EVALUATION OF PROPERTIES OF SELF-COMPACTING CONCRETE INCORPORATING BAGASSE ASH

A thesis submitted in partial fulfilment of the requirements for the award of the degree

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MASTER OF ENGINEERING

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Submitted by

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DECLARATION

I, Abdul Haseeb Wani, hereby declare that this thesis entitled **"Evaluation of properties of self-compacting concrete incorporating bagasse ash"** is an authentic record of my study carried out as requirements for the award of degree of **Master of Engineering in Structural Engineering** in the Civil Engineering Department, Thapar University, Patiala under the supervision of **Dr. Rafat Siddique** and **Dr. Shruti Sharma, Senior Professor and Associate Professor;** respectively, Department of Civil Engineering, Thapar University, Patiala during July 2015 to July 2017. The matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

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

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ABSTRACT

Self-compacting concrete is an engineered concrete that flows and de-airs without additional energy input. It fills and envelops even the sophisticated forms of reinforcement. It has gained a notable importance over the past few years owing to the numerous advantages that it offers. Such concrete requires a high slump which can be achieved by the addition of superplasticizers to the concrete mix. However, special attention needs to be paid to the mix proportioning.

Bagasse ash is a by-product of the sugarcane industry. It is the ash that is left after the sugarcane bagasse is used in the cogeneration boilers in the sugar industries for producing steam and electricity. Disposal of Bagasse ash has become a problematic concern for sugar industries owing to the increased land requirements and environmental restrictions. It thus becomes a pressing need to find alternate solutions to this problem. One such solution is the utilisation of Bagasse ash in concrete. This serves the purpose of both land disposal and environmental concerns.

In this study, an experimental program was carried out to study the properties of Self-compacting concrete (SCC) made with Bagasse ash. The mixes were prepared with four percentages (0, 5, 10 and 15) of Bagasse ash as partial replacement of cement. Properties investigated were; Slump-flow, V-funnel and L-box, Compressive strength, Splitting tensile strength, Chloride-ion penetration resistance and Water absorption. Compressive and splitting tensile strength tests were conducted at the age of 7 and 28 days. Rapid chloride-ion permeability test was carried at the age of 28 days and water absorption test was carried out at the age of 7 days after initial curing of 28 days.

Test results showed that there is an increase in the compressive and splitting tensile strength of the concrete specimens having up to 10% replacement level, however, there is a slight decrease at 15% level of replacement. Resistance to chloride-ion penetration of the specimens increased as the percentage of replacement was increased. The charge passed in all the specimens containing bagasse ash was lower than that of the specimen without bagasse ash. Water absorption of the specimens decreased up to 10% replacement level and increased at 15% level of replacement.

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ABBREVIATIONS

SCC	-	Self-compacting concrete
EFNARC	-	European Federation of National Associations Representing for Concrete
VMA	-	Viscosity modifying agent
SEM	-	Scanning electron microscope
XRD	-	X-ray diffraction
MPa	-	Mega Pascal
N/mm^2	-	Newton per square meter
kN	-	Kilo Newton
kg/m^3	-	Kilogram per cubic meter
w/b	-	Water binder
w/p	-	Water powder
GBA	-	Ground Bagasse ash
OPC	-	Ordinary Portland Cement
RCPT	-	Rapid Chloride-ion permeability test
C	-	Coulomb
IS	-	Indian Standard
kV	-	Kilo Volt
ASTM	-	American Society for Testing and Materials

CHAPTER 1

INTRODUCTION

1.1 GENERAL

There is no denying in the fact that Concrete is a fascinating building material. Concrete stands out as the most utilized building material in the world and it can sometimes prove to be problematic if not properly designed or placed. Traditional concrete comes with a key issue of supplying external energy in the form of compaction. This is usually done by vibrating pokers and vibrating tables. Concrete practice has shown that for on-site casting, vibration is not always carried out as it should be, thus lowering the quality of concrete.

Self-compacting concrete is not new. Highly specialised, expensive and difficult to control mixes for underwater placement were successfully produced a very long time ago. However, it was not until the late 1980’s that advances in admixtures allowed us to increase the fluidity of the fresh mix sufficiently to make it self-compacting but still cohesive enough to avoid the hitherto inevitable segregation. In simple terms, this concrete fills the formwork like a viscous liquid and does not need any external compaction energy.

Development in concrete technology such as high-performance concrete and reactive powder concrete in recent decades are very interesting, and increase our knowledge. However, it seems that most of these developments are only important for special applications, and not for mainstream concrete practice. This is different with SCC. Although in the first instance SCC was often considered a high-performance concrete on account of its unusual properties when fresh, and early applications tended to exploit its high potential strength, it was soon produced for nearly every strength class.

The building industry has always been very traditional and even conservative. Concrete technology forms an indispensable part of the construction process, whose productivity has only been slowly increasing over the last few decades, while other sectors of industry have achieved great improvements, sometimes massive leaps forward. The introduction of SCC provides an important opportunity to advance and make up some of the lost ground. The positive impact of SCC is so great that it is considered to be a major development and the fact that the first European Research Project on Self-compacting

Concrete, which effectively introduced SCC to Europe, was the first construction-related project ever to reach the final round of the prestigious EU Descartes Prize competition.

1.2 SELF-COMPACTING CONCRETE

1.2.1 Need for Self-compaction

Concrete construction practice has always preferred fresh mixes, that are easy to handle and place. It was also possible to substantially raise the level of consistence, to make the fresh mix flowable [1]. However, this could only be achieved by adding more water to the mix or by greatly increasing the amount of cement paste. It was also discovered very early in development of modern concrete that the high level of consistence (workability) based on high water content made the fresh mix very prone to severe segregation and greatly reduced the strength of the hardened mix. It became firmly embedded in good concrete practice from the late 1800's until the advent of plasticises and superplasticisers in the 1970's that fresh mixes of very high consistence, fluid, runny mixes, were synonymous with very poor quality hardened concrete which was best avoided. The alternative approach to raising consistence (workability) by a very much increased cement paste content led to problems due to excessive heat generation during hardening and greatly increased the cost of such concrete.

Compaction of fresh concrete of traditional consistence is often claimed to be the most unpleasant and tiring job on a typical construction site. In some countries it has become difficult to find workers prepared to carry this out. Supervision of the compaction process is also inherently difficult and it is therefore not surprising that a substantial proportion of concrete placed worldwide is, in reality, not adequately compacted. Sufficient compaction of fresh concrete is thus a basic requirement for good concrete construction. Lack of adequate compaction is one of the primary causes of the poor performance of hardened concrete, including its surface finish. Good quality concrete cannot be obtained without the mix being adequately compacted when fresh, this being achieved either by self-compaction or by an external compaction process.

1.2.2 Definition of Self-compacting concrete

The definition of SCC appears to be quite simple and obvious from the title itself. SCC is an engineered concrete that flows and de-airs without additional energy input. It fills and envelops even the sophisticated forms of reinforcement. Such concrete requires a high slump which can be achieved by the addition of superplasticizers to the concrete mix. However, special attention needs to be paid to the mix proportioning.

It becomes important to draw a line between a genuine SCC and a traditional fresh mix having a high workability often labelled as a 'flowing' concrete. SCC not only has a very high workability, but, unlike the 'flowing' concrete, it does not need compaction of any kind, completely resists segregation and maintains its stable composition throughout transport and placing. An SCC mix must therefore be both adequately fluid and cohesive. It still remains a common misconception that all SCC mixes are automatically special, high-performance concretes in terms of their properties when hardened. Very high-performance concrete can indeed be produced so that it is self-compacting when fresh. Hardened SCC can possess a wide range of properties: from a very low to a very high compressive strength, from a very poor to an extremely high durability. It thus follows that there is no single, unique 'recipe', or specific composition, which produces concrete that is self-compacting when fresh and produces a high-performance material when hardened.

It is also important to appreciate that a fresh mix, that possesses the minimum level of parameters, that define it as self-compacting, may not suit all practical applications where self-compaction is required. Applications require varying levels of the key characteristics which define the self-compaction. There are cases which require a 'higher' than minimum level of self-compaction. There can also be applications where SCC could not be used because the demands on its key characteristics when fresh would exceed the maximum levels obtainable in practice.

1.2.3 Brief history of self-compacting concrete

The concept of self-compaction considerably precedes that of 'modern SCC' even though it had not been defined as such [1]. There were important applications for concrete in practical situations where compaction was not physically possible.

Underwater concrete construction, foundations works using large diameter concrete piling, deep concrete diaphragm walling etc. are few of the many examples. Such early SCC's were invariably based on extremely high cement contents. Later, with the development of admixtures (plasticizers) in the 1960's, the production of these highly specialised mixes got easier than it was before.

Modern SCC dates from the second half of the 1980's when two independent directions of research were pursued, both paving the way for the introduction of SCC as it is currently known [2,3]. The better-known stream of development of modern day SCC originated in Japan. During the 1950's and 1960's, the post-war reconstruction of Japan created a boom in the building construction sector where speedy project delivery obscured the importance of quality. Many reinforced concrete structures started to deteriorate within a decade or two. The gravity of the situation prompted the government to initiate an investigation into the causes of the widespread unsatisfactory performance of concrete. This paved the way for setting up of a major research project aimed at a significant improvement of the durability of concrete construction. Led by H. Okamura of the University of Tokyo, the project team soon indicated that insufficient and improper compaction was the most common cause of deterioration of concrete structures. The project team, including K. Maekawa, K. Ozawa and M. Ouchi proposed a solution by increasing the workability of the fresh mix to an extent that compaction was no longer needed, the mix would become self-compacting [3,4]. Extensive trials and demonstrations were carried out and in the early 1990's. The self-compacting concrete was first used in significant practical applications in Japan [5]. The new, 'modern' SCC enabled an important step towards the improvement of the quality of concrete in general and its durability in particular.

SCC offered perceptible benefits for which an increasing amount of direct evidence from construction practice was being gathered. A wider and more rapid acceptance of SCC was clearly obstructed by an absence of standardised, or even generally agreed, methods for measuring the key properties of fresh SCC which guaranteed its self-compaction. This was compounded by a lack of independent, practical guidance for working with SCC; its specification and verification of conformance on construction sites and wide national differences in the costing of construction projects.

The first European national guidelines on SCC appeared in France and in the Nordic countries in Europe. The matter of international standardisation had to be resolved by a multinational project and in 2001, the European Commission approved and co-funded the 'Testing-SCC' project, led by the ACM Centre, the University of Paisley, Scotland. The project evaluated existing test methods, the final selection being subjected to a rigorous assessment of the performance of the tests in the short list of those suitable for standardisation. The demand from the industry became visibly so strong that rather than waiting for European or other international standards for the key properties of fresh SCC to appear, national guidelines, even standards were drafted and published, largely based on fragmented information published and without direct expertise and pre-normative assessment behind it. The uncoordinated activity in this area threatened to create obstacles in exploitation of SCC by proposing specifications based on different test methods. This was recognised by EFNARC, a grouping of European companies involved in the provision of materials for concrete production, which set up an international joint project group, which, in parallel with the work of SCC project, produced the first European guidelines for SCC [6]. Most of the SCC expertise then available was utilised, including the test methods proposed by the SCC project.

Overall, it is possible to conclude that the development of SCC technology is having a positive impact beyond its own boundaries. The need and curiosity to find out where and how, and if at all, the concrete which is self-compacting when fresh differs from that of traditional concrete has led to a revival of research in all parts of concrete technology.

1.2.4 Constituent materials

SCC can be made from any of the constituent materials that are normally used for structural concrete. As a general rule, materials that conform to the standards to the standards and specifications for use in concrete are suitable. However, SCC mixes are less tolerant to variations in material supply than traditional concrete, and so uniformity and consistency of supply throughout the production of the concrete are essential

1.2.4.1 Coarse aggregates

Type

Rounded, uncrushed coarse aggregates from, for instance, gravel deposits, might be expected to be preferred over angular crushed rock aggregates for achieving the high flow properties of SCC. However, they are not easily available in many locations, and crushed rock aggregates are commonly used. An analysis of 63 case studies published between 1993 and 2003 found that crushed rock was used in over 75% of the cases [7].

Lightweight aggregate has also been successfully used to produce SCC with a density of 1900 kg/m^3 for large scale production of precast building panels and mixes with densities down to 1400 kg/m^3 have been developed with expanded clay aggregates which have been pre-wetted to avoid loss of consistence after mixing. At least two studies have demonstrated the feasibility of using selected recycled aggregates in SCC with careful attention to mix designs.

Maximum size

In most of the applications of SCC, the maximum size aggregate of 16 mm or 20 mm, depending on local availability and practice, were used [7]. 10 mm, 12 mm or 14 mm aggregates have also been used, for example in the production of thin precast structural elements. 40 mm aggregate was used in the large volumes of concrete for the anchor blocks of the Akashi-Kaikyo bridge, a spectacular early use of SCC [8]. There is no real evidence of a pattern of variation of powder content with aggregate size indicating that the aggregate grading is probably a more important factor in mix design [7].

1.2.4.2 Fine aggregates

Like coarse aggregate, fine aggregates conforming to local standards and practice have generally been found to be suitable for SCC. The amount of very fine material is of importance though. While this is not necessarily pernicious, that below a limiting particle size should be considered as being part of the powder fraction for mix design purpose. There is a difference of opinion as to the limiting particle size, e.g. 75 µm is recommended in Japan [9] and 125 µm in Europe [10].

1.2.4.3 Cements and additions

A high powder content and a low water/powder ratio is needed for making SCC. In practice, typical Portland cements have been used in combination with one or more additions. Analysis of the case studies reveals that in over 25% of cases, a ternary blend of Portland cement with two additions was used and in about 5%, a quaternary blend. Common types of additions have been used: nearly inert material such as limestone powder, pozzolanic material such as fly ash or microsilica, and latent hydraulic such as ground granulated blast furnace slag. The European standard EN-206 [11] describes these additions as either Type I : nearly inert or Type II : pozzolanic or latent hydraulic, and moreover gives requirements for each.

SCC used in most of the early applications in Japan had powders as one of the constituents which were mixtures of a Portland blast furnace cement and fly ash (ternary blend). Further developments, mainly in Europe, made use of limestone powder, which, because of its lower water/powder ratios could be added in significant proportions without affecting the strength much. Some studies found that if the overall particle size distribution of the powder is varied by incorporating finer particles, e.g. by including finer ground limestone powder or ultra-pulverised fly ash, the viscosity and stability of the concrete gets increased and the production of SCC is met at satisfactory properties at a lower total powder content.

1.2.4.4 Admixtures

With the widespread availability of superplasticisers in the 1970's, the introduction and use of flowing concrete became a reality, which, in turn had significant advantages in many production situations [12]. With the development of SCC, the superplasticiser technology was exploited to a great extent, melamine formaldehyde and naphthalene formaldehyde-based materials were initially used. These materials very often experienced compatibility problems with cements such as workability retention, despite being successful to an extent.

The introduction of polycaboxylic ether (PCE)-based admixtures paved the way for an improved and consistent performance of SCC. The flexibility of their chemical structure is listed as being a distinctive advantage and because of this they their properties can be tailored to overcome compatibility issues and to meet the varying needs of SCC for different applications. They achieve dispersion in two ways. First, like other types of plasticisers and superplasticisers, they cling to the cement particles imparting a negative surface charge thus causing electrostatic and deflocculation, hence releasing water for increased mobility. In addition to this, their molecule-backbones have side chains of different lengths which physically keep the cement particles apart from each other thus allowing water to surround more of their surface area. This mechanism is known as steric hindrance or steric repulsion. Admixtures of this type are nowadays a preferred option and many products are now marketed as being particularly suitable for SCC.

1.2.4.5 Viscosity modifying agents

In order to improve the stability and robustness of SCC, the incorporation of viscosity modifying agents comes in handy. Viscosity modifying agents (VMA's) reduce the sensitivity of SCC to variations in the constituent materials, particularly the moisture content of the aggregate, thereby making SCC more robust.

VMA's can increase both the yield stress and plastic viscosity of the concrete and thus an increase in the dosage of the superplasticiser to offset the increase in yield stress may be required. Mixes incorporating VMA's can exhibit shear thinning, which can enhance flow during placement and thixotropy which enhances the stability at rest after placing.

1.2.4.6 Other admixtures

As with the traditional concrete, other admixtures are sometimes used to improve a variety of other properties, but in some cases these can also have an effect on the fresh properties of SCC. For instance, air-entraining agents will increase the frosh resistance of the hardened concrete, but will also contribute to the paste volume and modify its rheology, both of which can be of benefit. If more than one admixture is used, then compatibility is necessarily to be taken into account.

1.2.5 Properties of fresh self-compacting concrete

There are three key properties of fresh SCC:

- Filling ability
- Passing ability
- Segregation resistance

Requisite levels of all the three properties must be reached for fresh SCC in order to be self-compacting and to remain so while transporting and placing by selected means and in given conditions.

1.2.5.1 Filling ability

It is the ability of the fresh mix to flow under its own weight and completely fill all the spaces that are there in the formwork. Referred to as 'flow' or 'fluidity', it indicates how far a fresh mix might flow and how well it would fill the formwork and spaces of varying degrees of complexity. The filling ability is a governing factor for the self-compaction of SCC. The filling ability must be high enough and fluid enough to permit any air introduced during the mixing process, or trapped during placing, to escape and leave behind an adequately compact concrete.

1.2.5.2 Passing ability

The passing ability establishes how well the fresh mix can flow through the confined spaces, narrow openings and between the reinforcement. Determination of passing ability helps to evaluate the level of risk that the flow of the fresh mix will be impaired or even fully blocked by coarse aggregate, which will become wedged or form arches between bars or within narrow passages or openings.

Passing ability is linked to filling ability. It becomes necessary for the coarse aggregates to rearrange their positions within the mix, maintain a level of separation and not converge, interlock and block the gaps so that the concrete can pass freely through reinforcement. In order to be adequately self-compacting, for a fresh mix, it is needed to have a good filling and passing ability.

1.2.5.3 Segregation resistance

The phenomenon of segregation is related to the plastic viscosity and density of cement paste within fresh concrete. It is linked to two assumptions: a solid which is denser than a liquid has a tendency to sink and a viscous liquid flows with difficulty around a solid. Both these assumptions hold a significance in the case of fresh SCC. Segregation is likely to occur if the density of the aggregate is greater than that of the cement paste and viscosity of the paste is low.

Segregation resistance of the fresh mix is its ability to maintain the original (throughout uniform) distribution of its constituent materials during transportation, placing and compaction. An SCC mix possessing adequate filling and passing abilities can still segregate. However, it is unlikely to show in the usual form of honeycombed or uncompacted hardened concrete. There are possibilities of a fresh mix segregating while remaining basically self-compacting which suggests that the effects of this segregation on the fundamental properties of hardened concrete may be less serious than generally expected. In the cases of segregation that are not very severe, the high degree of compaction in good SCC is likely to mitigate the effects of the non-uniform distribution of aggregate on the strength and durability of the concrete, particularly when the strength of the paste/mortar is relatively high. Other properties which may characterise an SCC mix further and may be required for a given application include *flow-rate, pumpability, finishability, self-levelling and washout resistance.*

1.2.6 Tests for key properties of fresh self-compacting concrete

EFNARC 2005 [10] gives a list of the tests that can be conducted on fresh SCC to evaluate its workability. They are summarized below in Table 1.1.

Table 1.1: Tests for fresh properties of Self-compacting concrete [10]

Characteristic	Test Method	Measured value
Flowability/Filling ability	Slump flow	Total spread
	Kajima box	Visual filling
Viscosity/Flowability	T_{500}	Flow time
	V-funnel	Flow time
	O-funnel	Flow time
	Orimet	Flow time
Passing ability	L-box	Passing ratio
	U-box	Height difference
	J-ring	Step height, total flow
	Kajima box	Visual passing ability
Segregation resistance	Penetration	Depth
	Sieve segregation	Percent Laitance
	Settlement column	Segregation ratio

A brief description of some of the commonly done tests on fresh SCC is given below.

1.2.6.1 Slump-flow

The slump flow test was developed from the commonly used slump test, mainly used for traditional concrete. Initially used for high workability under water concretes that showed a collapsed slump, it was used for all SCC. This test allows a concrete mix to spread in all directions on a horizontal plane unlike the traditional concrete where there is a settlement in the vertical direction after the removal of the truncated cone mould. The test, hence, gives a measure of unconfined horizontal spread of the sample or mix.

In addition to this, the *flow rate* of concrete mix can also be measured which has been of great interest to the researchers. This is simultaneously determined when the slump-flow test is conducted. Flow rate is expressed as the time taken by the concrete mix from the moment the mould is lifted to the flowing concrete reaching a circle of 500 mm in diameter, concentric with the position of the mould. It is often referred to as T_{500}.

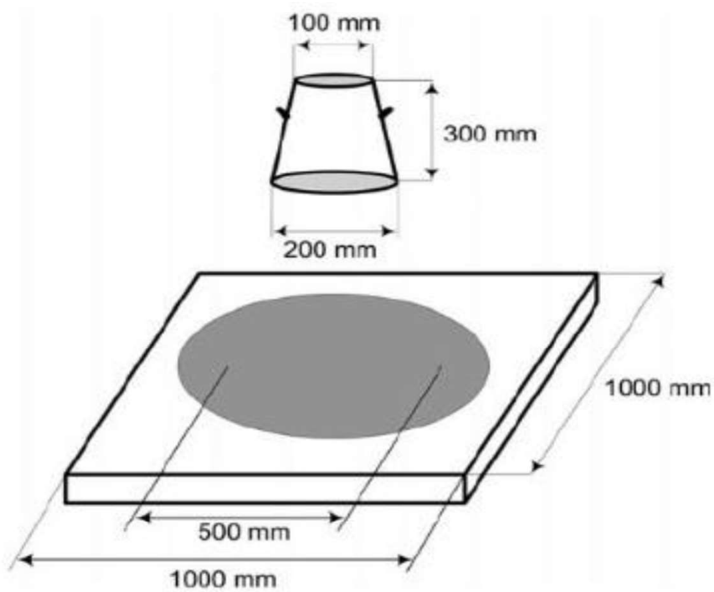
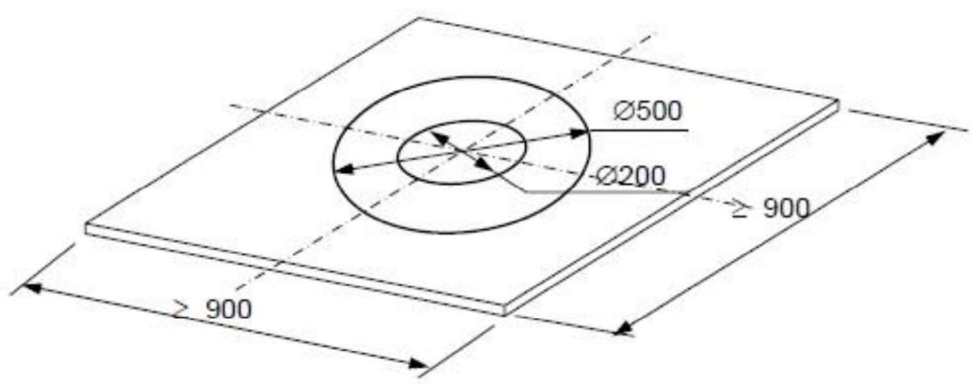


Fig. 1.1 (a) Slump flow test apparatus (Source: www.researchgate.net)



(b) Baseplate reference (EFNARC 2005 [10])

EFNARC 2005 gives the following slump-flow classes for a range of applications. They are listed in Table 1.2.

Table 1.2: Slump-flow classes for SCC [10]

Slump-flow class	Flow range	Appropriate for
SF1	550 – 650 mm	Unreinforced or slightly reinforced concrete structures and sections small enough to prevent long horizontal flow (e.g. piles and deep foundations)
SF2	660 – 750 mm	Normal applications e.g. walls, columns
SF3	760 – 850 mm	Structures with complex shapes

1.2.6.2 Orimet test

This test was developed in the early 1970's by Bartos [13] as a practical method for rapid assessment of high workability fresh concrete mixes on construction sites. It is based on the principle of an orifice rheometer and gives us an idea of the filling ability (fluidity) of fresh concrete. It also measures the flow-rate as the Orimet flow time t_0 (sec), which is the time taken for a concrete mix to flow out through the orifice. The apparatus is also applicable for mortars and grouts, using orifices of appropriately reduced diameters.

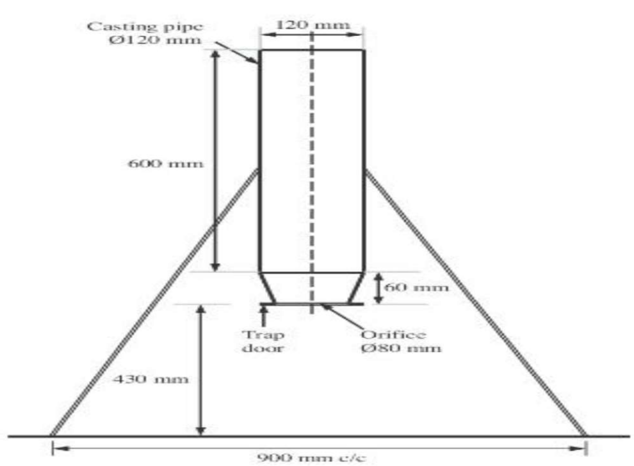


Fig. 1.2 Orimet test apparatus (Source: www.researchgate.net)

1.2.6.3 V-funnel test

This test was first used by Ozawa *et al.* in Japan to assess the viscosity of SCC [14]. It follows the principle of the Orimet, the only difference lying in the shape and size of the test device. The funnel uses a tapered container which ends in a short length of a pipe of rectangular cross section at the bottom unlike the Orimet test, where the sample of fresh concrete is held in a length of a straight casting pipe. The result is expressed as the time taken by the fresh concrete sample to completely pass from top of the funnel to the bottom of the funnel. It is expressed as t_v (sec).

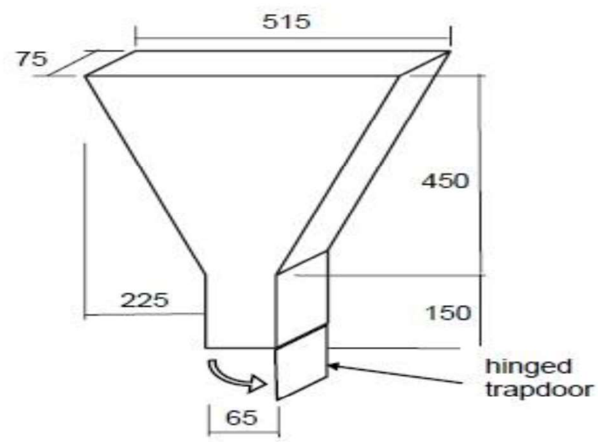


Fig. 1.3 V-funnel apparatus (EFNARC 2005 [10])

EFNARC 2005 gives the following viscosity classes with specific properties. They are listed in Table 1.3.

Table 1.3: Viscosity classes for SCC [10]

Class	T_{500}	V-funnel time	Property
VS1/VF1	≤ 2 s	≤ 8 s	Good filling ability even with congested reinforcement
VS2/VF2	>2 s	9 to 25 s	Exhibits thixotropic effects with increasing flow time

VS1/VS2 is viscosity class expressed by T_{500} and VF2/VF2is viscosity class expressed by V-funnel time.

1.2.6.4 J-ring test

The exact origin of this test is unknown, however, Bartos et al. developed the practical form of the test at the ACM Centre in Paisley [15], which is now widely used. The test primarily measures the passing ability and the filling ability of the fresh concrete sample, however, flow-rate can also be measured additionally. Fresh concrete sample is first confined by a circular arrangement of bars and then allowed to flow/spread in all directions. The final measured diameter is an indication of the flowability of fresh concrete under its own weight through obstructions (reinforcing bars)

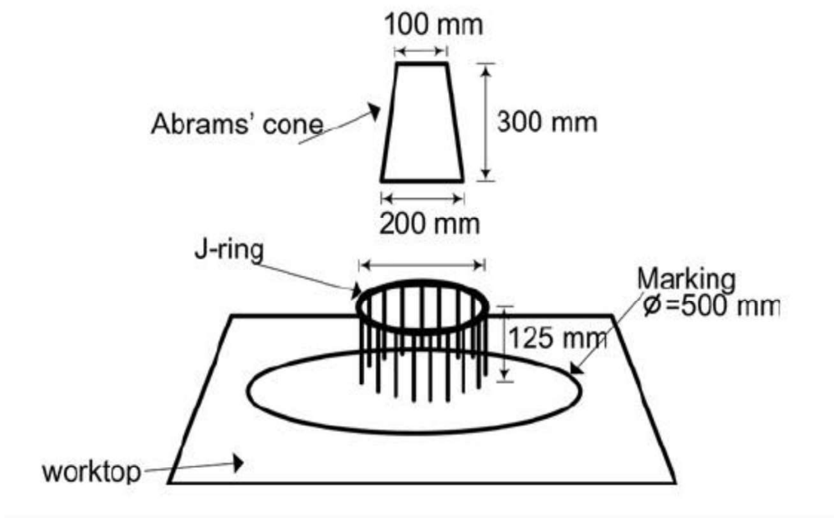


Fig. 1.4 J-ring test apparatus (Source: www.researchgate.net)

1.2.6.5 L-box test

This test was originally developed to assess the fluidity of a fresh underwater concrete mix by measuring the distance it could flow under its own weight without passing through any reinforcement. It aimed to measure the consistence of concrete during a partially confined (trough) flow. Later, it was developed further to include the passing ability of SCC, which has now become its primary application.

Additionally, the speed of flow of the fresh concrete sample can also be assessed. For this, the time taken by the sample to flow from the separating gate to either the end of the trough or specific distance (e.g. 400 mm) along its length is measured.

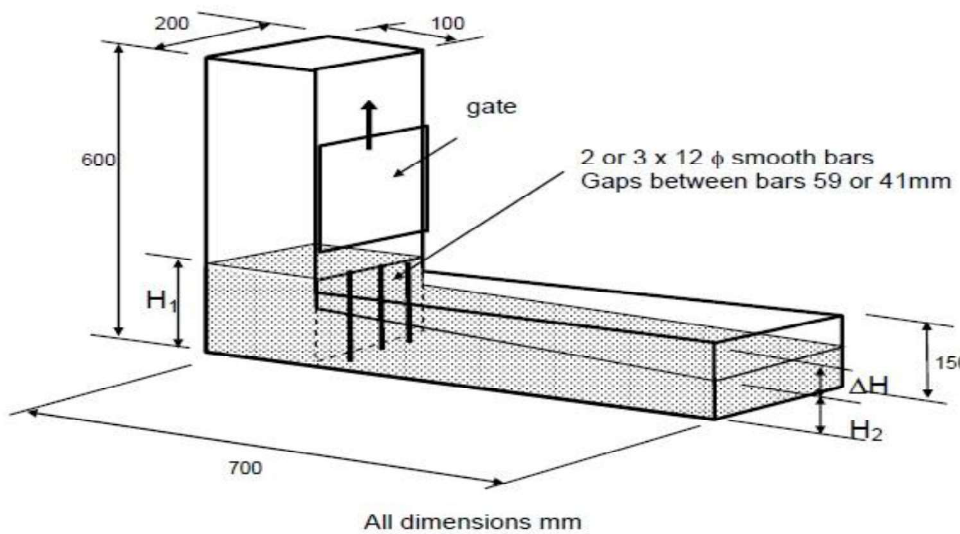


Fig. 1.5 General assembly of L-box (EFNARC 2005 [10])

EFNARC 2005 gives the following passing ability classes along with their specifications. They are given in Table 1.4 below.

Table 1.4: Passing ability classes for SCC [10]

Class	Passing ability	Specifications
PA1	≥ 0.80 with 2 rebars	Structures with a gap of 80 mm to 100 mm, e.g. housing, vertical structures
PA2	≥ 0.80 with 3 rebars	Structures with a gap of 60 mm to 80 mm, e.g. civil engineering structures

1.2.6.6 Sieve segregation test

This test was developed in France in the late 1990's by Cussigh [16] as a simple on-site method of quantitatively evaluating the resistance of SCC (in fresh state) to static segregation. Also known as the 'wet sieve segregation test' or 'screen stability test', this test is based on the principle of measuring how much separation occurs between the coarse aggregates and mortar in a sample of fresh concrete. The idea is to quantify the possibility of segregation by settlement/separation of coarse aggregate in an SCC mix.

Fig.1.6 Sieve segregation test (EFNARC 2005 [10])

EFNARC 2005 gives the segregation resistance classes (sieve segregation) and their applications. They are given in Table 1.5 below.

Table 1.5: Segregation resistance classes for SCC [10]

Class	Segregation resistance	Appropriate for
SR1	≤ 20%	Thin slabs and for vertical applications with a flow distance of less than 5 metres and a confinement gap greater than 80 mm
SR2	≤ 15%	Vertical applications if the flow distance is more than 5 metres with a confinement gap greater than 80 mm in order to take care of segregation during flow.

1.2.6.7 Settlement column segregation test

This test was developed independently by Poppe and De Schutter at the Magnel Centre of the University of Ghent, Belgium [17] and by Rooney at the ACM Centre in the University of Paisley, Scotland [18] in the late 1990's. It is the only test that assesses both static and dynamic segregation. The difference between the aggregate content at the top and bottom of the settlement column gives a segregation column ratio (SCR) which provides an idea of the susceptibility of the mix to segregation.

Fig.1.7 Settlement column segregation test (Source: www.researchgate.net)

1.2.6.8 Penetration test for segregation

This test was developed by Van et al. [19]. It detects a change in resistance against penetration of a suitable tool into fresh concrete, which is cause by the change in the concentration of the coarse aggregate in the upper layer of the concrete. Such a change in concentration of aggregate gives an idea of its settlement; it is a case of static segregation. The test is suitable for a rapid in-situ assessment of the static segregation resistance of fresh SCC.

Fig.1.8 Penetration test apparatus (Source: www.researchgate.net)

1.2.6.9 Other tests

(i) O-funnel test

This test was originally developed in Japan [15]. It is very similar to the V-funnel test and is closely related to the Orimet test. It is not in much use nowadays except for use as a proprietary product-linked test.

(ii) U-box test

This test was originally developed as an in-house test by a contractor in Japan [15]. It assesses the passing ability of the fresh concrete sample and is related to the L-box test. The result is expressed as a ratio between the level/height of concrete in the adjoining columns. The passing ability is highest when the levels in both the columns are same (provided there is no blocking).

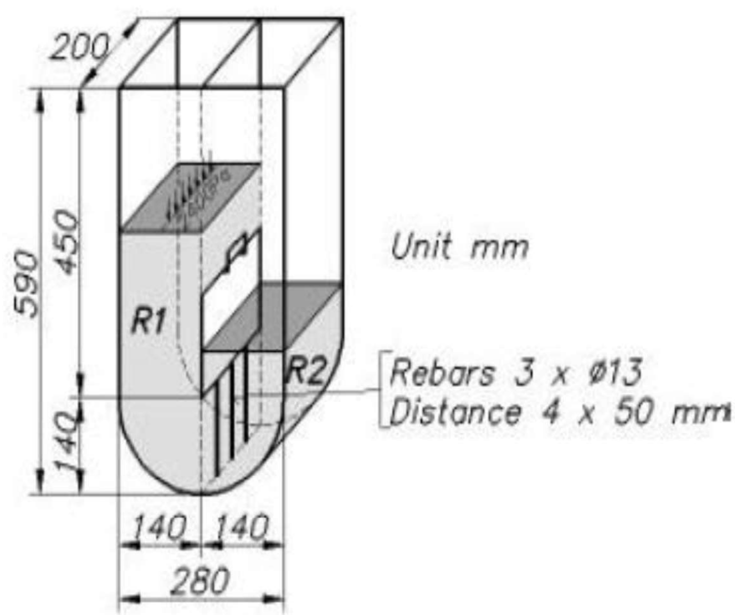


Fig.1.9 U-box apparatus (EFNARC 2002 [20])

Requisite levels of all the three key properties must be reached for a fresh concrete mix to be called as self-compacting. The acceptance/conformity criteria for properties of SCC as per EFNARC 2005 [10] is summarized in Table 1.6.

Table 1.6: Acceptance criteria for fresh properties of SCC [10]

Property	Criteria
Slump-flow class SF1	≥ 520 mm, ≤ 700 mm
Slump-flow class SF2	≥ 640 mm, ≤ 800 mm
Slump-flow class SF3	≥ 740 mm, ≤ 900 mm
Slump-flow class specified as target value	± 80 mm of target value
V-funnel class VF1	≤ 10 s
V-funnel class VF2	≥ 7s, ≤ 27s
V-funnel specified as a target value	± 3s
L-box class PA1	≥ 0.75
L-box class PA2	≥ 0.75
L-box specified as a target value	Not more than 0.05 below the target value
Sieve segregation resistance class SR1	≤ 23
Sieve segregation resistance class SR2	≤ 18

1.2.7 Advantages and disadvantages of self-compacting concrete

1.2.7.1 Advantages

SCC has numerous advantages, few of them are listed below:

- No vibration of fresh concrete is required .
- High quality and durability of concrete.
- Particularly suitable for complex forms, geometries and dense reinforcements.
- Easy and environment friendly placement of concrete.
- Number of workers required on construction site is reduced.
- Safer and healthier working environment is created.
- Faster speed of construction.
- Reduced noise generated by vibrators.

1.2.7.2 Disadvantages

- Higher cost of raw materials particularly due to high cementitious content and use of admixtures.
- Higher formwork costs owing to higher formwork pressure.
- Requires technical expertise to develop the mixes properly.
- Increased quality control requirements.
- Delayed setting time in few cases owing to the use of superplasticizers.
- Increased number of trial batches both at laboratory and sites.

1.3 BAGASSE ASH

By-products from various industrial processes are utilised as supplementary cementitious materials in concrete to lower the cement content and thus achieve durable and sustainable concrete. Researchers nowadays focus on ways of incorporating either industrial or agricultural wastes in concrete as a source of raw materials. Agro wastes such as rice husk ash, wheat straw ash, hazel nutshell and sugarcane bagasse ash are used as a pozzolanic material for the development of blended cements. The utilization of these wastes would not only prove to be economical, but also will help to create a sustainable and pollution free environment.

Sugarcane is one of the most important crops grown in more than 110 countries and its overall production amounts to more than 1500 million tons [21]. After the crushing of sugarcane in and extraction of juice from processed cane, the thrown-away fibrous matter (residue) amounting to about 40-45%, is called bagasse. Bagasse is utilised as a fuel in cogeneration boilers. The left-over residue (after burning) which is around 8-10%, namely bagasse ash, is collected using a baghouse filter. Bagasse ash is acquired as a by-product in large quantities (44,000 t/day) in India [22] as well as in other countries in the world known for sugar production and is dumped as a waste material, that renders the environment to severe problems. Bagasse ash disposal has become a matter of concern for sugar industries because of ever increasing land requirements and environmental restrictions.

Bagasse ash primarily consists of silica and can be utilised as a pozzolanic material in concrete. Raw bagasse ash has main component as silica (60–75%). CaO, K_2O, and other minor oxides viz. Al_2O_3, Fe_2O_3, and SO_3 are also present [23].

Thus, owing to the research findings and from the environmental constraints, Sugarcane Baggase ash, because of its good pozzolanic performance has been suggested as an excellent alternative cementitious material in concrete.

Fig.1.10 Bagasse obtained after crushing of sugarcane (Source: googleimages.com)

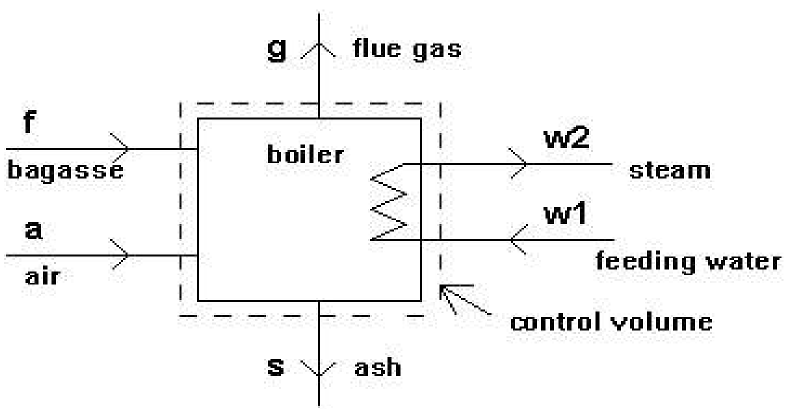


Fig.1.11 Process of bagasse ash production (Source: googleimages.com)

Fig. 1.12 Bagasse ash dumped in landfills (Source: sciencedirect.com)

1.3.1 Properties of bagasse ash

1.3.1.1 Physical properties

Typical physical properties of Bagasse ash are summarised in Table 1.7 below.

Table 1.7: Physical properties of Bagasse ash [24,25,26]

Property	Reported by			
	Amin [24]	Ganesan et. al. [25]	Rerkpiboon et. al. [26]	
			OBA	GBA
Density (g/cm^3)	0.4	0.59	-	
Specific gravity	1.8	1.85	1.92	2.27
Fineness passing 45 µm	95	99	-	-
Specific surface area (m^2/kg)	900	943	-	-
Mean grain size (µm)	5.1	5.40	-	-
Retained on a sieve No.325 (%)	-	-	65.73	0.42
Median particle size, d_{50}(µm)	-	-	-	5.68

OBA-Ordinary Bagasse ash; GBA-Ground Bagasse ash

1.3.1.2 Chemical Properties

Typical chemical properties of Bagasse ash are given in Table 1.8.

Table 1.8: Chemical properties of Bagasse ash [21, 22, 24, 25, 27]

Chemical Composition (%)	Reported by				
	Modani and Vyawahare [21]	Bahurudeen et. al. [22]	Amin [24]	Ganesan et. al. [25]	Akram et. al [27]
SiO_2	62.43	57.63	87.4	64.15	62.44
Al_2O_3	4.28	1.33	3.6	9.05	6.74
Fe_2O_3	6.98	1.50	4.9	5.52	5.77
CaO	11.8	6.14	2.56	8.14	6.16
MgO	2.51	1.56	0.69	2.85	2.97
Na_2O	-	0.22	0.15	0.92	3.15
K_2O	3.53	7.33	0.47	1.35	6.87
SO_3	1.48	3.52	0.11	-	0.72
LOI	4.73	21	8.25	4.90	2.58

1.3.2 Scanning electron microscope (SEM) images

Scanning electron microscope (SEM) images of Bagasse ash as reported by various researchers are given in Figures 1.13 and 1.14 below.

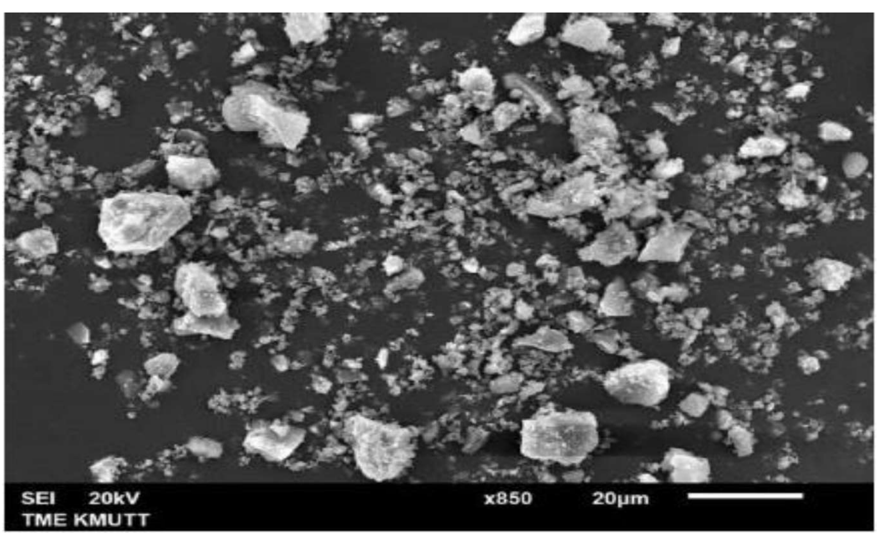


Fig. 1.13 SEM image of Ground Bagasse ash (Rerkpiboon et. al. [26])

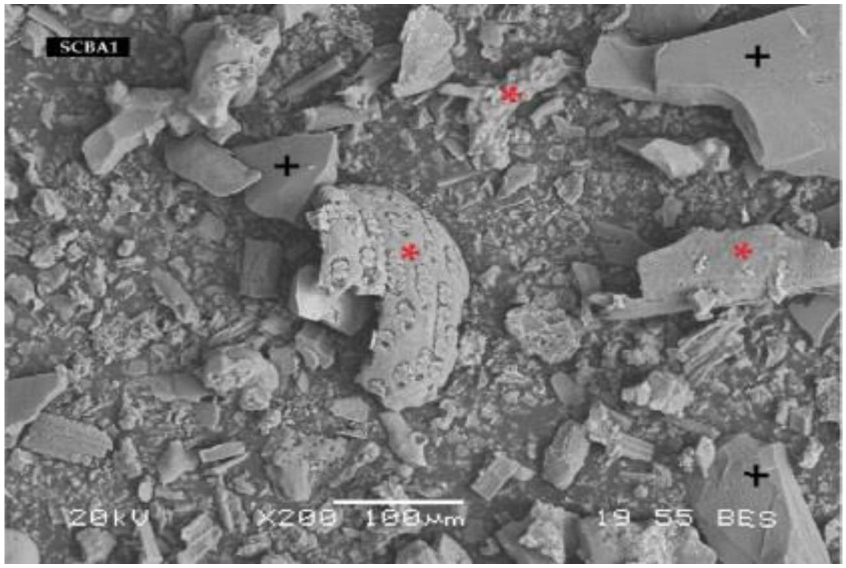


Fig.1.14 SEM image of Bagasse ash (Cordeiro et. al. [23])

1.3.3 X-ray diffraction (XRD) patterns

The X-ray diffraction patterns of Bagasse ash as studied by various researchers are given in figures 1.15 and 1.16 below.

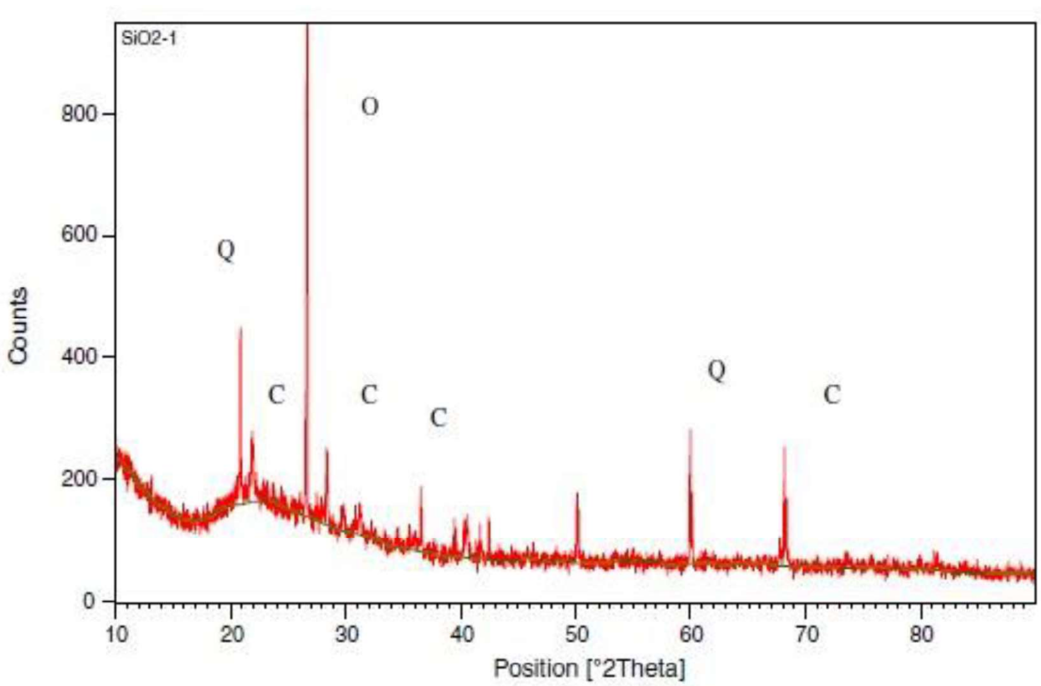


Fig. 1.15 X-ray diffraction analysis of Bagasse ash (Ganesan et. al. [25])

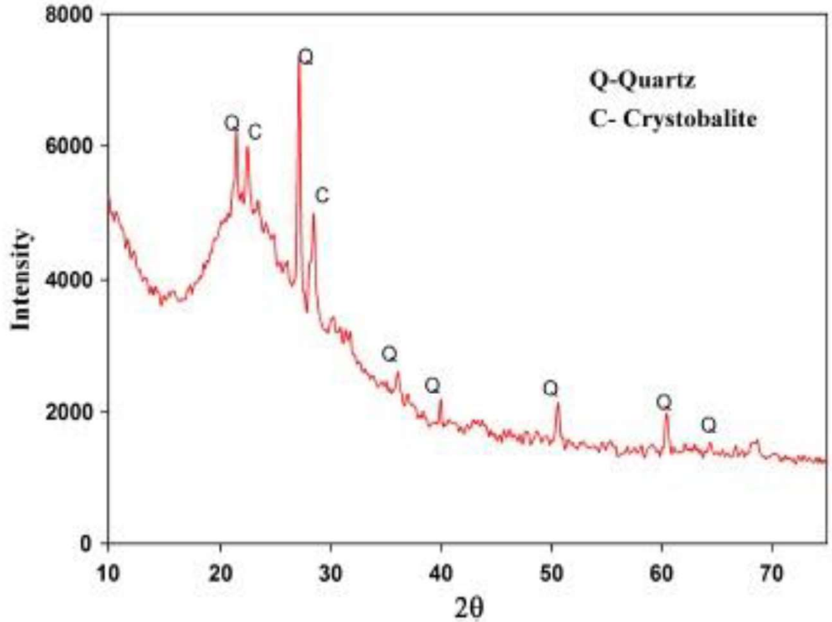


Fig.1.16 X-ray diffraction pattern of Bagasse ash (Bahurudeen et. al. [28])

1.3.4 Advantages of Bagasse ash

Some of the various advantages of Bagasse ash are listed below:

- Reduces negative environmental effect and landfill volume.
- Has high silica content.
- Has low specific gravity.
- Can be used as a farm fertilizer.
- Also suitable for making ceramic products.
- Increases workability of fresh concrete (increases viscosity in case of SCC).

1.4 ORIENTATION OF THESIS REPORT

This thesis is presented in five chapters as briefly described below:

Chapter-1 Presents an overview about Self-compacting concrete and Bagasse ash

Chapter-2 Literature review presents the work done by a few researchers in the field of Self-compacting concrete with Bagasse ash and normal concrete with Bagasse ash.

Chapter-3 Details the scheme of experimentation, materials used along with their properties, mix proportions, casting of specimens for studying mechanical and durability properties and methodology adopted for the testing of different properties.

Chapter-4 Presents the results and their analysis for the fresh properties (Slump-flow, V-funnel and L-box), strength properties viz. compressive strength and splitting tensile strength, durability properties viz. Water absorption and Chloride-ion penetration resistance of the SCC mixes incorporating Bagasse ash, which are then compared with the control mix.

Chapter-5 Summarises the major conclusions made in the study.

References

1.5 CLOSING REMARKS

This chapter presented an overview of Self-compacting concrete and Bagasse ash. SCC was introduced with its brief history, constituent materials and tests for fresh properties were also briefed. Properties of Bagasse ash along with its advantages were also summarised. The next chapter discusses about the literature pertaining to the field of Self-compacting concrete with Bagasse ash and normal concrete with Bagasse ash.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Self-compacting concrete is an engineered concrete that flows and de-airs with additional energy input. It fills and envelops even the sophisticated forms of reinforcement. It has numerous advantages over the traditional concrete and thus has gained significant importance over the past few decades. It facilitates and ensures proper filling and satisfactory structural performance of restricted areas and structural members that are heavily reinforced. Such concrete requires a high slump which can be achieved by the addition of superplasticizers to the concrete mix. However, special attention needs to be paid to the mix proportioning.

Owing to the increasing amount of waste materials and industrial by-products produced, solid waste management has become a vital concern in the present day world. Due to the scarcity of land-filling space because of its increasing cost, recycling and utilising the waste materials and the industrial by-products becomes the way out. Incorporating such waste materials and industrial by-products is not economical but also addresses disposal concerns to a great extent. Bagasse ash is one such Agro waste which has been used in concrete mostly as a replacement of cement. Researchers have found optimum percentages of Bagasse ash to be used in concrete so that the strength is not compromised.

This chapter discusses the literature related to the use of Bagasse ash in Self-compacting concrete and traditional concrete and other by-products as replacement of cement in Self-compacting concrete.

2.2 EFFECT OF BAGASSE ASH ON FRESH PROPERTIES OF SCC

Akram et al. (2009) [27] studied the making of low cost Self Compacting concrete incorporating bagasse ash. The research assessed the utilization of bagasse ash as viscosity modifying agent in Self Compacting concrete, and studied the relative costs of the materials utilised in Self Compacting concrete. The primary variables were the content of bagasse ash, dosage of superplasticizer and water/binder ratio. Cement and water content were kept as fixed parameters. The dosage of superplasticizer ranged from 2 % to 4 % by weight of binder content.

Slump flow test results for all of the control mixes were as per EFNARC range of SCC, whereas, for SCC mixes incorporating bagasse ash, the value of slump flow was between 333 mm and 815 mm, which went beyond the minimum and maximum range. The results indicated that the flow increased as the superplasticizer dosage was increased. However, the flow decreased proportionally when the bagasse ash quantity was increased. Slump flow test results are shown in Figure 2.1.

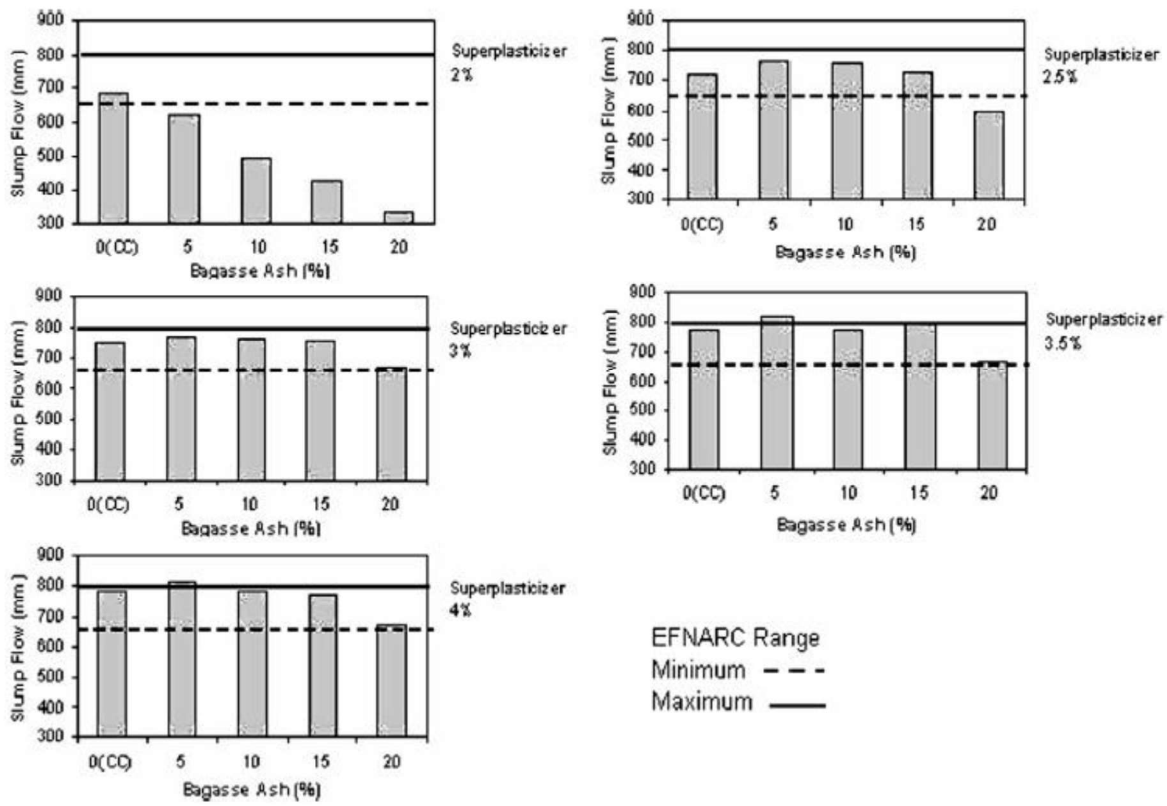


Fig. 2.1 Bagasse ash vs. slump with different percentage of superplasticizer (Akram et al. [27])

L-box test results indicated that the L-box ratio increased with the increase in dosage of superplasticizer. However, the ratio decreased proportionally with the increased quantity of bagasse ash. All the values obtained were from 0 to 1 and are shown in Figure 2.2.

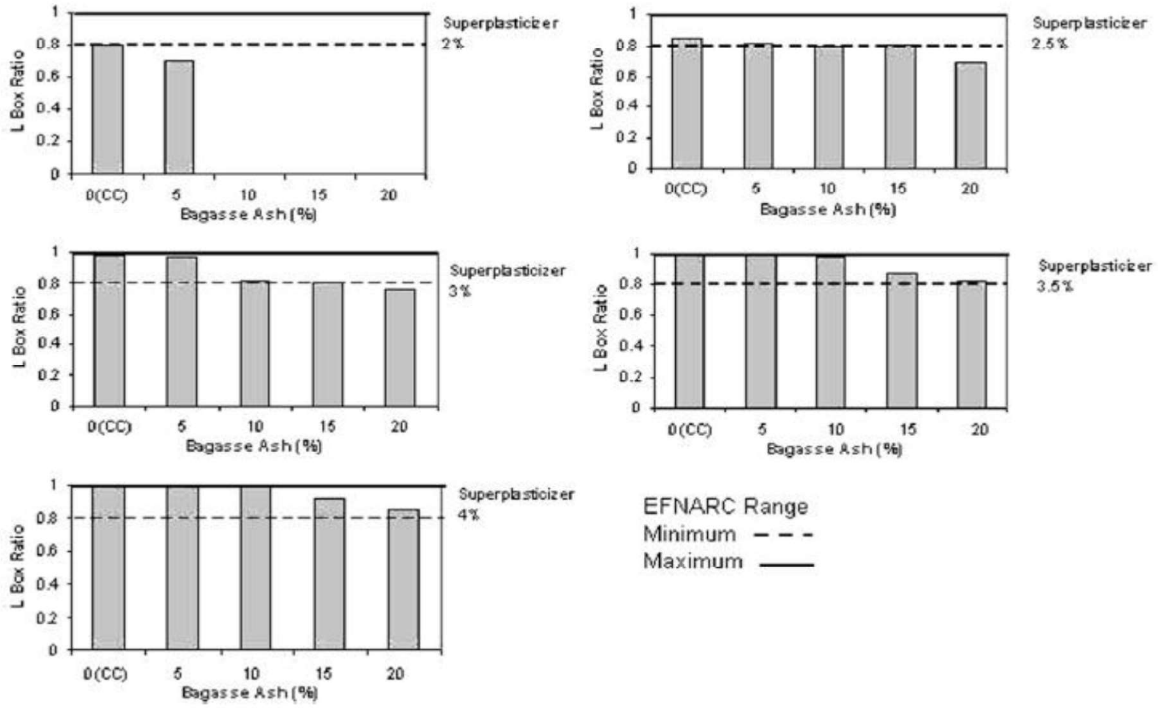


Fig. 2.2 Bagasse ash vs. L-box ratio with different percentage of superplasticizer (Akram et al. [27])

V-funnel test results were mostly more towards the minimum range which depicted more filling ability but lesser viscous mix. With the increase in the quantity of bagasse ash, the viscosity of the mix started increasing. V-funnel test results are shown in Figure 2.3.

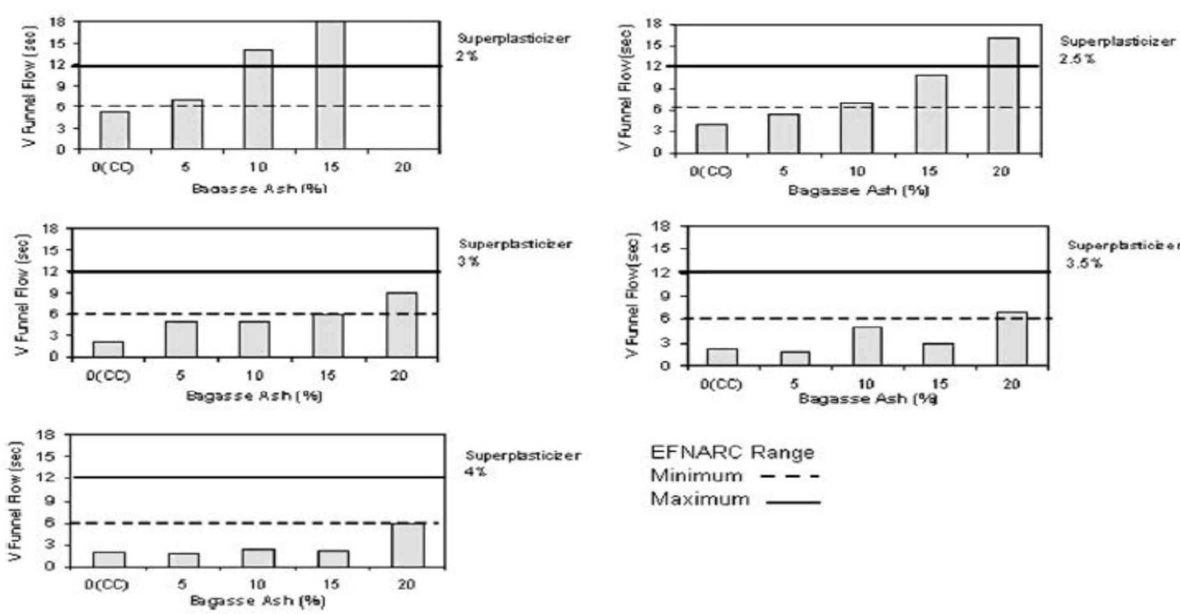


Fig. 2.3 Bagasse ash vs. V-funnel flow with different percentage of superplasticizer (Akram et al. [27])

Chopra et al. (2015) [29] reported the effect of Rice husk ash (RHA) as replacement of cement in self-compacting concrete. The percentages replaced were kept as 10, 15 and 20 %. 20 % RHA replacement had the lowest workability. Superplasticizer dosage was kept from 0.8 to 1.5 % and w/b ratio from 0.35 to 0.45. The mix with 1 % superplasticizer dosage and 0.41 as w/b ratio gave the optimum result. All the fresh properties were as per the range specified by the European guidelines. The workability decreased with the increase in RHA content. 20 % RHA mix had the lowest workability. The results are given in Table 2.1 below.

Table 2.1 Fresh concrete properties for mixes with and without rice husk ash

Type of test	RHA (%)				
	Range (EFNARC,2002)	0 %	10 %	15 %	20 %
Slump-flow (mm)	650 – 800	730	700	670	600
V-funnel (sec)	6 – 12	6	8	11	13
L-box (H_2/H_1)	0.8 – 1	1	0.9	0.8	Blocking
U-flow (H_2-H_1)	0 – 30	5	18	25	30

2.3 EFFECT OF BAGASSE ASH ON WORKABILITY OF NORMAL CONCRETE

Chusilp et al. (2009) [30] examined the physical properties of concrete incorporating Bagasse ash. The properties examined were compressive strength, water permeability and heat evolution. Type 1 Portland cement was replaced by using bagasse ash. The replacement level was kept as 10, 20 and 30 % by weight of binder. Slump values for the control mix, mix with 10, 20 and 30 % replacement was 150 mm, 160 mm, 180 mm and 190 mm respectively. All the slump values were between 150 and 200 mm. The control mix did not require any superplasticizer for the slump to be in the specified range. However, the concrete mixes containing 10, 20 and 30 % ground bagasse ash by weight of binder required 3.15, 5.25 and 7.35 kg/m^3 of superplasticizer, respectively.

Rerkpiboon et al. (2015) [26] investigated the strength and durability properties of concrete that contained up to 50% ground bagasse ash (GBA) as a replacement of ordinary Portland cement (OPC) by weight of binder. The superplasticizer used in the study was aimed at to control the slump of fresh concrete ranging between 50 and 100 mm.

The slump values of all the mixes ranged between 70 and 95 mm. The value of slump for control mix, mix containing 30 % and 40 % bagasse ash replacement was 70 mm. Mixes with 10 and 20 % bagasse ash replacement had slump value of 90 mm and the mix with 50 % bagasse ash replacement had slump value of 95 mm. The superplasticizer dosage for the mixes with 10, 20, 30, 40 and 50 % replacement by bagasse ash was kept as 0.4, 0.7, 1.0, 1.4 and 2.0 % by weight of binder respectively.

2.4 EFFECT ON COMPRESSIVE STRENGTH

Ganesan et al. (2007) [25] investigated the effect of Bagasse ash on physical and mechanical properties of hardened concrete. Cement was partially replaced by bagasse ash. A total of 7 mix proportions (with bagasse ash varying from 5% to 30% by weight of cement), the control mix included, were prepared. The water binder ratio was kept fixed at 0.53 and the design cube compressive strength was 25 MPa.

The compressive strength variation of the specimens at 7, 14, 28 and 90 days of curing is shown in Figure 2.4 below.

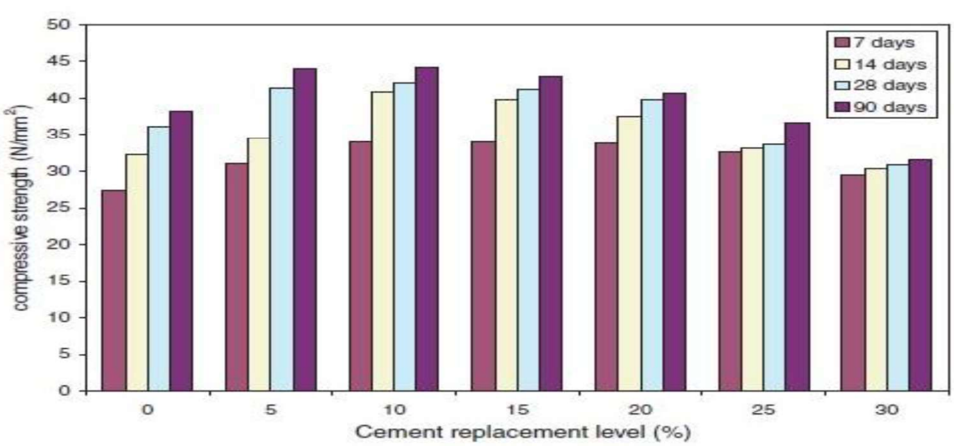


Fig. 2.4 Compressive strength of Bagasse ash blended concretes (Ganesan et al. [25])

It can be concluded from the above figure that there is an increase in the compressive strength up to 20% cement replacement, the reason being attributed to the silica content, fineness, amorphous phase, specific surface area and degree of reactivity of Bagasse ash.

Akram et al. (2009) [27] studied the making of low cost Self Compacting concrete incorporating bagasse ash. The research assessed the utilization of bagasse ash as viscosity modifying agent in Self Compacting concrete, and studied the relative costs of the materials used in Self Compacting concrete. Only five mixes out of twenty five different mixes met the specified criteria as suggested by EFNARC for making self-compacting concrete.

The compressive strength of all the twenty five mixes for 7 and 28 days are shown in Figs. 2.5 and 2.6.

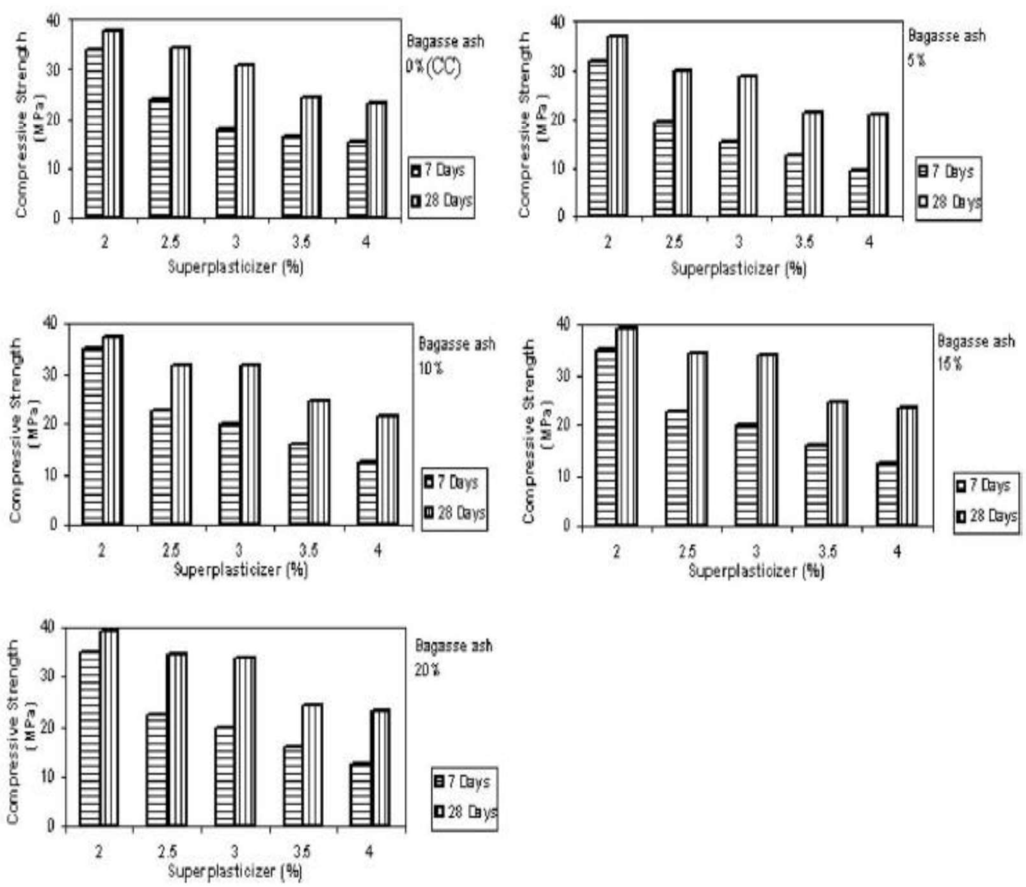


Fig. 2.5 Superplasticizer vs. Compressive strength with different percentage of bagasse ash (Akram et al. [27])

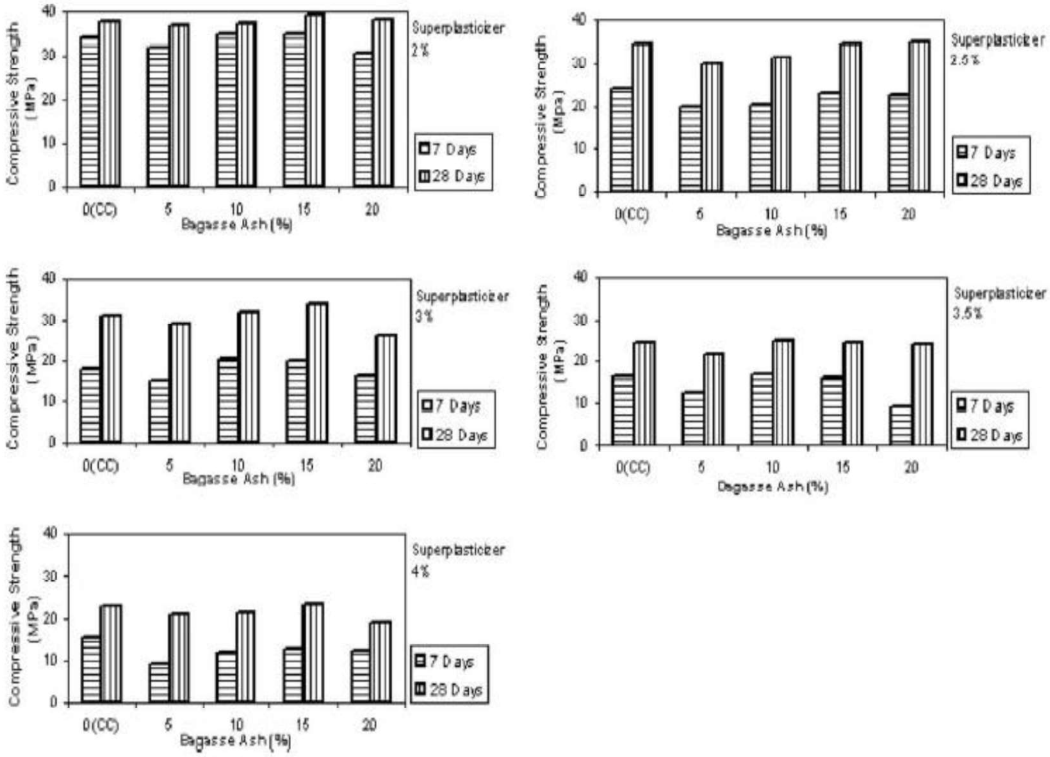


Fig. 2.6 Bagasse ash vs. Compressive strength with different percentage of superplasticizer (Akram et al. [27])

It is clear from Fig. 2.6 that the control concrete with 2 % superplasticizer dosage had the highest compressive strength of 37.71 MPa at the age of 28 days among the five control concrete mixes. Only two mixes i.e., mix containing bagasse ash as 15 % replacement and 2 % superplasticizer dosage and mix containing bagasse ash as 20 % replacement and 2 % superplasticizer dosage showed higher strength than control concrete at 28 days (Fig. 2.6). Mix with bagasse ash as 20% replacement and 4 % superplasticizer dosage had the lowest strength of 19.03 MPa at 28 days. This reduction in strength was mainly attributed to higher dosage of superplasticizer.

Chusilp et al. (2009) [30] examined the physical properties of concrete incorporating Bagasse ash. The properties examined were compressive strength, water permeability and heat evolution. Type 1 Portland cement was replaced by using bagasse ash. The replacement level was kept as 10, 20 and 30 % by weight of binder. The compressive strength of the concrete specimens was found after 28 and 90 days of curing. The compressive strength of control concrete was 36.9 MPa at the age of 28 days which went up to 41.8 MPa after 90 days. Concrete specimens having 10%, 20% and 30% ground bagasse ash by weight of binder showed compressive strengths greater than the control concrete both at 28 days and 90 days. At 28 days, concrete specimens having 10%, 20% and 30% ground bagasse ash had compressive strengths of 38.2, 40.5 and 39.3 MPa respectively. At 90 days, concrete specimens having 10%, 20% and 30% ground bagasse ash had compressive strengths of 44.4, 47.4 and 45.0 MPa respectively. Thus, the optimal replacement level was 20% bagasse ash. The results depicted that bagasse ash is a good pozzolanic material.

Amin (2011) [24] investigated the use of bagasse ash as partial replacement of cement and reported its impact on physical and mechanical properties of hardened concrete. Seven mixes were totally prepared which included bagasse ash ranging from 5% to 30% as cement replacement. The water binder ratio was kept as 0.45 and the design cube compressive strength was 25 MPa.

The compressive strength of all the specimens at 3, 7 and 28 days is shown in Figure 2.7 below:

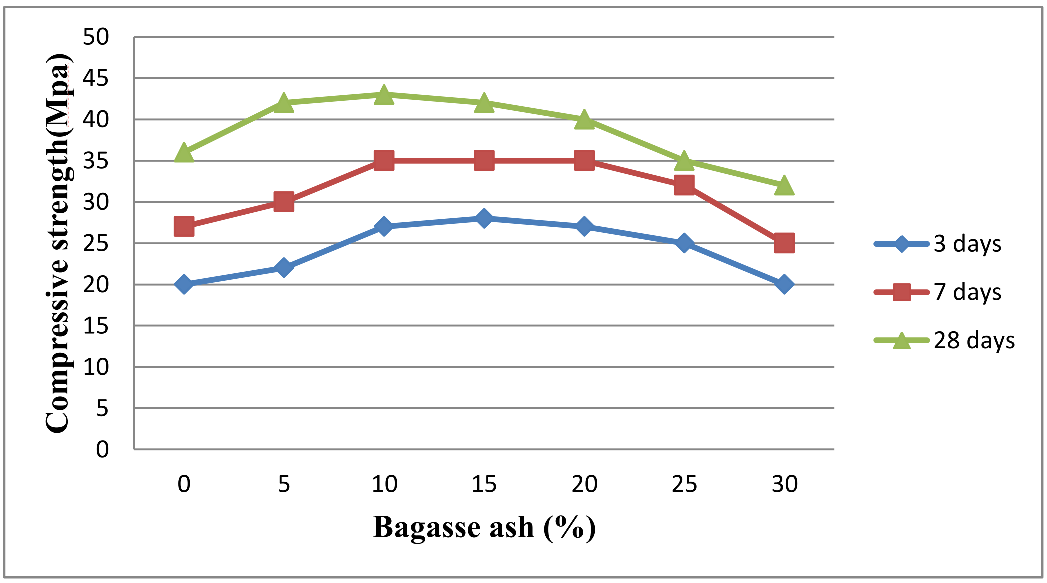


Fig. 2.7 % Bagasse ash Vs. Compressive strength (Amin [24])

From the above figure, it is clear that the compressive strength increases with increase in bagasse ash up to 10% and then slightly decreases up to 25% replacement level but the value is still greater than the control concrete. Hence, the optimal level of replacement is taken as 20%.

Chopra et al. (2015) [29] studied the effect of Rice husk ash (RHA) as replacement of cement in self-compacting concrete. The percentages replaced were kept as 10, 15 and 20 %. The compressive strength of the concrete specimens was evaluated after 7, 28 and 56 days of curing. The w/b ratio was kept fixed at 0.41 for all the mixes. Figure 2.8 shows the compressive strength variation of all the mixes.

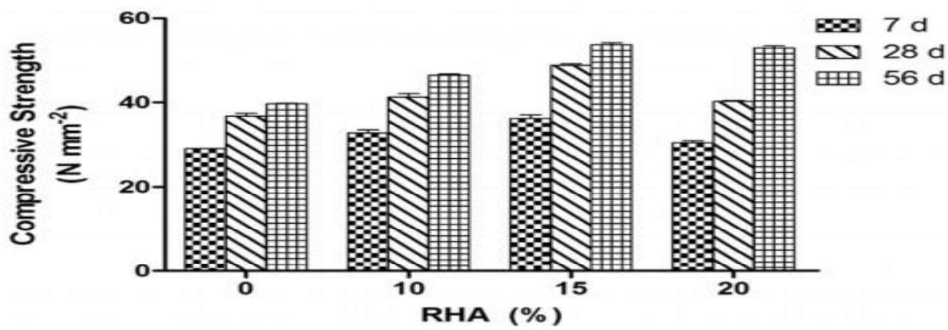


Fig. 2.8 Compressive strength of SCC at various ages (Chopra et al. [29])

From the figure above, it is evident that the compressive strength increases with the increase in percentage of RHA up to 15% RHA replacement. The strength decreases at 20% RHA replacement. The increase in compressive strength is mainly attributed to the micro-filling ability and pozzolanic activity of RHA.

Rerkpiboon et al. (2015) [26] investigated the strength and durability properties of concrete that contained up to 50% ground bagasse ash (GBA) as a replacement of ordinary Portland cement (OPC) by weight of binder. Replacement levels were 10, 20, 30, 40 and 50%. The compressive strength of the concrete specimens was found after 7, 28, 90 and 180 days of curing. Figure 2.9 shows the variation of compressive strengths of the specimens.

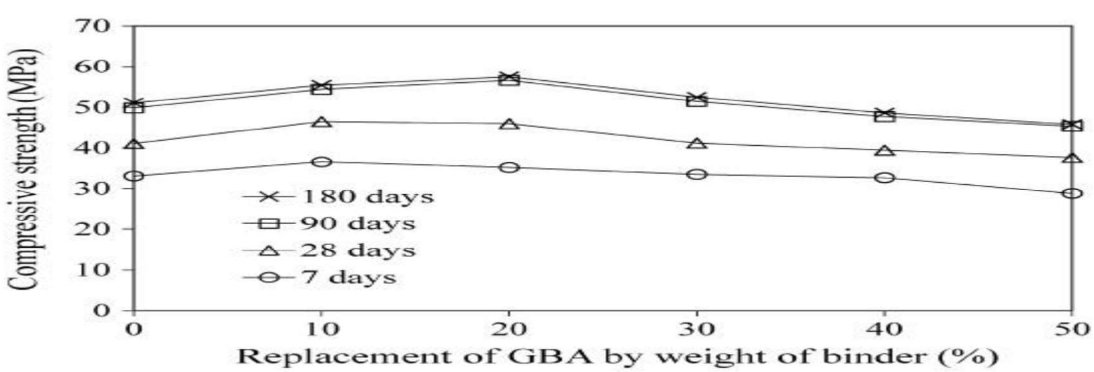


Fig. 2.9 Relationship between compressive strength and replacement of Bagasse ash (Rerkpiboon et al. [26])

It is clear from the figure that at 28 days, concrete with 10% replacement level had the highest compressive strength of 46.5 MPa. However, at the age of 90 and 180 days, concrete with 20% replacement level had the highest compressive strengths of 56.6 and 57.4 MPa, respectively. Thus, the optimal level of replacement to make the concrete with highest compressive strength was 20% by weight of binder.

2.5 EFFECT ON SPLITTING TENSILE STRENGTH

Ganesan et al. (2007) [25] investigated the effect of Bagasse ash on physical and mechanical properties of hardened concrete. Cement was partially replaced by bagasse ash. A total of 7 mix proportions (with bagasse ash varying from 5% to 30% by weight of cement), the control mix included, were prepared. Splitting tensile strength was found after 28 days of curing. Figure 2.10 shows the variation of splitting tensile strength with bagasse ash replacement levels.

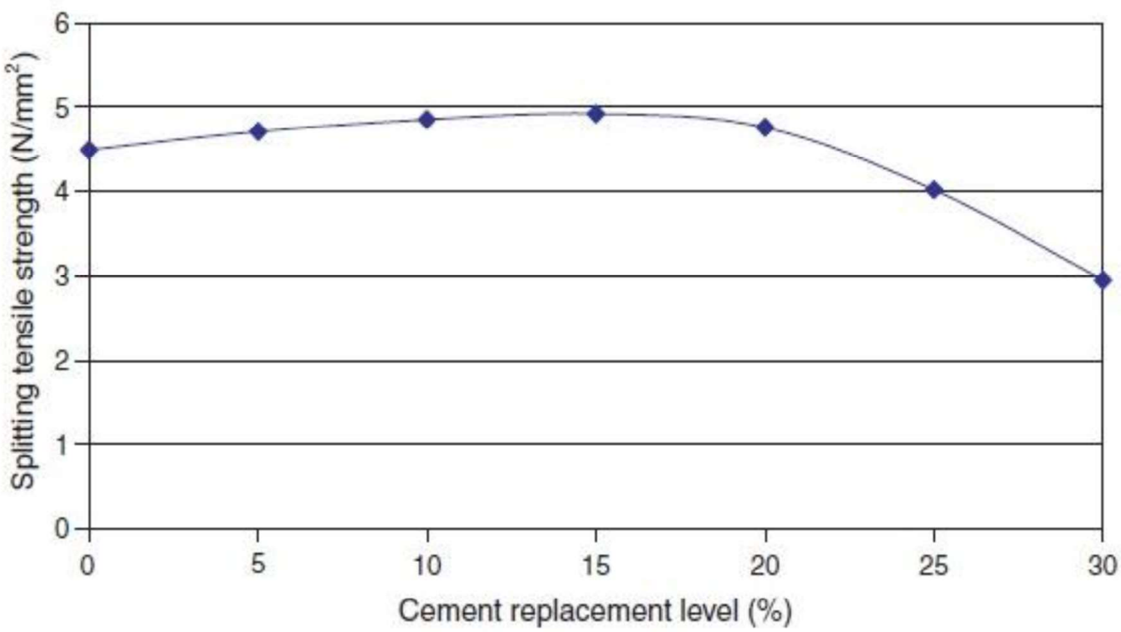


Fig. 2.10 Splitting tensile strength of Bagasse ash blended concretes (Ganesan et al. [25])

It can be clearly concluded from the above figure that the splitting tensile strength increases up to 20% replacement level and then decreases at 25% and 30% replacement levels. Thus, 20% replacement level of bagasse ash can be considered as the optimal limit.

Amin (2011) [24] investigated the use of bagasse ash as partial replacement of cement and reported its impact on physical and mechanical properties of hardened concrete.

Seven mixes were totally prepared which included bagasse ash varying from 5% to 30% as cement replacement. Splitting tensile strength of concrete specimens was found after 28 days of curing. Figure 2.11 shows the variation of splitting tensile strength with the replacement levels.

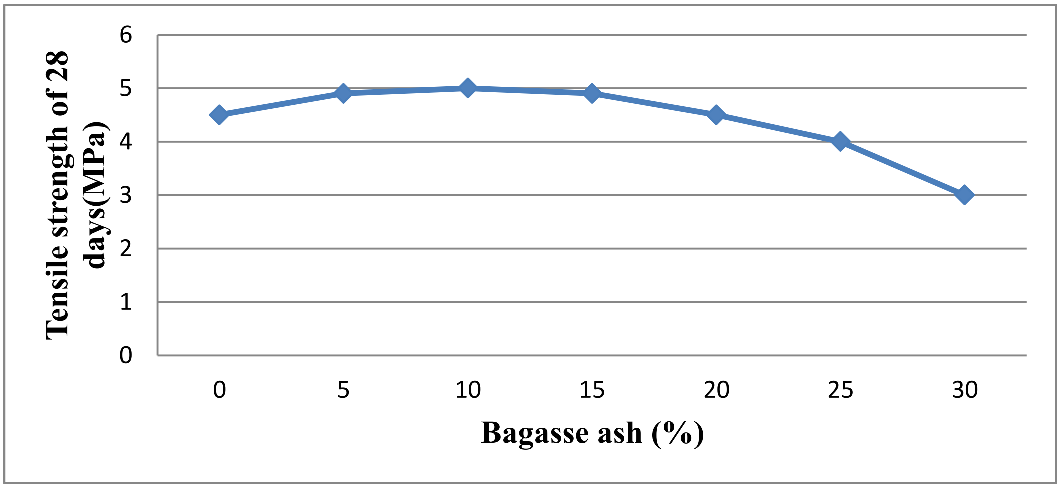


Fig. 2.11 28 days Split tensile strength (Amin [24])

From the above figure, it is evident that the splitting tensile strength increases up to 20% replacement level and then decreases at 25% and 30%. Hence, 20% of bagasse ash is considered to be the optimal limit.

Chopra et al. (2015) [29] examined the effect of Rice husk ash (RHA) as replacement of cement in self-compacting concrete. The percentages replaced were kept as 10, 15 and 20 %. The splitting tensile strength of the specimens was evaluated after 7, 28 and 56 days of curing. Figure 2.12 shows the variation of splitting tensile strength with the replacement level and curing age.

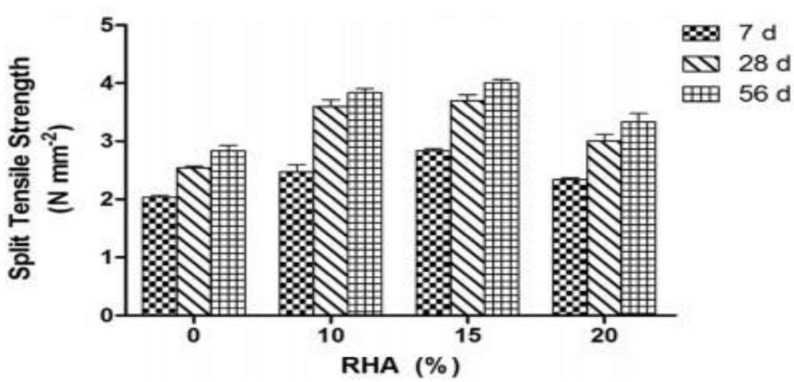


Fig. 2.12 Splitting tensile strength of SCC mixes at various ages (Chopra et al. [29])

It was noticed that the splitting tensile strength increased up to 15% RHA replacement and then decreased at 20%, but the value was still higher than the control mix.

2.6 EFFECT ON DURABILITY PROPERTIES

2.6.1 Chloride-ion penetration resistance

Ganesan et al. (2007) [25] investigated the effect of Bagasse ash on physical and mechanical properties of hardened concrete. Cement was partially replaced by bagasse ash. A total of 7 mix proportions (with bagasse ash ranging from 5% to 30% by weight of cement), the control mix included, were prepared. The resistance to chloride-ion penetration in terms of total charge passed through the bagasse ash blended specimens was measured after 28 and 90 days of moist curing. Figure 2.13 shows the RCPT results.

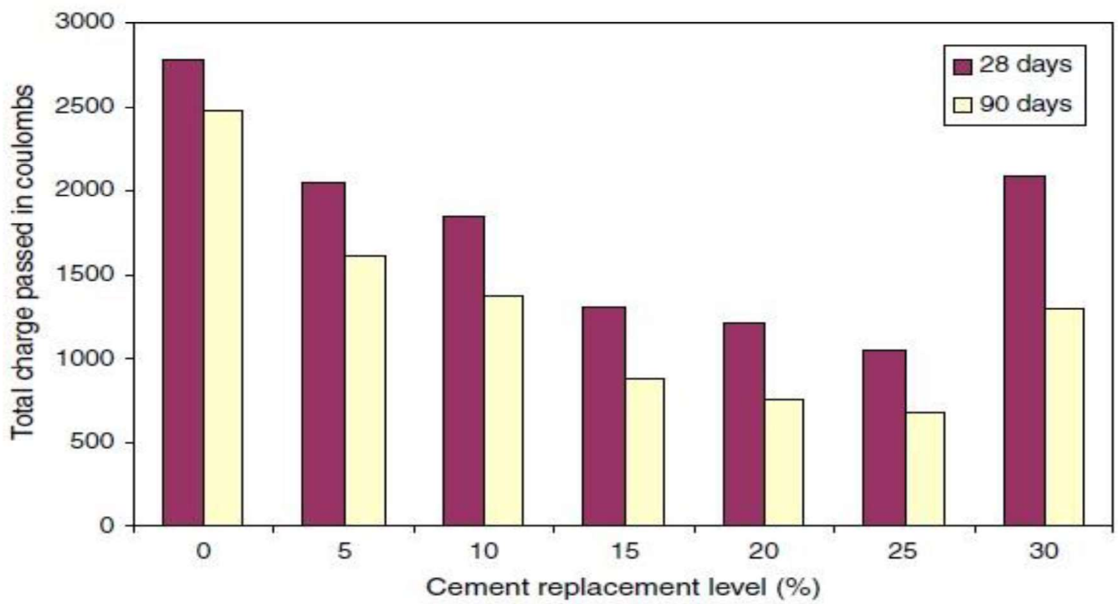


Fig. 2.13 Chloride permeability of Bagasse ash blended concretes (Ganesan et al. [25])

It can be clearly seen from the above figure that the charge passed decreased as the percentage of bagasse ash replacement increased up to 25%. The charge passed increased at 30% replacement level, however, it was lesser than the control concrete. This was valid for both 28 and 90 days curing results.

Amin (2011) [24] investigated the use of bagasse ash as partial replacement of cement and reported its impact on physical and mechanical properties of hardened concrete. Seven mixes were totally prepared which included bagasse ash varying from 5% to 30% as cement replacement. The resistance to chloride ion penetration (total charge passed through bagasse ash-blended concrete specimens) was measured after 28 and 90 days of moist curing. Figure 2.14 shows the RCPT results.

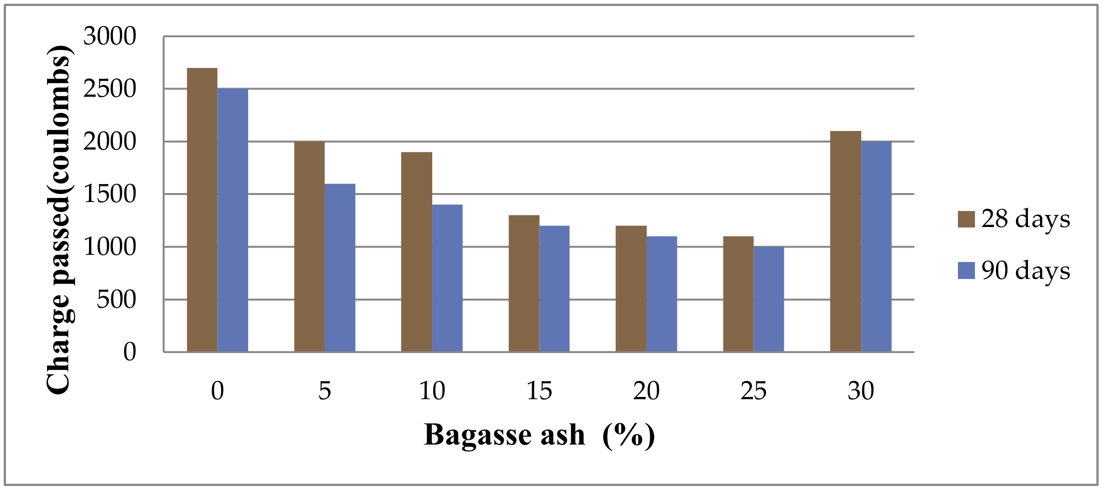


Fig. 2.14 Chloride penetration results from RCPT (Amin [24])

A clear observation made from the above figure was that the charge passed decreased as the percentage of bagasse ash replacement increased up to 25%. The charge passed increased at 30% replacement level, however, it was lesser than the control concrete.

Chopra et al. (2015) [29] examined the effect of Rice husk ash (RHA) as replacement of cement in self-compacting concrete. The percentages replaced were kept as 10, 15 and 20 %. The Rapid chloride penetration test (RCPT) results after 28 days of curing of the SCC mixes with different percentages of rice husk ash (RHA) are given in Figure 2.15.

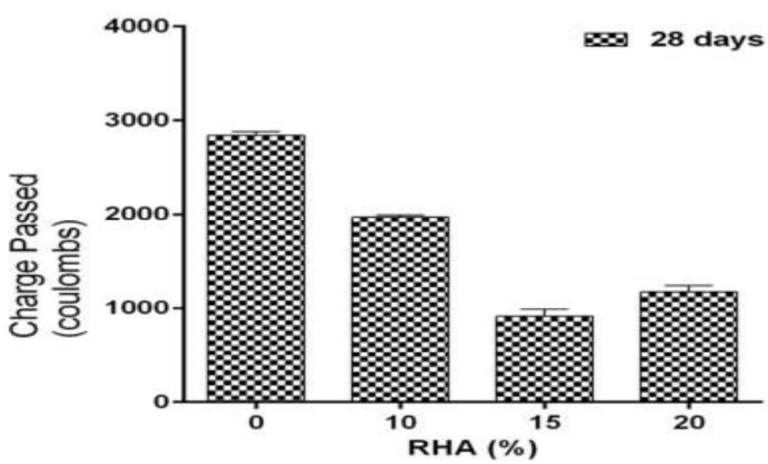


Fig. 2.15 RCPT result of SCC mixes at 28 days of curing (Chopra et al. [29])

From the above figure, it is clear that the charge passed decreased as the replacement level of RHA increased up to 15%. However, the charge passed at 20% replacement level increased, but it was still lower than the control mix.

Rerkpiboon et al. (2015) [26] investigated the strength and durability properties of concrete that contained up to 50% ground bagasse ash (GBA) replacing ordinary Portland cement (OPC) by weight of binder. Replacement levels were kept as 10, 20, 30, 40 and 50%. The Rapid chloride penetration test (RCPT) results after 28 days of curing of the concrete specimens with different percentages ground bagasse ash are given in Figure 2.16.

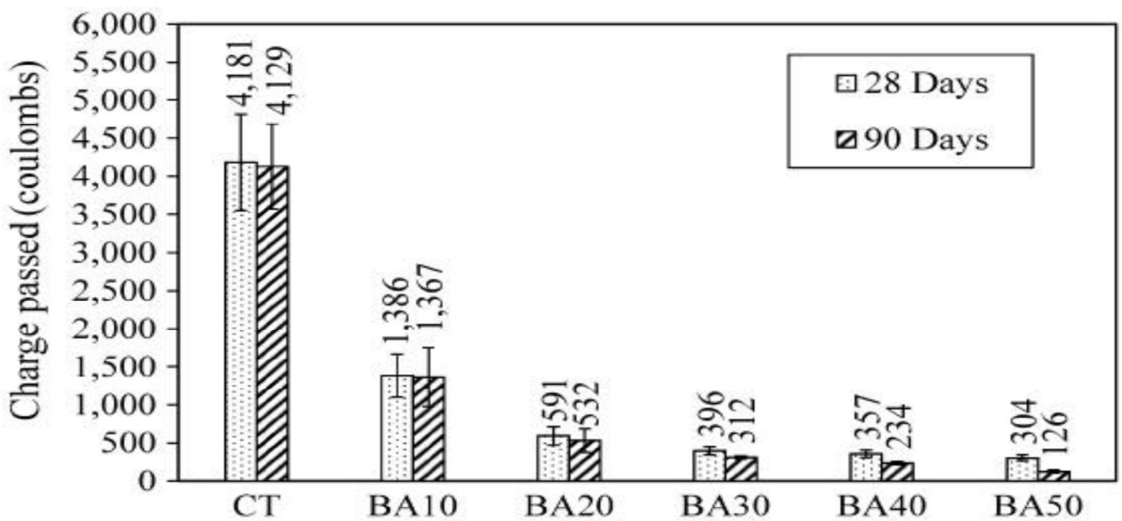


Fig. 2.16 Rapid chloride-ion penetration of control and Bagasse ash concretes (Rerkpiboon et al. [26])

2.6.2 Water absorption

Ganesan et al. (2007) [25] investigated the effect of Bagasse ash on physical and mechanical properties of hardened concrete. Cement was partially replaced by bagasse ash. A total of 7 mix proportions (with bagasse ash varying from 5% to 30% by weight of cement), the control mix included, were prepared. Water absorption values of Bagasse ash blended concrete specimens were found after 28 and 90 days of moist curing and are shown in Figure 2.17.

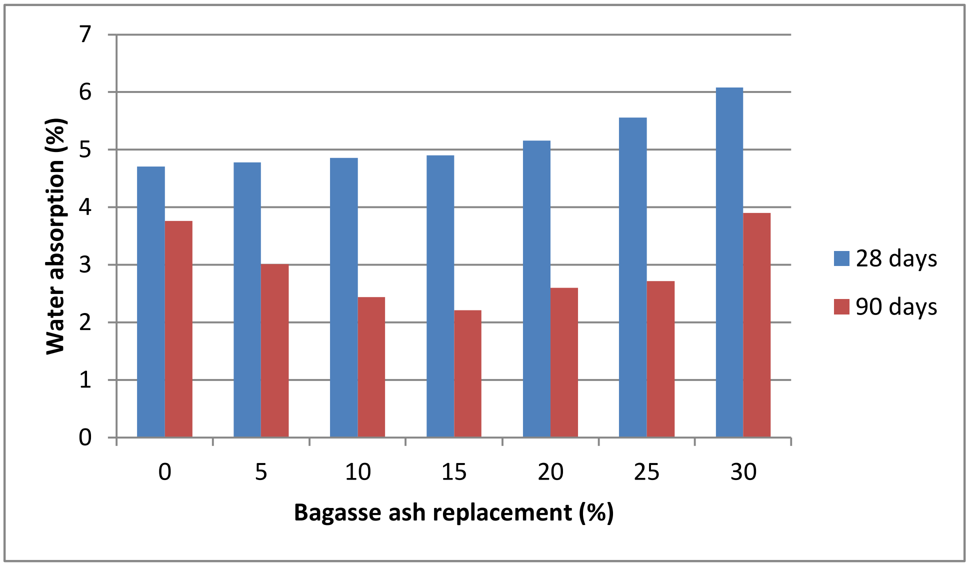


Fig. 2.17 Water absorption values of Bagasse ash blended concretes (Ganesan et al. [25])

Clearly, the percentage of water absorption values increase with the increase in level of replacements at 28 days curing owing to the finer nature of Bagasse ash than OPC and its hygroscopic nature. However, at 90 days curing, the percentage of water absorption values reduced to almost 50%, owing to the gradual closing of pores.

CHAPTER 3

EXPERIMENTAL PROGRAM AND METHODOLOGY

3.1 GENERAL

The selection of materials have to be ascertained for achieving the desired strength of a concrete. This chapter deals with the details of experimental program followed for the measuring of fresh properties, strength properties viz. compressive strength, splitting tensile strength and durability properties viz. chloride-ion penetration resistance and water absorption of self-compacting concrete (SCC) mixes made with varying percentages of bagasse ash as partial replacement of cement. The replacement levels were kept as 0, 5, 10 and 15% by weight of cementitious content. The basic tests carried out on the SCC samples are discussed in this chapter followed by a brief description about the mix design and curing procedure adopted. Lastly, various tests conducted on the specimens are discussed.

3.2 EXPERIMENTAL PROGRAM

The experimental program and test matrix is shown in Figure 3.1 below.

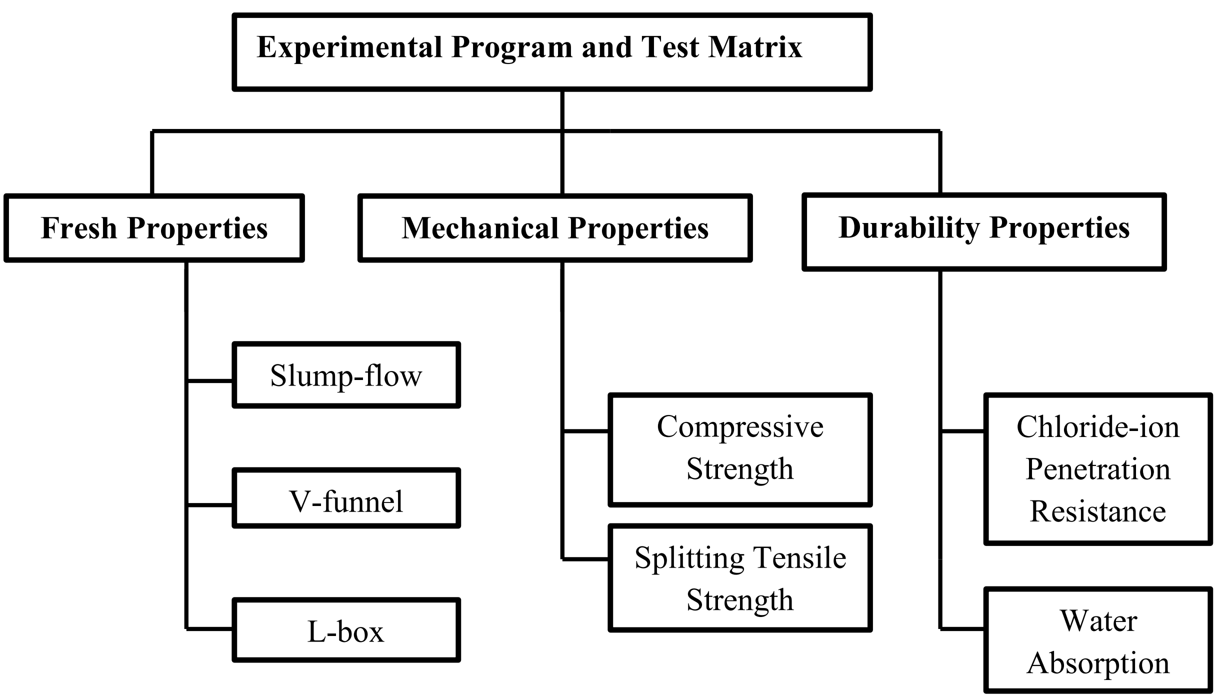


Fig. 3.1 Experimental program and test matrix

3.3 PROPERTIES OF CONSTITUENT MATERIALS

3.3.1 Cement

The cement used in the study was Ordinary Portland Cement (OPC), Grade 43, Ultra Tech. It was greyish in colour with a light greenish shade and was free from any lumps. Test results are given in Tables 3.1 and 3.2 below.

Table 3.1: Physical properties of Ordinary Portland Cement used

Physical property	**Test result**	**Specifications as per IS:8112-1989**	**Test Procedure as per**
Fineness (% retained on 90 micron sieve)	1.5	10% (Maximum)	IS 4031(Part 1):1996
Soundness (mm)	1	10mm (Maximum)	IS 4031(Part 3):1988
Standard consistency (%)	27.5	–	IS 4031(Part 4):1988
Setting time (min)			IS 4031(Part 5):1988
Initial	165	30 (Minimum)	
Final	237	600 (Maximum)	
Compressive strength (MPa)			IS 4031(Part 6):1988
3 day	26.25	23 (Minimum)	
7 day	36.88	33 (Minimum)	
28 day	48.42	43 (Minimum)	
Specific gravity	3.14	–	IS 4031(Part 11):1988

3.2: Chemical properties of Ordinary Portland Cement used (Courtesy: Ultra Tech Cements)

Particular	Test result	Specification as per IS 8112:1989	Test Procedure
$\frac{CaO - 0.7\ SO_3}{2.8\ SiO_2 + 1.2\ Al_2O_3 + 0.65\ Fe_2O_3}$	0.90	0.66 (Min.) 1.02 (Max.)	IS 4032:1985
$\frac{Al_2O_3}{Fe_2O_3}$	1.30	0.66 (Min.)	
Insoluble residue (% by Mass)	2.60	2.00 (Max.)	
Magnesia (% by Mass)	0.96	6.00 (Max.)	
Sulphuric Anhydride (% by Mass)	2.39	3.0 (Max.)	
Total loss on ignition (% by Mass)	2.94	5.00 (Max.)	
Total chlorides (% by Mass)	0.022	0.05 (Max.)	

3.3.2 Fine Aggregates

Locally available river sand conforming to Indian Standard Specifications IS: 383-1970 [40] was used in the study. The sand was initially sieved through 4.75 mm sieve so that the particles greater than 4.75 mm size are removed. Aggregates belonged to grading zone II. The sieve analysis results are given in Table 3.3 below:

Table 3.3: Sieve analysis of fine aggregates used

Sieve size	Weight retained in grams	% Retained	Cumulative % retained	% Passing	IS:383-1970 Limit (Zone-II)
10 mm	0	0	0	100	100
4.75 mm	13	1.3	1.3	98.7	90–100
2.36 mm	1	0.1	1.4	98.6	75–100
1.18 mm	385	38.5	39.9	60.1	55–90
600 micron	169	16.9	56.8	43.2	35–59
300 micron	267	26.7	83.5	16.5	8–30
150 micron	120	12	95.5	4.5	0–10

Fineness modulus: 2.784 *Weight of sample taken in grams = 1000*

The physical properties of fine aggregate are given in Table 3.4 below.

Table 3.4: Physical properties of fine aggregates used

Property	Value
Specific gravity	2.57
Bulk Density (kg/m^3)	1430
Fineness modulus	2.784
Water absorption (%)	1.21

3.3.3 Coarse Aggregates

Locally available coarse aggregates (crushed stone) conforming to Indian Standard Specifications IS: 383-1970 [40] were used in the study. The maximum size of the aggregates used was 10 mm. The sieve analysis results are given in Table 3.5 below.

Table 3.5: Sieve analysis of Coarse aggregates used

Weight of sample taken in grams = 5000

Sieve size	Weight retained in grams	% Retained	Cumulative % retained	% Passing	IS:383-1970 Limit
12.5 mm	0	0	0	100	100
10 mm	264	5.28	5.28	94.72	85–100
4.75 mm	3893	77.86	83.14	16.86	0–20
2.36 mm	657	13.14	96.28	3.72	0–5

The physical properties of Coarse aggregates are given in Table 3.6 below.

Table 3.6: Physical properties of Coarse aggregates used (10 mm)

Property	Observed value
Colour	Grey
Specific gravity	2.62
Bulk Density (kg/m^3)	1590
Water absorption (%)	0.63

3.3.4 Water

Potable water is normally considered satisfactory for mixing and curing of concrete. In this study, potable water available in the material testing laboratory was used for making SCC specimens. It was devoid of any detrimental contaminants.

3.3.5 Bagasse ash

Bagasse ash procured from Bhagwanpura Sugar Mills, Dhuri, Punjab was used in the study. The ash was first oven dried at 110° C for 24 hours to remove the evaporable moisture from it. This moisture is due to the water present in it which is mixed at the time of disposal. The ash was black in colour which indicated presence of carbon content. Some of the images of the Raw Bagasse ash and the Processed Bagasse ash are shown in Figure 3.2 below.

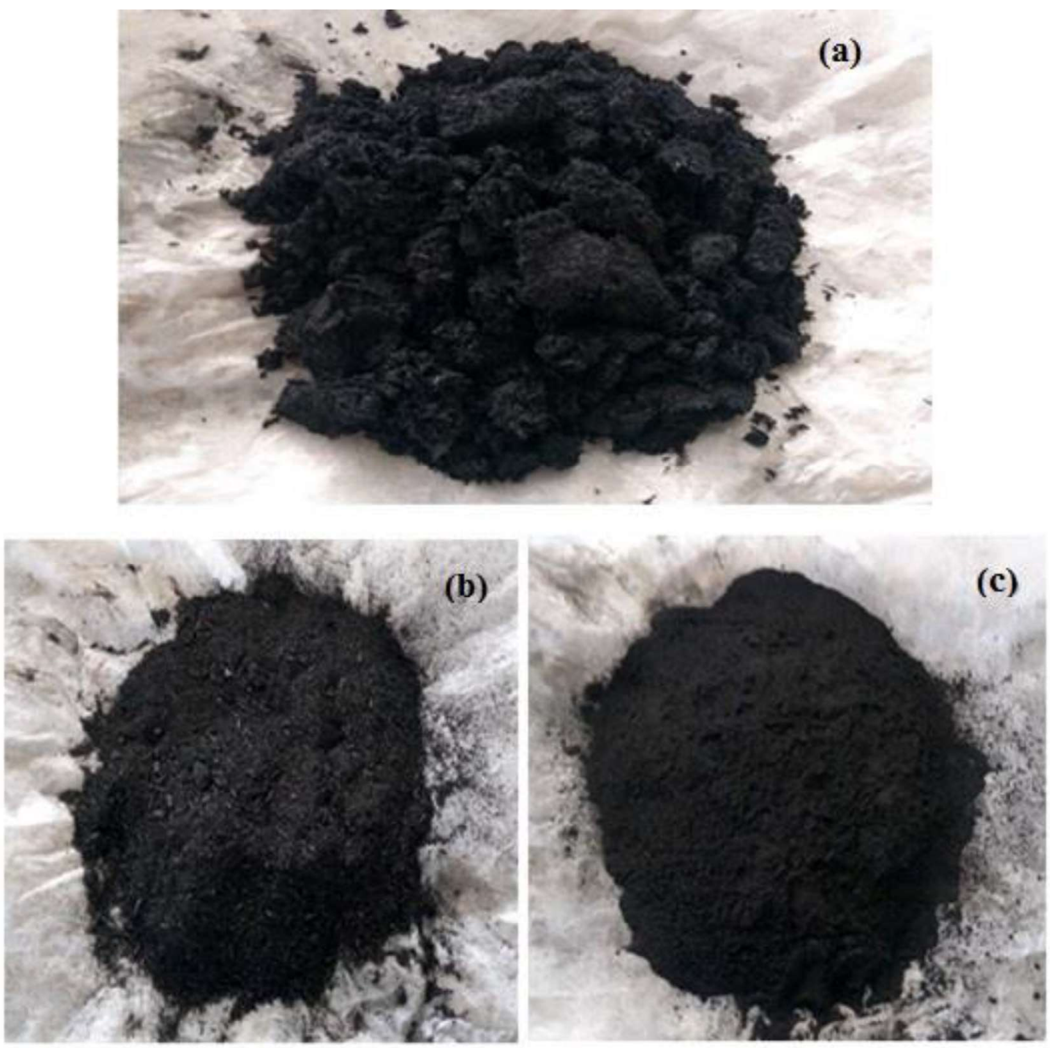


Fig. 3.2 Bagasse ash used: a) Raw bagasse ash, b) Processed bagasse ash, c) Sieved bagasse ash

The oven dried sample was then sieved through 90 micron sieve to make the particle size same as that of cement. Physical properties of Bagasse ash are given in Table 3.7 below.

Table 3.7: Physical properties of Bagasse ash

Property	Observed value
Colour	Black
Specific gravity	2.32

The same sample was then tested for chemical composition. Oxide composition of this Bagasse ash sample was determined using AAA spectroscopy and the results are presented in Table 3.8 below.

Table 3.8: Chemical composition of Bagasse ash (Courtesy : SAI Labs, Thapar University, Patiala, Punjab)

Chemical composition (%)	Test Method	Result
SiO_2	IS: 1727-1967, Reaffirmed-2004	57.01
Al_2O_3	IS: 1727-1967, Reaffirmed-2004 & AAS	1.64
CaO	IS: 1727-1967, Reaffirmed-2004 & AAS	4.13
Fe_2O_3	IS: 1727-1967, Reaffirmed-2004 & AAS	0.74
MgO	IS: 1727-1967, Reaffirmed-2004 & AAS	1.39
Na_2O	Digestion followed by flame photometer	0.14
SO_3	IS: 1727-1967, Reaffirmed-2004	0.55
K_2O	Digestion followed by flame photometer	1.84
Loss on ignition	IS: 1727-1967, Reaffirmed-2004	27.0

3.3.5.1 X-ray Diffraction (XRD)

XRD of the sample was characterised by X-ray diffractometer with Cu radiation for the identification of existing phases, crystal structure, lattice parameter of the crystalline solids. The 2Ө values for XRD patterns were in the range of 10˚-90˚. XRD analysis done is shown in Figure 3.3 below.

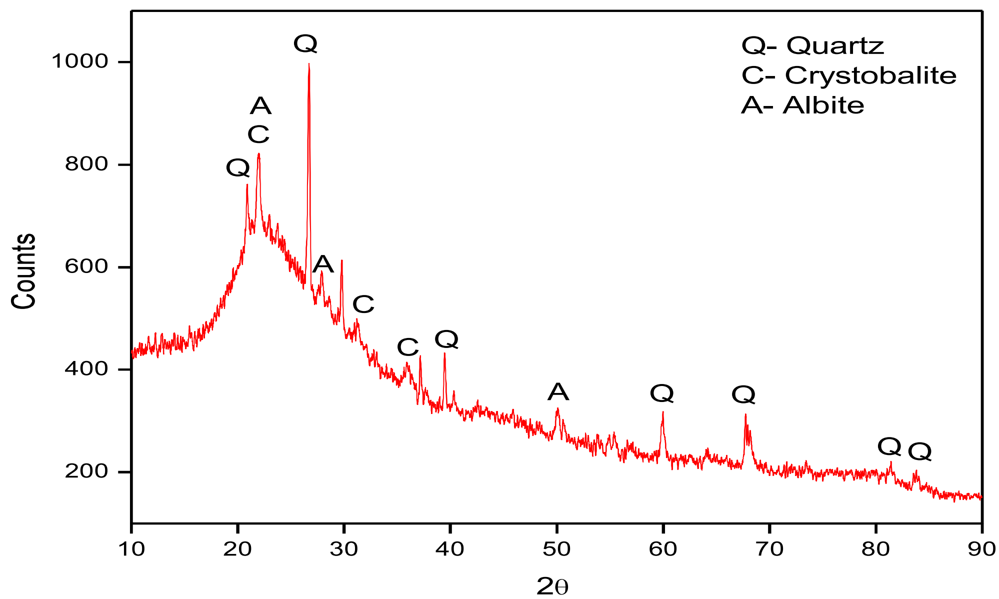


Fig.3.3 X-ray diffraction analysis of Bagasse ash

From the XRD pattern of bagasse ash sample, peaks of Quartz, Crystobalite and Albite were found. It indicated that the sample mainly consisted of amorphous silica.

3.3.5.2 Scanning Electron Microscopy (SEM)

The microstructure of Bagasse ash was examined using Scanning Electron Microscope at accelerating voltage of 15kV. SEM images of the Bagasse ash sample were obtained and are shown in Figure 3.4. The images shown are of four magnifications; ×170, ×500, ×1000 and ×1500. The clear idea of the particle shape and size was indicated by the image having ×500 magnification.

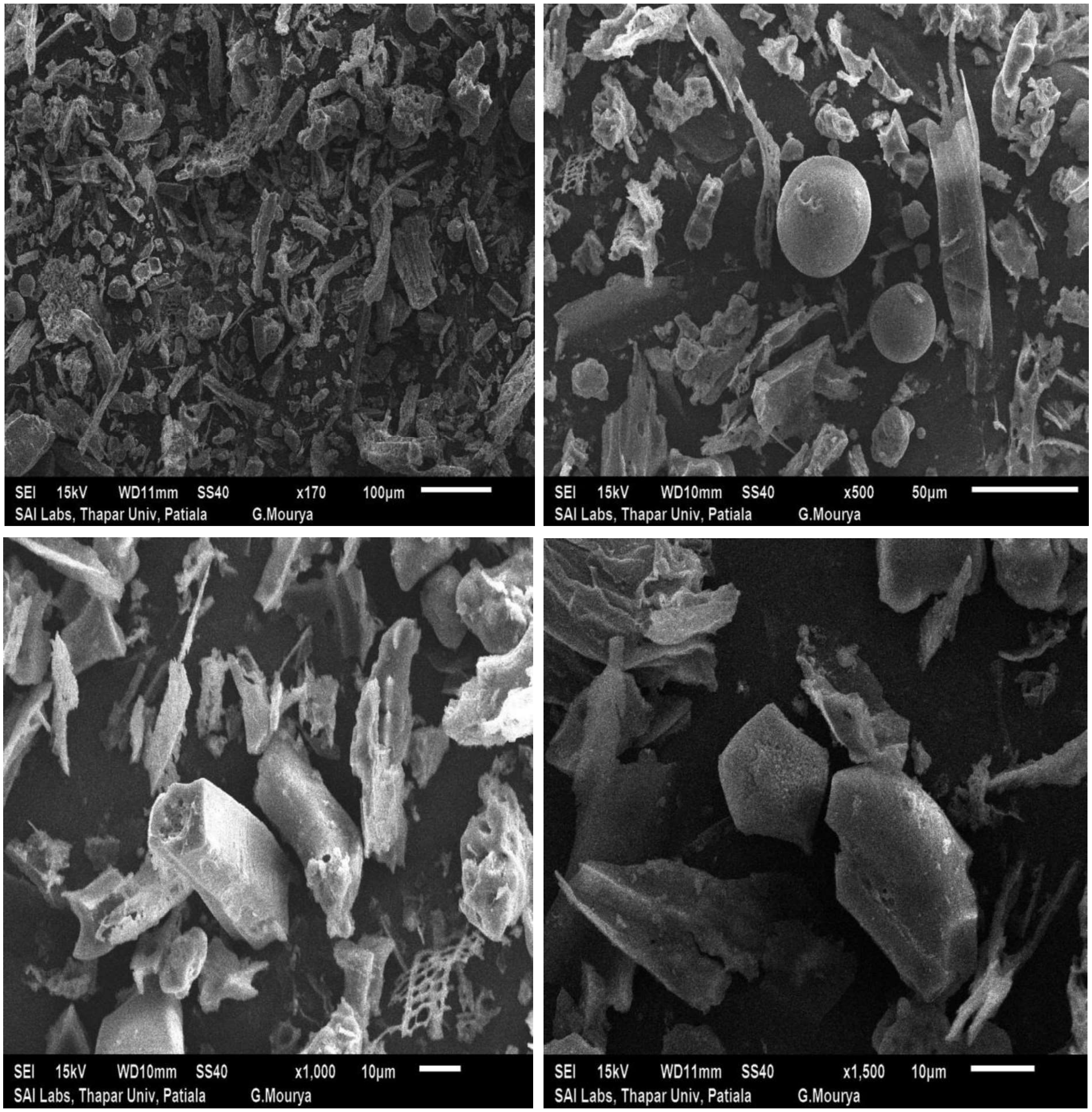


Fig. 3.4 SEM images of Bagasse ash

The SEM images show that the bagasse ash consists of spherical particles. It also has fibrous irregular shaped particles present.

3.3.6 Admixture

AURAMIX 400 procured from FOSROC Constructive Solutions was used in the study. It comes under the latest generation of superplasticizers and is Polycarboxylic ether (PCE) based. AURAMIX 400 complies with IS: 9103-1999 [43]. It has long lateral chains that possess the ability to disperse the cement particles to a great extent. It is a high performance retarding superplasticizer mainly used where retardation and high workability are required. The optimum dosage of AURAMIX 400 to meet the specific requirements was determined by trials using the constituent materials. The prescribed dosage ranges between 0.5 to 3.0 litres/ 100 kg of cementitious material. The dosage can be altered depending on the workability to be achieved. However, too much dosage can lead to bleeding of the mix. In the present study, the dosage ranged from 1% to 1.25% based upon the workability of the mix desired. The specifications of the superplasticizer are given in Table 3.9.

Table 3.9: Specifications of the superplasticizer used

Characteristics	Value
Type	Polycarboxylic Ether Polymer
Physical state	Liquid
Colour	Light yellow
Volumetric mass @ 20˚ C	1.09 kg/litre
pH	Minimum 6
Chloride content	Nil
Alkali content	Typically less than 1.5 g Na_2O equivalent/ litre of admixture

3.4 MIX PROPORTION OF SCC

SCC is designed to be both fluid and cohesive; it has to possess both properties in correct proportions. There is no standard method of mix design for SCC. Laboratory trials should be used to verify properties of the initial mix composition with respect to the specified characteristics and classes. If required, adjustments to the mix composition should then be made. Before arriving at the mix proportion, it is important to have a glance at the test results of the ingredients. They are given in Table 3.10.

Table 3.10: Test results of ingredients

Type of Cement	OPC
Specific gravity of Cement	3.14
Specific gravity of Fine aggregate	2.57
Specific gravity of Coarse aggregate	2.62

Specific gravity of Bagasse ash	2.32
Specific gravity of Superplasticizer	1.09

A total of four trials were conducted before arriving at the final mix proportion of SCC. The fifth trial was successful which met all the requirements for fresh properties of SCC. One of the key issues in making SCC is to set the balance between the w/p ratio and the superplasticizer dosage. Any of the two being higher than required may lead to segregation and/or bleeding as was observed in the third trial conducted. The fine aggregate content is normally higher than the coarse aggregate content in SCC so that the desired flowability is achieved. The fine aggregate content was kept as 55% of total aggregate volume.

The final mix proportion of SCC made with varying percentages of bagasse ash as cement replacement (0, 5, 10 and 15% by weight of cementitious content) is given in Table 3.11 below.

Table 3.11: Mix proportion of SCC with Bagasse ash

Mix Notation	Cement (kg/m^3)	B.A (kg/m^3)	F.A (kg/m^3)	C.A (kg/m^3)	Water (kg/m^3)	w/p ratio	S.P (%)
SCC-CM	500	0	865	724	210	0.42	1.0
SCC-BA5	475	25	865	724	210	0.42	1.0
SCC-BA10	450	50	865	724	210	0.42	1.2
SCC-BA15	425	75	865	724	210	0.42	1.25

Where,

CM: Control Mix

BA: Bagasse ash; 5, 10 and 15 are the replacement levels (by weight of cementitious content)

F.A: Fine aggregate

C.A: Coarse aggregate

w/p ratio: Water powder ratio

S.P: Superplasticizer

The control mix was designed for a target strength of 40 MPa.

3.5 CASTING AND CURING

Prior to casting, the moulds were properly made clean (dirt free) and oiled. The screws were stiffened to correct dimensions before casting. It was made sure that there is no gap left in the moulds from where there could be any possible leakage of slurry. Careful procedure was adopted in the batching, mixing and casting operations. The concrete mixture was prepared in Pan mixer (shown in Figure 3.5). Coarse and fine aggregates were mixed thoroughly first by dry mixing in the pan mixer for about 2 minutes. Cement was then added to this mixture and all the three ingredients were mixed to uniform colour. Half of the total water required was first added carefully and whole of the superplasticizer amount was added immediately (with remaining water added with it). After a while, the remaining water was then added. Superplasticizer takes around 4-5 minutes to disperse its charge and hence the mixing continued up to around 6 minutes. After proper mixing, the mix was first checked for fresh properties, because only if it fulfilled the workability requirements, it would be called as self-compacting concrete. Only when the mix satisfied all the fresh property requirements, the specimens were casted, else another trial was conducted and the process continued till the fresh properties requirements were met.

Fig. 3.5 Pan mixer

For each mix, 16 specimens were casted both for 7 and 28 days of testing. Table 3.12 summarises the details.

Table 3.12: Specimen details

Specimen	Specifications (mm)	Test Conducted
Cubes	150×150×150	Compressive strength
	70.5×70.5×70.5	Water absorption
Cylinders	150×300	Splitting tensile strength
	50×100	Rapid chloride-ion permeability

3.6 TESTING PROCEDURE

After the period of curing, the specimens were taken out from the curing tank and their surfaces were wiped off and then allowed to dry for about 5 minutes. Besides measuring the fresh properties of SCC (Slump flow, L-box, V-funnel), the following tests were performed on hardened SCC.

(i) For strength properties

- Compressive strength (IS: 516-1959 [44])
- Splitting tensile strength (IS: 5816-1999 [45])

These properties were determined at the age of 7 and 28 days.

(ii) Durability properties

- Chloride-ion penetration resistance (ASTM C 1202 [46])
- Water absorption

The rapid chloride-ion permeability test specimens were tested the age of 28 days, whereas the water absorption test specimens were tested at the age of 7 days after initial curing of 28 days.

3.7 TESTS CONDUCTED

3.7.1 Fresh Concrete tests

There are three key properties of fresh SCC:

- Filling ability
- Passing ability
- Segregation resistance

Requisite levels of all the three properties must be reached for fresh SCC in order to be self-compacting and to remain so while transporting and placing by selected means and in given conditions.

3.7.1.1 *Slump-flow test*

The slump-flow and T_{500} is a test that assesses the flowability and the rate of flow SCC when there are no obstructions of any kind. The result gives an idea about the filling ability of SCC. T_{500} time gives a measure of the viscosity of SCC.

Apparatus

The apparatus shall conform to EN 12350-2 [47] as detailed below:

- *Baseplate* made from a flat plate with surface area of minimum 900 mm × 900 mm. Minimum thickness of plate shall be 2 mm. The surface of the plate shall be flat, smooth and non-absorbent. The centre of plate shall be marked with a cross whose lines are parallel to the edges of the plate. Two circles of 200 mm and 500 mm diameter shall be marked which have centres coinciding with that of the plate. Baseplate with slump-cone is shown in Figure 3.6.
- *Ruler*.
- *Stop watch*.
- *Weighted collar* (optional).

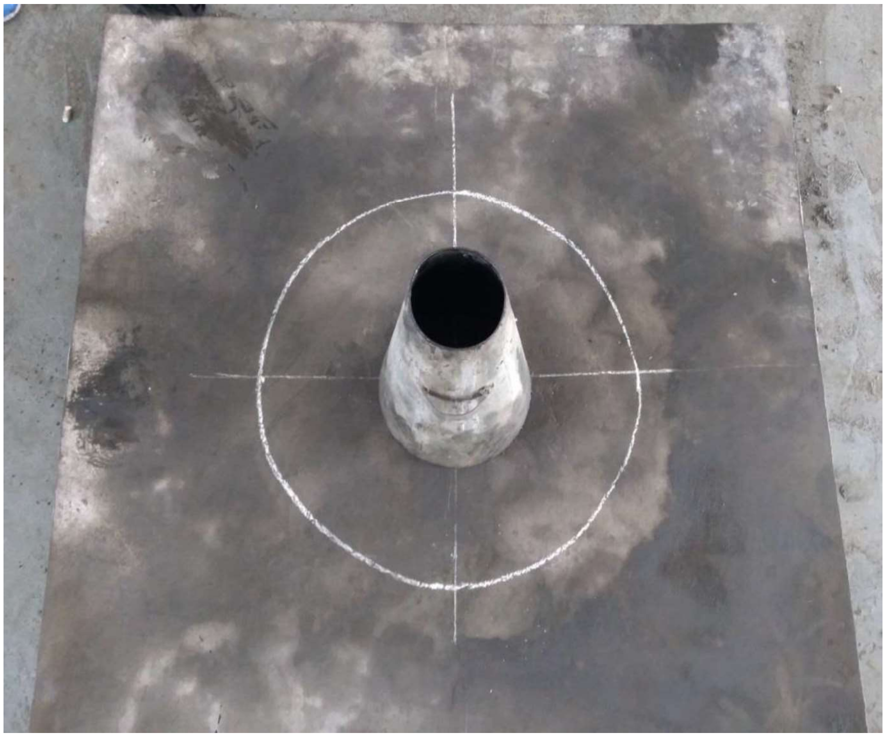


Fig. 3.6 Baseplate with slump-cone

Procedure

- Prepare the cone and base plate as mentioned in EN 12350-2 [47]
- Place the cone exactly on the 200 mm circle on the baseplate (ensuring the centres coincide). Hold the cone steady and make sure that concrete doesn't leak from beneath the cone.
- Fill the cone with concrete. Make sure that no agitation or rodding is done while filling the cone and then strike off the extra concrete from the top of the cone.
- Allow the filled cone to stand for a maximum of 30 s.
- Lift the cone up vertically in a single move without fiddling with the flow of fresh concrete sample. To measure T_{500} time, start the stopwatch at the moment when the cone loses contact with the baseplate and record the time that it takes for the concrete to reach the 500 mm circle at any point.
- Measure the largest diameter of the flow spread (without disturbing the base plate or concrete) and record it as d_m to the nearest 10 mm. After this, measure the diameter of flow spread at right angles to d_m to the nearest 10 mm and record it as d_r to the nearest 10 mm.
- Check the concrete for any segregation or bleeding.

Test result

- The slump-flow is the mean of d_m and d_r expressed to the nearest 10 mm.
- The T_{500} time is reported to the nearest 0.1 s.

Fig. 3.7 Slump-flow test in progress

3.7.1.2 *V-funnel test*

The V-funnel test assesses the viscosity and filling ability of SCC.

Apparatus

The apparatus set up is briefed below and is shown in Figure 3.7.

- *V-funnel* (made from metal), dimension tolerance being ± 1 mm, is fitted with a quick release, watertight gate at its base and supported so that the top of the funnel is horizontal.
- *Container,* to hold the test sample and shall have volume greater than that of the funnel (not less than 12 litres).

- *Stop watch.*
- *Straight edge*.

Procedure

- Clean both the funnel and the bottom gate.
- Make the surface inside the funnel including the gate as damp/moist.
- Close the gate and then pour the sample of concrete into the funnel, without any agitation or rodding and then strike off the top for any surplus concrete with the straight edge.
- Place the container under the funnel so that the concrete passing is retained.
- After a delay of (10 ± 2) s from filling the funnel, the gate is opened and the time, t_v is measured to 0.1 s, from the time of opening the gate to the time when we can see vertically through the funnel into the container below.

Test result

t_v is the V-funnel flow time measured to 0.1 s.

Fig. 3.8 V-funnel test in progress

3.7.1.3 *L-box test*

L-box test assesses the passing ability of SCC to flow through tight openings including spaces between the reinforcing bars and other hindrances without segregation or blocking. Generally, it has two variants; the two bar test and the three bar test. The three bar is a stimulation of more congested reinforcement.

Apparatus

The apparatus set up is briefed below and is shown in Figure 3.9.

- L-box shall be of rigid make-up having smooth surfaces that shall not be easily attacked by cement paste or be vulnerable to rusting. For the cleaning to be easy, the vertical hopper may be kept removable. The volume of the vertical hopper shall be 12.6 – 12.8 litres when filled level with the top. For the two bar test, the assemblies holding the reinforcement bars shall have two smooth bars of 12 mm diameter with a gap of 59 mm. The three bar test shall have 3 smooth bars of 12 mm diameter with a gap of 41 mm.
- Ruler.
- Container having a minimum volume of 14 litres.

Fig. 3.9 L-box set-up (3 bar variant)

Procedure

- Support the L-box on a levelled horizontal surface and make sure the the gate between the vertical and horizontal sections is closed.
- Pour the concrete into the filling hopper of the L-box and allow to stand for (60 ± 10)s.
- Make note of any segregation and then raise the gate to let the concrete flow into the horizontal section of the box.
- After the movement of concrete has stopped, measure the vertical distance at the end of the horizontal section of the L-box, between the top of concrete and the top of the horizontal section of the box at three equally spaced positions across the width of the box.
- These three measurements are used to calculate the mean depth of concrete as H_2 mm. the same procedure is adopted to calculate the depth of concrete behind the gate as H_1 mm.

Test result

The passing ability is calculated as the ratio of H_2 and H_1.

Fig. 3.10 L-box test in progress

3.7.2 Hardened Concrete tests

3.7.2.1 *Compressive strength test* (IS: 516-1959 [44])

The compressive strength test is performed on cubes to determine compressive strength at various ages.

Apparatus

The testing machine shall be of any reliable type, of sufficient capacity for the tests and capable of applying the load at the rate that is specified. In this study, Automatic Compression Testing Machine (ACTM) having a capacity of 5000 kN was used. The apparatus set up for compressive strength test is shown in Figure 3.11.

Fig. 3.11 Compressive strength test set-up

Age at test

Tests shall be done at familiar ages of the test specimens, most common being 7 and 28 days. The ages shall be calculated from the time of addition of water to the dry ingredients.

Number of specimens

At least three specimens shall be made for testing at the selected age.

Procedure

- Cube specimens having dimensions 150×150×150 mm were cast for compressive strength as per Indian standard specifications IS: 516-1959 [44].
- After casting, all test specimens were given a finishing.
- Specimens were demoulded after 24-hours of casting and then were put in curing tanks where the temperature was around 26°.
- Cubes were placed in a manner that the load applied was at right angles to the face of the cube.
- The load was applied at a constant rate of 5 MPa / sec.
- Compressive strength test for cubes was carried out at 7 and 28 days.
- All the specimens were tested in the Automatic Compression Testing Machine (ACTM).

3.7.2.2 *Splitting tensile strength test* (IS: 5816-1999 [45])

The splitting tensile strength is performed on cylinders to determine the splitting tensile strength at various ages. It is a well-known indirect test for measuring the tensile strength of concrete.

Apparatus

Any compression testing machine, of sufficient capacity for the tests and capable of applying the load at the rate that is specified. In this study, Automatic Compression Testing Machine (ACTM) having a capacity of 5000 kN was used. The apparatus set up for Splitting tensile strength is shown in Figure 3.12.

Fig. 3.12 Splitting tensile strength test set-up

Age at test

Tests shall be done at familiar ages of the test specimens, most common being 7 and 28 days. The ages shall be calculated from the time of addition of water to the dry ingredients.

Number of specimens

At least three specimens shall be made for testing at the selected age.

Procedure

- Cylindrical specimens having dimensions 150×300 mm were cast for splitting tensile strength as per Indian standard specifications IS: 5816-1999 [45].
- After casting, all test specimens were given a finishing.
- Specimens were demoulded after 24-hours of casting and then were put in curing tanks where the temperature was around 26˚.
- Before placing the specimen in the testing machine, the bearing surfaces of the testing machine and the loading strips were wiped clean.

- The specimen shall be placed exactly in the centre with packing strip and/or loading pieces carefully positioned along the top and bottom of the plane of loading of the specimen.
- The load was applied at a constant rate of 2 MPa / sec.
- Splitting tensile strength test for cylinders was carried out at 7 and 28 days.
- All the specimens were tested in the Automatic Compression Testing Machine (ACTM).

3.7.3 Durability tests

Rapid chloride-ion permeability test and Water absorption test were carried out to measure the durability of the SCC mixes.

3.7.3.1 *Rapid chloride-ion permeability test* (ASTM C 1202 [46])

This test method is used to measure the electrical conductance of concrete. It provides a rapid indication of resistance to chloride ions by concrete. Generally, the cylindrical concrete specimens 100 mm in diameter and 200 mm in height are first casted and then cut by a water-cooled diamond saw to get the specimens (to be tested) having 50 mm thickness and 100 mm diameter. After the curved surface of the concrete specimen is coated with epoxy, the specimen is saturated in vacuum and then soaked for 18 hours. Figures 3.13 and 3.14 show the test apparatus. The specimen is then placed in the test apparatus set-up. One end of the specimen is put into a solution containing 3.0% sodium chloride (NaCl) and the other end into 0.3 M sodium hydroxide (NaOH). A constant 60 V potential is applied across the test specimen to speed up the rate of chloride penetration. Current across the specimen is measured at least every 30 minutes during the 6-hour duration of the test. Two or three specimens are tested for each concrete sample or mix. The total charge passing through the specimen (Coulombs) is found by calculating the total area under the plot of time versus current. Thus, higher coulomb values at the completion of the test indicate higher permeability.

Fig. 3.13 Rapid chloride-ion permeability test set-up

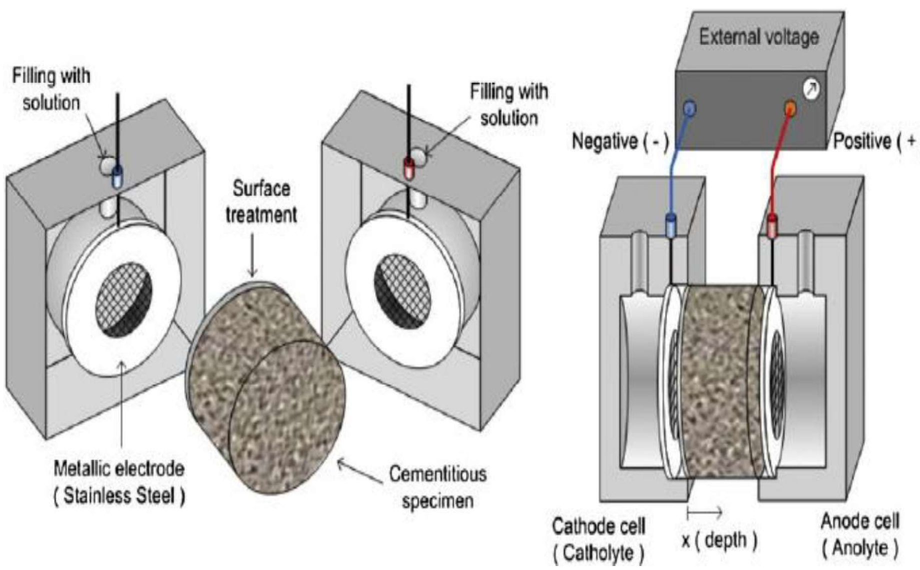


Fig. 3.14 Rapid chloride-ion permeability test (Source: www.researchgate.net)

The rapid chloride permeability test, however, does not directly measure the depth or rate of chloride penetration. For quality control and acceptance testing applications, ASTM C 1202 [46] recommends the use of qualitative terms rather than the numerical results of the test, both shown in Table 3.13.

Table 3.13: Chloride-ion penetrability based on charge passed (ASTM C 1202)

Charge passed (Coulombs)	Chloride-ion penetrability
4000	High
2000 – 4000	Moderate
1000 – 2000	Low
100 – 1000	Very low
100	Negligible

3.7.3.2 *Water absorption*

Percentage of water absorption is a measure of the pore volume or porosity in hardened concrete, which is occupied by water in saturated condition. Water absorption test was conducted on cube specimens having dimensions 70.5×70.5×70.5 mm at the age of 7 days after initial curing of 28 days. After casting the cubes, they were first put into curing tank and taken out after a period of 35 days (28 + 7). They were then oven dried for 24 hours at a temperature of 110° C. The dry weight of the specimens was noted and then they were immediately immersed in water for a duration of 96 hours. After that, the specimens were taken out and the surplus water was wiped with a soft cloth and then their saturated weight was noted down.

The difference between the saturated mass and the oven dry mass expressed as a fractional percentage of oven dry mass gives the water absorption.

3.8 CLOSING REMARKS

This chapter presented an overview of the Experimental program and the methodology adopted in the study. Properties of constituent materials, mix proportion, casting and curing set-up, testing procedure and the tests conducted were discussed in detail in this chapter. The next chapter deals with the discussion of results of the tests that were conducted in this study.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 GENERAL

This chapter presents the findings of experimental investigation in detail. Test results of fresh properties, compressive strength, splitting tensile strength, rapid chloride-ion permeability and water absorption of self-compacting concrete with bagasse ash are presented in this chapter. Bagasse ash was used as a partial replacement of cement in SCC at 5, 10 and 15% replacement levels.

4.2 EFFECT OF BAGASSE ASH ON FRESH PROPERTIES OF SCC

The results of various fresh properties tested by Slump flow test, L-box test and V-funnel test are summarised in Table 4.1.

Table 4.1: Fresh properties of SCC with Bagasse ash

Mix	Slump flow		V-funnel (s)	L-box (H_2/H_1)	w/p ratio	S.P (%)
	Dia. (mm)	T_{500} (s)				
SCC-CM	660	1.6	7	0.98	0.42	1.0
SCC-BA5	632	3	9.4	0.91	0.42	1.0
SCC-BA10	590	4.4	11.8	0.85	0.42	1.2
SCC-BA15	570	5.6	13.2	0.80	0.42	1.25

4.2.1 Slump flow

- The slump flow value for control mix was 660 mm, which can thus be classified into SF2 (slump flow range 660-750 mm) slump-flow class as per EFNARC 2005 [10] guidelines.
- The slump flow values for the mixes containing bagasse ash were in the range of 570-632 mm, which show that these mixes belonged to the SF1 (slump flow range 550-650 mm) slump-flow class as given by EFNARC 2005.

- The value of slump flow decreased as the percentage of bagasse ash increased up to 15%. Control mix having 0% bagasse ash had the highest slump flow value. As the percentage of bagasse ash was increased (5, 10 and 15%), the slump flow value decreased, although the superplasticizer dosage was increased at 10% and 15% replacement levels. This may be due to the increased water intake by the bagasse ash, owing to its fineness.
- T_{500} time ranged from 1.6 to 5.6 seconds. The control mix had a T_{500} time of 1.6 seconds which can be thus classified into VS1 ($T_{500} \leq 2$ s) viscosity class as per EFNARC 2005. T_{500} time for the mixes containing bagasse ash was in the range of 3 to 5.6 seconds which show that these mixes belonged to VS2 ($T_{500} > 2$ s) viscosity class as per EFNARC 2005.
- T_{500} time increased as the percentage of bagasse ash increased up to 15%. This is due to the increase in viscosity of the mixes as the percentage level is increased, owing to the filler effect of bagasse ash.

All the mixes satisfied the guidelines laid by EFNARC 2005 for Slump-flow test.

4.2.2 V-funnel time

- The V-funnel time for control mix was 7 seconds and hence can be called as VF1 (V-funnel time ≤ 8 s) viscosity class as per EFNARC 2005.
- The V-funnel time for the mixes containing bagasse ash were in the range of 9.4 to 13.2 seconds which shows that these mixes belonged to VF2 (V-funnel time ranging from 9 to 25 s) viscosity class as per EFNARC 2005.
- The V-funnel time increased as the percentage of bagasse ash increased up to 15%. Control mix having 0% bagasse ash had the lowest V-funnel time. As the percentage of bagasse ash was increased (5, 10 and 15%), the V-funnel time increased, although the superplasticizer dosage was increased at 10% and 15% replacement levels. This is due to the increase in viscosity of the mixes containing bagasse ash. Bagasse ash increases the viscosity of the mix due to finer particle size. Since V-funnel time is related to viscosity, therefore, it increases as the percentage of bagasse ash increases.

All the mixes satisfied the guidelines laid by EFNARC 2005 for V-funnel test.

4.2.3 L-box ratio

- The L-box ratio of all the mixes was between 0.8 and 1.0 which is as per EFNARC 2005 guidelines.
- The L-box ratio decreased with the increase in percentage of bagasse ash up to 15% indicating that the passing ability decreases with increase in percentage of bagasse ash. Since passing ability is related to viscosity, so, the reason for decrease in L-box ratio will be the same as that for the V-funnel time.

Hence, all the mixes could be designated as self-compacting as they conformed to the fresh property (Slump-flow, V-funnel and L-box) specifications laid down by EFNARC 2005.

4.3 EFFECT OF BAGASSE ASH ON HARDENED PROPERTIES OF SCC

4.3.1 Effect on Compressive Strength

The compressive strength test results of SCC mixes are given in Table 4.2 and shown in Figure 4.1.

- SCC-CM (0% bagasse ash) developed compressive strength of 34.29 and 40.21 MPa at the age of 7 and 28 days.
- Among the SCC mixes with bagasse ash, SCC-BA5 (5% bagasse ash) had the highest compressive strength of 37.13 MPa at 7 days and 44.67 MPa at 28 days, which was also highest among all the mixes.
- SCC-BA10 (10 % bagasse ash) and SCC-BA15 (15 % bagasse ash) reported a compressive strength of 35.30 and 33.91 MPa at 7 days; 42.23 and 40.10 MPa at 28 days, respectively.
- The compressive strength of SCC-BA15 mix was slightly lower than that of the control mix (SCC-CM) both at 7 and 28 days.

Table 4.2: Compressive strength of SCC mixes

Mix	Compressive strength (MPa)		Average Compressive strength (MPa)	
	7 days	28 days	7 days	28 days
SCC-CM	33.16	39.31	34.29	40.21
	35.10	39.92		
	34.60	41.40		
SCC-BA5	35.77	46.07	37.13	44.67
	38.66	43.61		
	36.96	44.31		
SCC-BA10	36.30	42.77	35.30	42.23
	35.12	42.60		
	34.48	41.32		
SCC-BA15	32.96	40.51	33.91	40.10
	35.26	38.83		
	33.49	40.96		

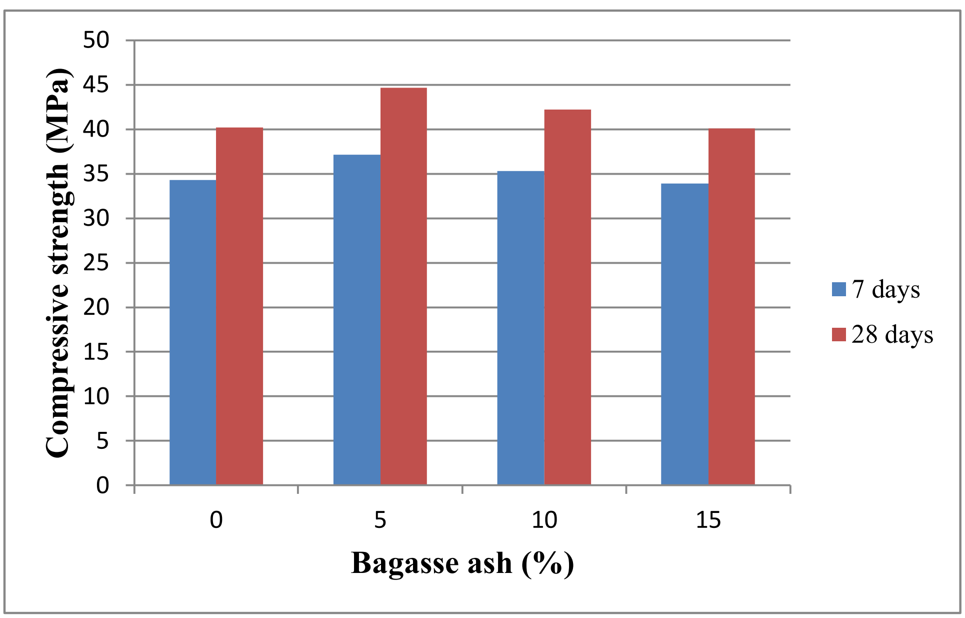


Fig. 4.1 Variation of compressive strength of SCC mixes

Figure 4.1 gives us an indication that the compressive strength of both SCC-BA5 and SCC-BA10 mixes was higher than SCC-CM mix both at 7 and 28 days. When compared to the control SCC mix, the compressive strength of bagasse ash containing SCC mixes increased up to 10% replacement level and then slightly decreased at 15% replacement of cement by bagasse ash.

The reasons for increase in compressive strength up to 10% replacement level may be due to high silica content, fineness, amorphous phase, degree of reactivity of bagasse ash and pozzolanic reaction between calcium hydroxide and reactive silica in bagasse ash as reported by previous works [48-53] for traditional concrete. The reason for the SCC mix having highest compressive strength (mix with 5% replacement) may also be because of the reduced bleeding and increased viscosity of the mix that was observed (when compared with control SCC mix), when the superplasticizer dosage for SCC-BA5 mix was kept same as that of SCC-CM mix. Variation of compressive strength with the superplasticizer dosage is shown in Figure 4.2. Figure 4.3 shows the increase in percentage of compressive strength of SCC mixes containing Bagasse ash with respect to the control mix.

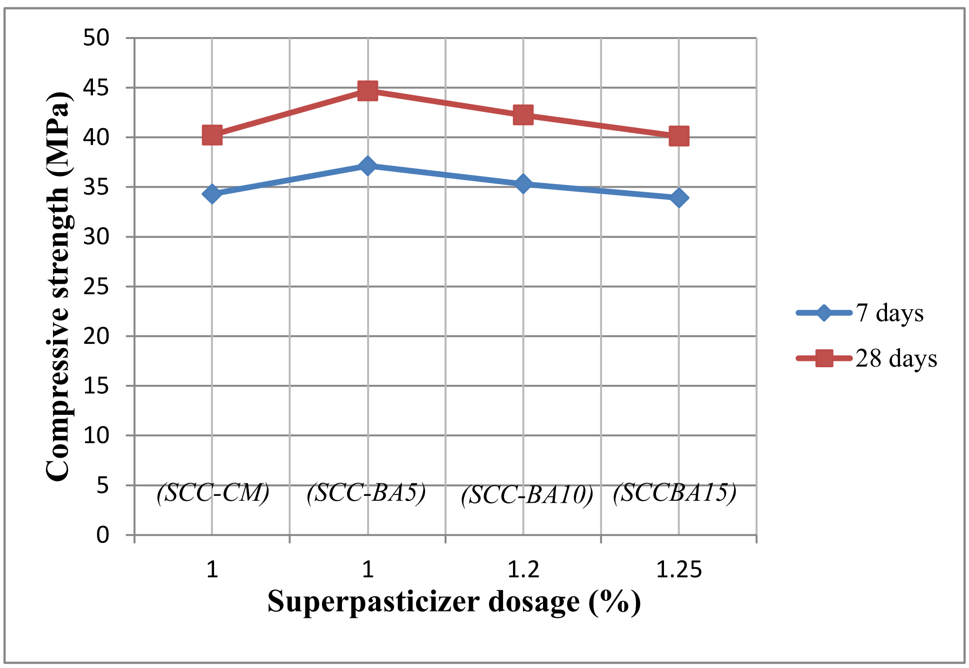


Fig. 4.2 Variation of compressive strength of all mixes with superplasticizer dosage

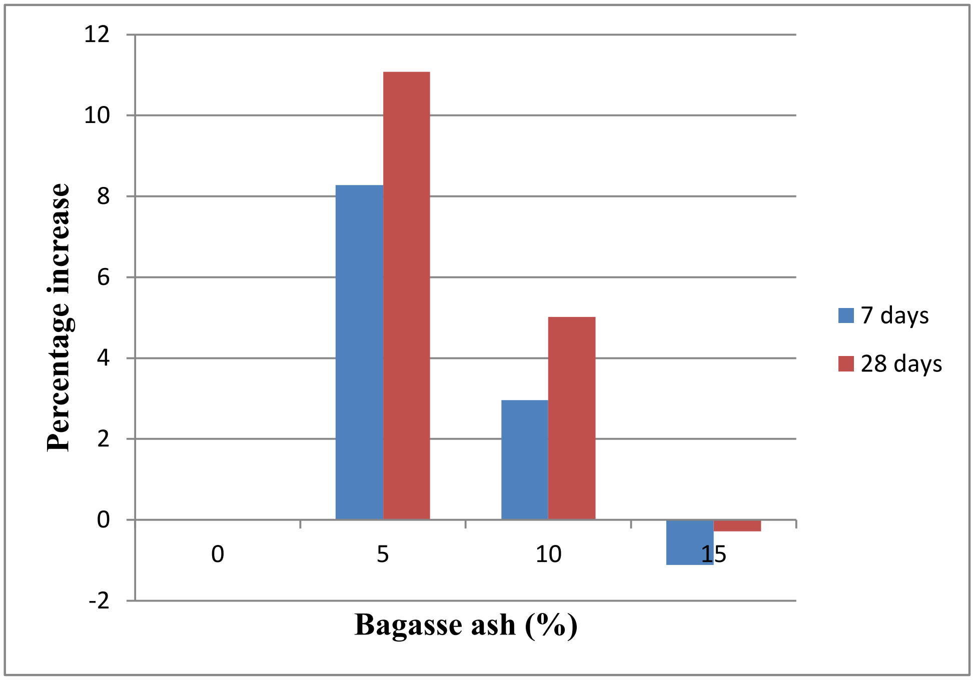


Fig. 4.3 Percentage increase of compressive strength Vs. Bagasse ash

4.3.2 Effect on Splitting Tensile Strength

The splitting tensile strength test results of SCC mixes are given in Table 4.3 and shown in Figure 4.4.

- SCC-CM (0% bagasse ash) developed splitting tensile strength of 2.68 and 3.09 MPa at the age of 7 and 28 days.
- Among the SCC mixes with bagasse ash, SCC-BA5 (5% bagasse ash) had the highest splitting tensile strength of 2.89 MPa at 7 days and 3.38 MPa at 28 days, which was also highest among all the mixes.
- SCC-BA10 (10 % bagasse ash) and SCC-BA15 (15 % bagasse ash) reported a splitting tensile strength of 2.78 and 2.65 MPa at 7 days; 3.30 and 3.05 MPa at 28 days, respectively.
- The splitting tensile strength of SCC-BA15 mix was slightly lower than that of the control mix (SCC-CM) both at 7 and 28 days (the percentage decrease being more in 28 day case).

Table 4.3: Splitting tensile strength of SCC mixes

Mix	Splitting tensile strength (MPa)		Average Splitting tensile strength (MPa)	
	7 days	28 days	7 days	28 days
SCC-CM	2.93	3.22	2.68	3.09
	2.51	2.96		
	2.60	3.09		
SCC-BA5	3.10	3.41	2.89	3.38
	2.91	3.27		
	2.66	3.46		
SCC-BA10	2.65	3.40	2.78	3.30
	2.75	3.28		
	2.94	3.24		
SCC-BA15	2.78	3.17	2.65	3.05
	2.53	3.01		
	2.63	2.95		

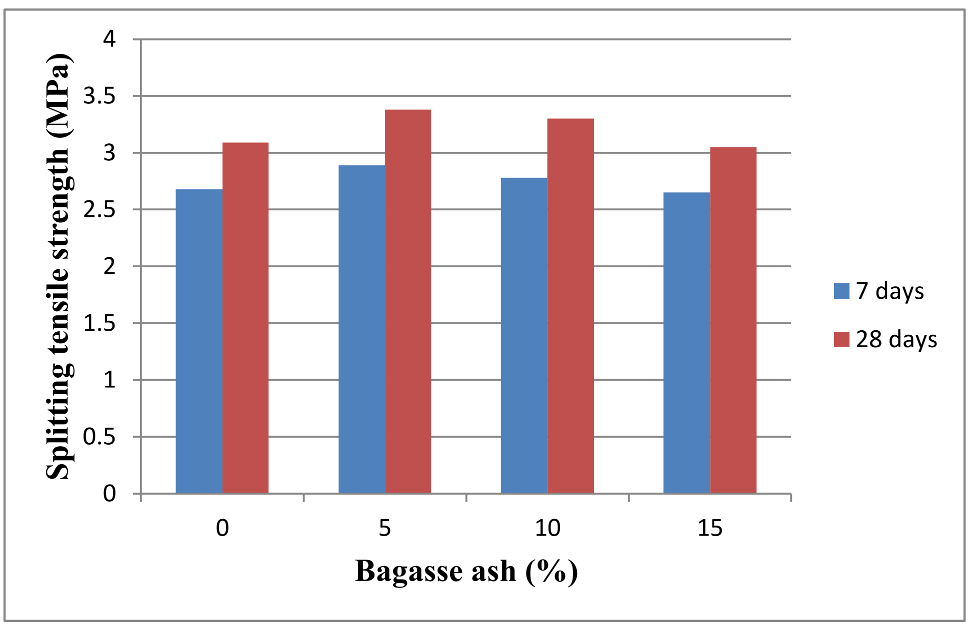


Fig. 4.4 Variation of splitting tensile strength of SCC mixes

Figure 4.4 gives us an indication that the splitting tensile strength of both SCC-BA5 and SCC-BA10 mixes was higher than SCC-CM mix, both at 7 and 28 days. When compared to the control concrete mix, the splitting tensile strength increased up to 10% replacement level and then slightly decreased at 15% replacement of cement by bagasse ash.

The reasons may be similar as mentioned in the compressive strength test results i.e. due to high silica content, fineness, amorphous phase, degree of reactivity of bagasse ash and pozzolanic reaction between calcium hydroxide and reactive silica in bagasse ash. The reason for the SCC mix having highest splitting tensile strength (mix with 5% replacement) may also be because of the reduced bleeding and increased viscosity of the mix that was observed (when compared with control SCC mix) when the superplasticizer dosage for SCC-BA5 mix was kept same as that of SCC-CM mix. Variation of splitting tensile strength with the superplasticizer dosage is shown in Figure 4.5. Figure 4.6 shows the increase in percentage of splitting tensile strength of SCC mixes containing bagasse ash with respect to the control mix.

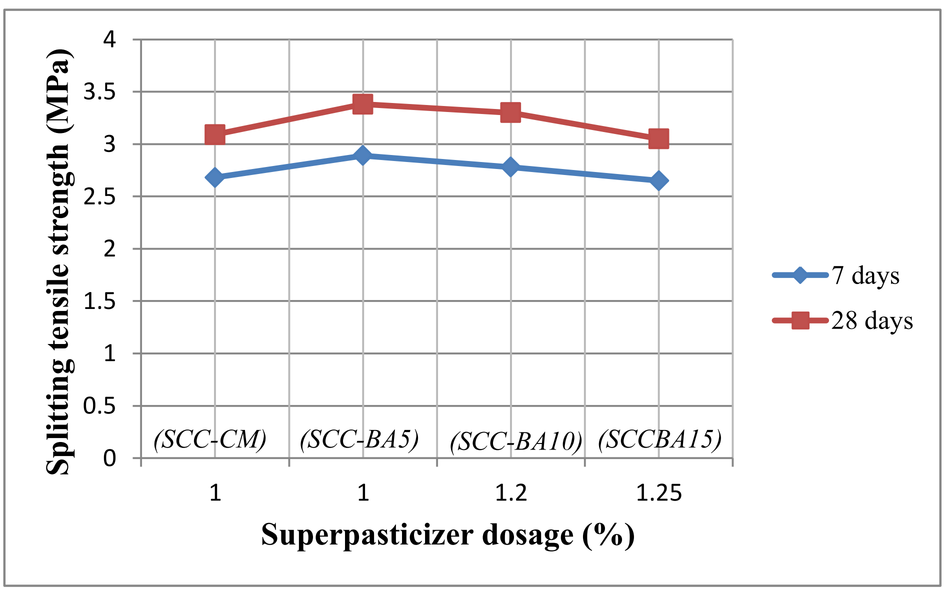


Fig. 4.5 Variation of splitting tensile strength of all mixes with superplasticizer dosage

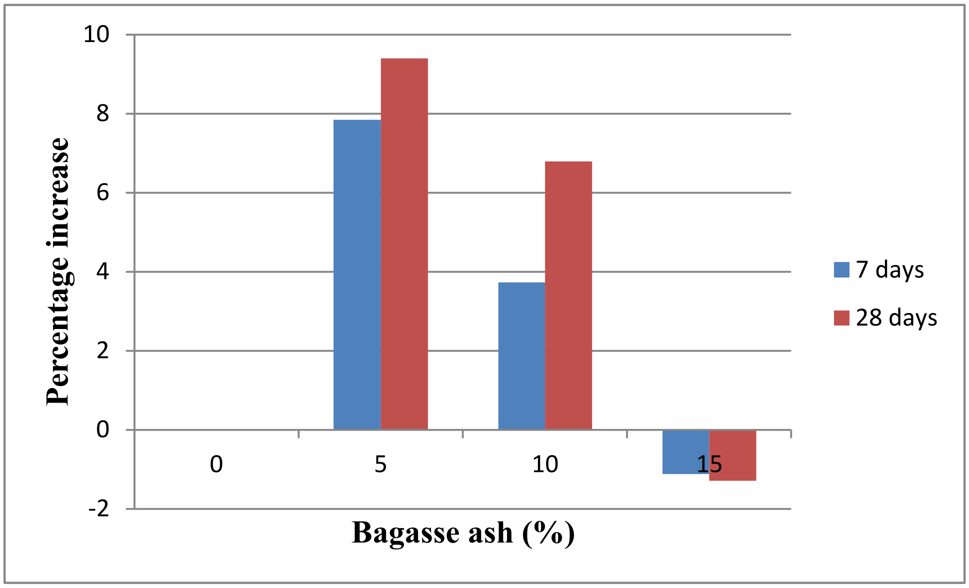


Fig. 4.6 Percentage increase of splitting tensile strength Vs. Bagasse ash

4.4 EFFECT OF BAGASSE ASH ON DURABILITY PROPERTIES OF SCC

4.4.1 Effect on Chloride-ion penetration resistance

The ability of concrete to resist the ingress of chloride ions is an important parameter when it comes to determining the life of concrete structures exposed to marine environments.

The rapid chloride-ion permeability test (RCPT) results showed that the charge passed (Coulombs) decreased with the increase in replacement levels of bagasse ash in self-compacting concrete. The RCPT was conducted at the age of 28 days. Test results of SCC mixes are given in Table 4.4 and shown in Figure 4.7.

Table 4.4: Charge passed and rating for SCC mixes

Mix	Charge passed in Coulomb (C)	Chloride ion penetrability (ASTM C 1202)
SCC-CM	1309	Low
SCC-BA5	1171	Low
SCC-BA10	995	Very low
SCC-BA15	1183	Low

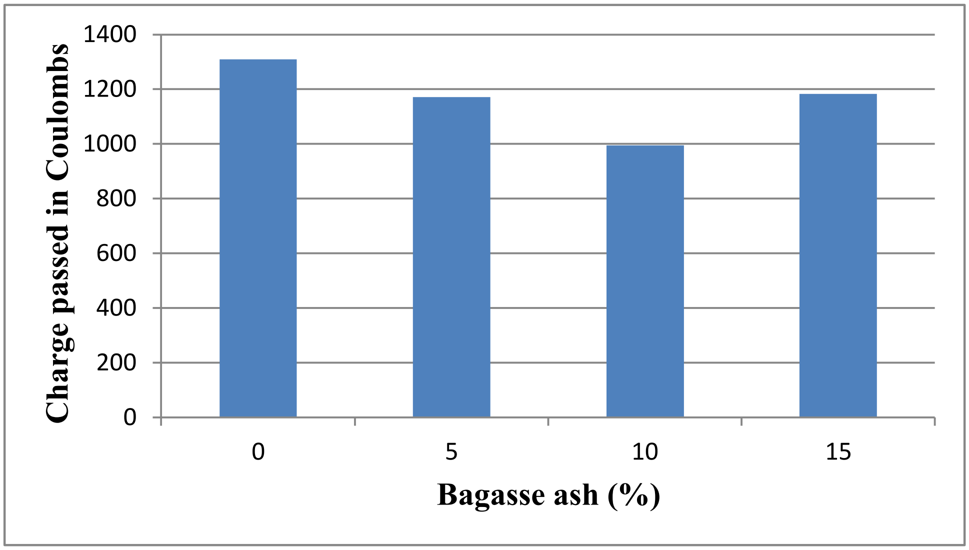


Fig. 4.7 Chloride penetration of SCC mixes

- The charge passed through SCC-CM (0% bagasse ash) was 1309 C.
- However, for SCC mixes with bagasse ash, coulomb charged decreased with the increase in bagasse ash content up to 10%.
- For SCC-BA5 (5% bagasse ash), the charge passed was 1171 C and for SCC-BA10, the charge passed was 995 C. At 15% replacement level, the charge passed increased but was still lower than that of the control mix. For SCC-BA15, the charge passed was 1183 C. All the mixes had 'low' chloride penetrability except for SCC-BA10 mix, which had 'very low' chloride penetrability.

The transport of chloride ions through bagasse ash blended SCC mixes depends on the pore structure of the concrete. Owing to its fineness, bagasse ash fills the micro and macro pores present in concrete, as reported by [54]. The fineness of bagasse ash contributes to a finer pore structure and this fact is responsible for reduced chloride ion permeation. Figure 4.8 shows the decrease in chloride permeability with increase in replacement level of bagasse ash.

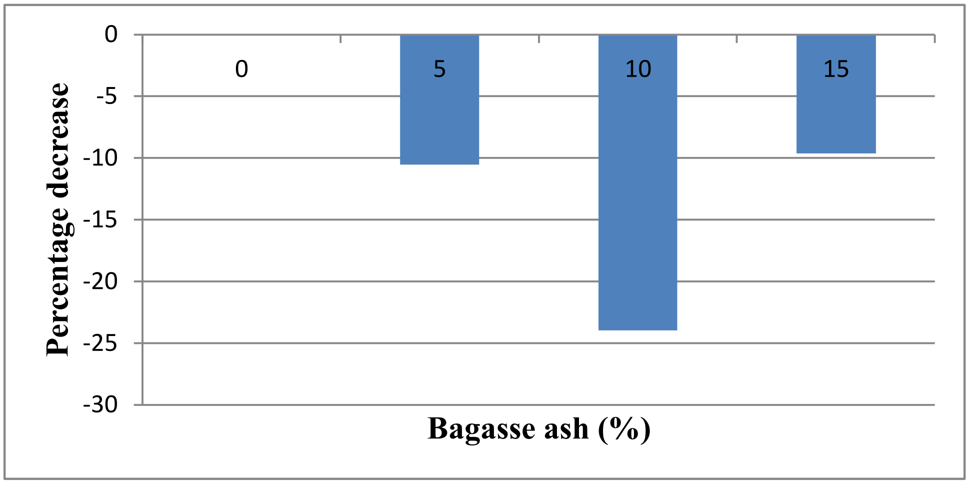


Fig. 4.8 Percentage decrease of chloride-ion penetration Vs. Bagasse ash

4.4.2 Effect on Water absorption

Water absorption of 70.5 mm cubes was measured at the age of 7 days after initial curing of 28 days. The results are given in Table 4.5 and shown in Figure 4.9 below.

Table 4.5: Water absorption of SCC mixes

Mix	Weight of Cube after 24 hour Oven drying, W_1 (g)	Weight of cube after 96 h immersion in water, W_2 (g)	Water absorption (%) = $(W_2 - W_1)/ W_1$ *100	Average water absorption (%)
SCC-CM	836.5	852.5	1.91	1.94
	830.0	847.5	2.11	
	836.0	851.0	1.79	
SCC-BA5	856.0	868.0	1.40	1.31
	820.0	832.5	1.52	
	836.0	844.5	1.02	
SCC-BA10	819.5	835.5	1.95	1.86
	820.0	836.5	2.01	
	828.0	841.5	1.63	
SCC-BA15	826.0	845.0	2.30	2.25
	818.0	837.5	2.38	
	817.0	834.0	2.09	

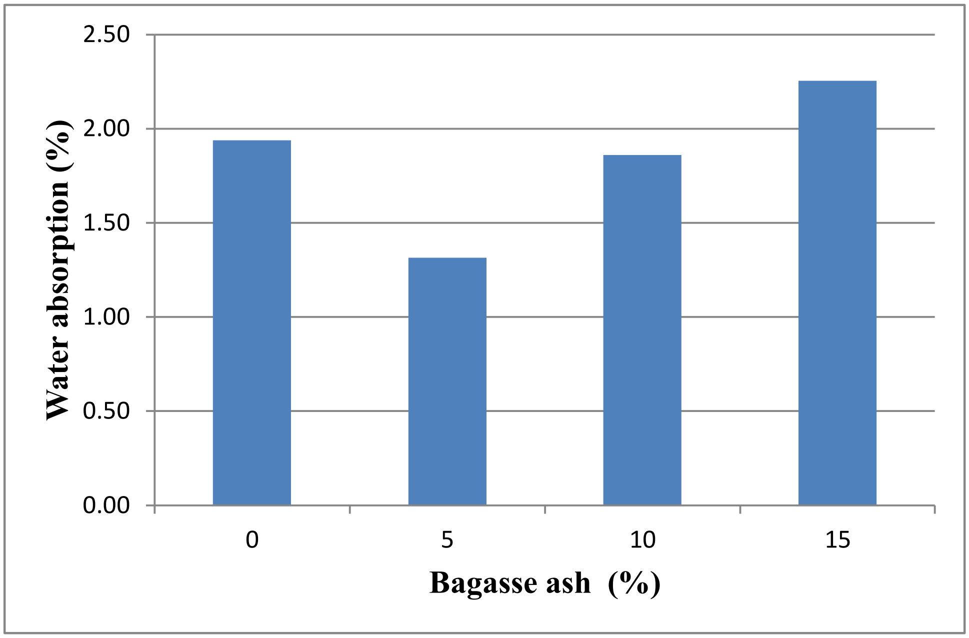


Fig. 4.9 Water absorption of SCC mixes

- SCC-CM (0% Bagasse ash) recorded a water absorption value of 1.94%.
- SCC-BA5 (5% Bagasse ash) recorded the lowest water absorption value of 1.31% among all the mixes. This could be due to SCC-BA5 mix having the highest compressive strength among all the mixes at 28 days, rendering the pore structure dense and hence lower the water absorption.
- Water absorption value of SCC-BA10 (10% Bagasse ash) was 1.86% and that of SCC-BA15 (15% Bagasse ash) was 2.25%; highest among all the mixes.

4.5 CLOSING REMARKS

This chapter presented the analysis of results along with their discussions. Test results of fresh properties (Slump-flow, V-funnel and L-box), strength properties (compressive strength and splitting tensile strength) and durability properties (chloride-ion penetration resistance and water absorption) of SCC mixes containing varying percentages of bagasse ash (0, 5, 10 and 15%) as partial cement replacement were discussed in detail. The next chapter presents the conclusions based on these results.

CHAPTER 5

CONCLUSIONS

This study investigated the effect of bagasse ash on the fresh properties (Slump-flow, V-funnel and L-box), strength properties (compressive and splitting tensile strength) and durability properties (chloride-ion penetration resistance and water absorption) of self-compacting concrete. Cement was partially replaced with bagasse ash with 5, 10 and 15% being the replacement levels. On the basis of results obtained from this experimental investigation, following conclusions can be drawn:

- Fresh property test (Slump-flow, V-funnel and L-box) results show a progressive decrease as the bagasse ash replacement level increases, however all the results meet the specified guidelines by EFNARC 2005 for self-compacting concrete. SCC mix with 5% bagasse ash shows an increase in viscosity and a reduction in bleeding when compared to the control mix.
- Compressive strength of the mix with 5% replacement of cement with bagasse ash shows the highest value, both at 7 and 28 days, among all other mixes. SCC mix with 10% replacement of cement with bagasse ash shows a slight decrement in compressive strength value than the mix with 5% replacement (at both 7 and 28 days), however, the value is still greater than that of the control mix. Compressive strength drops down slightly below that of the control mix at 15 % replacement level.
- Splitting tensile strength of the mix with 5% replacement of cement with bagasse ash shows the highest value both at 7 and 28 days, among all other mixes; much like the compressive strength result. SCC mix with 10% replacement of cement with bagasse ash shows a slight decrement in splitting tensile strength value than the mix with 5% replacement (at both 7 and 28 days), however, the value is still greater than that of the control mix. At 15 % replacement level, splitting tensile strength value slightly drops down below that of the control mix.
- The charge passed in coulombs in all the mixes with bagasse ash was lesser than the charge passed in the control mix. Thus, inclusion of bagasse ash as a replacement of cement in SCC reduces the chloride ion permeability of concrete.

- Water absorption at 5% replacement level is the lowest among all other mixes. However, an increase in the water absorption value is observed at 10 and 15% replacement levels; the value of water absorption at 15% replacement level being higher than that of the control concrete.
- Hence, it can be concluded that optimum replacement of cement with bagasse ash in self-compacting concrete comes out to be 10%; at which the SCC has satisfactory flow characteristics, improved compressive and splitting tensile strength and better durability properties as compared to control mix.

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