitted by

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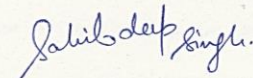
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JUNE 2018**

DECLARATION

I, Sahibdeep Singh Setia hereby declare that the work which is presented in this thesis report entitled "**Properties of concrete incorporating bagasse ash**" in fulfilment of requirement for the award of degree of **Master of Engineering in Structures**, submitted at **Civil Engineering Department, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala**, is an authentic record of the work carried out under the guidance of **Dr. Rafat Siddique, Dean, Research & Sponsored Projects and Senior Professor, Department of Civil Engineering, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala** and **Dr. Malkit Singh, Additional Superintending Engineer, Punjab State Power Corporation Ltd., Patiala** from January 2018 to June 2018.

The matter presented in this has not been submitted either in part or full to any other university or institute for the award of any other degree.

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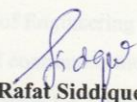


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CERTIFICATE

This is to certify that the above declaration made by the student concerned is correct according to the best of my knowledge and belief.


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ABSTRACT

About 44 thousand tons / day sugarcane bagasse ash is produced from cogeneration process in sugar mill industries. The sugarcane bagasse ash can be utilized as replacement of cement in concrete as it possesses pozzolanic properties rather to dump at nearby locations of industries which causes numerous health problems to local living communities. The incorporation of sugarcane bagasse ash in concrete also reduces the CO₂ emission by reduction of cement production up to some extent. In this study, experimental testing was done to explore the suitability of sugarcane bagasse ash in concrete by performing slump test, unit weight, strength in compression and splitting tensile, pulse velocity and chloride permeability and results were compared with control concrete. The sugarcane bagasse ash was utilized as partly replacement of cement at 10%, 20%, 30% & 40% level by weight in concrete. SEM morphology analysis and chemical compound changes by XRD analysis were also be checked in this study. The results showed 10% incorporation of sugarcane bagasse ash as replacement of cement as optimum value. Higher incorporation levels did not improve the strength and durability properties significantly with comparison to control concrete. The SEM and XRD results showed the increase in hydration products formation with the inclusion of Sugarcane bagasse ash with cement in concrete.

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ABBREVIATIONS

Abbreviations	Word(s)
SCBA	Sugarcane bagasse ash
ASTM	American Society for Testing and Material
BIS	Bureau of Indian Standards
CH	Calcium Hydroxide
CS	Calcium Silicate
CTM	Compression Testing Machine
E	Ettringite
EDS	Energy Dispersive X-ray Spectroscopy
ITZ	Inter Transition Zone
OPC	Ordinary Portland Cement
P	Portlandite
SCM	Supplementary Cementitious Material
UTM	Universal Testing Machine
Q	Quartz
w/c	Water-cement ratio
XRD	X-Ray Diffraction
w/b	Water-binder ratio
LOI	Loss on Ignition
IST	Initial Setting Time
FST	Final Setting Time
BA	Bagasse ash

LIST OF UNITS

Units	Word(s)
kg	Kilogram
g	Gram
mg	Milligram
°C	Degree Celsius
%	Percent
m	Metre
cm	Centimetre
mm	Millimetre
μm	Micrometre
N	Newton
MPa	Mega Pascal
kg/m ³	Kilogram per cubic meter
N/mm ²	Newton per square millimetre
kN	Kilo Newton
hr.	Hour
min	Minute
sec	Second
l	Litre
ml	Millilitre
m/s	Metre per second
km/s	Kilometre per second
θ	Theta

1.1 GENERAL

Concrete is the synthetic material that is very common around the world. Concrete products are the second-most used up product on earth after water; each person uses nearly about 3 tonnes a year averagely. Portland cement is the chief constituent of concrete that is used to bind all the ingredients like aggregates. The concrete industry utilizes about 1.6 BT of Portland cement to produce some twelve billion tonnes of concrete a year. Natural resources are consumed in large quantity in production of concrete. Due to the scarcity of natural resources, construction costs are increasing day by day and disrupting the ecological balance. So it is the time to introduce a few substitutes for these natural ingredients of concrete. The material must also be "ecologically friendly" during manufacture and also aesthetically pleasing when used in buildings. Its success is when raw materials are widely distributed around the world, raw material prices being low and the properties and performance of concrete giving it a large scale of application. Concrete services have steadily increased to meet the needs of society.

The reason for the enormous use of concrete in the construction industry is the versatility, reliability, and durability due to its strength, stiffness, durability, formability, efficiency, and cost-effectiveness.

1.2 CEMENT

Cement material is extensively utilized across the world as a binder in concrete. India is the 2nd biggest cement producer in the world and accounts for nearly 8% of total cement production with an in effect capacity of 234 MT/yr. Due to the growing demand for concrete resulting from increased infrastructure development, cement production accounts for about 2.5 percent of total worldwide CO₂ emissions from industries. So there is a need to focus on the alternative of cement. Also, management of waste products is presently a hot topic that needs consideration in India. The waste from agricultural segment only has generated nearly 600 MT of bio-waste mass. In Asia alone, nearly 4.4 BT of non-biodegradable waste are generated every year. However, about 960 MT of non-biodegradable waste was generated each year from agricultural activities, mining activities, industrial processes and municipal processes.

The manufacturing process of cement needs a huge amount of energy and the demand for cement is also increasing significantly. World cement demand was in 2005 with the amount of 2,283 million tons for which China was leading producer with 1064 MT and India in the 2nd

position. Total production of cement was increased to about 3300 MT in 2010. It is estimated that CO₂ emission from the Indian cement production industries is predicted to be reach 835 MT by the year 2050 i.e. five times increase compared to present CO₂ emissions.

1.3 SUPPLYMENTARY CEMENTITIOUS MATERIALS

Many industrial wastes and by-products like fly ash, waste slag, rice husk ash, rice straw ash and silica fume materials are getting utilized as supplementary cementitious materials in concrete to enhance its durability and also reduce cement content. The global potential for CO₂ emission reduction in cement manufacturing process through the production of Portland pozzolana cement is projected to be at least 56 MT of CO₂ per year. In India, blended cement production was 37% of total cement production in 2000, but this considerably increased to 67% in 2011. Fly ash and slag are widely used for blended cement production. In addition to this, a number of waste and by-products generated from other industries are abundantly available in the major cement producing countries – some of these have a potential for use as supplementary cementitious material. Utilization of these materials as mineral admixture instead of using limited naturally available resources for producing cement will tackle the problem of disposal of waste materials and help to achieve sustainable concrete.

Blended cement is technically superior to ordinary Portland cement, as their use results in improved fresh and hardened properties, in addition to resistance against aggressive agents compared to cement (OPC). Durability performance of concrete with blended cement is significantly improved due to hydration reaction and pore infillment. The potential for application of any supplementary cementitious material depends on the availability of such material and its pozzolanic characteristics.

1.3.1 Sugarcane bagasse ash

India positions second in the production of sugarcane in the world. Total production of sugarcane in India in 2003 was reported as 289.6 million tonnes and in China 92.3 million tonnes. Currently 91.2 MT of sugarcane bagasse wastes is generated yearly in India. Raw sugarcane crop is processed to get eatable products like sugar and jiggery which generates the fibrous waste i.e. bagasse material as a lateral item. This collected bio-waste mass is then get utilized as fuel in the boilers for the various industrial operations. This bagasse ash contained pozzolanic properties which make it fit for use as in blended cement.

The combustion process of these bagasse generates ash as a lateral item. About forty-four thousand tons of load of bagasse ash is produced in India daily. Land disposal of sugarcane

bagasse ash influences adversely on the surroundings as it pollutes the soil components and the surface as well underground water also get polluted. The land disposal of sugarcane bagasse ash is show in Figure 1.1. It is estimated that the cement industry influences nearly 6-7% of CO₂ emissions altogether in the world. Consequently, a proper system has been implemented to solve the disposal concerns of biomass waste ashes.



Figure 1.1: Land disposal of sugarcane bagasse ash in India.

There is no contribution of CO₂ emission to environment by combustion of these biomass waste due to the cogeneration system. In this system, the quantity of CO₂ (carbon dioxide) evolved by the bio-waste combustion is approximately equivalent to spend throughout its whole plant growth age. Hence, the evolved CO₂ (carbon dioxide) counterbalances the spent quantity of CO₂ (carbon dioxide). Figure 1.2 clarifies the broad outline of the production of biomass waste ash from cultivated means. Horizontal direction arrows specify method; however vertical direction arrows specify waste produced by particular method.

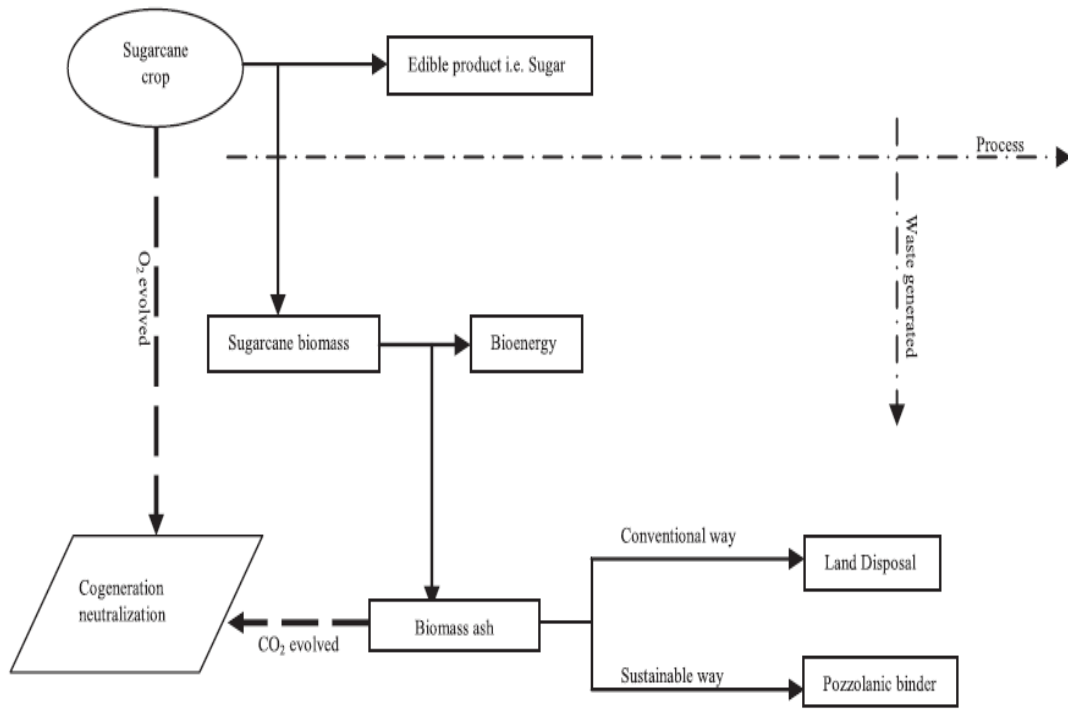


Figure 1.2: Production process of sugarcane bagasse ash from sugarcane crop. (Vasudha et al.,2017)

1.3.2 Availability of sugarcane bagasse ash

The fibrous material obtained from sugarcane crop known as bagasse is used as fuel for manufacturing sugar in sugar mill. This process undergoes the process of cogeneration process. Sugarcane bagasse based cogeneration system makes sugar mill capable of energy efficient. There were 224 sugar mills out of 589 in which modern cogeneration system installed in year 2012, almost five times increase in units since 1950 due to increase in sugar demand. Now the residual product of bagasse as bagasse ash is also very important product in structural or civil engineering. Bagasse ash can be utilized as binder material as cement in mortar or concrete. But the importance of this ash is not illustrated till date at a large scale. The availability of sugarcane bagasse ash is listed by Figure 1.3.

Statewise Bagasse Ash Generation (%)

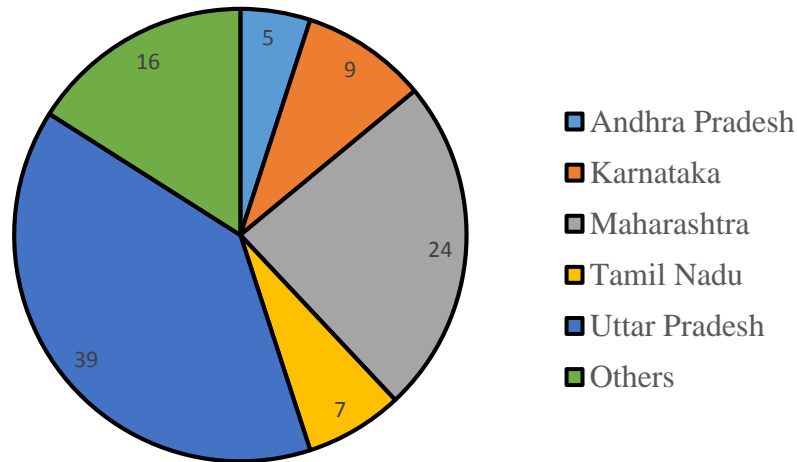


Figure 1.3: State wise sugarcane ash generation in India

1.3.3 Properties of sugarcane bagasse ash

The physical properties and chemical properties are mainly governing by the material's pozzolanic nature. The considerations accountable for the pozzolanic properties are its growth conditions with regions, its burning temperature and period of burning. The properties of bagasse ash have a very major effect on fresh and hardened concrete properties of SCBA cement concrete. Many researchers encapsulate the processing techniques to achieve maximum pozzolanic reactivity.

1.3.3.1 Physical properties

Since sugarcane mills differ in their degree of maturity, in the range and extent of plant process controls and in the degree to which bagasse feed is controlled on the plant, their physical properties, i.e. shape, and size, surface texture, micro fine content etc., will vary. Sugarcane mill' output will be different, even if the bagasse is the same.

Chusilp et al. (2009) reported the physical appearance of bagasse ash and observed particle size lower than cement i.e. 10 μm by giving grinding operation to it after burning at nearly about 600-800 $^{\circ}\text{C}$ that's fit for getting its optimum pozzolanic nature. They tested for the specific gravity and obtained value was lower than cement i.e. 2.2 for sugarcane bagasse ash. The water absorption for these partially burnt particles was observed to be high in their study. They observed the material retained on sieve of 45 microns was 2.8 percent. They found in their study that the particles were rough and irregular in shape.

Rukzon et al. (2012) had investigated the sugarcane bagasse ash material and observed that the mass retained of particles of bagasse ash on sieve of 45 microns was about 2-5 percent after grinding done by ball mill apparatus. They also tested for Blaine fineness and obtained the results as 1250 m²/kg. The mean particle size was observed lower than cement i.e. 16.4 μm. As there was higher surface area and finer particle size was observed, the density was obtained significantly lower than cement i.e. 2240 kg/m³ which makes it light weight supplementary cementitious material in concrete.

Somna et al. (2012) tested the physical behaviour of sugarcane bagasse ash and observed the particles of bagasse ash as finer than cement as the particles retained on sieve of 45 microns was nearly 0.42. The sp. gravity and mean particle size of sugarcane bagasse ash were found as 2.27 and 5.6 μm respectively. The effect on the strength reactivity index of sugarcane bagasse ash for curing period of 7 and 28 days significantly observed with increased values of 87.4 and 112.7 percent respectively.

Montakarntiwong et al. (2013) reported the observations taken by testing two types of sugarcane bagasse ash material obtained from different sources. They tested the strength and heat evolution of concrete incorporated with sugarcane bagasse ash and found strength activity index at 28 days of curing age to be higher than control i.e. 102 and 100 percent for both specimens. The weight retained on sieve of 45 microns was observed as less than 5 percent for both the ashes and specific gravity of sugarcane bagasse ash was observed as 2.47.

Sua-iam et al. (2013) studied the physical behaviour of sugarcane bagasse ash and concluded the sp. gravity and sp. surface area to be 2.35 and 27.4 m²/kg respectively. They found the material particle size as 107.9 μm and used it in manufacturing the self-compacting concrete.

Cordeiro et al. (2012) encapsulate the study of sugarcane ash used as partial replacement of cement which they burnt for 2 hours at 700⁰C -900⁰C for having maximum pozzolanic properties. The particle size of sugarcane bagasse ash was obtained as 2.7 μm after grinding the material in that testing conditions. The obtained sugarcane bagasse ash was tested for Blaine fineness and density and found the results as 2560 kg/m³ and 893 m²/kg correspondingly.

Amin (2011) investigated the SCBA properties and determined sp. gravity and mean particle size of particles were 1.80 and 5.1 μm respectively. The specific surface area of SCBA was found as 900 m²/kg, about three times that of cement. The weight of sugarcane bagasse ash retained mass on 45 micron sieve was observed as 5%.

Bahurudeen et al. (2016) investigated the behaviour of SCBA and determined the sp. gravity and Sp. surface area of SCBA were observed as 1.91 and $169\text{m}^2/\text{kg}$ respectively. The moisture content observed in raw bagasse ash was 46%.

Rerkpiboon et al. (2015) encapsulate the conclusions regarding the physical properties by giving the observation that the specific gravity and median size of SCBA were 2.27 and $5.68\mu\text{m}$ respectively. The weight retained of SCBA mass on 45-micron sieve was observed as 0.42%.

Table 1.1 and Table 1.2 showed the typical physical properties of cement and sugarcane bagasse ash.

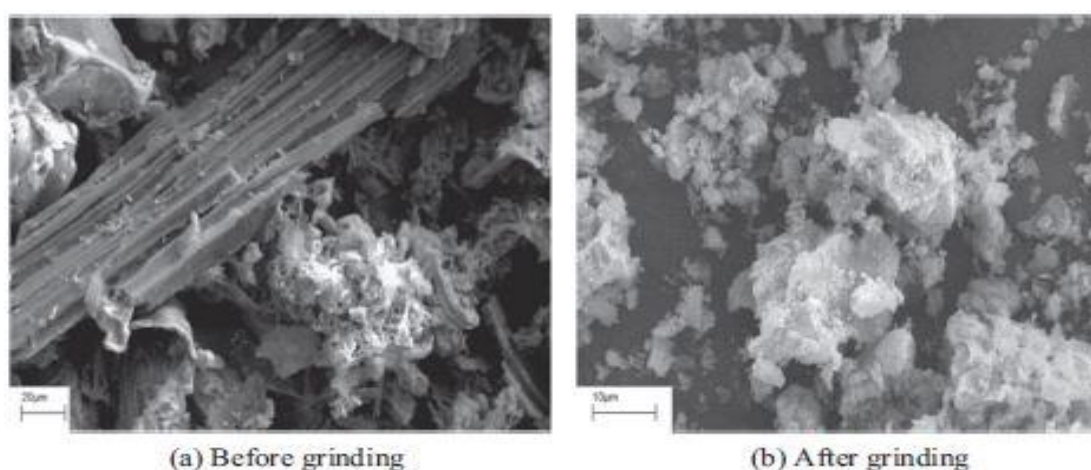


Figure 1.4: SEM images of bagasse ash. (*Cordeiro et al., 2012*)

Table 1.1: Typical physical properties of cement

Physical properties Research reported by	Density	Specific gravity	Fineness passing $45\ \mu\text{m}$	Specific surface area (Blain's) (m^2/kg)	Mean grain size(μm)
Ganesan et al. (2007)	1.56	3.1	85	326	22.50
Rerkpiboon et al. (2015)	-	3.13	-	-	14.6
Rukzon et al. (2012)	3140	3.14	-	360	25.0
Chusilp et al. (2009)	-	3.14	-	-	-
Cordeiro et al. (2012)	-	3.14	-	-	16.9

Table 1.2: Typical physical properties of SCBA

Physical properties Research reported by	Density	Specific gravity	Fineness passing 45 μm	Specific surface area (Blain's) (m^2/kg)	Mean grain size(μm)
Ganesan et al. (2007)	0.59	1.85	99	943	5.40
Rerkpiboon et al. (2015)	-	2.27	65.73	-	5.68
Rukzon et al. (2012)	2240	2.24	-	1250	16.4
Chusilp et al. (2009)	-	2.20	-	-	-
Cordeiro et al. (2012)	-	2.53	-	-	2.7

1.3.3.2 Chemical properties

The chemical properties of sugarcane bagasse ash were investigated by different researchers and proposed a common conclusion that the chemical compounds like silicon dioxide (SiO_2), aluminium oxide (Al_2O_3), iron oxide (Fe_2O_3), calcium oxide (CaO) and potassium oxide (K_2O) in majority and found sulphur trioxide and oxides of magnesium in small quantity in their study. The results regarding the chemical composition is presented in Table 1.4.

Cordeiro et al. (2009) shows that the presence of silica in form of quartz was 78.3 percent and 16 percent was available in form of cristobalite on burning the material at temperature of 700-9000C. They found that the amorphous silica content in material was present as 24 ± 4 percent and give better results in pozzolanic nature as compared to crystalline nature. This whole morphology was based on the combustion temperature.

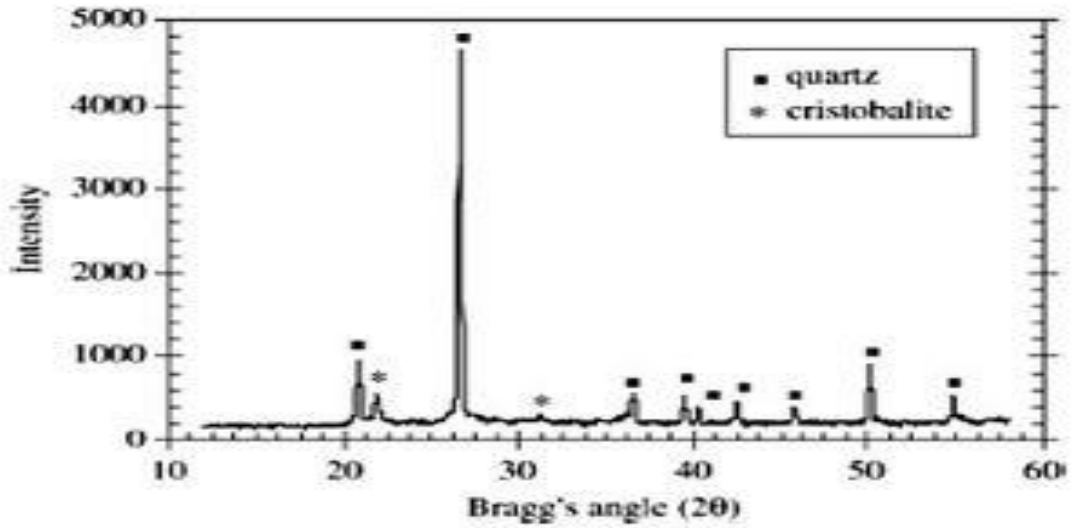


Figure 1.5: XRD analysis of sugarcane bagasse ash. (Cordeiro et al.,2009)

Paya et al. (2002) reported the results of XRD method to justify that the presence of crystalline silica because of existence of impurities like unburnt particles. The peaks of silica oxides and mullite are also observed in their study.

Table 1.3: The chemical properties of OPC cement

Research reported by	Oxide composition							
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	K ₂ O	Na ₂ O	LOI
Chusilp et al. (2009)	20.90	4.76	3.41	65.41	1.25	-	-	0.96
Cordeiro et al. (2012)	20.90	4.20	5.30	63.50	-	0.4	0.2	1.1
Ganesan et al. (2007)	19.25	5.04	3.16	63.61	4.56	0.51	0.08	3.12
Rerkpiboon et al. (2015)	20.80	5.50	3.16	64.97	1.06	0.55	0.08	2.89
Rukzon et al. (2012)	25.1	5.5	5.9	55.0	3.4	0.5	-	0.9
Singh et al. (2000)	19.75	4.84	3.26	62.66	4.19	0.54	0.06	-
Tantawy et al. (2012)	20.88	6.08	3.18	63.0	3.24	0.24	0.22	2.35

Table 1.4: The chemical properties of bagasse ash

Composition (Oxides) Research reported by	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	K ₂ O	Na ₂ O	LOI
Chusilp et al. (2009)	64.88	6.40	2.63	10.69	1.55	-	-	8.16
Cordeiro et al. (2012)	78.3	8.9	3.6	2.2	-	3.5	0.1	0.4
Ganesan et al. (2007)	64.15	9.05	5.52	8.14	2.85	1.35	0.92	4.90
Rerkpiboon et al. (2015)	55.04	5.14	4.06	11.03	0.91	1.22	0.24	19.60
Rukzon et al. (2012)	65.0	4.8	0.9	3.9	-	2.0	-	10.5
Singh et al. (2000)	63.16	8.40	9.70	5.40	2.90	-	-	6.90
Srinivasan et al. (2010)	78.34	8.55	3.61	2.15	-	3.46	0.12	0.42

1.3.4 Standards for pozzolanic material

ASTM specification C618-78 explains the conditions for pozzolanic materials to have these compulsory chemical compound in defined quantity so that the pozzolanic activity can achieved. These are siliceous/siliceous & aluminous material which owns slight or no cementitious significance however present in fine form than cement and in the existence of water react with calcium hydroxide which is later product of hydration of cement at room temperature to make chemical compounds having cementitious properties. The pozzolanic material also react with the C₃A and other hydration compound which are responsible for early strength and also improve the later durability properties of concrete.

Supplementary cementitious material has cost less than cement but if can be replaced with cement, the overall properties of concrete will have improved. The concrete made with excess cement content have a common issue of large production of heat of hydration which is not desirable in massive construction works. These SCM also improve the matrix of cement by reducing the voids and subsequently the porosity also reduced.

Colour: Sugarcane bagasse ash is known also as powdered ash. It is the most common artificial supplementary cementitious material now a day. The bagasse ash particles are black in color

due to the presence of high content of unburnt carbon content in it because of the insufficient burning of sugarcane bio-waste mass.

Surface Texture: The surface texture of the bagasse ash is rough and irregular.

Particle Shape: The shape of raw sugarcane bagasse ash is a tube-like structure with dense and angular after grinding of ash in different mills like a vibratory mill or ball mill.

Water absorption: The water absorption of sugarcane bagasse ash is low if the unburnt carbon content is low (detected by LOI analysis) as per the literature.

1.3.5 Advantages of sugarcane bagasse ash

Sugarcane bagasse ash wastes are picked as a supreme material in built-up products due of its little manufacturing costs in addition of its eco-friendly material as end product. It is ultimate because it is available in huge amount from the wide sugarcane agriculture manufacturing and creating its quantity unbroken and constant. The sugarcane bagasse ash is processed by adopting different methodologies so as to improve its usage in construction industry and also make the cost of processing being effectively low. The usage of sugarcane bagasse ash improved the strength and durability aspects of concrete with inclusion of cement. The product is so useful because of its recyclable nature of it.

1.3.6 Applications of sugarcane bagasse ash

The applications of sugarcane bagasse ash concrete are discussed below:

- Sugarcane bagasse ash and sugarcane straw ash as partially replaced by cement then act as additive admixture in the manufacturing of concrete and sugarcane bagasse ash light weight ash block.
- SCBA waste is varied with tapioca starch as well as glycerol to manufacture multiple materials.
- The manufacturing units of tableware packing material can have achieved by use of sugarcane bagasse ash.
- To manufacture the refractory products with incorporation of sugarcane bagasse ash in Arabic gum and water solution.
- SCBA waste is partially replaced with cement and manufactured as paver blocks perform better than control concrete paver blocks.
- SCBA waste is also used in the manufacturing of unburnt bricks, its performance is far better than ordinary bricks in durability aspect.

1.4 SUGARCANE BAGASSE ASH INCORPORATED CONCRETE

Bagasse ash as the supplementary cementitious material is a by-product of sugar industries and it cannot be used as it is in concrete. There are some processing techniques to make improvements in its pozzolanic properties. A few notable studies are discussed here

- Processing by burning at controlled temperature.
- Processing by grinding in ball mills
- Processing by both burning at adequate temperature and grinding at a particular size.

Sugarcane bagasse is utilized as energy (i.e. fuel) in the cogeneration boiler to cause steam production of sugar as well as electricity. Bagasse is burnt at around 500°C to use its extreme fuel value in sugar industries in a controlled process. The rest product after burning, specifically, ash is stored by means of a bag-house filter. With the bagasse fibrous particles combustion at controlled temperature in the cogeneration plant of sugar mill under 500-600 °C, amorphous silica oxide in reactive form is available due to the pozzolanic properties present in raw material. This amorphous silica oxide helps bagasse ash to act as beneficial supplementary cementitious material in concrete. Physical properties and chemical properties of sugarcane bagasse ash mainly depend upon the burning temperature, cooling conditions. Researchers conclude on this concern that the moderate temperature for getting the maximum pozzolanic properties is 600°C. After burning at a temperature of 600°C, particles are observed to be partially burnt. There are many unburnt fibrous particles present in it. These particles delay the strength of concrete due to organic nature. Hence, researchers concluded that these particles must be removed by sieving through 300 microns so as to remove coarse particles and get a better performance of SCBA concrete.

Furthermore, many researchers conclude that the size of pozzolan material particles has a significant role in the performance of concrete as smaller the particle size of pozzolan, the higher the strength and it acts as a micro-filter in pores of cement matrix and enhances the strength. So as to achieve a good performance processing by grinding is preferred to be done with ball mill apparatus for a particular time.

Many researchers suggest to do both burning and grinding in a fixed manner so as to achieve a better result as compared to ordinary concrete.

Use of SCMs are significantly enhancing the microstructure of concrete and helps to attain less permeable concrete, Pore structure, pore connectivity, and interfacial transition zone (ITZ) of concrete influence to a great extent. The permeability of concrete is considerably reduced because of pore refinement besides additional C–S–H compound formation.

1.5 SIGNIFICANCE OF RESEARCH

Degradation of environment takes place mainly due to excess accumulation of industrial by-products wastes and excess extraction of natural resources, which effect the environment badly. In the growing countries like India, large quantity of sugarcane is grown to meet the society demand of sugar and other sugarcane products. Then the raw product of sugarcane is utilized in sugar mill as a fuel and large volume of sugarcane bagasse ash are getting accumulated near the dump yard of sugar mill and are becoming the issue for surrounding community.

The growing trend of utilization of industrial as well as agricultural waste helps in management of these such waste a lot. Fly ash has been implemented in manufacturing of cement since long. Though, the utilization of sugarcane bagasse ash as SCM is not common but the product is very useful in construction industry and the main reason of this report is to promote the utilization of these such wastes. The published literature is insufficient to bring sugarcane bagasse ash in practical use. As such sugarcane bagasse ash is not used in any form in construction industry. The use of sugarcane bagasse ash will serve 2 objectives, firstly the disposal of this bio-waste material and secondly use as construction material and helping in reduction of CO₂ emission from production of cement. The utilization of an agricultural waste has an important point to maintain the biological balance and improve the economy of construction materials.

1.6 OBJECTIVES AND SCOPE OF RESEARCH WORK

The present work has following main objectives:

- Study the influence of SCBA incorporated with cement on the rheological properties of fresh concrete.
- Study the influence of SCBA incorporated with cement on strength properties of hardened concrete.
- Study the influence of SCBA incorporated with cement on durability properties of hardened concrete.

The scope of the present research work includes the following points:

- ❖ Characterization of material
- ❖ Design of conventional concrete mix
- ❖ Preparation of concrete mixes with different cement replacement level
- ❖ Studying the properties of fresh mixture of control concrete along with sugarcane bagasse ash incorporated concrete
- ❖ Casting of specimens of control along with sugarcane bagasse ash concrete

- ❖ Testing for strength properties of hardened concrete i.e. control as well as sugarcane bagasse ash concrete
- ❖ Testing for durability properties of hardened concrete i.e. control as well as sugarcane bagasse ash concrete

1.7 METHODOLOGY

Research was carried out in two levels. In first level, after characterization of material, two type of sugarcane bagasse ash materials were used with different loss on ignition values. The sugarcane bagasse ash concrete made with sugarcane bagasse ash having LOI of 24.53% designated as concrete 'A' and sugarcane bagasse ash concrete made with sugarcane bagasse ash having LOI of 6.27% designated as concrete 'B'. Properties of fresh concrete, strength properties of hardened concrete and durability properties of hardened concrete of type A concrete was evaluated and then the strength properties and durability properties of hardened concrete of type B concrete was evaluated. Then in second level, their comparative results were made in presentative form.

1.8 THESIS OVERVIEW

Chapter-1 Introduces the aim of the research, sugarcane bagasse ash production, physical properties and chemical properties of material, disposal issues, utilization of sugarcane ash, objective and scope of research work.

Chapter-2 Presents detailed literature review on properties effected by sugarcane bagasse ash incorporated with cement on strength and durability properties of concrete. Brief review of solid waste materials as supplementary cementitious material is also discussed.

Chapter-3 This chapter presents the procedure of test methods applied in this research work for characterization of materials and laboratory test accomplished to evaluate the results of properties of concrete with control specimens.

Chapter-4 presents the results of characterization of sugarcane bagasse ash cement materials, properties of concrete in fresh stage, strength properties and durability properties of concrete, analysis of microstructures with the help of Scanning Electron Microscopy and phase identification done using X-Ray diffractogram are also presented in this chapter.

The properties associate with bagasse ash incorporated with cement have been discussed since the 1980s. The recent studies have only focused on ordinary strength concretes and it has been perceived that SCBA utilized as a partial incorporation in cement does improve effectively many concrete properties i.e. rheological properties, hardened properties as well as durability properties. Since then, several types of research have reported the involvement of bagasse ash in cement effect normal concrete, lightweight concrete, and self-compacting concrete.

2.1 PROPERTIES OF BLENDED CEMENT

2.1.1 Consistency

Singh et al. (2000) investigated the consistency of sugarcane incorporated cement and reported that the increase in water content with increase in sugarcane bagasse ash content. They performed the tests at different Bagasse ash content incorporated in cement like 10%, 20%, and 30%. They observed that there was an increasing pattern followed by SCBA content. They observed water consistency as 0.310 in controlled cement paste and the value got increased with incorporation content i.e. for 30%, the value was 0.460. They observed that higher sp. surface area of the spongy particles of material demands high need of water for maintaining optimum consistency and irregular surface of the sugarcane ash particles was also observed in their work.

Tantawy et al. (2012) studied and observed that water consistency increased with bagasse ash content. Bagasse ash noticeably accounts for increased volume of surface water which connected to the specific surface area of the structure. They observed that the water consistency increases with increase in SCBA content from 0.274 to 0.350 with respect to replacement of SCBA 0 to 25% respectively.

Ganesan et al. (2007) investigated the behavior of sugarcane waste ash blended cement in consistency of cement in which the obtained volume of water content increases results in increase of sugarcane bagasse ash incorporation in cement. They found the consistency to be 0.32 and 0.49 as for incorporation of bagasse ash in cement from 0–20%. The entire behavior was observed due to the material's hygroscopic nature and the higher specific surface area. That's only why the sugarcane bagasse ash holds more water for maintaining the desired consistency of cement paste.

Bahurudeen et al., (2016) investigated the water consistency of blended cement (SCBA replaced cement) in which they observed that the water consistency increased with increase in SCBA content. They concluded that the water consistency of OPC cement was 30% and SCBA incorporated cement was 50% due to its hygroscopic nature of particles and also the specific surface area was lower than cement observed for which the quantity of water increased was observed to get a proper consistency.

Bahurudeen et al. (2015) investigated the water consistency of blended cement (SCBA replaced cement) in which they observed that the water consistency up to 25% replacement of cement with SCBA at an interval of 5% and observed that increased pattern with an increase in SCBA content. They concluded that the water consistency of OPC cement was 30% and SCBA at 25% replacement with cement was 44% due to its hygroscopic nature of particles and also the specific surface area was lower than cement observed for which the quantity of SCBA was observed to be increased and the water required to get proper consistency was increased.

Amin (2011) investigated the water consistency of blended cement and observed the pattern of increasing amount of water content with the increased amount of sugarcane bagasse ash content. The consistency of blended cement was tested up to 30% replacement at an interval of 5% and observed that the consistency between 0 and 20% replacement was observed as 0.32 and 0.49% replacement.

2.1.2 Setting time

Ganesan et al. (2007) investigated the behaviour of setting time of sugarcane bagasse ash incorporated cement paste. They observed that the increase in the sugarcane bagasse ash amount increases the initial as well as FST. IST was observed at replacement level of cement for 0% and 20% and found as 79 min and 184 min, correspondingly. Final ST of cement paste blended with sugarcane bagasse ash was observed for replacement level at 0% and 20% and was found to be 300 min and 402 min, correspondingly. They observed all result observations were followed the limits as per IS 8112-1995. In their study, they observed this pattern of SCBA based cement concrete due to cement dilution taken placed in the process.

Singh et al. (2000) Studied and observed the results on testing the IST and FST and found that increase in bagasse ash content enhances the time of hydration process and retart the setting time of cement paste. The behaviour in setting time of cement incorporated with 10% replacement of sugarcane bagasse ash was observed negligible but for the higher amount replacement of material with cement showed the large increase in time of IST and FST due to

higher sp. surface area which increases the water adsorption on surface and the decrease in OPC content in whole composite was also responsible for this concern.

Abbasi et al. (2013) studied the setting time of bagasse ash in concrete. They kept the w/b ratio constant as 0.40 and mix design of control concrete was taken as 1:3.25:3.25. They observed that 17 minutes' delay in initial setting time of potential pozzolanic material and 15 minutes in final setting time.

Bahurudeen et al. (2016) investigated the setting time behaviour of SCBA contented cement. They obtained the delay in setting time of cement incorporated with SCBA. They observed that the initial setting time of OPC cement as 125 min. and SCBA cement as 190 min., similarly the final setting time of OPC was observed as 165 min. and SCBA cement as 330 min. They concluded this behaviour of SCBA cement was due to the lower specific surface area of SCBA than cement and thus water requirement of SCBA cement was increased.

2.1.3 Compressive strength

Singh et al. (2000) investigated the compressive strength of blended cement and observed that there was increase in compressive strength upto 10% on 28 days of curing with respect to control but the performance of compressive strength of blended cement was observed on an opposite nature on further inclusion in cement with SCBA and the results were on lower side. They concluded that the compressive strength of cement decreased with excess SCBA due to segmentation of large size capillary pores and also due to insufficient hydration process because of lack of cement content.

Ganesan et al. (2007) investigated the behavior of SCBA blended cement by testing the compressive strength. They observed that the compressive strength of blended cement increased with increase in SCBA content upto 20% of replacement after that the strength was observed in the decreased pattern at the higher replacement of cement. They concluded that the strength of 10% replaced cement paste was significantly increased and the strength of 20% was observed compared to control with the result value of 21.43 MPa and 27.86 MPa at curing period of 7 and 28 days respectively.

Amin (2011) studied the behavior in compressive strength of blended cement and observed the results at 3 days, 7 days and 28 days of curing. They observed that compressive strength of blended cement at replacement upto 30% at interval of five and gave conclusion that strength increased upto 20% replacement and after that the strength showed a decreased trend. The

strength was increased due pozzolanic reaction as well as higher specific surface area concluded by reasearchers.

2.1.4 Pozzolanic reactivity

Cordeiro et al. (2009) reported the test results on pozzolanic activity and concluded results by burning the samples of sugarcane bagasse ash on temperature of 400 to 800⁰C at interval of 100⁰C so as to get an estimate of pozzolanic activity at different temperature burning. They found 600⁰C as optimum temperature for getting high pozzolanic activity in their study and the temperature higher than 600⁰C convert the behavior of material by making it of crystalline nature which decreased the pozzolanic activity of sugarcane bagasse ash. They found the lower LOI values with regards to burning at temperature of 600⁰C which enhances the pozzolanic activity of structure.

Singh et al. (2000) reported the pozzolanic reactivity of cement incorporated with bagasse ash. They investigated the pozzolanic activity by two methods i.e. physical and chemical methods in which the strength in compression of controlled specimen was related with 35% of sugarcane bagasse ash incorporated cement specimen. The evaluation of pozzolanic activity was done by estimating the CaO content. In chemical methodology, the mixture of 1g calcium oxide, Sugarcane bagasse ash and 250g of water was prepared and boiled at temperature of 90⁰C consistently for 16 hrs. Then the content of free calcium oxide was determined by titration and content of fixed calcium oxide was evaluated. They concluded the reduction made LOI value by 6.90 due to unburnt carbon presence.

2.1.5 Heat evolution during hydration

Bahurudeen et al. (2015) studied the heat evolution performance of sugarcane bagasse ash in cement. They observed that the results by sample mixing for five days and concluded the heat produced for control specimens was higher than the 10 percent sugarcane bagasse ash incorporated specimens. The heat of hydration for control cement specimens was observed as 200kJ/kg and the heat of hydration for 10% was estimated 23 percent less than control. This reaction was observed due to variation in alkali content and due to presence of C3S, C3A and calcium sulphate in lesser amount in sugarcane bagasse ash.

Ghiasvand et al. (2014) studied the heat evaluation behaviour. They concluded that result by taking tests on assumption that the sugarcane bagasse ash cement reduces the heat of hydration problem. The incorporated cement with sugarcane bagasse ash showed 43 percent less heat of

hydration in test results as compared to control cement paste and concluded to be utilized in massive structures.

Chusilp et al. (2009) investigated that heat evaluation behavior of sugarcane bagasse ash incorporated cement and concluded that the results of incorporation of material with cement at 10 to 30% showed the decrease in heat generation by about 33% max at 30% of replacement. The heat of hydration of control cement paste was observed as considering the cement content of 350kg/m³. And the heat of hydration decrease in sugarcane bagasse ash cement was maximum with 10°C at 30% replacement level

2.2 PROPERTIES OF CONCRETE INCORPORATING SUGARCANE BAGASSE ASH

2.2.1 Workability

Hussein et al. (2013) investigated the slump values for all the fresh concrete mixes in which they kept water content and superplasticizer dosage as constant (0.6%) in all seven mixes. They kept the mix design for control concrete as 1:1.5:2 & w/b ratio was taken as 0.38. They observed effect of sugarcane ash on the workability of fresh concrete was better. They said that the rheological properties of concrete improve with the incorporation of sugarcane bagasse ash in cement by observing the test results of slump i.e. 160mm on controlled concrete and 215mm on 30% incorporated cement respectively. They found the decrease in water demand of concrete with increase in sugarcane bagasse ash content in cement due to low LOI i.e. 1.4% and smoother texture of particles like fly ash particles.

Priya et al. (2016) studied the sugarcane bagasse ash incorporated concrete and found that with the increment of sugarcane bagasse ash amount in cement, the workability of concrete improves significantly. They kept the water cement ratio as constant i.e. 0.50 and the mix proportion for concrete mix was considered as 1:1.62:3.02. the results for slump test was observed as 70mm for control concrete and 160mm for 25% incorporated cement concrete. They also observed workability by compaction factor test and concluded the same trend in results, the compaction factor test results were observed as 88 for control concrete and for 25% replacement as 96 respectively. The results significantly represent that the water requirement was decreased with incorporation of sugarcane waste ash.

Cordeiro et al. (2010) studied the rheological properties for all the concrete mixes. They kept that the w/b ratio as 0.34 constant in four mixes and the observation of results of SCBA on slump of concrete was observed. The mix proportions for control concrete was considered as

1:1.89:1.79 and slump of concrete mixture was observed improved with the SCBA content. The slump value was obtained as 130 mm for control specimens and 170 mm for 20% incorporated cement specimens. SCBA incorporation reduced the water requirement in concrete due to regular morphology and quartz particles presented and also indicated the low LOI value i.e. 0.42. The unburnt carbons were not present, hence reduced the water requirement in concrete.

Ganesan et al. (2007) investigated the slump result values for all the concrete in which they kept water to cement/SCBA content ratio (0.53) as constant in all seven mixes. They kept the mix proportions for control concrete as 1:1.5:3.0. They observed the workability by tested the slump of concrete and observed the reading as 98mm for 10% and 64mm for 30% cement replaced with sugarcane bagasse ash respectively. The observed pattern of improved slump of concrete was due to fine particle size and also the absence of unburnt carbon particle as observed in testing of sugarcane bagasse ash incorporated concrete.

Abbasi et al. (2013) reported the results of testing done by replacement of bagasse ash with cement on the workability of concrete and concluded that as the replacement of bagasse ash increased in cement from 0-10%, the value of slump was also increased from 4.5cm to 6cm. They kept the w/b ratio as 0.4 and superplasticizer dosage constant. They considered the mix design for control concrete was taken as 1:3.25:3.25. The result showed that in replacing of SCBA increased, the workability was also increased.

Cordeiro et al. (2012) observed rheology property of sugarcane bagasse ash blended cement concrete in which they observed that the partial replacement of SCBA with cement. They kept the w/b ratio as 0.60 and then the mix design for control concrete was considered as 1:1.98:2.73 and it caused an increase in slump value. The replacement of SCBA with cement was 20% and the slump was increased to 170mm from 140mm as observed in controlled concrete.

Rukzon et al. (2012) investigated the rheological behaviour of high-strength concrete and reported that the workability of concrete at higher strength was achieved by the addition of chemical plasticizer. They observed in their study that with a constant water content, the dosage of plasticizer was increased so as to achieve a good workability of 210mm. They kept water binder ratio as 0.30 as a constant parameter and the dosage of superplasticizer was increased from 7.5 to 19.5 in respect to control to 30% replacement cement concrete in their study.

Rerkpiboon et al. (2015) reported the results of the workability behaviour of SCBA blended cement concrete in which they determined that with the constant water binder ratio (0.45) and varying the quantity of superplasticizer from 0.4 to 2.0% by weight of the binder. They

prepared mix design for 1:1.67:1.27. The consistent workability was observed in-between 70-95mm. The high water requirement was observed due to highly porous, irregular particle shape of SCBA was concluded.

Chusilp et al. (2009) investigated the rheological properties of SCBA blended cement concrete and concluded that the slump values were increased with the increased amount of SCBA in concrete with a constant value of water binder value as 0.50. But to achieve the required value of slump for all the concrete mixes incorporated with SCBA content from 10-30%, the amount of superplasticizer was increased from 3.15 to 7.35. The superplasticizer content was not required for control concrete specimens.

2.2.2 Compressive strength

Ganesan et al. (2007) reported the resultant strength in compression of SCBA blended concrete. The incorporation of ash waste in cement to manufacture the concrete was up to 30% by weight of cement content in gap of 5%. They observed the test results of strength of concrete by incorporation of sugarcane bagasse ash at curing period of 7, 14, 28 and 90 days and concluded that the 20% addition of bagasse ash was optimum for having good results. The strength in higher incorporation of sugarcane bagasse ash was showing lower strength than control concrete. The strength increased by around 10.67% to 20% at curing age up to 90 days in 20 percent replaced concrete. The performance after 20 percent replacement of sugarcane bagasse ash in cement was not obtained at all good at that test conditions.

Rerkpiboon et al. (2015) obtained the results of sugarcane bagasse ash incorporated cement concrete by preparing the moulds of cylindrical shape of 100mm dia and 200mm height. The results showed improvement at 10-30% of sugarcane bagasse ash replacement with cement at curing age of up to 180 days as compared to control concrete then after up to 50% the results showed lower values of compressive strength. The compressive strength of control concrete was observed by considering the water binder ratio constant as 0.45 and the results were improving up to 111% for 10% replacement and 112% for 20% replacement respectively. The increase in compressive strength of concrete was due to more fineness and low LOI of material concluded by the researchers.

Rukzon et al. (2012) concluded test results of compressive strength of concrete incorporation of cement with sugarcane bagasse ash up to 30% replacement on gaps of 10%. They observed the minor change in compressive strength of concrete i.e.6%. The water cement ratio was considered as 0.3 constants and the mix proportions for control concrete was 1:1.27:1.65. The improvement in compressive strength was obtained by pozzolanic reaction done between silica

oxide present in sugarcane bagasse ash and Ca(OH)_2 hydration product formed after cement reaction. The target strength was taken as 65 MPa and with the replacement of 30% cement with sugarcane bagasse ash, the strength results of compressive strength was observed as 68 MPa. The concluded that the sugarcane bagasse ash up to 20% replacement can be used effectively to get significantly better results.

Chusilp et al. (2009) discussed the results of compressive strength of concrete made with addition of sugarcane bagasse ash in substitute of cement in concrete and concluded that the results improved up to 30% of sugarcane bagasse ash. The test was performed at 28 and 90 days of curing period and the results of 30% replacement were 47.5 and 45 MPa for 28 and 90 days of curing and the control concrete strength were 36.9 and 41.8MPa on same curing period. They observed the pozzolanic reaction in concrete structure.

Cordeiro et al. (2012) investigated the effect of bagasse ash content in concrete on conventional strength concrete and High-Strength concrete. They considered the mix design of control concrete as 1:1.98:2.73 and w/b ratio as 0.6. They observed the test readings at 0% and 20% replacement of SCBA. They observed that there was increase in strength of both conventional and highly graded concrete.

Abbasi et al. (2013) discussed the compressive strength of concrete incorporated with sugarcane bagasse ash. They observed the increase in strength of 10% replacement of sugarcane bagasse ash with cement at age of 7 days and 28 days of curing. They found 10% increase and 25% increase in strength of 10% sugarcane bagasse ash incorporated concrete as compared to control concrete in their study.

Cordeiro et al. (2010) determined the strength of concrete at 7, 28, 90 and 180 days of curing. They observed that the compressive strength of control concrete as 71.2 MPa and the highest value for 10% replacement of cement with sugarcane bagasse ash as 74.3 MPa and then the value for strength was showing decreasing trend as on increase value of replacement. They found the strength values at 15% and 20% as 72.1 and 70.5MPa respectively.

Bahurudeen et al. (2015) discussed the results of compressive strength of concrete incorporated with sugarcane bagasse ash. They found the results as 20% replacement as optimum and the results of compressive strength of 10% replacement of cement with sugarcane bagasse ash showed significant improvement and then there was decrease in strength with 15% to 25% replacement of cement with respect to 10% replacement concrete. The results showed at early age i.e. 3 days of curing better performance and similar trend was observed at all ages for all replacement level except for 25 percent of replacement of cement.

2.2.3 Splitting tensile strength of concrete

Ganesan et al. (2007) discussed strength in splitting tensile of concrete incorporated with sugarcane bagasse ash. They considered the w/b ratio as 0.53 and mix design of control concrete as 1:1.5:3.0. The improvement of split tensile strength was observed with 20 percent of replacement but after that with the higher replacement levels i.e. for 25 and 30 percent, there was decrease in strength was obtained as compared to control specimen's results.

Srinivasan et al. (2010) discussed the results of split tensile strength of concrete incorporated with sugarcane bagasse ash on curing ages of 7 and 28 days. They tested the specimens by replacement of cement at 5 to 15%. They kept w/b ratio constant as 0.48. The maximum results were obtained at 5 percent replacement and there was increasing pattern followed by higher replacement levels with control concrete specimens.

Priya et al. (2016) concluded the test results of split tensile strength of concrete incorporated with sugarcane bagasse ash. They considered the w/b ratio as 0.50 and mix design of control concrete as 1:1.62:3.02. The highest value of split tensile strength at 10% replacement observed as 3.077 MPa. The results having higher replacement values showed the decrease in strength values but up to 20% of replacement the strength was considerably comparable with control concrete. The results so obtained mainly due to cement dilution in cement matrix with sugarcane bagasse ash concluded by researchers.

2.2.4 Flexure strength

Srinivasan et al. (2010) mentioned the test reports of flexure strength of concrete specimens in which incorporated with sugarcane bagasse ash. The test was conducted with cement to binder ratio as 0.48 and cement replacement at 5 – 25% by weight of cement and the curing for 7 and 28 days done. They observed the decrease in strength at 7 days of curing and 5 and 10% specimens showed a little decrease in flexure strength at curing of 28 days at that testing conditions.

Priya et al. (2016) investigated the results of flexure strength of concrete and concluded that by considering the water cement ratio as 0.50 and mix proportion for control concrete as 1:1.62:3.02, the mix designated as M2 in their study having 10 percent Sugarcane bagasse ash showed the highest results but with M5 specimens having 25 percent sugarcane bagasse ash showed the lower strength as compared to control mix concrete.

2.2.5 Elastic modulus

Rerkpiboon et al. (2015) reported test results of elastic modulus of concrete incorporated with sugarcane bagasse ash in cement. They observed the test results by considering the water binder ratio as 0.45 and concrete proportions for control specimens as 1:1.66:2.12. The modulus of elasticity did not change with sugarcane bagasse ash incorporated cement as compared to control specimens. They observed the results from 10% to 50% of replacement.

Srinivasan et al. (2010) investigated elastic modulus of concrete incorporated with sugarcane bagasse ash in cement. They obtained the results by considering the water binder ratio as 0.48 and the results showed that the decrease pattern of progression. They concluded this type of results were achieved due to the excess of sugarcane bagasse ash in concrete and enable to achieved the required pozzolanic action because of dilution effect in concrete.

Priya et al. (2016) conveyed test result about elastic modulus of SCBA blended concrete. They observed that results by taking 6 samples of concrete in which the SCBA content varied from 0% to 25% and w/b ratio constant as 0.50. They considered mix design of control concrete as 1:1.62:3.02. They observed that the mod. of elasticity of concrete increased with incorporation of SCBA up to 10% then the modulus of elasticity decreased.

2.2.6 Water absorption

Ganesan et al. (2007) conveyed results of testing behavior of SCBA in water absorption. They observed that the particles of SCBA were hygroscopic in morphology and also observed finer in size. They performed test at duration's i.e. 28 days and 90 days by taking w/b ratio constant as 0.53 and mix design of control concrete as 1:1.5:3.0. They observed that the water absorption of concrete increased with the incorporation of sugarcane bagasse ash at 28 days of duration. However, the results of curing at 90 days, the water absorption results were decreased noticeably. They concluded that the particles of sugarcane bagasse ash fill the cement matrix by its finer size. They concluded the water absorption reduction in specimens nearly about 40 percent with incorporation of 20% sugarcane bagasse ash and maximum of 50 percent at curing age of 90 days due in reduction of pores in concrete.

2.2.7 Sorptivity

Ganesan et al. (2007) conveyed test reports of sorptivity values of bagasse ash incorporated cement concrete. They were scheming for SCBA concrete specimens by curing of 28 and 90 days and considering w/b ratio constant as 0.53 and mix proportion of control concrete as 1:1.5:3.0. the results of sorptivity were obtained at 28 days of curing, the decrease in values

was observed and at 90 days of curing, the results showed that up to 15% of incorporation was significant but after that with higher incorporation of sugarcane bagasse ash increase the sorptivity due to its porous behavior.

2.2.8 Chloride permeability

Ganesan et al. (2007) reported their study on chloride permeability of concrete incorporated with sugarcane bagasse ash in cement. They considered the w/c proportion as 0.53 and design proportions for control concrete as 1:1.5:3.0. They observed the results for 28 and 90 days of curing and concluded that there was decrease in chloride permeability charge in coulombs up to 25% of sugarcane bagasse ash incorporation in cement. Then the charge was observed higher than 25% on higher incorporation. The reading of chloride permeability was taken at both 28 and 90 days of curing and concluded that the 20% incorporation of sugarcane bagasse ash was optimum for concrete as it reduced the charge by 50 percent with respect to control specimens.

Rerkpiboon et al. (2015) investigate the test reports of chloride permeability of concrete incorporated by sugarcane bagasse ash in cement. The water binder ratio and mix proportions for control was considered as 0.45 and 1:1.66:2.12 respectively. Then the results were observed at 28 and 90 days of curing and concluded that the highest charge was passed in control concrete i.e. 4000 coulombs but with the incorporation of sugarcane bagasse ash, the results of charge in coulombs decreases significantly and fall to only 126 coulombs for 50 percent of replacement. They concluded that the 10 and 20 percent of incorporation reduced the charge to about half than the control concrete at both days of curing.

Rukzon et al. (2012) investigated the chloride permeability of concrete incorporated with sugarcane bagasse ash in cement. They considered the w/b ratio as 0.30 and mix design of control concrete as 1:1.27:1.65. They tested the samples at 7, 28 and 90 days of curing. The resistance to charge pass through concrete specimen of sugarcane bagasse ash was observed increased with incorporation as compared to control concrete. The charge passed through sugarcane bagasse ash up to 30% incorporated was 285 coulombs at 90 days of curing on the other hand the charge passed through the control concrete was observed as 950 coulombs. The observed pattern of results was concluded due to the finer particle size of sugarcane bagasse ash and also the pozzolanic reaction of incorporated cement considered.

3.1 INTRODUCTION

Experimental program encapsulates laboratory tests on properties of component materials of concrete (such as OPC cement, river sand, aggregates and SCBA), after casting and curing of specimens of required dimensions, testing of specimens to estimate the results of sugarcane bagasse ash incorporation in cement on different properties of concrete specimens. Experimental program is illustrated in Figure 3.1.

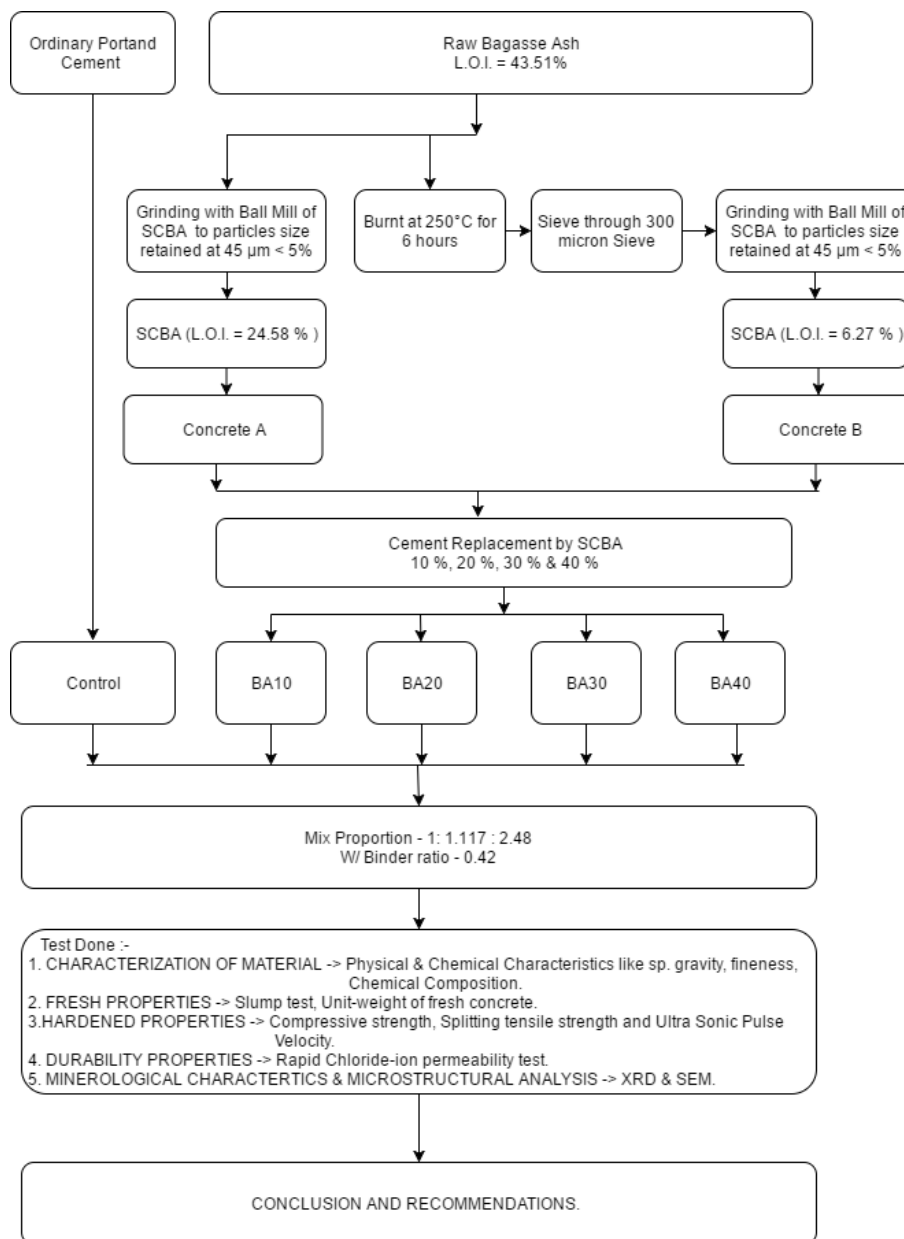


Figure 3.1: Experimental programme of the report

3.2 CHARACTERIZATION OF MATERIALS

3.2.1 Cement and sugarcane bagasse ash

Ordinary Portland cement grade 43 (AMBUJA CEMENT) following to Indian standard code 8112-1989 was used in this study. Consistency, compressive strength and IST and FST of lean cement and sugarcane bagasse ash incorporated cement were determined as per IS: 4031-1988.

a) *Water Consistency*

The test of water consistency of lean cement paste and bagasse ash incorporated cement at different level i.e. 10, 20, 30 and 40 percent are done here. This test is performed with the help of Vicat apparatus in which 10 mm dia plunger is fixed to evaluate the consistency of material. The cement paste is prepared by mixing a certain assumed water content in percentage by the weight of cement content. This cement paste is inserted into the mould of Vicat apparatus and allow the plunger to inject into the paste, the reading from top i.e.33-35 mm must be achieved to get the cement paste at normal consistency. The cement is mixed with water at regular increased percentage of water so that the required value of plunger reading can be obtained and the cement paste consistency can be judged. The test is conducted as per guidelines given by Indian standard code 4031(part-4) -1988.

b) *Setting times*

The test of setting time is conducted to evaluate the time requirement of cement paste to hydrate in system. The test is conducted as similar to consistency test of cement but in this test the plunger adjustments and water content is different as compared to water consistency. Test is conducted only after judging consistency of cement because the water content in this test is used as 0.85 times to the consistency water. Then the adjustment for plunger for initial setting time used is 1 mm square plunger needle and the initial setting time is evaluating by injecting the plunger needle freely by its self-weight to the depth measured of 33-35 mm from top of the measuring scale. The time taken by the plunger needle failed to inject up to this depth at given water content is initial setting time of cement paste. The test is also performed with blended cement made by incorporated of sugarcane bagasse ash in it at that test conditions. Then the final setting time is evaluating by changing the needle adjustment with annular collar and the time taken by cement paste to give a mark able remark on cement paste at given water content is final ST of cement paste and the test is also done with blended cement made with incorporation of sugarcane bagasse ash at different level of 10,20, 30 and 40 percent and the results of both setting time readings are noted down.

c) *Compressive strength*

Thirty cubes of size 70.6 mm x 70.6 mm x 70.6 mm were cast as per Indian standard code 4031 (Part-6)-1988 for testing for compressive strength of cement only and SCBA incorporated cement for 7 and 28 days curing period. Sand samples following to IS: 650-1966 is followed to cast the cement mortar in 1:3 cement-sand mix ratios. The quantities of ingredients of cement/SCBA and sand mixer are given as below:

Cement = 200 g

Standard Sand = 600 g

Water = $(P/4 + 3.0)$ percent of collective mass of cement and standard sand,

Where,

P = water content of consistency of cement paste.

In compressive strength of sugarcane bagasse ash incorporated cement, the cement was replaced with SCBA at 10, 20, 30 and 40% replacement so as to conclude the compressive strength of this cement (SCBA incorporated cement) with control cement specimens. These Cubes were casted and then compacted by means of a vibrating machine with frequency of 200 Hz, applied for 2 minutes. Then these cubes were after demoulding, cured in a water bath at $27 \pm 1^\circ\text{C}$. Compressive strength of cubes was determined at 7 and 28 days of curing age. The strength of these sugarcane bagasse ash incorporated cement specimen results are compared with control specimens.

3.2.2 Fine aggregate

The natural river sands used as fine aggregates was collected from Pathankot source in Punjab, India in this research work. Sand collected from Pathankot was compatible to second zone followed by IS code 383-1960. This fine aggregate specimen was sieved through 4.75 mm sieve to eliminate the coarser material before use in concrete. Particle size distribution, specific gravity and water absorption of sand specimen were evaluating by following Indian standard code 2386 (Part I and II)-1963 procedure.

a) *Particle size distribution*

The natural sand sample is tested for its particle size evaluation in which the material was dried for 24 hours in oven at about $100-105^\circ\text{C}$. Then the sand is allowed to cooled down and used 500gram sample for test of particles size. The sample of sand was poured into the set of sieves arranged in decreasing manner like 4.75mm, 2.36mm, 1.18mm, $600\mu\text{m}$, $300\mu\text{m}$, $150\mu\text{m}$ and

then 90 μ m and the pan is fitted at bottom. The retained material on each sieve was measured down and the fineness modulus of sand is evaluated by the summation of cumulative % of retained mass on sieve up to 150 microns divide by 100.

b) *Water absorption of sand and specific gravity*

Specific gravity of sand sample was evaluated by apparatus of pycnometer given in Indian standard code 2386 (Part 3)-1963. The sample of 500grams sand was poured in water for 24 hours. Then after 24 hours the water from sample drained out and the sand sample was allowed to make surface dry condition for test conditions. This weight of sand sample was noted as W_1 and then this sand sample was poured in pycnometer apparatus and the air trapped was escaped out by rotating the apparatus sidewise and then the apparatus was filled with water and weight the apparatus and noted down as W_2 . Then the pycnometer apparatus was filled only with water up to top level and noted as W_3 . The water absorption was calculated by drying this sample in oven at 110 $^{\circ}$ C for 24 hours and noted down the weight as W_4 .

Water absorption of sand and specific gravity of sand were evaluated by following:

$$\text{Specific gravity} = W_4 / [W_1 - (W_2 - W_3)]$$

$$\text{Water absorption} = [100 \times (W_1 - W_4)] / W_4$$

where

W_1 = weight of saturated surface dry sample, gm.

W_2 = weight of pycnometer containing sample and filled with water, gm.

W_3 = weight of pycnometer filled with water, gm.

W_4 = weight of oven dried sample, gm.

3.2.3 Coarse aggregate

Coarse aggregates sample was get available from Pathankot source, Punjab, India. Coarse aggregate was tested for fineness modulus test, specific gravity and water absorption capacity. To get these test result values the specimen of coarse aggregate was immersed in water for 24 hours initially and then these were allowed to dry at room temperature for that time at which the surface water did not be observed. This is compulsory for test condition followed by Indian standard code 2386 (Part 3)-1963. Then the sample of 3 kilograms was taken to perform the test and denoted the weight as W_1 . Then the sample of coarse aggregate was poured into the basket arrangement in water and the weight was measured and denoted as W_2 . Then the sample after weigh kept in oven for 24 hours at 110°C and then weight down and denoted as W_3 .

$$\begin{aligned}\text{Specific gravity} &= W_3 / (W_1 - W_2) \\ \text{Water absorption} &= [100 (W_1 - W_3)] / W_3\end{aligned}$$

where

W_1 = weight of saturated surface dry aggregate, gm.

W_2 = weight of saturated aggregate in basket, gm.

W_3 = weight of oven dry aggregate, gm.

3.2.4 Superplasticizer

Auramix 200 superplasticizer was used to achieve the required workability. It is high performance plasticizer used for high reduction and long workability retention. Its appearance was yellowish to brownish liquid, having Ph value of minimum 6.0 and specific gravity of 1.03-1.07 at 27 degrees of temperature. It had no chloride content and alkali content less than 1g Na_2O equivalent/ litre of admixture. Auramix 200 plasticizer is manufactured by Fosroc company and compiles with IS: 9103, BS:5075 and ASTM-C-494 (Type -G). It was water based admixture and the quantity was fixed by hit and trail to produce the required workability.

3.3 MIX DESIGN

Control concrete mixtures designated as Concrete BA 0 was designed as per guidelines given in BIS 10262-1982 to achieve 28-day compressive strength of 33.80 MPa.

28-days Compressive strength	25 MPa
Degree of quality control	Good
Maximum size of coarse aggregate	20 mm
Degree of workability (Compaction Factor)	0.9

Type of Exposure

Mild

Target 28 days' compressive strength

31.2 MPa

Table 3.1: Mix proportions of control concrete

Mix	Water-cement ratio	Cement (kg/m ³)	Fine aggregate (kg/m ³)	Coarse aggregate (kg/m ³)	Water (kg/m ³)	Superplasticizer (kg/m ³)
Control concrete	0.42	456.1	509.8	1135.4	191.58	0.319

3.4 CASTING PROCESS AND CURING OF SPECIMENS

The casting of concrete specimens for concrete A were done in mixer having capacity of about 0.06 m³. Set of fifteen cubes of size 150 mm×150mm×150mm for compressive strength determination of sugarcane bagasse ash incorporated cement in concrete were casted for particular replacement at 0, 10, 20, 30 and 40 percent of cement by weight at 3 days, 7 days, 14 days, 28 days and 56 days of curing. Similarly, the casting of cylinder of size 150mm×300mm were casted to evaluate the strength in splitting tensile of specimens at same curing. Then set of 15 cylinder of size 100mm×200mm in size for evaluating the chloride permeability test results were casted at each curing age of 7,28 and 56 days. These above set of casting was also be done for concrete B but only for curing age at 7 and 28 days. Then these casted specimens curing in fresh water at room temperature after demoulding of it was done for particular curing age. Figure 3.2 show the casting of specimens.



Figure 3.2: Casting of concrete cubes for compressive strength

3.5 TESTING PROCEDURE

3.5.1 Workability

Workability of mixes was determined by slump test given in Indian standard code 1199-1959. The mould was cleaned from inner surface and oiled it. Then, was filled in four layers with concrete.



Figure 3.3: Experimental set up for measuring slump of fresh concrete

Each layer was compacted by 25 strokes of the 16 mm diameter rounded edge tamping rod. These strokes were circulated uniformly over the whole cross section of the slump apparatus. The excess material of concrete was struck off with the help of trowel after tamping the top layer. The mould was raised from concrete mix immediately but slowly in a straight up direction. As shown in Figure 3.3, slump reading was measured immediately from the top of apparatus with the help of scale.

3.5.2 Unit weight of fresh concrete

Weight of concrete was recorded immediately after casted. The weight of apparatus suggested by ASTM C138 was recorded initially (W_m) and then the concrete samples were prepared with different concrete mixes that is control and SCBA incorporated cement concrete and individually poured into it in four layers. Each layer of concrete was compacted with tamping rod of 16mm diameter for 25 times. After the cylindrical apparatus was filled with four layers and compacted with tamping rod, the extra material was wiped out and the top surface of cylindrical specimen was cleaned. Their weight in cylindrical apparatus was recorded (W_c).

Then, the volume of cylindrical apparatus was measured as (V_m). The unit weight of concrete was measured by ratio of subtraction of final weight (W_c) and initial weight of apparatus W_m to the volume of cylindrical apparatus (V_m).

3.5.3 Compressive strength

Strength results in compression of concrete was assessed by testing the cubes of size $150 \times 150 \times 150$ mm in CTM under the continues pace rate of 5 kN/sec. the test was performed by following the procedure in Indian standard code 516-1959. The cubes so tested should be free from surface water and the loading should not be instant or shock. Loading was done on the opposite sides of cube as cast on working conditions preferably. Each set of test result was considered by taking average of three results of compression testing of cubes. Compression test results was computed by the maximum load taken by the cube specimen divided by the cross sectional area of cube in MPa.

Compression test result was computed by given formula

$$f_{ck} = \text{Load (P)} / \text{Area(A)}$$

Where, P = maximum load applied on cube, kN

A = cross-sectional area of cube of size (150 x 150 x 150) mm



Figure 3.4: Compression testing machine (Capacity 3000 kN)

3.5.4 Splitting tensile strength

The test of splitting tensile of concrete was carried over the cylindrical specimen of size $150 \text{ mm} \times 300 \text{ mm}$. the test performed according to Indian standard code 5816-1999. The cylindrical

specimens after cleaning the surface water, kept in universal testing machine to perform the test. The loading was applied at constant rate of 2.0 kN/sec without any jerk or shock produced. The maximum load carrying capacity of specimen was observed and noted down. Then the splitting tensile test results are computed by the given formula and the average of three test results was taken into account.

$$\sigma_{st} = 2P/\pi DL$$

Where

P = Load applied, kN

D= Dia. of cylinder

L= Longitudinal dimension of cylinder



Figure 3.5: Split Tensile Strength testing machine

3.5.5 Pulse velocity

The test involves determination of pulse velocity through concrete following to ASTM C597-02. The apparatus used for determining the pulse velocity through concrete was battery operated portable ultrasonic non-destructive digital indicating tester used. longitudinal stress pulse waves are generated by an electro transducer kept in contact with one face and are received by another transducer kept in contact with other face of concrete specimen. The time

(T) taken by pulse to pass through specimen of length (L) is known as transit time. Pulse velocity intensity (V) is calculated by computed the difference of distance between the two transducers (L) by transit time (T). The average of three specimens was considered as the result of pulse velocity of concrete specimen. The apparatus set for the test is shown in Fig 3.11 and values of pulse velocity for grading concrete as per BIS 13311-92 (Part-I) are illustrated in Table 3.2.

Table 3.2: Grading as per IS 13311-92 (Part 1)

Pulse velocity (m/sec)	Concrete quality grading
Above 4500	Excellent
3500-4500	Good
3000-3500	Medium
Less than 3000	Low



Figure 3.6: Testing of pulse velocity of concrete

3.5.6 Chloride permeability

Rapid chloride ion permeability test was performed by following the instructions in ASTM C 1202-10. Total charge of electric conductivity from concrete specimen of 50mm thick

cylindrical specimen of diameter of 100mm. The solutions of sodium hydroxide and sodium chloride in definite concentration given in ASTM code were prepared and each solution was poured into the sides of apparatus as shown in Figure 3.7. The results of chloride permeability were computed by considering the average of charge passed through three specimens and the degree of chloride permeability of concrete specimen can evaluate by the comparing the charge passed results with standard given in per Table 3.3. Prooveit data processor used in this study for measuring the chloride permeability is shown in Figure 3.7 and Figure 3.8 shows the display of charge passed through concrete during the test.



Figure 3.7: Experimental set up for measuring chloride ion penetration

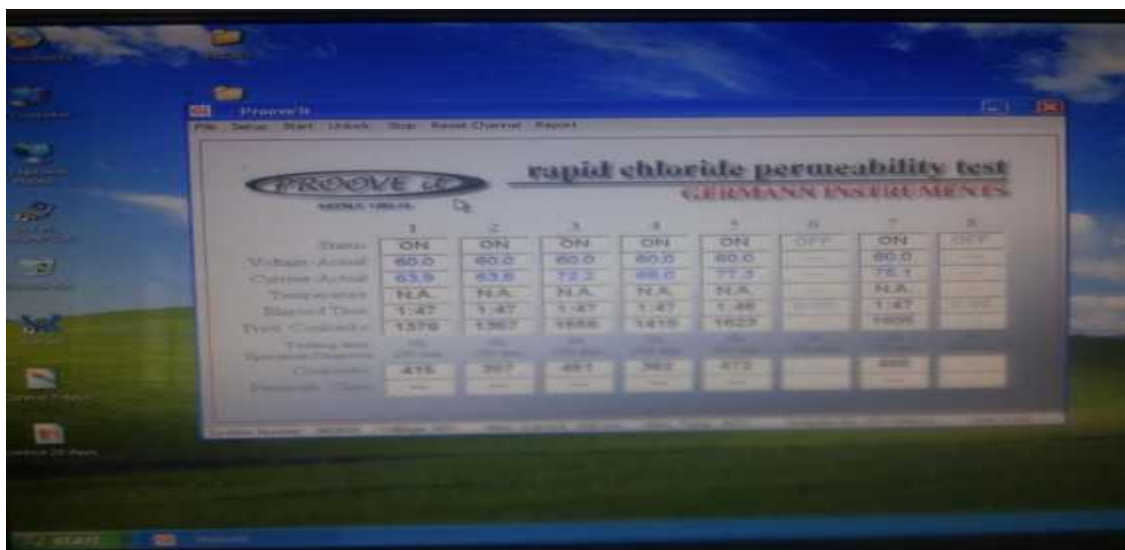


Figure 3.8: Display of charge passed during the test

Table 3.3: Charge in coulombs v/s chloride permeability

Charge in coulombs	Chloride permeability
Greater than 4000	Highly
2000 to 4000	Intermediate
1000 to 2000	Low
100 to 1000	Very low
Less than 100	Negligible

3.5.7 Scanning Electron Microscopy (SEM)

Scanning electron microscopy enables to investigate the chemical composition of ingredients of cement matrix. It helps to identify the morphology of different components of concrete like cement paste, aggregates (i.e. fine and coarse aggregates) and the ITZ structure between cement matrix and aggregates by their SEM images at different magnification levels. The topographical identification can also be done by the application of SEM images. The application of scanning electron microscopy enhances the ability to characterize the concrete microstructure and helps in ascertaining the factors affecting the mechanical properties and durability of concrete. In morphology structure of specimens, ettringites appears like needle shaped, the calcium hydroxide appears like the smoothed cut shaped of ice at different angle and the calcium silicate hydrate gel structure looks like cotton type rough spongy type. The presence of C-S-H gel structure demolished with the space acquired by ettringites in voids of structure.

The pieces of concrete incorporated with sugarcane bagasse ash in cement by its weight were collected after testing done in compression testing machine at particular curing age of 28 days and the collection was done from the core of specimens. These specimen pieces were prepared by gold coating done on specimens and fixed up on SEM stub to evaluate the SEM images by secondary electron imaging mode. Secondary electrons are the low energy resulting from an in-elastic collision of primary beam electron with an electron of a specimen's atom. Secondary electron produced near the surface escape and result in image of surface topography. The experimental set up for scanning electron microscope is shown in Figure 3.9. Energy dispersive spectroscopy was used to perform the chemical analysis of concrete material.



Figure 3.9: Experimental set up for scanning electron micrograph

3.5.8 X-Ray Diffraction (XRD) Analysis

XRD is a useful way for recognition of crystalline compositions for instance calcium hydroxide $[\text{Ca}(\text{OH})_2]$, ettringite compounds, and calcium silicate hydrates (C-S-H) etc. present in the concrete by processing the sample collected from core of cube specimen after testing done for compression strength test by crushing and sieving the material from 75 microns so that the coarse material like aggregate content (i.e. fine and coarse aggregates) separated out. The microstructure behaviour of ITZ of concrete incorporated with sugarcane bagasse ash in cement at different replacement level can be compared with the control one by the phase detection of compound formed in the structure by using X rays. The amorphous phases of concrete result can be identified by X-ray diffraction method in which the peaks of calcium silicate hydrate matched with the control results. The test was performed by considering the diffraction angle 2θ between $5-70^\circ$ for identification of phase of chemical compounds in cement powder sieved from 75 microns. The phase detection of chemical compound of cement paste power at different incorporation with sugarcane bagasse ash in it was done at curing age of only 28 days and the results by using the software like “X’Pert Highscore Plus” and “Origin pro” was presented.



Figure 3.10: X-Ray diffraction (XRD) instrument

4.1 INTRODUCTION

The chapter represents the results /observations of initial characterization of materials used for concrete and properties of fresh concrete (workability, unit weight), hardened concrete (strength in compression and splitting tensile and pulse velocity) and also properties for durability aspect (resistance of chloride charge permeability test) of concrete mixes incorporating sugarcane bagasse ash as replacement of cement (OPC). Test results are compared with control concrete so as to analyze the effect of sugarcane bagasse ash in concrete. Microstructural analysis using scanning electron micrographs and phase identification by using X- Rays diffractogram are also discussed in this chapter. A comparative study of properties of hardened concrete made with sugarcane bagasse ash having low value of LOI as partial replacement of cement is also presented in this chapter.

4.2 CHARACTERIZATION OF MATERIAL

4.2.1 Cement

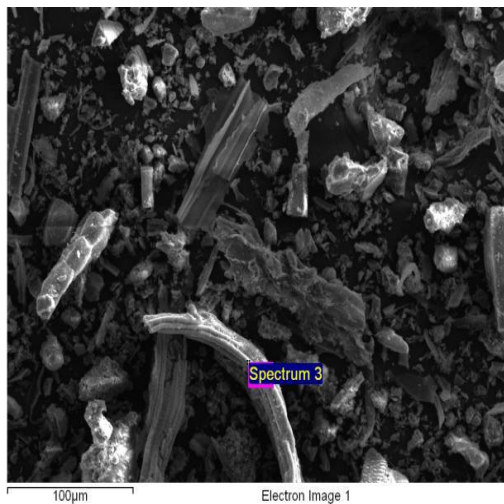
The test results of properties of cement grade 43 (OPC 43 grade) manufactured by Ambuja Cement company are given in Table 4.1. OPC cement used in this study used that was free from any contamination of any lumps and also fulfilled the requirements of BIS: 8112-1989.

Table 4.1: Physical properties of OPC 43 grade cement

Physical properties		
Properties	Test results	BIS values (IS:8112-1989)
Fineness retained on 90 μ m (%)	1.2	≤ 10
Specific gravity	3.06	-
Standard consistency (%)	29.5	-
IS Time (min)	119	30
FS time(max)	225	600
Compressive strength (N/mm ²)		
7 days	29.0	> 28.81
28 days	44.8	> 43.00

4.2.2 Sugarcane waste ash

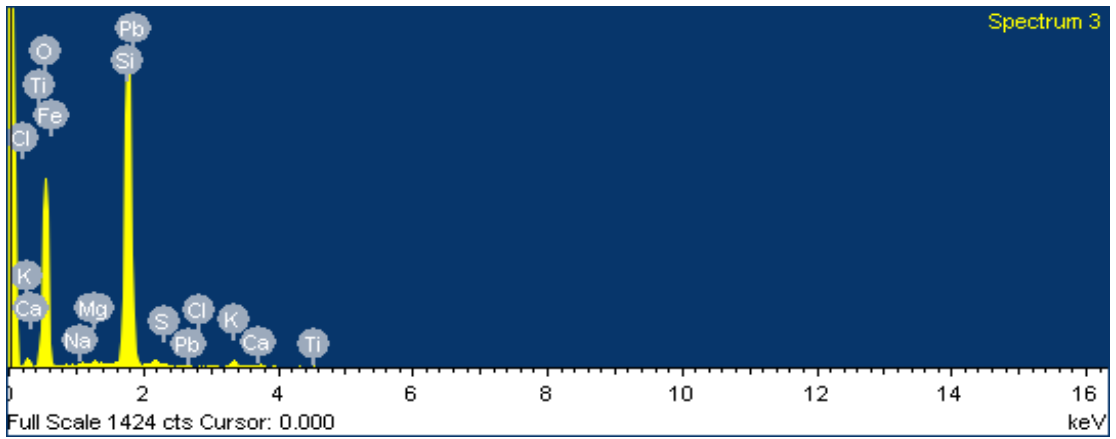
Sugarcane waste bagasse ash was available from Bhagwanpura Sugar mill, Dhuri, Sangrur, Punjab, India. Chemical composition analysis of sugarcane ash is presented in Table 4.2. Chemical analysis of sugarcane bagasse ash was performed using energy dispersive spectrometer (EDS) analysis. The chemical analysis showed that sugarcane bagasse ash was mainly composed of silica, alumina, magnesium, calcium and potassium content with the minimum content of lead, carbon content. The total composition of silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3) present in sugarcane bagasse ash was observed as 74.88%. The loss of ignition of two samples of sugarcane bagasse ash (processed) was evaluated and observed results as 24.58% and 6.27% respectively. The second type of processed bagasse ash was observed as Class F ash. The specific gravity and fineness of sugarcane bagasse ash were estimated as 1.91 and 3.5 grams retained on $45\mu\text{m}$ sieve as per standard provision. The EDS spectra of sugarcane bagasse ash are shown in Figure 4.1 and Figure 4.2. From these observed figures of sugarcane bagasse ash, the particles morphology was noted that the particles are hygroscopic, rough and irregular in shape. The SEM and EDS show that the morphology of sugarcane bagasse ash and its chemical compounds. The SEM and EDS figures are shown below to give a better understanding of the morphology of sugarcane bagasse ash.



a. SEM image of raw bagasse ash

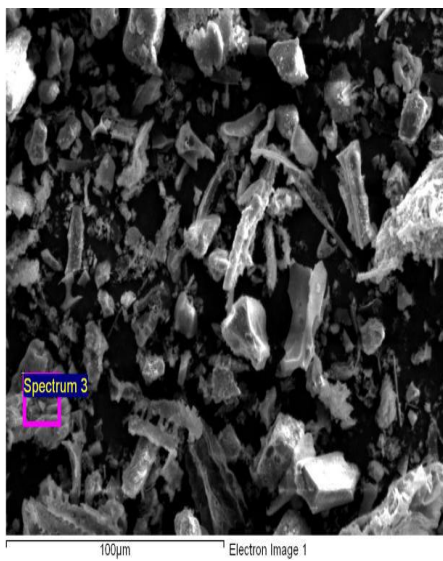


b. Actual raw bagasse ash



c. EDS of raw bagasse ash

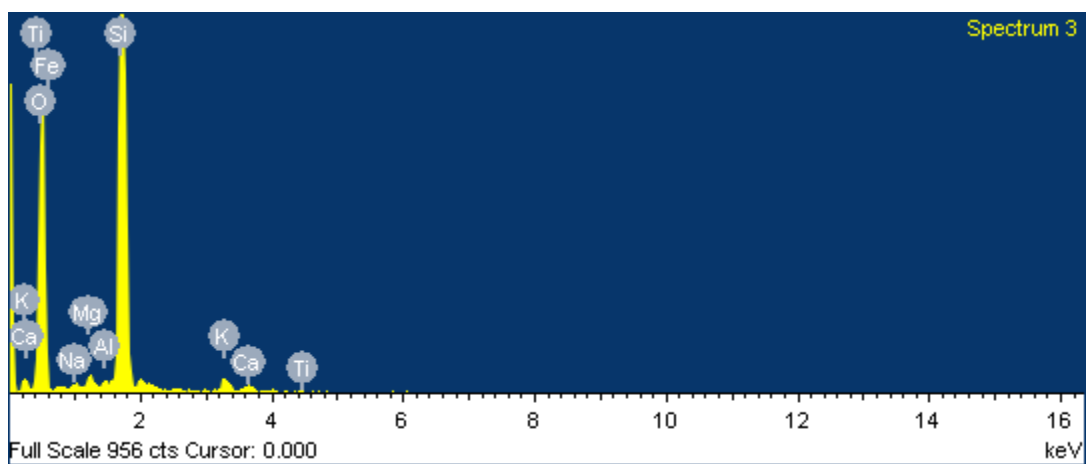
Figure 4.1: SEM and EDS of raw bagasse ash



a. SEM image of processed bagasse ash



b. Actual processed bagasse ash



c. EDS of processed bagasse ash

Figure 4.2: SEM and EDS of processed bagasse ash

Table 4.2: Chemical composition of sugarcane bagasse ash

Compound	Composition (%)			
	SCBA (Raw)	SCBA1 (Processed)	SCBA2 (Improved)	ASTM C618-12a requirements (%)
Silicon dioxide (SiO ₂)	93.76	61.13	70.09	-
Aluminium oxide (Al ₂ O ₃)	0.25	0.07	0.19	-
Iron oxide (Fe ₂ O ₃)	0.53	0.52	0.93	-
SiO ₂ +Al ₂ O ₃ +Fe ₂ O ₃	94.54	61.72	71.21	70 min
Potassium oxide (K ₂ O)	1.78	1.02	4.26	-
Calcium oxide (CaO)	1.19	0.27	2.91	-
Magnesium oxide (MgO)	0.91	0.02	10.75	5.0 max
Sulphur trioxide (SO ₃)	0.29	0.32	0.83	5.0 max
Sodium oxide (Na ₂ O)	0.11	0.15	0.84	1.5 max
Loss on ignition (%) @ 1000 ^o C	43.51	24.58	6.27	6.0 max

4.2.3 Fine aggregates

Locally available natural river sand from Pathankot region of Punjab was used as fine aggregate in making concrete specimens. The physical properties of the sand were tested and observed the sand was of zone second as per standard specifications made by BIS 383:2016. The physical properties of fine aggregates are given in Table 4.3.

Table 4.3: Physical properties of fine aggregates

Physical properties	Test results
Specific gravity	2.56
Water absorption (%)	1.10
Moisture content	Nil
Grading zone	Zone II
Fineness modulus	3.21

Table 4.4 Sieve analysis results of fine aggregates

Sieve size	Mean weight retained (g)	Retained (%)	Cumulative retained (%)	Passing (%)	Limits for zone II as per BIS 383:2016
4.75mm	42.33	4.252	4.252	95.748	100
2.36mm	162	6.276	10.528	79.472	90-100
1.18mm	236.5	23.761	44.289	55.711	75-100
600 microns	160.66	16.141	60.43	39.57	55-90
300 microns	319.16	32.09	92.5	7.5	35-59
150 microns	72	7.23	99.73	0.27	8-30
Pan	2.66	0.27	100	0	0-10
			∑C=321.52		

Total weight of specimen =1000 gm

Fineness modulus of five aggregates =∑C/100

$$= 3.21$$

4.2.4 Coarse aggregate

Aggregates of 20mm nominal size and 10mm nominal size are used in combination as coarse aggregates. Both these types of aggregates are locally available and as per Indian Standard Specifications are given in BIS 383:2016. The physical properties of both of these aggregates are given in Table 4.5.

Table 4.5: Physical Property Coarse Aggregates

Property	Results values	
	10 mm	20 mm
Specific gravity	2.68	2.59
Water absorption (%)	1.5	1.2
Fineness modulus	6.23	6.88
Type of aggregates	Crushed	Crushed

Table 4.6: Sieve analysis of 10 mm coarse aggregates

I.S. sieve size	Mean weight retained (kg)	Weight retained (%)	Weight passed (%)	Cumulative weight retained (%)
80 mm	0	0	100	0
40 mm	0	0	100	0
20 mm	0	0	100	0
10 mm	0.97	32.33	67.67	32.33
4.75 mm	1.78	59.33	8.34	91.66
Pan	0.25	8.33	0.01	99.99
				∑C=123.99

x

Total weight of specimen = 5Kg

Fineness modulus of 10 mm coarse aggregates = $(C + 500)/100$

$$= 6.23$$

Table 4.7: Sieve analysis of 20 mm coarse aggregates

I.S. sieve size	Mean weight retained (kg)	Weight retained (%)	Weight passed (%)	Cumulative weight retained (%)
80 mm	0	0	100	0
40 mm	0	0	100	0
20 mm	0.12	4.0	96	4
10 mm	2.54	84.66	11.34	88.66
4.75 mm	0.22	7.33	4.01	95.99
Pan	0.12	4.0	0.01	99.99
				∑C=188.65

Fineness modulus of 20mm coarse aggregates = $(C+500)/100$

$$= 6.88$$

4.3 PROPERTIES OF BLENDED CEMENT CONTAINING SCBA1 (LOI =24.58%)

4.3.1 Water consistency

The standard consistency of lean cement paste and sugarcane bagasse ash incorporated cement paste was determined with Vicat apparatus as per Indian standard BIS: 4031 (Part-4)-1988.

Table 4.8 present mix proportions and water consistency of blended cement

Table 4.8: Results of standard consistency of blended cement containing SCBA1

S.no.	Cement (g)	SCBA (g)	Water (g)	Water consistency (%)
1	400	0	118.0	29.5
2	360	40	130.0	32.5
3	320	80	182.0	45.5
4	280	120	214.0	53.5
5	240	160	244.0	61.0

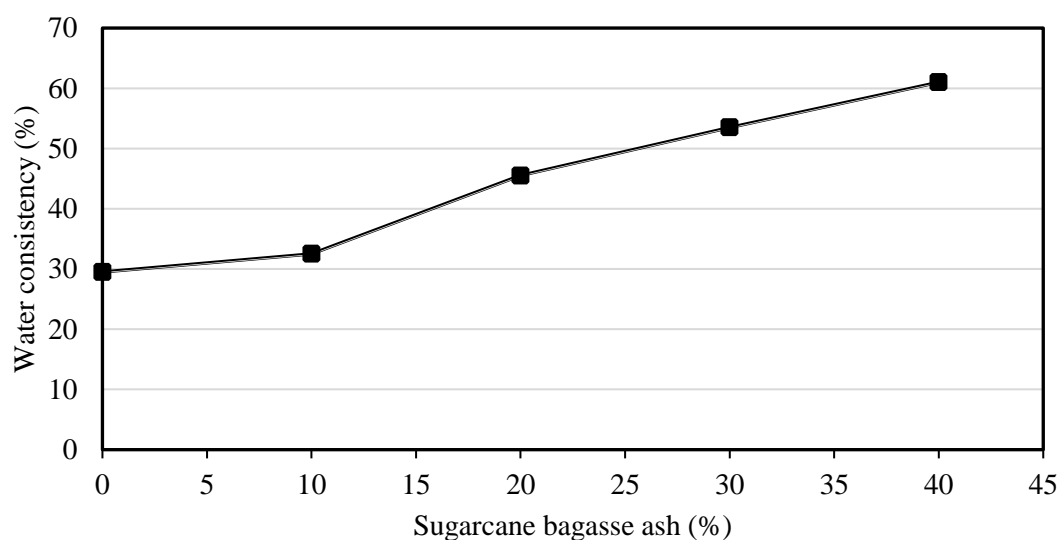


Figure 4.3: Water consistency of blended cement containing SCBA1

Figure 4.3 shows the variation in water consistency with sugarcane bagasse ash content. From above results, it was observed that the standard consistency of blended cement incorporating sugarcane bagasse ash increased with the increase in sugarcane bagasse ash content. The results showed the increasing trend of water requirement in sugarcane bagasse ash blended cement with the increase amount of sugarcane bagasse ash because of hygroscopic nature of sugarcane bagasse ash particles. Higher specific area is also responsible for excess demand of water to maintain the required consistency of cement paste. The results of similar trend were also

reported by researches done by Singh et al. (2000); Ganesan et al. (2007); Amin (2011); Tantawy et al. (2012); Bahurudeen et al. (2015).

4.3.2 Initial and Final setting times

Setting times of lean cement paste and SCBA blended cement paste was obtained by following the procedure of Indian standard BIS: 4031 (Part-5)- 1988. The certain limits have been given by code that the time for initial setting below 30 min. and for final setting above 600 min. is not permissible for normal test conditions. Sugarcane bagasse ash incorporated cement paste are prepared to determine the test results for this concern. The results of setting time are given in Table 4.9.

Table 4.9: Initial and final setting time of blended cement containing SCBA1

SCBA1 (%)	Consistency (%)	Sample mass (g)		Water (g)	Setting time (minutes)	
		Cement	SCBA1		Initial	Final
0	29.5	400	0	100	102	218
10	32.5	360	40	110.5	125	236
20	45.5	320	80	154.5	286	358
30	53.5	280	120	182	298	432
40	61.0	240	160	208	319	490

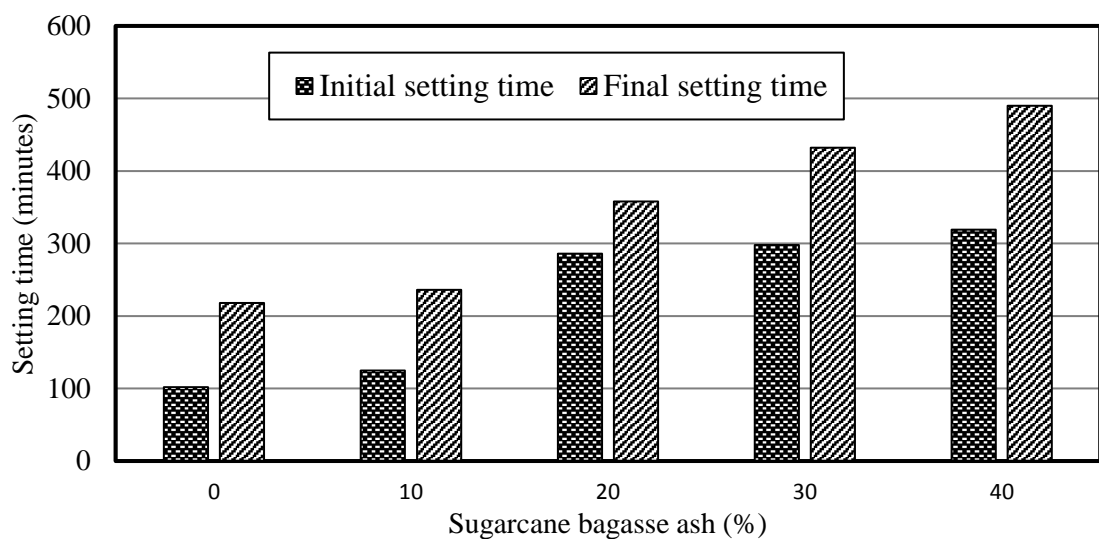


Figure 4.4: The results of setting time of blended cement containing SCBA1

From above results, it was observed that the setting times of blended cement prolongs with the incorporation of SCBA in cement (OPC). The results showed that both the IST and FST prolongs results with sugarcane bagasse ash content increment. Still, the certain limits have been given by code that the time for initial setting below 30 min. and for final setting above 600 min. is not permissible for normal test conditions. The prolongation of setting was recognized to chemical composition changes in cement. This effect can be justified by the reduction in influence of OPC cement responsible for late hydration and lower strength of cement. The specific surface area of sugarcane bagasse ash is also higher than cement so the quantity of OPC cement decreases in blended cement as such the setting time prolongs with the increase amount of sugarcane bagasse ash. The similar trend of results observed was reported by researches done by Ganesan et al. (2007); Singh et al. (2000); Abbasi et al. (2013); Bahurudeen et al. (2016).

4.3.3 Compressive strength

Fifteen cubes of size 70.6 mm x 70.6 mm x 70.6 mm were cast as per BIS: 4031 (Part-6)-1988 for testing for compressive strength of cement only and cement with SCBA1 incorporated. Standard sand conforming to BIS: 650-1966 was used to make the cubes in 1:3 cement-sand mix ratios. The compressive strength results of bended cement are given in Table 4.10 and Figure 4.5.

Table 4.10: Compressive strength of blended cement containing SCBA1

S.no.	SCBA (%)	Compressive strength (MPa)	
		7 days	28 days
1	0	29.0	44.8
2	10	31.4	47.0
3	20	30.2	45.8
4	30	27.4	37.1
5	40	19.8	31.5

From above results, it is seen that the compressive strength of blended cement increases with the incorporation of sugarcane bagasse ash in blended cement up to 10% significantly with respect to control cement specimens and the 20% replacement of sugarcane bagasse ash blended cement mortar is considerable comparable to control cement results. After that the

results of compressive strength of blended cement having higher percentage of sugarcane bagasse ash content i.e. 30% and 40% shows the decrease in compressive strength due to dilution effect of cement. The strength gains up to 10% replacement of sugarcane bagasse ash with cement observed due to pozzolanic reaction of blended cement in presence of high content of silica observed in chemical composition of sugarcane bagasse ash particles.

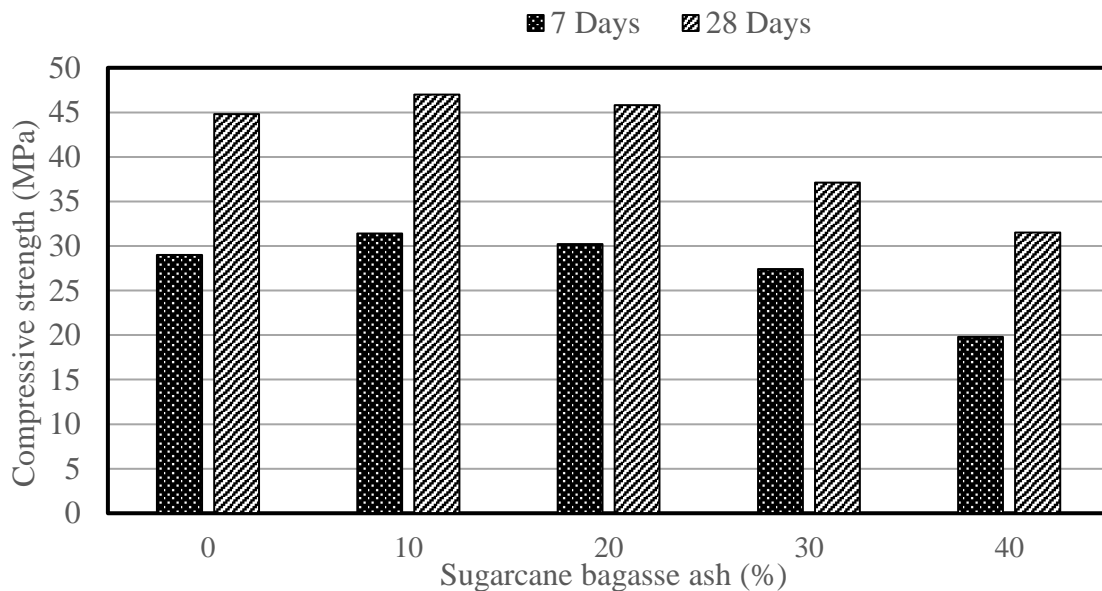


Figure 4.5: Compressive strength of blended cement containing SCBA1

The pozzolanic reaction prolongs due to deficiency of cement content in appropriate quantity so the compressive strength of higher replacement of sugarcane bagasse ash shows the decrease trend of strength. The similar results trend observed was discussed by researches done by Singh et al. (2000); Ganesan et al. (2007); Amin (2011).

4.4 CONCRETE MIX DESIGN

4.4.1 Mix proportioning of concrete

Table 4.11 gives a summary of mix proportioning of different concrete mixes with all aggregate in SSD condition. Control concrete is denoted as CM, whereas, concrete mixes made with replacing cement with sugarcane bagasse ash at a replacement level of (10, 20, 30 and 40) % are denoted as BA 10, BA 20, BA 30, and BA 40, respectively.

Table 4.11: Mix proportioning of concrete with aggregate in dry conditions

Mix designation	Cement (kg/m ³)	SCBA (kg/m ³)	w/b ratio	Water content (kg/m ³)	Fine aggregate (kg/m ³)	Coarse aggregate (kg/m ³)	
						10 mm	20 mm
BA 0	456.1	0	0.42	191.58	509.8	681.24	454.16
BA10	456.1	45.61	0.42	191.58	509.8	681.24	454.16
BA20	456.1	91.22	0.42	191.58	509.8	681.24	454.16
BA30	456.1	136.83	0.42	191.58	509.8	681.24	454.16
BA40	456.1	182.44	0.42	191.58	509.8	681.24	454.16

4.5 PROPERTIES OF CONCRETE INCORPORATING SCBA1

4.5.1 Workability

Workability of all concrete mixes was evaluated as slump in mm, for performance assessment of sugarcane bagasse ash incorporated cement in concrete on workability aspect and the observations are given in Table 4.12.

Table 4.12: Slump test of concrete incorporating SCBA1

Mix designation	Slump (mm)
BA 0	85
BA10	88
BA20	91
BA30	75
BA40	68

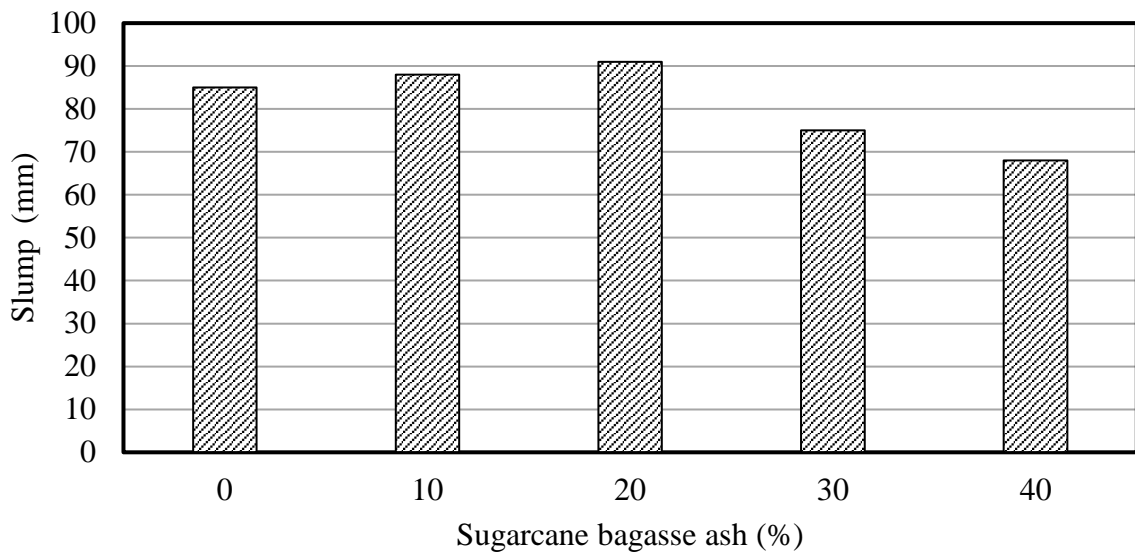


Figure 4.6: Slump test of concrete incorporating SCBA1.

It can be observed that slump of all concrete mixes containing sugarcane bagasse ash and control concrete was within the range of 50-100 mm. With the incorporation of sugarcane bagasse ash as substitute of cement (OPC), workability of concrete goes on increasing up to 20% of replacement level and then the decrease in workability is more profound at higher replacement levels of 30% and 40%. The water content in all the five mixes kept constant as mentioned in mix proportioning in Table 4.11. The amount of superplasticizer increased with the increase replacement of sugarcane bagasse ash in cement. There was no need of superplasticizer in control concrete observed and the slump of control mix was 85 mm. However, the sugarcane bagasse ash concrete (BA10, BA20, BA30 and BA40) with replacement of sugarcane bagasse ash at 10%, 20%, 30% and 40% by weight of cement binder required superplasticizer at 0.6, 0.7, 0.9 and 1.0% by weight of binder (i.e. cement and bagasse ash) respectively. The slump values of sugarcane bagasse ash concretes having replacement at 10, 20, 30 and 40% were 88, 91, 75 and 68 mm, respectively. The amount of superplasticizer increased with sugarcane bagasse ash content in concrete because of its high porous surface of particles, irregular shape morphology and rough texture observed. Similar trend has been reported in previous researches by Rukzon et al. (2012); Rerkpiboon et al. (2015); Chusilp et al. (2009).

The decrease in workability due to the addition of sugarcane bagasse ash as partial substitute of cement can be attributed to the difference in particle size and shape of cement and sugarcane bagasse ash particles. The specific surface area of sugarcane bagasse ash was observed higher than of cement so the water adsorption of particles increases the water need. Moreover, SEM images show that sugarcane bagasse ash particle has irregular shape with rough surface texture.

Thus, when the cement was replaced with equal weight of sugarcane bagasse ash, specific surface area was increased due to the presence of small size of sugarcane bagasse ash as compared to cement.

It must be noted that slump values of concrete lie in the slump scale of 50-100 mm, which is medium degree of workability as per Indian Standard Specifications BIS 456:2000. It means that all concrete mixes may be used for the casting of heavily reinforced sections, such as slabs, beams, columns etc.

It can be concluded that inclusion of ash as substitute to cement (OPC) leads to increase in water demand of concrete, i.e., higher water content will be needed to produce concrete with same workability as that of control concrete. As increase in water content will have negative impact on compressive strength, so use of superplasticizers may be one of the options, which can be used to counteract the negative influence of sugarcane bagasse ash inclusion on workability of concrete.

4.5.2 Unit weight of concrete

Unit weight of concrete was recorded immediately after casting. The weights of apparatus guided by ASTM C138 was recorded and then the concrete samples were prepared with different concrete mixes that is control and SCBA incorporated cement concrete and individually poured into it in four layers in given apparatus. Their weight in cylindrical apparatus was recorded. The results of unit weight of fresh concrete was measured by given formula in experimental program chapter. The results of unit weight of concrete are presented in Table 4.13.

Table 4.13: Unit weight of concrete incorporating SCBA1

Mix designation	Unit weight (wt./vol.) (kg/m ³)
BA0	2285.7
BA10	2209.5
BA20	2150.5
BA30	2097.1
BA40	2082.9

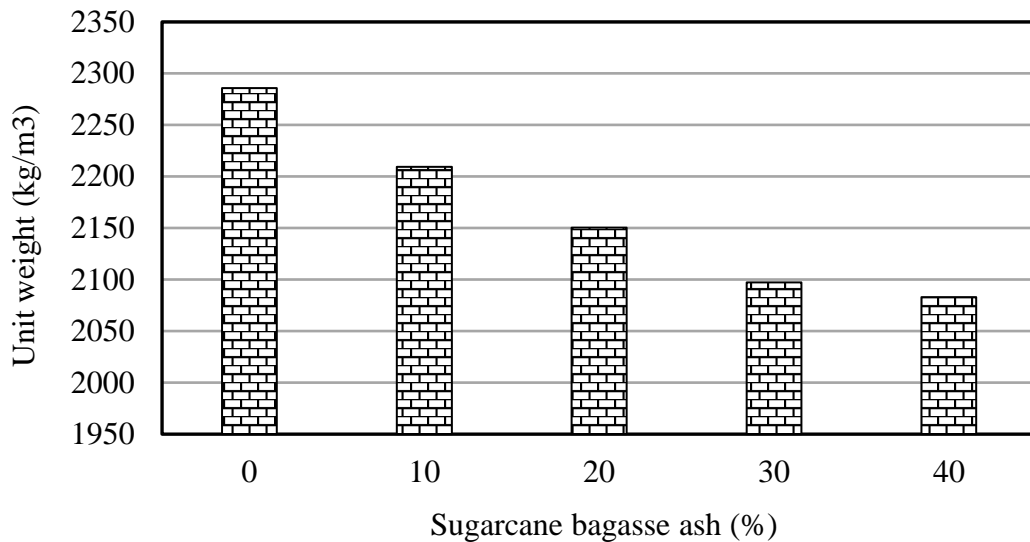


Figure 4.7: Unit weight of concrete incorporating SCBA1

The decrease in unit weight of concrete mixes containing waste ash as incorporation in cement is mainly attributed to the lower specific gravity of sugarcane bagasse ash i.e. 1.91 compared to 3.06 of cement which dominated the filling effect of micro-fines present in the sugarcane bagasse ash. The micro fines tend to fill up the voids present in concrete and makes the microstructure of concrete denser. Moreover, specific gravity of sugarcane bagasse ash is lighter than that of cement. Thus, substitution of cement with comparatively lighter particles may also be the reason behind the decrease in unit weight of concrete. Thus, up to 20% replacement level, unit weight of concrete with sugarcane bagasse ash inclusion decreases permissible. It means that 20% cement replacement level may have optimum amount of micro-fines to fill up all the voids in concrete without effecting the strength of concrete. So, at 40% replacement level, the concrete may now have excessive micro-fines, which instead of filling the voids, acted as fine aggregate and occupied the additional space in the concrete. This may be the reason that after 20% sugarcane bagasse ash replacement level, unit weight of the concrete showed a decreasing trend.

4.5.3 Compressive strength

Compressive strength of concrete incorporating SCBA1 as cement replacement at age of curing of 3, 7, 14, 28 and 56 days were evaluated by comparing all the result strength of control concrete. The compressive strength of concrete specimens was tested according to the specifications given by BIS 516-1959. The results are presented in Table 4.14.

Table 4.14: Compressive strength of concrete incorporating SCBA1

Mix designation	Compressive strength (MPa)				
	3 days	7 days	14 days	28 days	56 days
BA 0	19.53	24.13	29.20	33.80	36.80
BA10	21.73	29.80	30.46	35.80	37.40
BA20	19.20	21.50	26.66	27.90	28.86
BA30	13.63	17.80	19.56	20.93	21.80
BA40	9.86	10.20	13.20	14.20	14.0

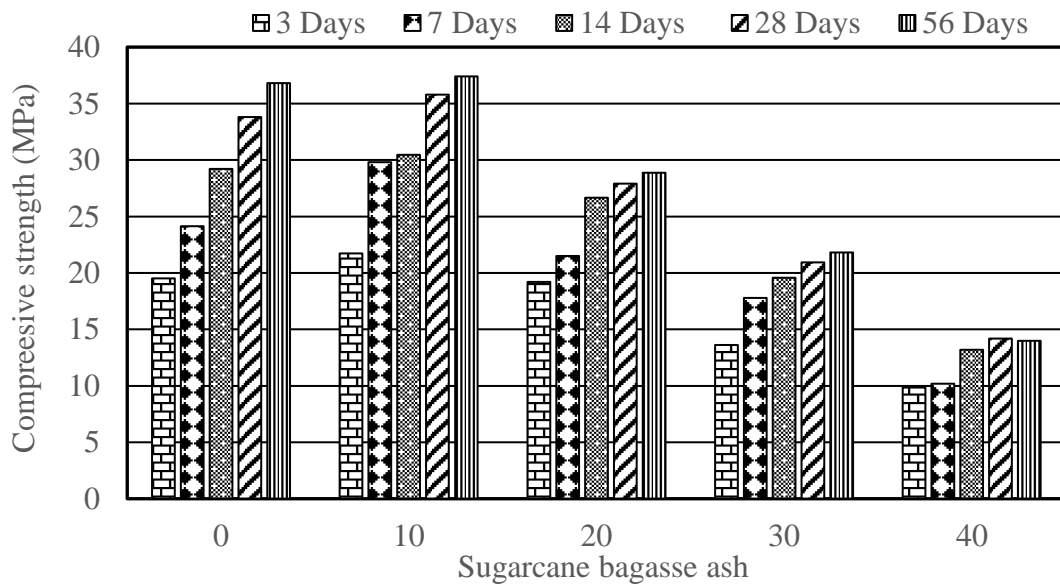


Figure 4.8: Compressive strength of concrete incorporating SCBA1

It can be observed that inclusion upto 10% sugarcane bagasse ash as replacement of cement leads to enhancement in compressive strength of concrete at all ages as related to control specimen. For 3 days of curing, strength in compression of control mix was 19.53 MPa, whereas compressive strength of BA10, BA20, BA30 and BA40 concrete mixes was 21.73, 19.20, 13.63 and 9.86 MPa, respectively. Similarly, for 7 days of curing, strength in compression of control was 24.13 MPa, whereas compressive strength of BA10, BA20, BA30 and BA40 concrete mixes was 29.80, 21.50, 17.80, and 10.20 MPa, respectively. For 14 days of curing, strength in compression of control was 29.20 MPa, whereas compressive strength BA10, BA20, BA30 and BA40 concrete mixes was 30.46, 26.66, 19.56 and 13.20 MPa,

respectively. For 28 days of curing, strength in compression of control mix was 33.80 MPa, whereas compressive strength BA10, BA20, BA30 and BA40 concrete mixes was 35.80, 27.90, 20.93 and 14.20MPa, respectively. For 56 days of curing, strength in compression of control was 36.80 MPa, whereas compressive strength BA10, BA20, BA30 and BA40 concrete mixes was 37.80, 28.86, 21.80 and 14.0 MPa, respectively. It means that compressive strength of concrete goes on increasing with increase in cement replacement level and attains a maximum value at cement replacement level of 10% and then starts decreasing. The results show this type of pattern because of higher value of LOI in material which is responsible for lower improvement of compressive strength of concrete. The higher replacement of cement with sugarcane bagasse ash shows the strength value lower than control concrete value due to dilution effect of cement with sugarcane bagasse ash. Concrete mixes show similar trend at all ages of testing. Similar trend in compressive strength was also observed in previous researches by Ganesan et al. (2007); Abbasi et al. (213); Cordeiro et al. (2010).

4.5.4 Splitting tensile strength

Splitting tensile strength of different concrete mixes was evaluated at age of 3, 7, 14, 28 and 90 days to study the effect of partial replacement of cement with sugarcane bagasse ash and observations are given in Table 4.15.

Table 4.15: The results of splitting tensile strength of concrete

Mix designation	Splitting tensile strength (MPa)				
	3 days	7 days	14 days	28 days	56 days
BA 0	1.905	2.035	2.075	2.725	3.11
BA10	1.915	2.315	2.865	3.315	3.56
BA20	1.680	2.29	2.40	2.91	3.45
BA30	1.460	1.625	1.775	2.26	2.95
BA40	1.080	1.410	1.545	1.70	1.885

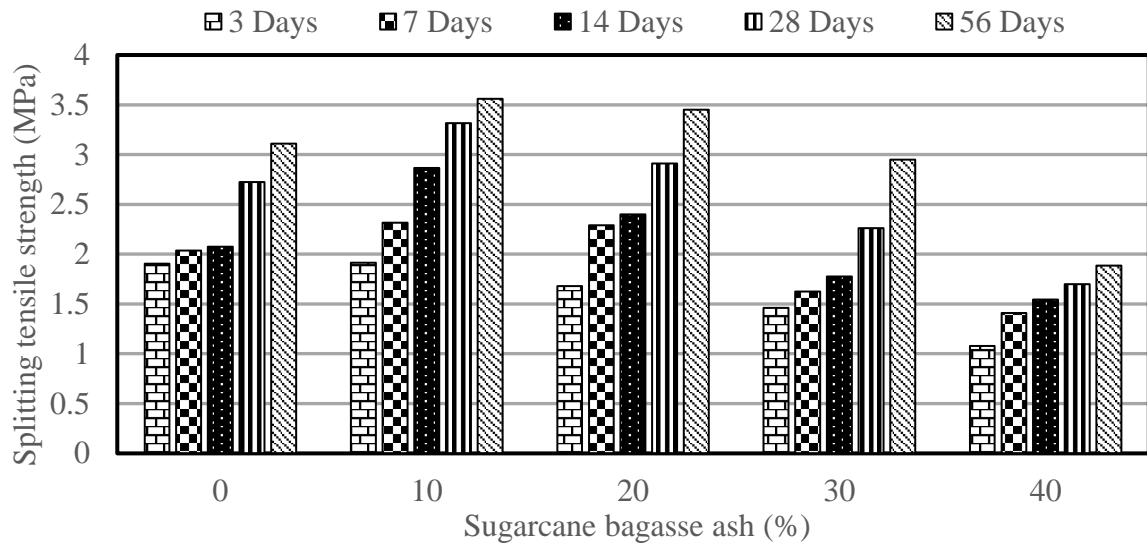


Figure 4.9: Splitting tensile strength of concrete incorporating SCBA1

It can be observed that inclusion upto 10% of ash waste in cement (OPC) leads to enhancement in split tensile strength of concrete at all ages as compared to control mix. At 3 days, split tensile strength of control mix was 1.905 MPa, whereas compressive strength of BA10, BA20, BA30 and BA40 concrete mixes was 1.915, 1.680, 1.460 and 1.080 MPa, respectively. Similarly, at 7 days, split tensile strength of control mix was 2.035 MPa, whereas split tensile strength of BA10, BA20, BA30 and BA40 concrete mixes was 2.315, 2.29, 1.625, and 1.410 MPa, respectively. At 14 days, split tensile strength of control mix was 2.075 MPa, whereas split tensile strength BA10, BA20, BA30 and BA40 concrete mixes was 2.865, 2.40, 1.775 and 1.545 MPa, respectively. At 28 days, split tensile strength of control mix was 2.725 MPa, whereas split tensile strength BA10, BA20, BA30 and BA40 concrete mixes was 3.315, 2.91, 2.26 and 1.70MPa, respectively. At 56 days, split tensile strength of control mix was 3.11 MPa, whereas split tensile strength BA10, BA20, BA30 and BA40 concrete mixes was 3.56, 3.45, 2.95 and 1.885 MPa, respectively. It means that split tensile strength of concrete goes on increasing with increase in cement replacement level and attains a maximum value at cement replacement level of 20% and then starts decreasing. The results show this type of pattern because of higher value of LOI in material which is responsible for lower improvement of split tensile strength of concrete. The higher replacement of cement with sugarcane bagasse ash shows the strength value lower than control concrete value due to dilution effect of cement with sugarcane bagasse ash. Concrete mixes show similar trend at all ages of testing. Similar trend in split tensile strength was also observed in previous researches by Ganesan et al. (2007); Srinivasan et al. (2010); Priya et al. (2016).

4.5.5 Pulse velocity

The pulse velocity test results are illustrated in Table 4.16 and Figure 4.10. At 28 days of curing and 56 days of curing, the pulse velocity through sugarcane bagasse ash blended cement concrete were compared with control concrete in which no sugarcane bagasse ash was replaced with cement and the results were showing improved trend. From the results, the observation of the pulse velocity value of concrete increases with the incorporation of sugarcane bagasse ash in cement. The results indicated the values of pulse velocity are in excellent position as per presented by IS 13311-92.

Table 4.16: Ultra-sonic pulse velocity of concrete incorporating SCBA1

Mix designation	Pulse velocity (m/s) at curing age	
	28 days	56 days
BA0	6413.3	6325
BA10	6510	6480
BA20	6720	6443.3
BA30	6363.3	6485
BA40	6561.6	6351.6

The results of sugarcane bagasse ash concrete are not very much comparable with the control and shows the velocity values almost similar at all curing ages. This pulse velocity results attributes to increase in gel/ space ratio due to continued hydration process with curing age. Higher values of pulse velocity observed in report indicate that the quality of sugarcane bagasse ash concrete in terms of density, homogeneity and uniformity of concrete specimen. The results were confirmed by permeable pore space test results shown in Table 4.18. Higher values of pulse velocity indicate that the noticeable decrease in permeable pore space. With the increase in curing age, the results of pulse velocity values attain almost similar values.

4.5.6 Rapid Chloride-ion Permeability

Rapid chloride-ion permeability test was conducted and charge passed in coulombs was recorded for different concrete mixes at age of 7, 28 and 56 days to study the effect of partial replacement of cement with sugarcane bagasse ash and observations are given in Table 4.17.

Table 4.17: RCPT results of concrete incorporating SCBA1

Mix designation	Total charge passed at 7 days (coulombs)	Total charge passed at 28 days (coulombs)	Total charge passed at 56 days (coulombs)
BA 0	4263	3248	2777
BA10	3222	3056	2662
BA20	3040	2603	2321
BA30	2935	2292	1783
BA40	2363	2207	1592

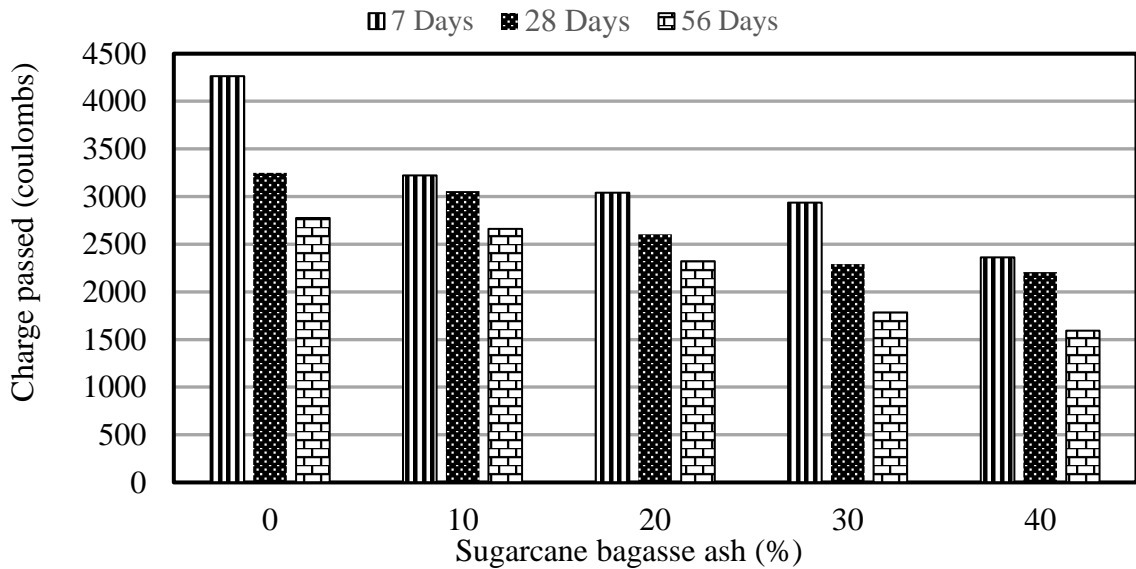


Figure 4.10: Charge passed through concrete incorporating SCBA1

The resistance increased was credited to denser microstructure of concrete obtained with partial substitution of cement with sugarcane bagasse ash. As explained earlier, with increase in cement substitution rate, micro-fines tend to fill up the voids in concrete, giving a denser microstructure as compared to control concrete, leaving less voids. That may be the reason behind the increase in chloride-ion penetration resistance. It should be noted that concrete mix with 20% cement replacement level has the significant lower chloride-ion permeability with respect to control concrete at 28 days of curing, which is the same concrete mix that has maximum compressive strength at 28 days. Figure 4.10 demonstrates the correlation between total charge passed at 7, 28 and 56 days of curing ages. The results showed the decrease pattern in chloride permeability up to 40% replacement at 28 days of curing period but there were

significantly changes occurred in decrease in permeability in 30% and 40% sugarcane bagasse ash concrete at 56 days of curing age because of higher value of LOI of material. The water left after hydration process get absorbed in pores of concrete up to some extent. Similar trend was observed by researches done by Ganesan et al. (2007); Cordeiro et al. (2010).

4.6 PROPERTIES OF CONCRETE INCORPORATING SCBA2 (LOI = 6.27)

4.6.1 Compressive strength

Compressive strength of concrete incorporated with SCBA2 cement at age of curing of 7 days and 28 days were evaluated by comparing all the result strength of control concrete. The compressive strength of concrete specimens was tested according to the specifications given by BIS 516-1959. The results are presented in Table 4.19 and Figure 4.11.

Table 4.18: Compressive strength of concrete incorporating SCBA2

Mix designation	Compressive strength	
	7 days	28 days
BA0	24.60	33.80
BA10	32.60	39.1
BA20	24.6	32.80
BA30	16.2	18.2
BA40	12.2	12.8

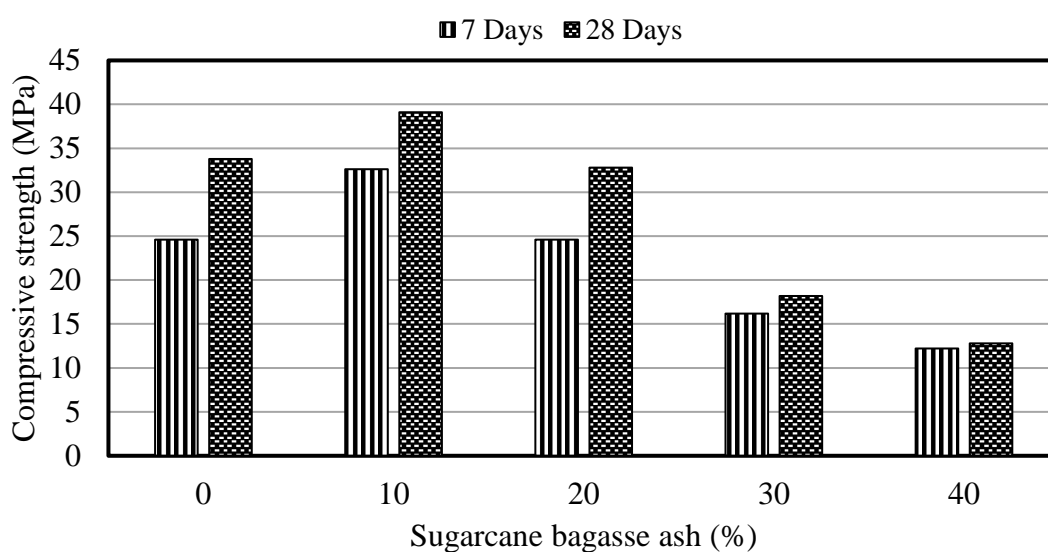


Figure 4.11: Compressive strength of concrete incorporating SCBA2

It can be observed that inclusion upto 10% sugarcane bagasse ash as replacement of cement leads to significant enhancement in compressive strength of concrete at all ages as compared to control mix. At 7 days, compressive strength of control mix was 24.60 MPa, whereas compressive strength of BA10, BA20, BA30 and BA40 concrete mixes was 32.60, 24.60, 16.20 and 12.20 MPa, respectively. Similarly, at 28 days, compressive strength of control mix was 33.80 MPa, whereas compressive strength of BA10, BA20, BA30 and BA40 concrete mixes was 39.1, 32.80, 18.20, and 12.80 MPa, respectively. It means that compressive strength of concrete goes on increasing with increase in cement replacement level and attains a maximum value at cement replacement level of 10% and then starts decreasing. The results show this type of pattern because of lower value of LOI of material which is responsible for significant improvement of compressive strength of concrete. The higher replacement of cement with sugarcane bagasse ash shows the strength value lower than control concrete value due to dilution effect of cement with sugarcane bagasse ash. Concrete mixes show similar trend at all ages of testing. Similar trend in compressive strength was also observed in previous researches by Bahurudeen et al. (2015); Rerkpiboon et al. (2015); Cordeiro et al. (2012); Chusilp et al. (2009).

4.6.2 Rapid chloride permeability

Rapid chloride-ion permeability test was conducted and charge passed in coulombs was recorded for different concrete mixes at age of 7, 28 and 56 days to study the effect of partial replacement of cement with sugarcane bagasse ash and observations are given in Table 4.19 and Figure 4.12.

Table 4.19: The results of chloride permeability of concrete incorporating SCBA2

Mix designation	Total charge passed at 7 days (coulombs)	Total charge passed at 28 days (coulombs)
BA0	4156	3022
BA10	2286	2046
BA20	1704	1113
BA30	1458	927
BA40	1295	717

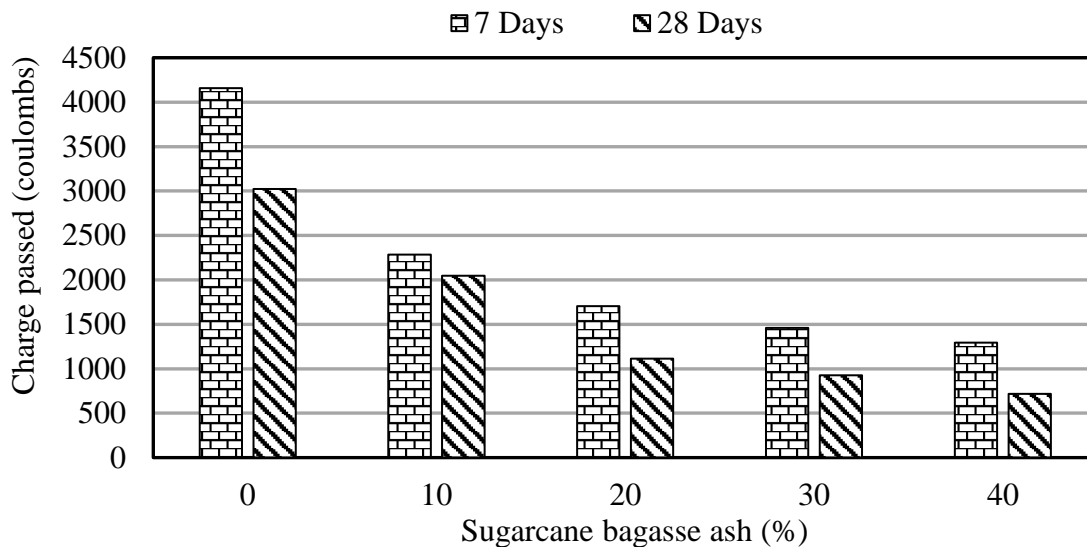


Figure 4.12: Total charge passed through concrete incorporating SCBA2

The increase in chloride-ion penetration resistance can be attributed to denser microstructure obtained on partial substitution of cement with sugarcane bagasse ash. As explained earlier, with increase in cement substitution rate, micro-fines present in concrete matrix tend to fill up the voids in concrete, giving a denser microstructure compared to control concrete, leaving less voids. That may be the reason for the increase in chloride-ion penetration resistance. It should be noted that concrete mix with 40% cement replacement level has the significant lower chloride-ion permeability with respect to control concrete at 28 days of curing. Figure 4.12 demonstrates the correlation between total charge passed at 7, and 28 days of curing ages. The results showed the decrease pattern in chloride permeability up to 40% replacement at 7 days and 28 days of curing. The results so obtained was because of micro filling of voids of cement matrix. Sugarcane bagasse ash fills the voids by forming additional CSH gel and the concrete specimen get a denser microstructure with improved permeability capacity. The compressive strength of the specimen was also improved by the pores refinement of matrix. The sugarcane bagasse ash gets utilised in hydration process and the effect of lower LOI was also be clearly justified by the improvement of chloride permeability.

4.7 COMPARISON OF PROPERTIES OF CONCRETE MADE WITH SUGARCANE BAGASSE ASH HAVING DIFFERENT LOI VALUES

4.7.1 Compressive Strength

Now the relationship between the LOI value of pozzolanic material and the strength properties is discussed and the change that occurred due change in LOI content of sugarcane bagasse ash in the study is encapsulated under following.

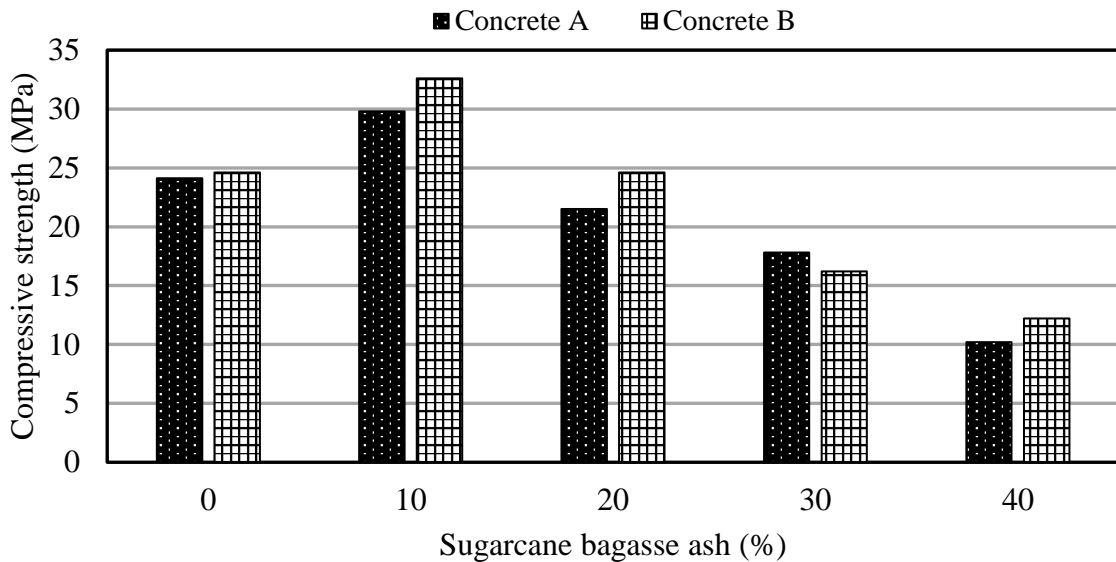


Figure 4.13: Comparison of compressive strength of concretes incorporating SCBA1 and SCBA2 at 7 days of curing age.

Figure 4.13 shows that the compressive strength of concrete made with sugarcane bagasse ash having low value of LOI content (i.e. concrete B) incorporation in cement performed well up to 20% of incorporation as compared to sugarcane bagasse ash cement having higher LOI value (i.e. concrete A). The results of compressive strength of concrete B was observed higher than the concrete A at same curing age of 7 days because of low LOI value in which the content of unburnt fibrous particles of sugarcane raw material was less obtained that's why the pozzolanic performance of this cement was better obtained due to having the most desirable silica content in rich quantity and the presence of unburnt carbon was obtained in small traces obtained. The concrete in which supplementary pozzolanic materials are used, the quantity of additional calcium silicate hydrate gel formation happened due to the reaction between the Portlandite i.e. calcium hydroxide and the silica oxide present in cement (sugarcane bagasse ash cement). The reaction occurred in presence of water and optimum temperature. The results improved in compressive strength of concrete B was due to the void filling effect done because of sugarcane bagasse ash higher surface area and smaller particle size in pores of cement matrix at initial stage of curing of 7 days in sugarcane bagasse ash incorporated concrete observed in this study. The behaviour of strength in compression of concrete at 28 days of curing with variation of sugarcane bagasse ash having different LOI content in cement was encapsulated under following.

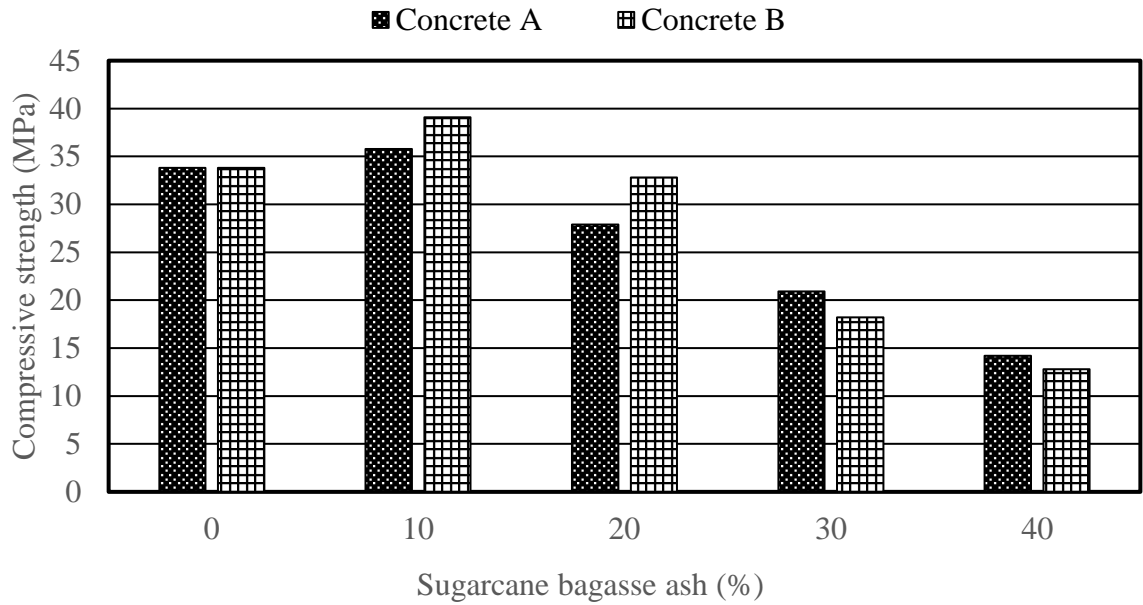


Figure 4.14: Compressive strength v/s LOI content of blended cement in concretes at 28 days of curing age.

The similar results were observed at 28 days of curing as on 7 days of curing observed. The improvement in compressive strength of concrete B up to 20% incorporation of sugarcane bagasse ash having low LOI value was due to the pozzolanic behaviour of material as the unburnt carbon content in this was obtained low and the contribution of forming the additional hydration product i.e. calcium silicate hydrate gel was more as observed. The voids were filled with addition C-S-H gel and the strength of concrete made with low valued sugarcane bagasse ash gained obviously.

4.7.2 Chloride Permeability

The chloride permeability of concrete made with sugarcane bagasse ash incorporation in cement having different LOI values were observed under same curing ages and the results are encapsulated under.

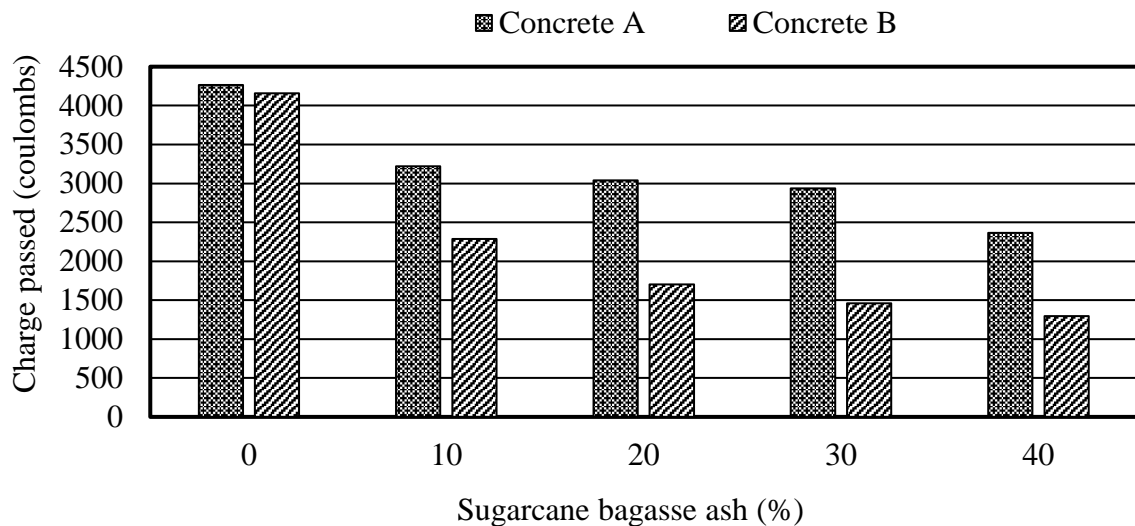


Figure 4.15: Chloride permeability v/s LOI content of blended cement in concretes at 7 days of curing age

The resistance of charge penetration increment was attributed to increase in matrix refinement with increase in partial substitution of cement with sugarcane bagasse ash. As explained earlier, with increase in cement substitution rate, micro-fines present in concrete matrix tend to fill up the voids in concrete, giving a denser matrix as compared to control concrete, leaving less voids. That may be the reason behind the increase in chloride-ion penetration resistance. It should be noted that concrete mix with sugarcane bagasse ash having low value of LOI showed that up to 40% cement replacement level the significant lower chloride-ion permeability with respect to control concrete at 7 days of curing. Figure 4.15 demonstrates the correlation between total charge passed of both the concrete made with sugarcane ash with different LOI values. The results showed the decrease pattern in chloride permeability up to 40% replacement in both the concrete but the significant decrease was observed in concrete B. The reason being for this was observed due to less unburnt carbon's presence in material which enhanced the pozzolanic reaction in concrete and also do filling effect at early stage of curing i.e.7 days.

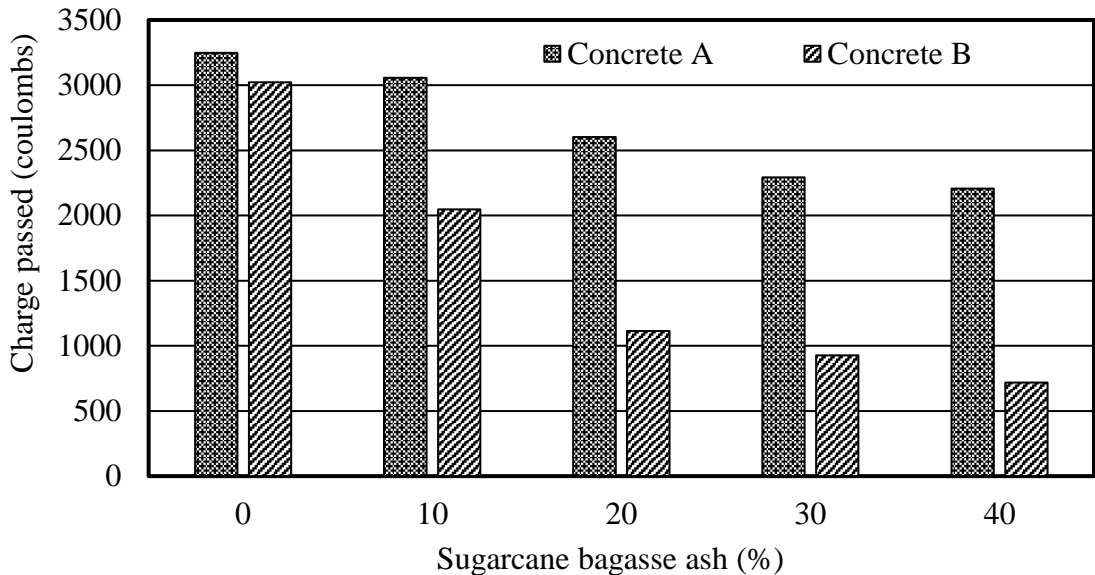


Figure 4.16: Chloride permeability v/s LOI content of blended cement in concretes on 28 days of curing

Comparable trend of results was obtained on 28 days of curing period as that of 7 days. The decrease in chloride charge penetration was observed as compared to control concrete in both the test concrete specimens but the noticeable difference in resistance against chloride permeability was obtained in concrete B as the less amount of fibrous unburnt carbon presence and high amorphous silica reaction done in hydration process made the concrete more reliable for utilization in actual practises.

4.8 SCANNING ELECTRON MICROSCOPY

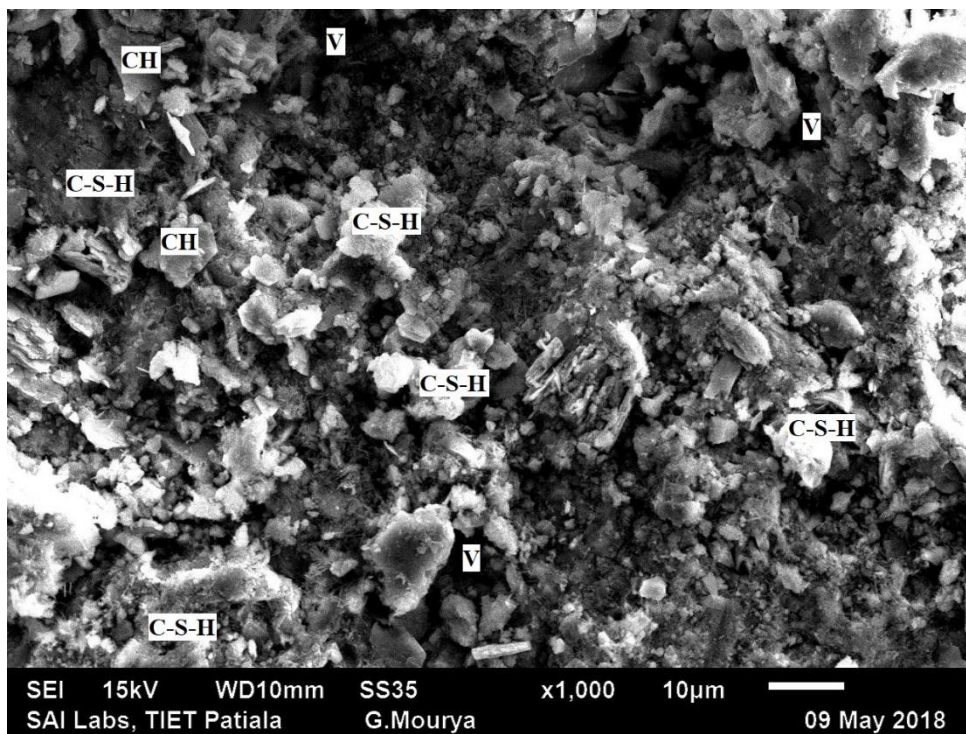
To study the various changes in the microstructure of concrete with addition of sugarcane bagasse ash as a partial substitute of cement, scanning electron microscope (SEM) analysis was performed. Concrete samples collected from all concrete mixes at age of 28 days were analyzed at different magnifications to study the microstructure of each concrete mix.

Figure 4.17 to 4.19 show the SEM morphology of different concrete mixes at age 28 days at magnification factor of 1000, 2500 and 5000 respectively. It can be observed that inclusion of sugarcane bagasse ash has a very profound effect on microstructure of concrete. Control concrete has maximum voids among all concrete mixes. As the substitution rate of cement with sugarcane bagasse ash is increasing, voids go on reducing. The improvement in microstructure of concrete can be attributed to the filling effect of sugarcane bagasse ash micro-fines, which tends to fill up voids present in concrete, making the microstructure denser. Microstructure of concrete plays a very significant role in affecting hardened as well as durability properties of concrete. The reduction in voids in concrete mixtures containing

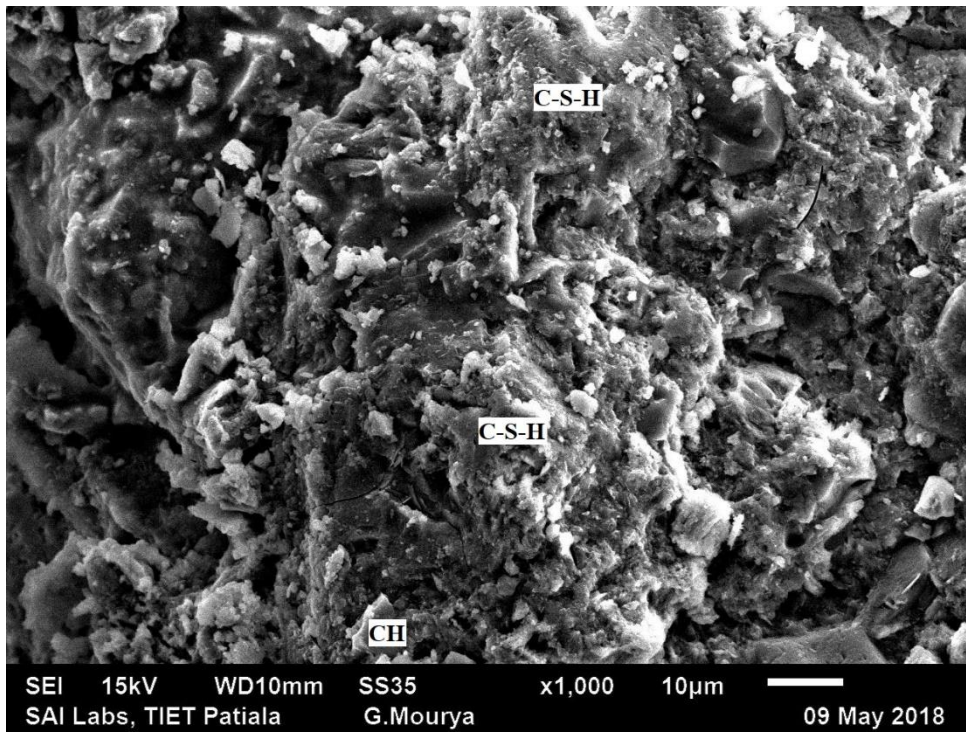
sugarcane bagasse ash was the main reason behind its superior hardened and durability properties as compared to control mix.

SEM analysis also confirmed the reason behind the increase in pozzolanic activity of concrete with sugarcane bagasse ash as partial replacement of cement. SEM images show that at 28 days, concrete mix with 10% cement replacement level has minimum voids and thus, it has maximum strength.

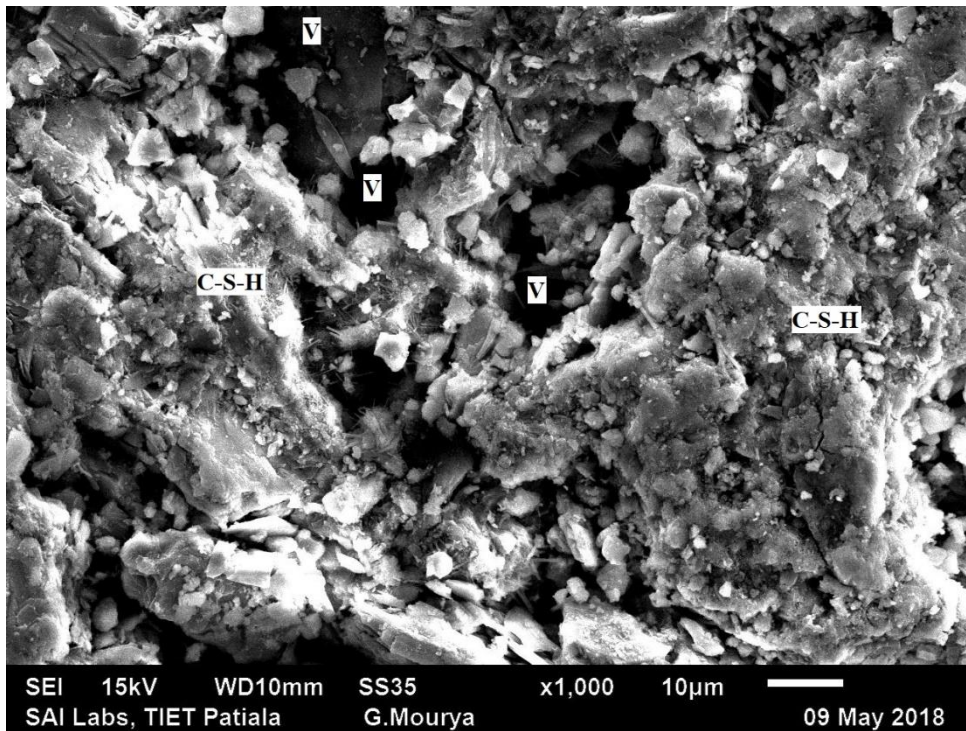
It can be concluded that the improvement in strength and durability properties of concrete with addition of sugarcane bagasse ash as partial substitute of cement can be mainly attributed to the denser microstructure of concrete mixes containing sugarcane bagasse ash and also production of additional C-S-H attributes a lot in hydration of cement in concrete.



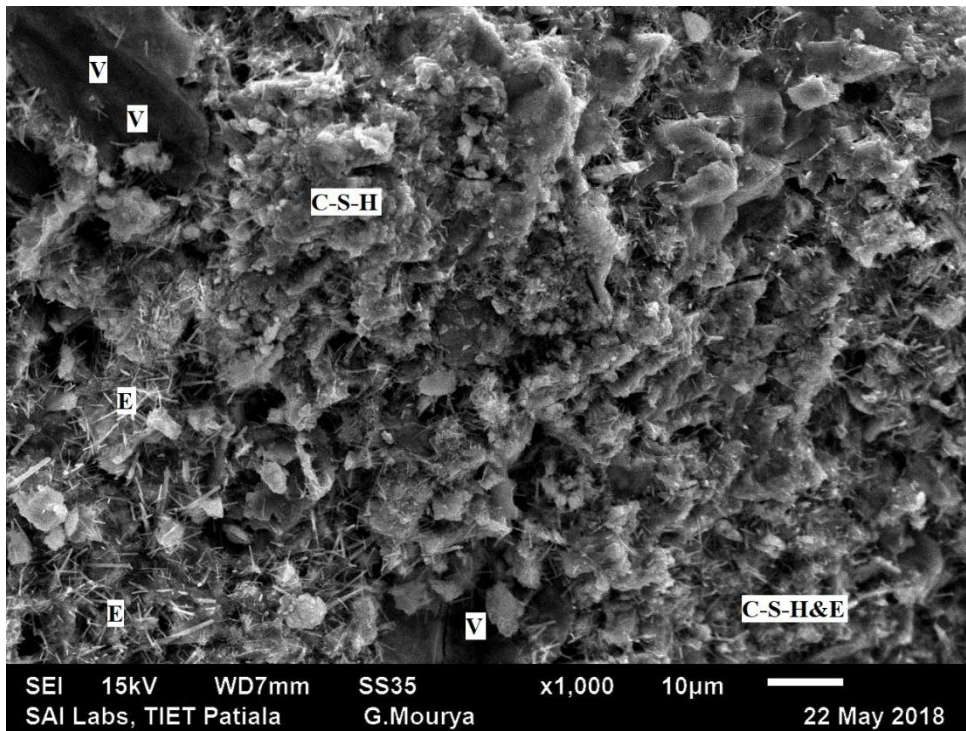
BA0 - Control concrete



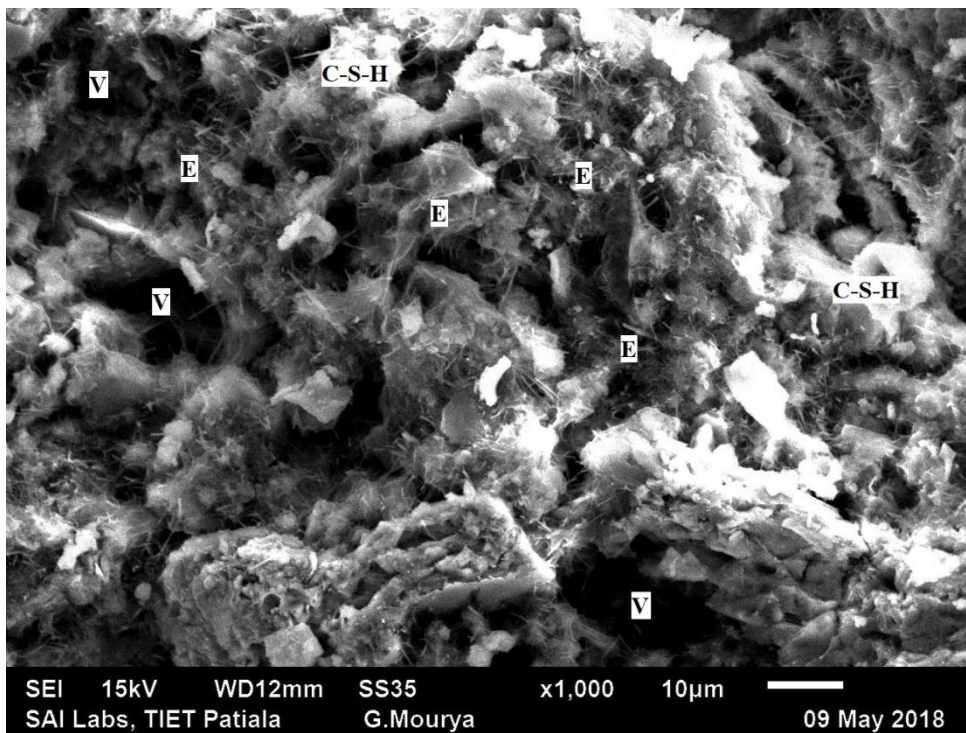
BA10 -10% cement replacement



BA20 – 20% cement replacement

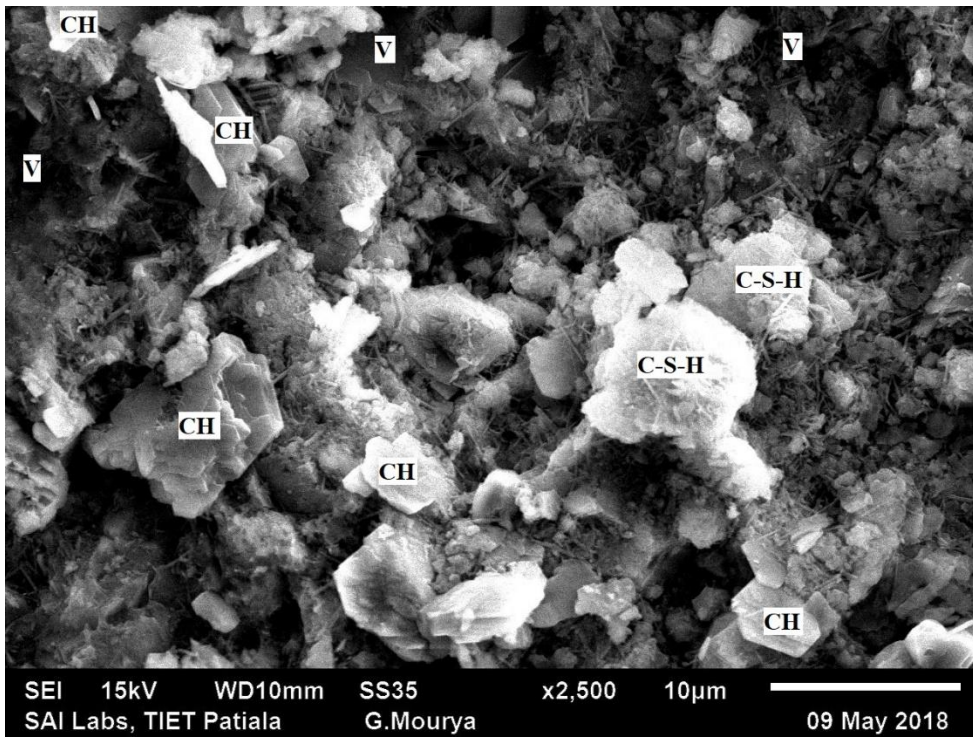


BA30 – 30% cement replacement

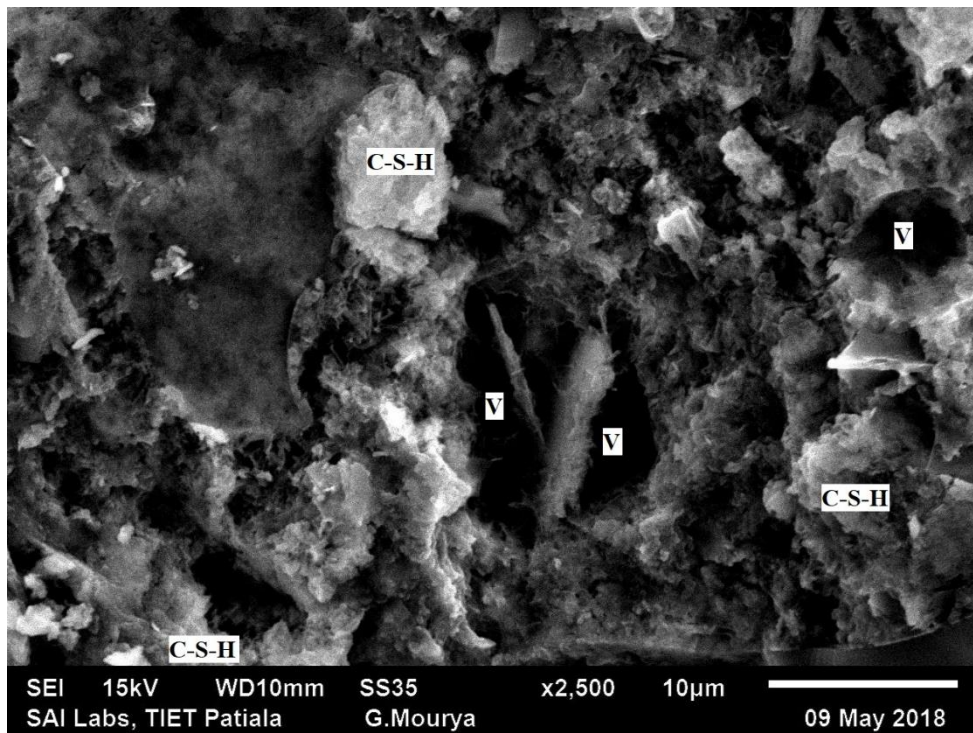


BA40 – 40% cement replacement

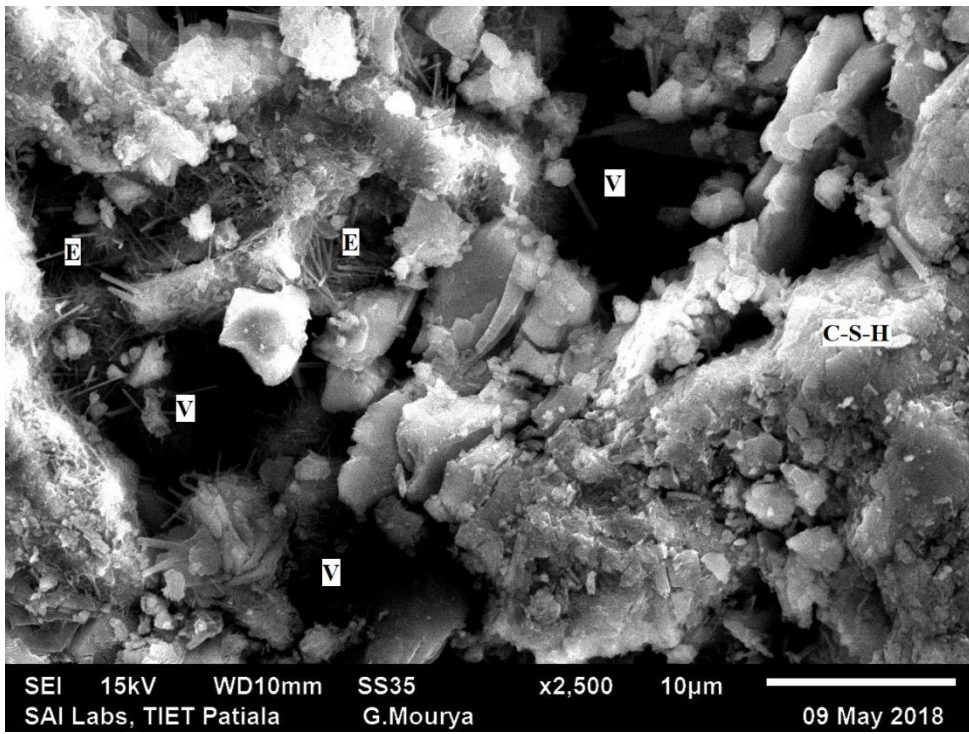
Figure 4.17: SEM morphology of concrete incorporating sugarcane ash in cement at age of 28 days with magnification factor of 1000



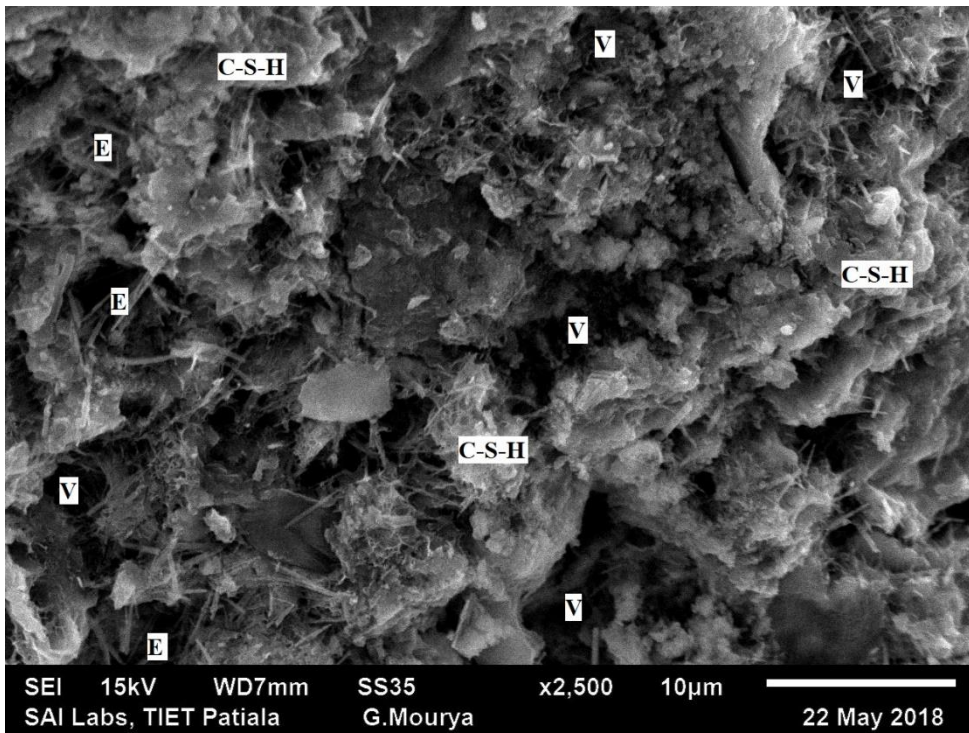
BA0 - Control concrete



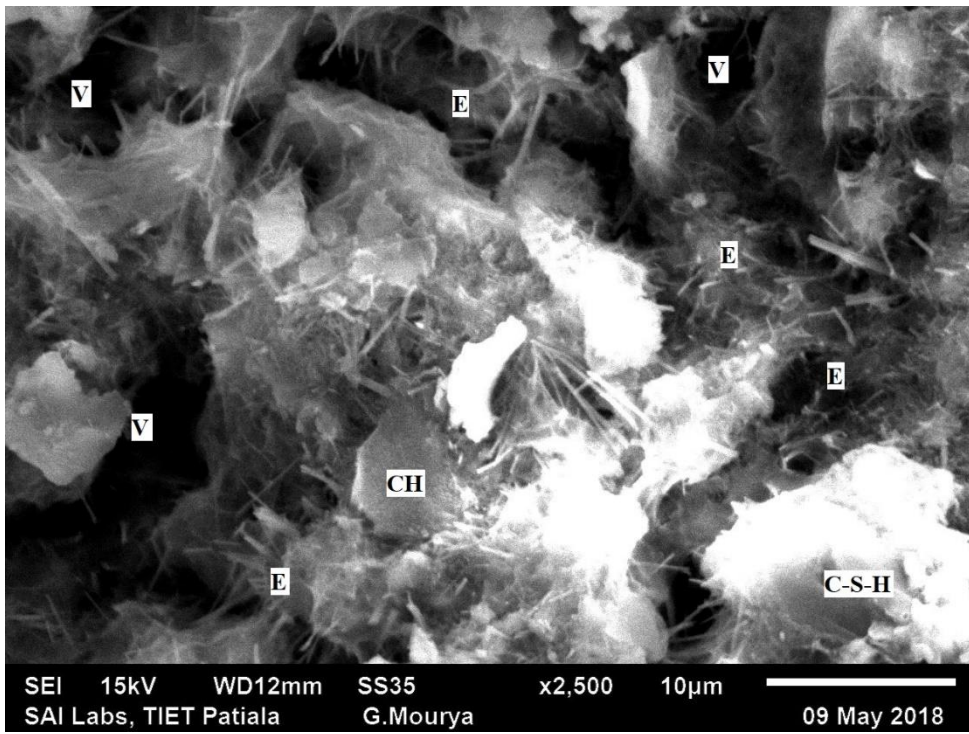
BA10 -10% cement replacement



BA20 – 20% cement replacement

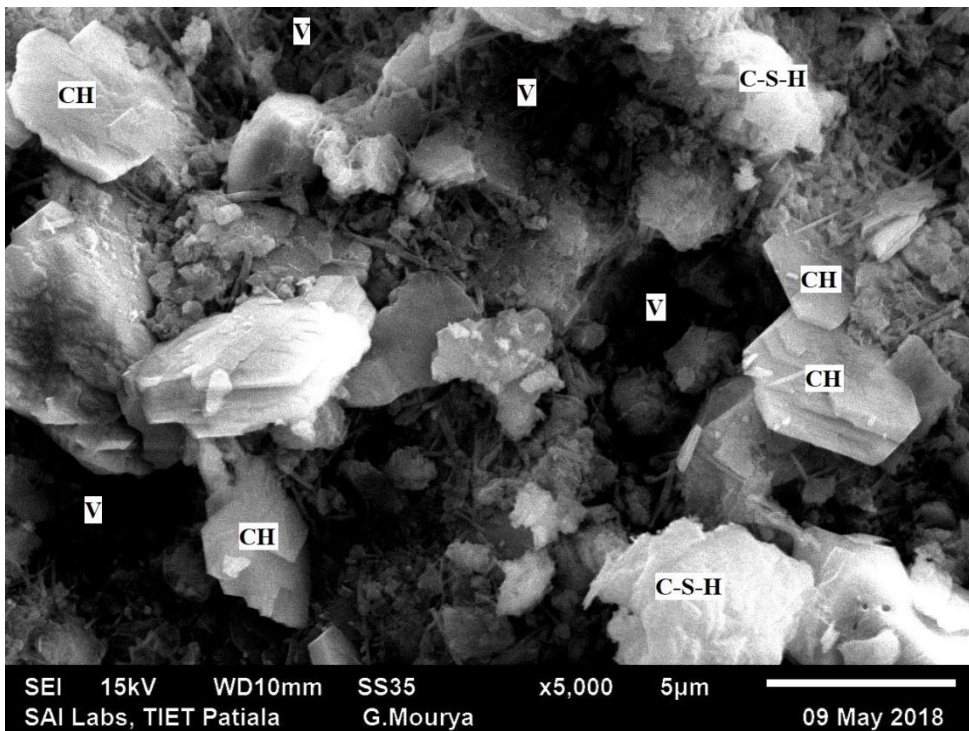


BA30 – 30% cement replacement

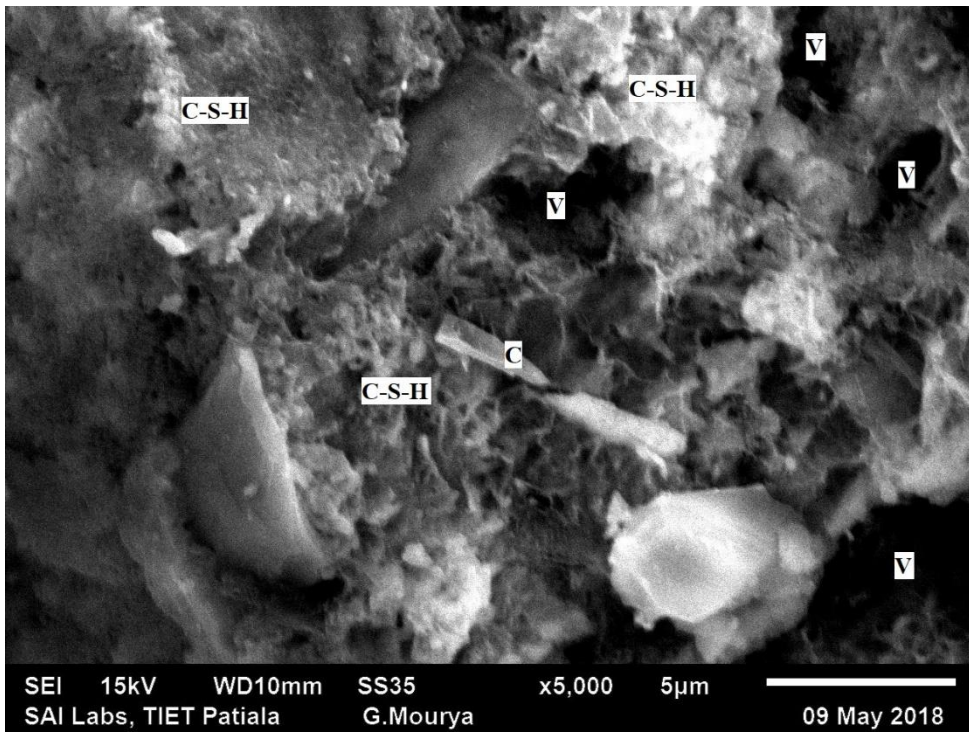


BA40 – 40% cement replacement

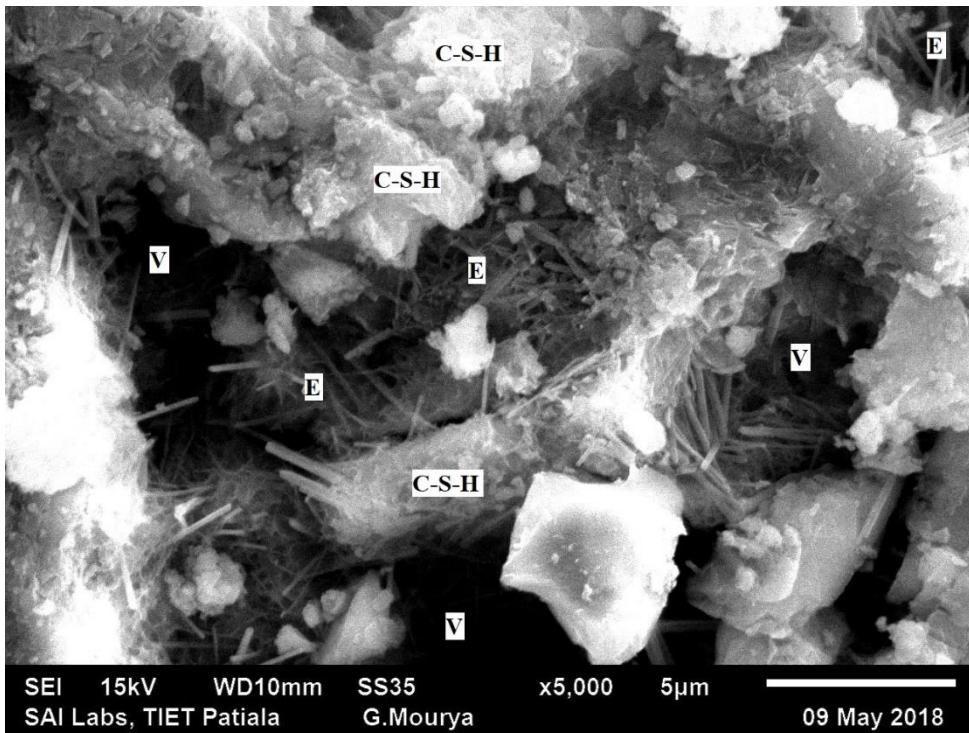
Figure 4.18: SEM morphology of concrete incorporating sugarcane ash in cement at age of 28 days with magnification factor of 2500



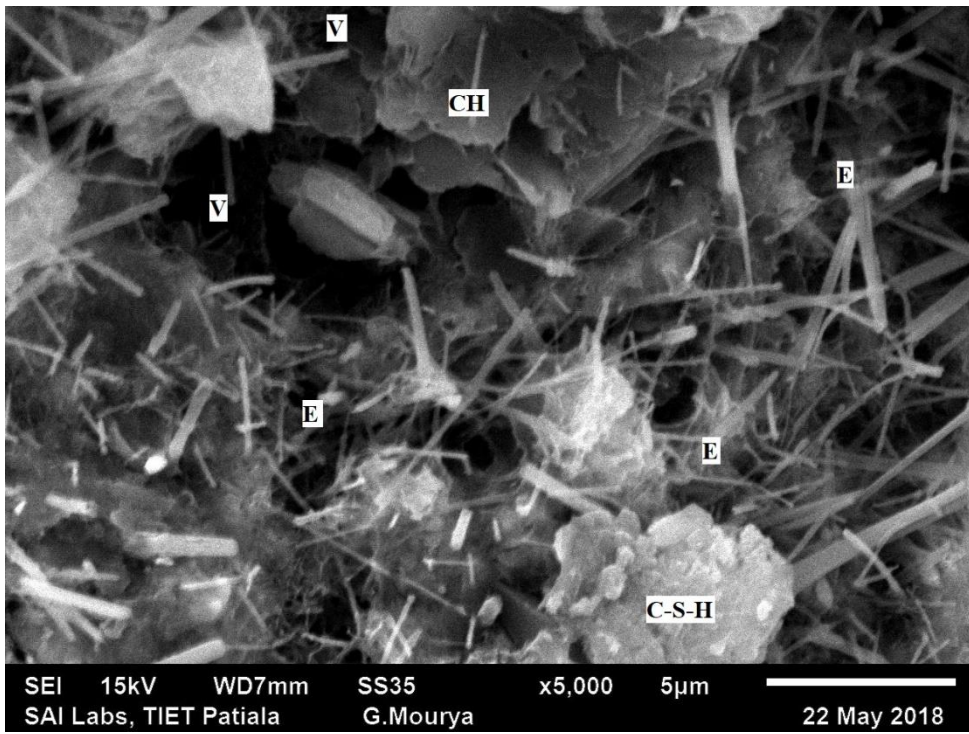
BA0 - Control concrete



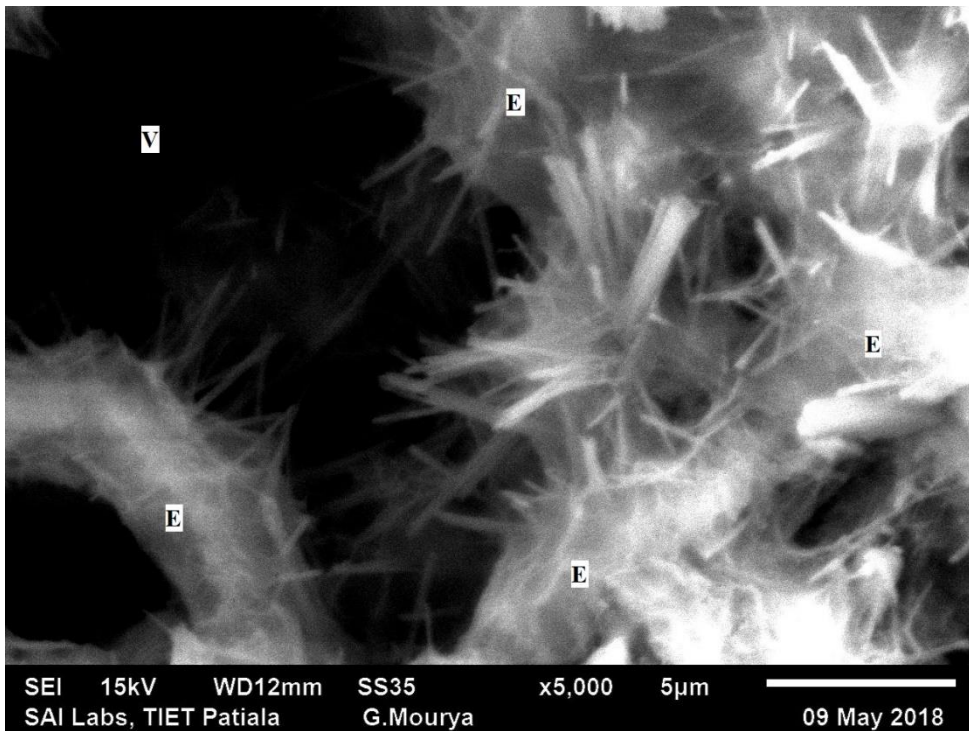
BA10 -10% cement replacement



BA20 – 20% cement replacement



BA30 – 30% cement replacement



BA40 – 40% cement replacement

Figure 4.19: SEM morphology of concrete incorporating sugarcane ash in cement at age of 28 days with magnification factor of 5000

4.9 X-RAY DIFFRACTION ANALYSIS

XRD is a useful way for recognition of crystalline compositions for instance calcium hydroxide [Ca(OH)₂], ettringite compounds, and calcium silicate hydrates (C-S-H) etc. present in the concrete by processing the sample collected from core of cube specimen after testing done for compression strength test by crushing and sieving the material from 75 microns so that the coarse material like aggregate content (i.e. fine and coarse aggregates) separated out. The results of this analysis are discussed by comparing the intensity of silica oxide in peak matching technique. The concrete made with incorporation of pozzolanic material in cement enhances the strength properties and durability properties by giving the high silica content in utilization of making the additional C-S-H gel by reacting with calcium hydroxide during hydration process of concrete. In this study, the observation taken into account was that the silica was present in silica oxide compound form and it contributed to enhance the pozzolanic reaction in structure by reacting with the calcium hydroxide and the filling of voids by formation of C-S-H gel in structure was also observed in SEM images at different magnifications. X-ray diffractograms of concrete specimens with sugarcane bagasse ash content from 10% to 40% at age of 28 days are illustrated in Figure 4.20 to 4.24, respectively, at diffraction angle 2θ between 5 and 70°.

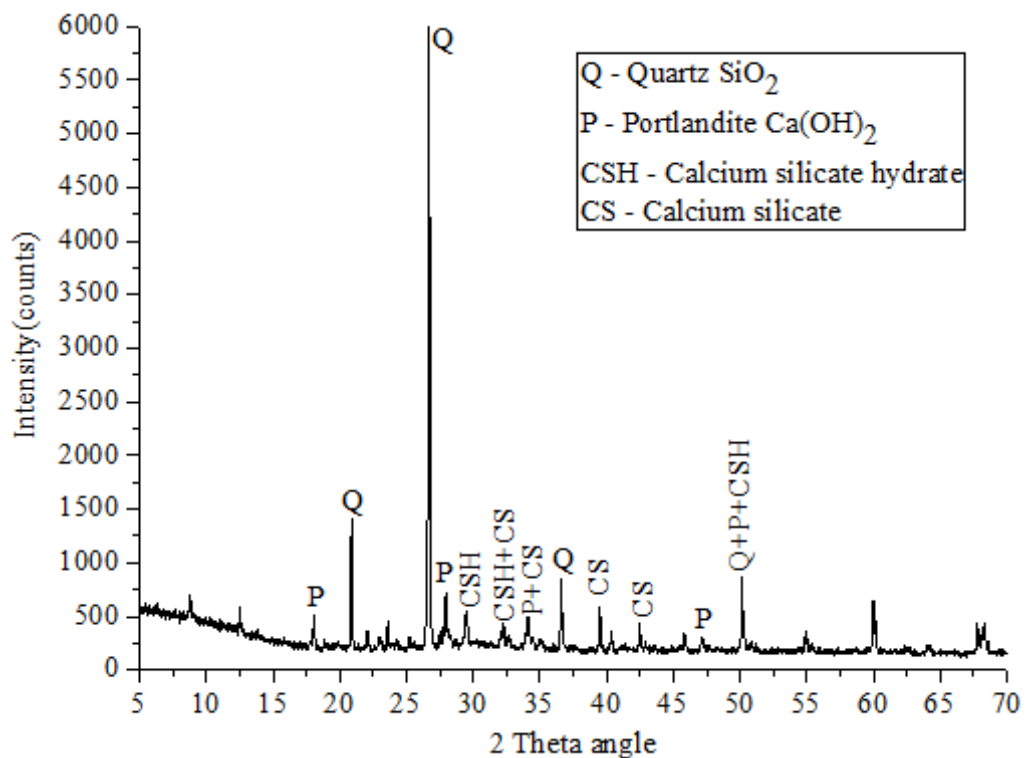


Figure 4.20: XRD results of control concrete at 28 days of curing age

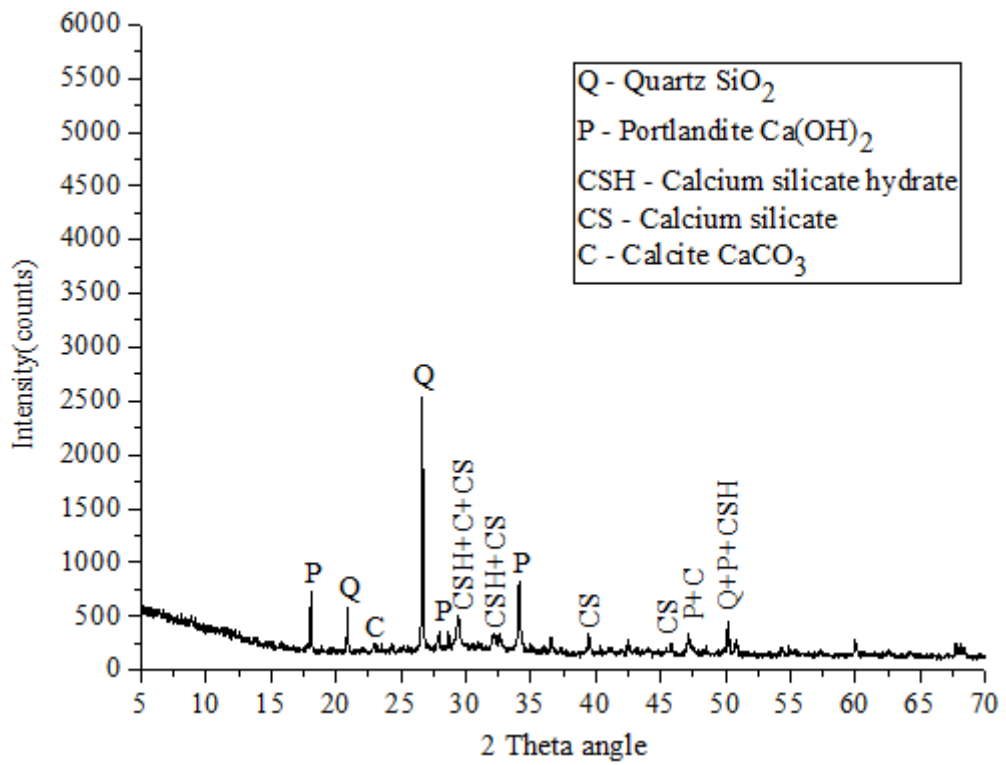


Figure 4.21: XRD results of 10% cement replacement at 28 days of curing age

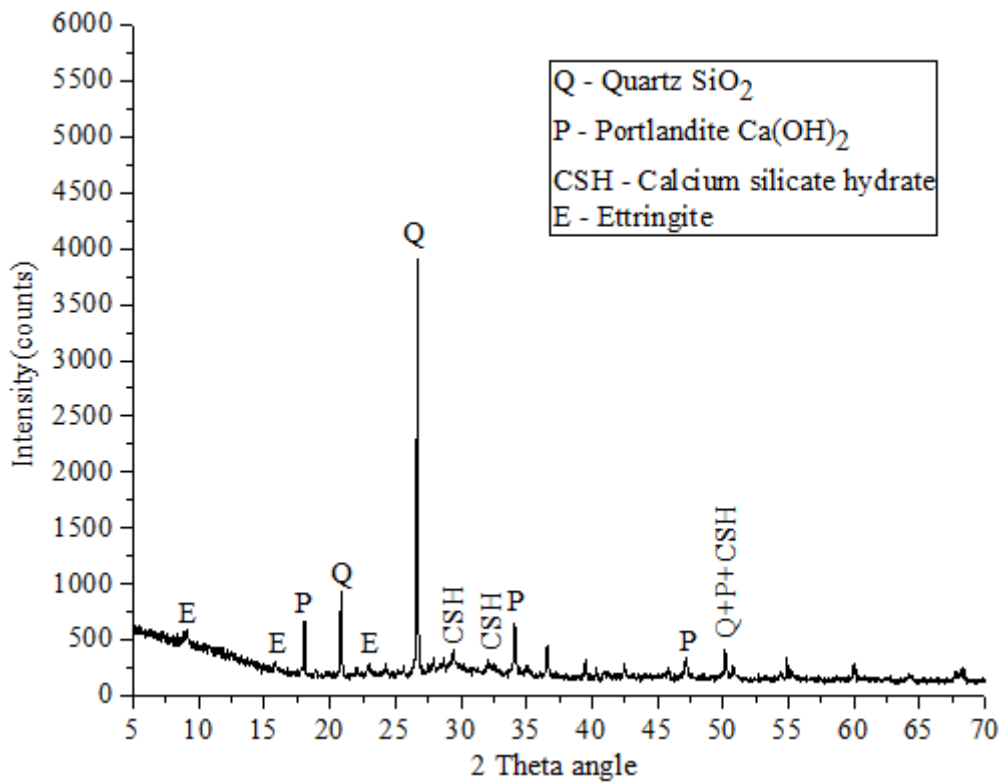


Figure 4.22: XRD results of 20% cement replacement at 28 days of curing age

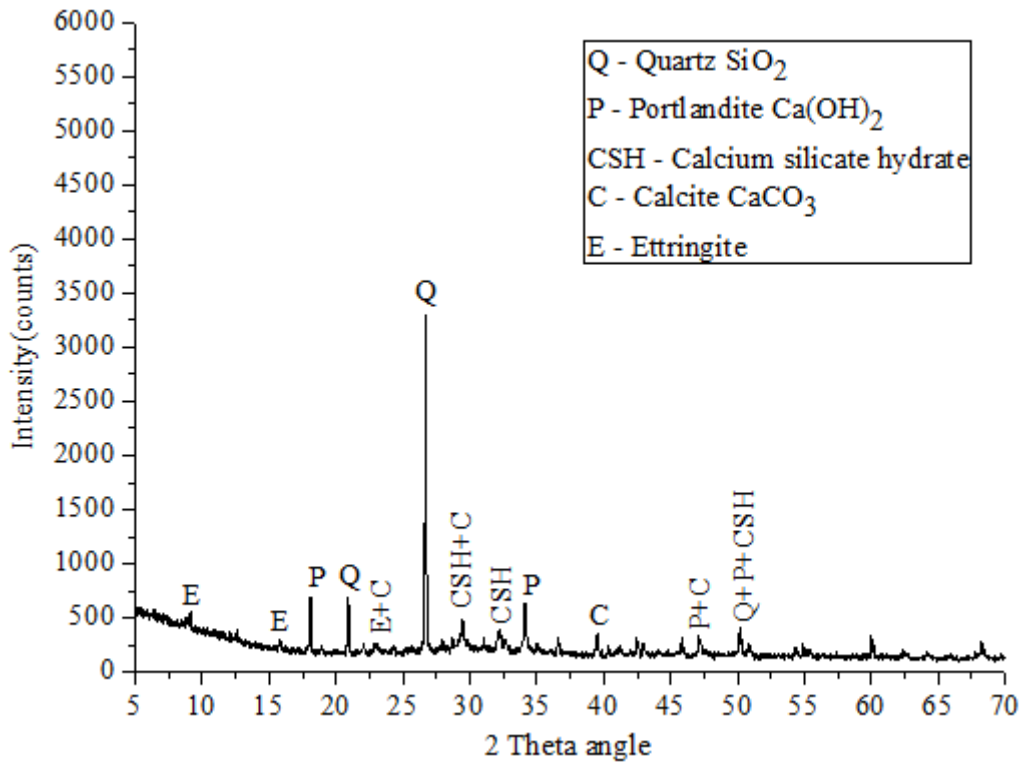


Figure 4.23: XRD results of 30% cement replacement at 28 days of curing age

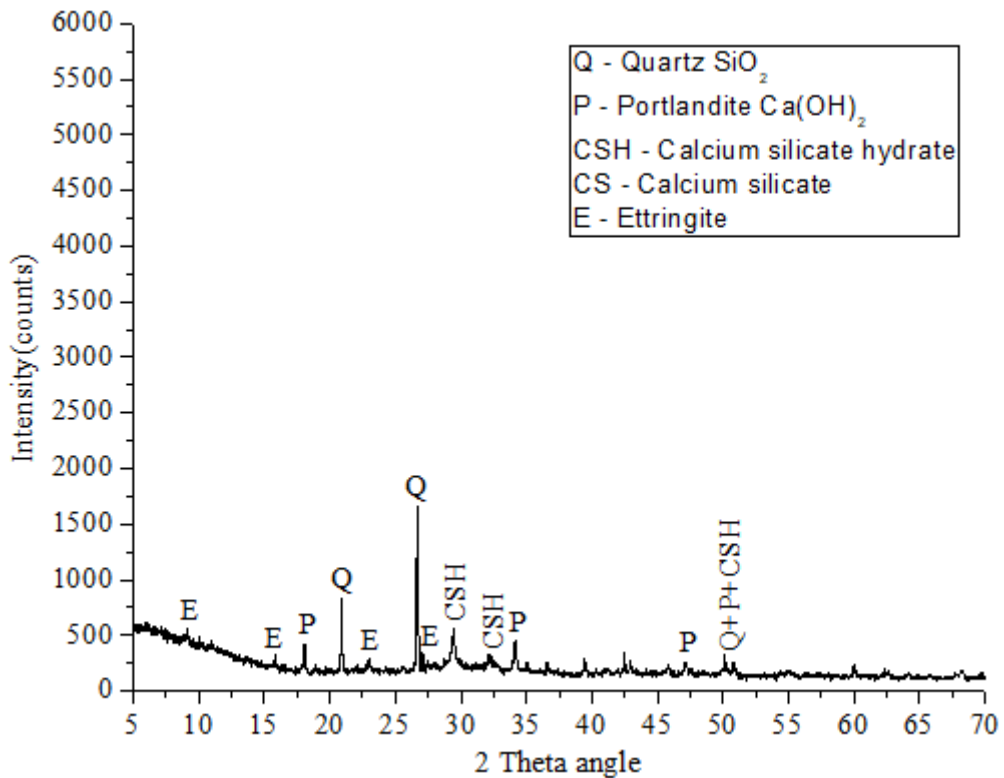


Figure 4.24: XRD results of 40% cement replacement at 28 days of curing age

Figures 4.20 to 4.24, the observations of results of XRD analysis are discussed at curing age of 28 days, various phases of chemical compounds present in specimen mixes incorporating with

sugarcane bagasse ash were quartz (SiO_2), calcium silicate, portlandite (Ca(OH)_2), calcium silicate hydrate (C-S-H gel) and calcite (CaCO_3). Comparing the X-ray diffraction results of control concrete with all the concrete mixes specimens incorporating sugarcane bagasse ash, hydration products have formed in analysis up to 20% incorporation without any formation of any unwanted compounds but after that with the higher incorporation rate the formation of ettringite compounds formed which decrease the chemical bond of concrete ingredients and also the strength and durability properties did not perform well. Thus, the formation of ettringite compounds in structure badly effect the compressive strength and chloride permeability properties at higher incorporation of sugarcane bagasse ash i.e. 30% and 40%. Thus, the increase in strength of sugarcane bagasse ash incorporated concrete was observed due to void filling by formation of hydration product in concrete structure and also the durability aspect improved by this reason.

5.1 GENERAL

The present study was accompanied to study the reliability of sugarcane bagasse ash as a partial replacement of cement in concrete. (Workability & unit weight) of fresh concrete, (Compressive strength, splitting tensile strength & pulse velocity) of hardened concrete and rapid chloride permeability of concrete were tested by replacing cement with sugarcane bagasse ash at different varying percentages by weight of cement in concrete. XRD analysis and SEM morphology analysis was also accomplished on all concrete specimens to evaluate the chemical compounds changes in cement paste as well as microstructure of concrete with the incorporation of sugarcane bagasse ash as partial replacement of cement. Test results indicate that sugarcane bagasse ash, is a suitable substitute of cement in concrete.

- 1) Workability of concrete incorporated with sugarcane bagasse ash in cement showed better results by improving the slump values. The results of workability increased up to 20% of inclusion but after that the workability decreased with higher addition of sugarcane ash i.e. at 30% and 40%. The increase in specific surface area of sugarcane bagasse than cement particles was main reason of decreased workability because at higher incorporation of sugarcane bagasse ash with cement, the quantity of cement decreases in concrete with dilution effect and the porous, irregular and rough particle of sugarcane bagasse ash particles absorb the water and due to smaller particle size of sugarcane bagasse ash the more surface absorption occurred and concrete need more water. The workability of sugarcane bagasse ash concrete maintained at good workable condition by adding the superplasticizer in it at required amount in test conditions.
- 2) Unit weight of concrete decreased with the increase in incorporation of sugarcane bagasse ash in cement. The decrease in unit weight observed due to the lower specific gravity of material. The significant decrease in unit weight was observed at all cement replacement levels up to 40%. Thus the conclusion was obtained that the material can used in concrete as light weight pozzolanic material.
- 3) Compressive strength of concrete specimens incorporated with sugarcane bagasse ash of varying LOI content were compared and observed that the strength of concrete denoted as concrete B having the low LOI content has higher strength than concrete A having comparatively high LOI content. In this study the sugarcane bagasse ash having LOI content of 6.27 % observed efficient and recommended to use as partial substitute

of cement up to 20% in concrete. The strength of concrete B observed efficient because of its low unburnt carbon content which help in improving the hydration process and formed additional C-S-H gel and also filled the voids in structure.

- 4) Splitting tensile strength of concrete was tested with incorporation of sugarcane bagasse ash in cement and observed the results in improved manner. The splitting tensile strength of concrete increased with 3.56MPa as highest result value at 10% replacement but the results of 20% inclusion was also comparable increased as compared to control concrete. Hence the incorporation of sugarcane bagasse ash up to 20% was recommended as conclusion. The reason for improvement of splitting tensile strength was observed as formation of additional calcium silicate hydrate gel in structure due to reaction between amorphous silica and the calcium hydroxide in cement matrix.
- 5) Chloride permeability of concrete specimens made with sugarcane bagasse ash incorporation decreased with the prolong curing. The chloride permeability test was performed at two types of concrete specimens made with sugarcane ash of varying LOI content and compared the results of both. Then the conclusion was made that the concrete which have sugarcane bagasse ash of low value of LOI content showed better results in durability aspect and recommended to use as partial replacement of cement in concrete. The sugarcane bagasse ash has very higher silica content which involved in hydration process and reacted with calcium hydroxide compound present in concrete during hydration process. This was the reason observed for improvement in resistance of chloride penetration in concrete as observed.
- 6) SEM morphology analysis was performed to have the demonstration of sugarcane bagasse ash incorporated concrete in which the densification of cement matrix was observed with the gaining of additional hydration products in form of calcium silicate hydrate gel up to 20% replacement but after that at higher substitution quantities of sugarcane bagasse ash in cement made dilution effect and also formation of ettringite compound in structure decreased the strength of concrete. The durability properties were also effected in reverse manner due to the same reason.
- 7) X-ray diffraction analysis showed that there is qualitative change in various phases of cement containing sugarcane bagasse ash as partial replacement of cement as compared to control concrete specimens. Various phases present in all concrete mixes were identified as quartz, portlandite, calcium silicate hydrate, calcium silicate, ettringite and calcite. The decrease in count of quartz i.e. silica oxide found the formation of additional hydration product like calcium silicate hydrate gel and the improvement in strength as well as

durability properties were obtained with incorporation of sugarcane bagasse ash up to 20% effectively in cement.

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