PRODUCTION OF LOW COST SELF COMPACTING CONCRETE USING BAGASSE ASH

By

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DEDICATED

TO

MY PARENTS AND FAMILY

ACKNOWLEDGEMENT

I am thankful to All Mighty Allah who gave me the strength to accomplish this research work.

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ABSTRACT

Self Compacting Concrete (SCC) is a development of conventional concrete, in which the use of vibrator for compaction is no more required. This property of self compacting concrete has made its use more attractive all over the world. But its initial higher supply cost over conventional concrete, has hindered its application to general construction. Therefore, for producing low cost SCC, it is prudent to look at the alternates to help reducing the SSC cost. In this study use of bagasse ash in SCC as viscosity modifying agent is evaluated. Variations of bagasse ash and superplasticizer contents and their affect on fresh and hardened properties of SCC are also studied. Hence, this research work is aimed at evaluating the usage of bagasse ash in SCC, and to study the relative costs of the materials used in SCC.

In this research study, the main variables are the proportion of bagasse ash, dosage of superplasticizer for flowability and water / binder ratio. The parameters kept constant are the amount of cement content equal to 500 kg/m^3 and the water content equal to 255 kg/m^3.

Test results substantiate the feasibility to develop low cost self-compacting concrete using bagasse ash. In the fresh state of concrete, the different mixes of concrete have slump flow in the range of 333 mm to 815 mm, L-box ratio ranging from 0 to 1 and flow time ranging from 1.8 seconds to no flow (stucked). Out of twenty five different mixes, five mixes were found to satisfy the requirements suggested by the European federation of national trade associations representing producers and contractors of specialist building products (EFNARC) guide for making self compacting concrete. The compressive strengths developed by the self compacting concrete mixes with bagasse ash at 28 days were comparable to the control concrete.

Cost analysis showed that the cost of ingredients of specific self compacting concrete mix is 37.72 percent less than that of control concrete, both having compressive strength above 34 MPa.

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Chapter 1

INTRODUCTION

1.1 GENERAL

As the structural architecture is getting increasingly intricate, accordingly the modern reinforced concrete design is becoming more advanced and heavily reinforced. Major part of the structure consists of conventional concrete which requires compaction in order to fill the complete formwork for achieving desired strength, durability and homogeneity. It is a well known fact that insufficient compaction drastically lowers the ultimate performance, no matter how well it has been produced and how good is the mix design. Concrete is normally compacted by vibrators often operated by untrained labour and the supervision of this process is inherently difficult. Therefore, standard methods for strength verification on separately cast specimens, which are easy to compact, cannot reliably indicate substandard poorly compacted concrete placed in situ.

Moreover, vibrations can lead to white finger syndrome (a disease) and there is a significant environmental noise imposed on both the work place and around the site. Recent research has also shown that even the perceived full compaction does not actually produce homogeneous, uniform concrete (Wallevik and Nielsson 1998). A compelling case for removing the need for compaction from the general-purpose concrete process has been with us for a very long time.

Self-Compacting Concrete (SCC) is that type of concrete, which requires no inner or outer vibration for the compaction. According to European Project Group (2005), SCC can be defined as "concrete which is able to flow and consolidate under its own weight, completely fill the formwork even in the presence of dense reinforcement, whilst maintaining homogeneity and without the need of any additional compaction".

SCC was first proposed in 1986 by Okamura at Kochi University of Technology, Japan (Barbhuiya and Nimityongskul 2005). The pioneering work established the basic principles of SCC. It offered the best solution in terms of quality control during casting of concrete. The benefits include, no need for compaction, time saving, reduced labour cost and conserving energy. Furthermore, surface finish characteristics can be enhanced thereby minimizing the need for remedial work.

The use of self compacting concrete is spreading world wide because of its very attractive properties in the fresh state as well as after hardening. The use of SCC will lead to a more industrialized production, reduce the technical cost of in situ cast concrete constructions, improve the quality, durability and reliability of concrete structures and eliminate some of the potential for human error. It will replace manual compaction of fresh concrete with a modern semi-automatic placing technology and in that way improve health and safety at and around the construction site. However, this type of concrete needs a more advance mix design and more careful quality assurance with more testing and checking than traditional vibrated concrete.

1.2 PROBLEM STATEMENT

The main requirements for the production of SCC are its high viscosity to avoid the blockage of coarse aggregate when concrete flows through obstacles and high deformability. There are two ways of increasing the viscosity of concrete; first to increase the powder content, second to incorporate a viscosity modifying chemical admixture. The high deformability can be achieved only by the employment of superplasticizer, keeping the water-powder ratio to a very low value. The addition of admixtures in SCC makes its construction expensive. However, the use of less expensive fine materials such as bagasse ash can ensure the required concrete properties without increasing the cost.

Therefore, for producing low cost SCC it is essential to first evaluate whether bagasse ash can be used in SCC, and if so, how its variations will affect the fresh and hardened properties of SCC. Hence, this research study is aimed to investigate the suitability of bagasse ash as a viscosity modifying agent in SCC. It is envisaged that successful utilization of bagasse ash in SCC mixes will achieve desired properties, reduce cost, and provide a solution regarding the disposal and environmental problems related with this industrial by-product.

1.3 OBJECTIVES

The primary objective of this research study is to evaluate and explore the possibility of producing low cost self compacting concrete by using bagasse ash instead of commercially available viscosity modifying admixtures. The specific objectives of this research study are as follow:-

- To develop low-cost SCC using bagasse ash that is locally available in Pakistan as an industrial waste.
- To investigate the influence of the variations of bagasse ash and superplasticizer (used for flowability) on various properties of SCC in fresh and hardened state.
- To study the relative costs of the materials used in SCC.

1.4 SCOPE AND LIMITATIONS

The main variables in this research study are:-

- Water / binder ratio. (0.45, 0.43, 0.41, 0.39 and 0.37)
- Quantity of bagasse ash. (5, 10, 15 and 20 percentage by weight of cement)
- Dosage of superplasticizer for flowability. (2, 2.5, 3, 3.5 and 4 percentage by weight of cement)

The following parameters are kept constant in the research study:-

- Total amount of cement content 500 kg/m^3.
- Quantity of water 225 kg/m^3.
- The ratio of coarse aggregate to fine aggregate content 6:7 (by weight).
- Crushed gravel having a maximum size of 20 mm and 10 mm in equal weight proportion combination as coarse aggregate.
- Grading of sand.

In this study, the binder refers to Ordinary Portland Cement (OPC) and bagasse ash. The control concrete is having cement content of 500 kg/m^3 and water to cement ratio of 0.45. Sikament NN branded superplasticizer for flowability and polycarboxylate based Sika Viscocrete 1, were used for making control concrete.

Chapter 2

LITERATURE REVIEW

2.1 GENERAL BACKGROUND

SCC, which was known as self leveling and cohesive concrete, was firstly studied in 1975-1976 in Europe, according to the data available in the international literature. Moreover, case histories concerning placing of self leveling concrete without vibration were published in the 1980's in Japan. The concept of SCC was first proposed in 1986 by Okamura at Kochi University of Technology, Japan, as a solution to the growing durability concerns of the Japanese government (Barbhuiya and Nimityongskul 2005).

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By 1988, the concept was developed and ready for the first real-scale tests. The first prototype was developed and published in 1988 and is presently followed the Japanese construction industry. SCC using superplasticizers is also being widely used in Europe and has now started gaining global acceptance (Bartos and Grauers 1999).

SCC has been successfully used in different types of structures. The first application of SCC, in Japan, was in a building in June 1990. SCC was then used in the towers of Shinkiba Ohashi Bridge in 1991. The anchorages of Akashi-Kaikyo (Akashi Straits) Bridge opened in April 1998, a suspension bridge with the longest span in the world (1,991 meters), is a typical example of SCC as shown in Fig. 2.1. The resulting concrete has an excellent surface finish is shown in Fig. 2.2. (Okamura and Ouchi 2003). But potential benefits from applications of SCC is not being fully realized because of the cost of additional supervision, site control and the need to rely on technical advice from suppliers of specialist admixtures or assistance from the few contractors or organizations.

Fig. 2.1. Akashi-kaikyo bridge,Japan, using SCC

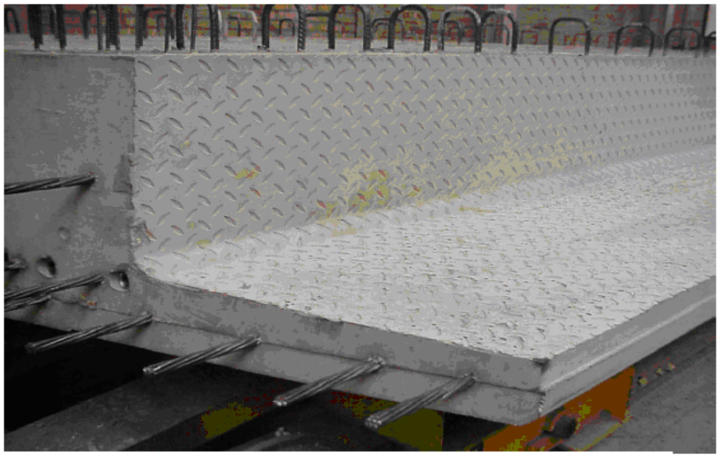

Fig. 2.2. Excellent finish of a concrete element using SCC

SCC can provide tangible opportunities for both the designer and the contractor. Ganesan et al. (2003) gave following advantages of SCC which can greatly improve construction systems as compared over conventional concrete:-

- SCC has made possible in placing the concrete more affordable without vibration in complex shape concrete elements especially in congested reinforcement or casting in remote areas. Thus more innovative designing is possible with SCC.

- High workability and cohesion property of SCC has made pumping of concrete to be placed farther, at faster rate and with lower pumping pressure.
- Elimination of vibrators for compaction of concrete has reduced noise. Thus achieving a calm working environment, thereby, giving it the name “silent concrete”.
- Vibrator operating causes blood circulation problems leading to “white fingers” disease. SCC has reduced this risk giving it the acronym “healthy concrete”.
- Self compacting mixes give homogeneous concrete in the hardened state as it is free of the quality of mechanical vibrator. The influence of bad workmanship is considerably reduced.
- Due to the cohesiveness of the SCC, the formwork does not need to be tighter, as required for traditional vibrated concrete.
- High quality surface finish is feature of SCC. A good level of flowability results in smooth surfaces, minimizing the need for additional surface finish and screeding.

The salient mentioned above regarding the usage of SCC substantiate, reduction in construction cost, shorten construction time, lesser remedial work, less labor required, and finally cost effective.

2.2 MIX COMPOSITION, PROPERTIES AND CONCEPT OF SCC

The composition of SCC consists of the same components as conventionally vibrated ordinary concrete, which are cement, aggregate, water, additives and admixtures. In order to accommodate the requirements for its key properties when fresh, the approach to the mix design of SCC differs from that of ordinary concrete. Compared with ordinary concrete, SCC mix design must lead to a fresh mix that has the following basic properties (Barbhuiya and Nimityongskul 2005).

- Filling ability: (unconfined flowability) SCC must be able to flow into all the spaces within the formwork under its own weight. This is related to workability, as measured by the slump-flow.
- Passing ability: (confined flowability) SCC must flow through tight openings such as spaces between steel reinforcing bars, under its own weight.
- Resistance to segregation: (stability) SCC must meet the above two requirements while its original composition remains uniform during transport and placing.

Segregation resistance plays an important role for SCC because poor segregation resistance can cause poor deformability, blocking around reinforcement and high drying shrinkage as well as non-uniform compressive strength of concrete. Again, a highly flowable concrete is not necessarily self compacting, because SCC should not only flow under its own weight but also fill the entire form and achieve uniform consolidation without segregation. Hence, the method for achieving self compactability involves not only high deformability of paste or mortar, but also resistance to segregation between coarse aggregate and mortar when the concrete flows through the confined zone of reinforcing bars. Typical acceptance criteria for SCC with a maximum aggregate size up to 20mm, is shown in Table 2.1 (EFNARC 2002).

Table 2.1. Acceptance Criteria for SCC

Method	Properties	Unit	Typical Range of Values	
			Minimum	Maximum
Slump-flow by Abrams Cone	Filling ability	mm	650	800
T_{50cm} Slump-flow	Filling ability	sec	2	5
J-ring	Passing ability	mm	0	10
V-funnel	Filling ability	sec	6	12
V-funnel at $T_{5minutes}$	Segregation resistance	sec	0	+3
L-box	Passing ability	(H_2/H_1)	0.8	1.0

Table 2.1. (Continued)

Method	Property	Unit	Typical Range of Values	
			Minimum	Maximum
U-box	Passing ability	(H_2-H_1) mm	0	30
Fill-box	Passing ability	%	90	100
GTM screen stability test	Segregation resistance	%	0	15
Orimet	Filling ability	sec	0	5

To achieve these basic properties, SCC mix was redesigned (Vachon). The mix design procedure focused on three different aspects:-

- Reduction of the coarse aggregate content in order to reduce the friction, or the frequency of collisions between them, increasing the overall concrete fluidity.
- Increasing the paste content to further increase fluidity.
- Managing the paste viscosity to reduce the risk of aggregate blocking when the concrete flows through obstacles.

The role of high volume of paste (cement + additions/filler + efficient water + air) in the concrete is to minimize friction between aggregates, to increase workability and to create a dispersion effect. Okamura effectively produced SCC using this Excess Paste Theory (Tviksta 2000), by increasing the amount of fines to combat aggregate segregation and bleeding while reducing the amount of coarse aggregates as shown in Fig. 2.3. In doing so, he greatly reduced the frequency of aggregate collisions; subsequently reducing internal friction and stress while increasing overall concrete fluidity.

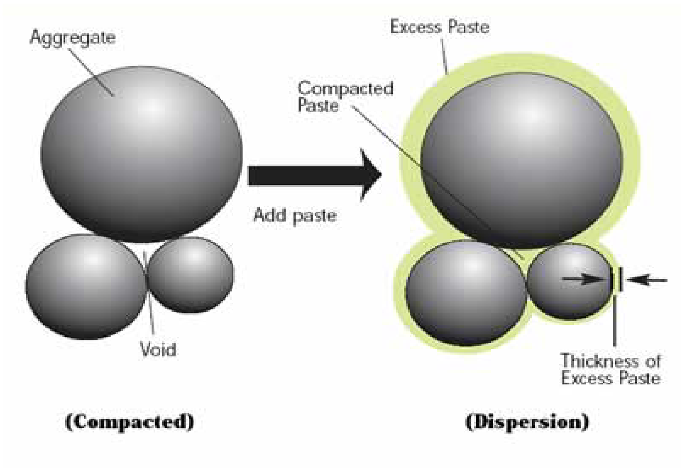

Fig. 2.3. Excess paste theory

SCC mixes, therefore, contain higher than normal proportions of fine materials. The total fines content is balanced against the aggregate size and grading and the water content, assisted by admixtures as shown in Fig. 2.4 (Tviksta 2000). The high powder content acts as lubricant for the coarse aggregates and the high amount of superplasticizer is used for better workability. Drying shrinkage and creep are under long-term investigation, but preliminary results do not indicate abnormal increases.

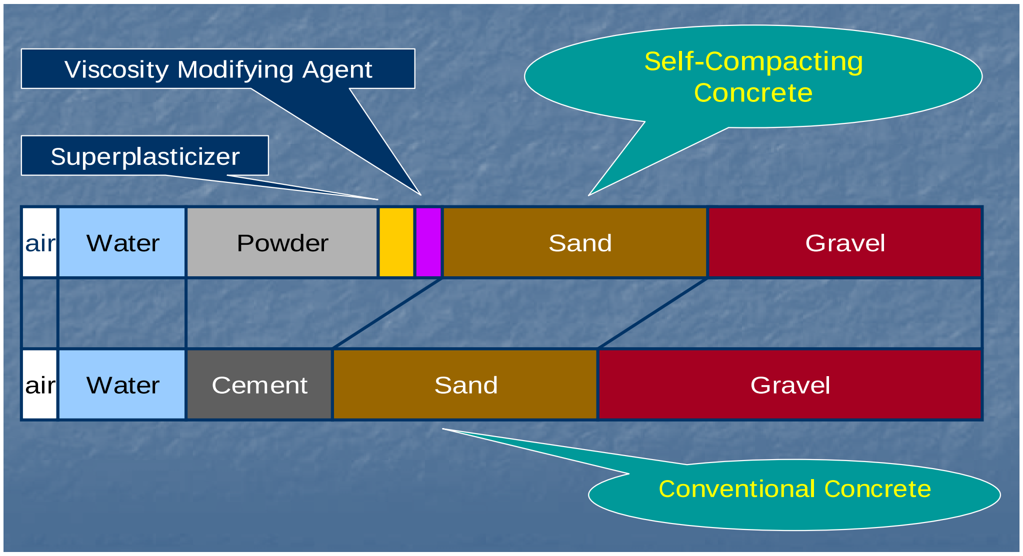

Fig. 2.4. Comparison in mix proportioning of SCC and conventional concrete

To achieve the required fresh properties of deformability, segregation resistance and passing ability, SCC often uses a combination of a greater number of constituent materials than in normal concrete. For example, the paste can contain one or more cement replacement materials, inert fine fillers, superplasticizers, and viscosity agents. Hence besides OPC, fine material like bagasse ash, fly ash, blast furnace slag, limestone powder, silica fume, quartzite powder or dolomite powder should also be used if the requirement of SCC is achieved.

Recently, some researchers investigated the behavior of SCC with several types of pozzolanic material like fly ash, dolomite powder, blast furnace slag, limestone and silica fume to replace some part of cement (Barbhuiya 2005). Fly ash and limestone powder are found to be the traditional materials to be used in controlling the segregation potential and deformability of fresh SCC. This research deals with the utilization of an alternative material, which is bagasse ash, for SCC applications. Limited amount of research works has been done on SCC in the developing countries. The benefits of this investigation will be two-fold, firstly, reducing the construction cost while using SCC, secondly, using bagasse ash, which is an industrial waste, makes it environment friendly also.

2.3 PREVIOUS RESEARCH

Kim and Han (1997) investigated the rheological properties of binders for self-compacting high performance concrete. The binders were composed of OPC, fly ash, two types of ground blast furnace slag and limestone powder. Test results indicated that the binders incorporating fly ash are more appropriate than the other types of binders for quality control of SCC.

Murai et al. (1998) conducted a research to clarify the applicability of classified fly ash on SCC. The properties of SCC using classified fly ash were compared with properties of SCC using other admixtures, such as blast furnace slag powder, limestone powder and ordinary fly ash. In this study, SCC that had maximum rising height by box test under the same amount of aggregates in each admixture was obtained; consistency of fresh concrete and durability of hardened concrete was examined. It was found from the test results that under the same mix proportion condition with fixed slump flow value and amount of aggregate, classified fly ash were inferior to other admixtures from the stand point of self-compactability.

Yahia et al. (1999) carried out investigation on the effect of rheological parameters on self-compactability of concrete containing various mineral admixtures. They concluded that the use of fly ash and blast furnace slag in SCC reduces the dosage of superplasticizer needed to obtain similar slump flow compared to concrete made with Portland cement only.

Bouzoubaa and Lachemi (2001) have demonstrated that it is possible to design an SCC incorporating high volumes of class F fly ash. In terms of mix design cost, the economical SCC that achieved a 28 day compressive strength of approximately 35 MPa was done with 50 percent replacement of cement by fly ash with water to cementitious materials ratio of 0.45. This SCC can replace the control concrete with similar 28 days compressive strength (35 MPa) with no extra cost.

Ho et al. (2001) studied the utilization of alternative materials, such as quarry dust, for SCC applications. Results from rheological measurements on pastes and concrete mixes incorporating limestone or quarry dust were compared. It was found that the quarry dust, as supplied, could be used successfully in the production of SCC. However, due to its shape and particle size distribution, mixes with quarry dust required a higher dosage of superplasticizer to achieve similar flow properties.

Sonebi and Bartos (2002) carried out an investigation to study the filling ability and plastic settlement of SCC. The SCC mixes incorporated various combinations of fine, inorganic powders and admixtures. The slump flow of all SCC's was greater than 500 mm and the time in which the slumping concrete reached 600 mm was less than 3 seconds. The flow time was found to be less than 5 seconds. The results on SCC were compared to a control mix.

Knights and Wimpenny (2002) have developed an SCC mix for a major underwater concreting pour at a navel dockyard. The use of 75 percent ground granulated blast furnace slag (GGBS) in combination with the blending of single-sized limestone aggregate and limestone fines provided a mix with a low heat of hydration and thermal expansion coefficient to address the risk of early age thermal cracking. Careful selection of the type and dosage of superplasticizer and an underwater admixture gave a concrete with acceptable flow characteristics and good resistance to paste and fines washout and segregation.

Felekoglu et al. (2003) carried out a comparative study on the use of mineral and chemical types of viscosity enhancers in self-compacting concrete. The best performance, on early strength development has been obtained by incorporation of limestone powder. Mixes with fly ash showed poor early strength development due to the slow pozzolanic reaction nature of fly ash. However, the best performance on 28 days compressive strength has been obtained in mixes with fly ash. By incorporating fly ash, it was possible to produce high strength self-compacting concrete (60 MPa) with cement contents as low as 340 kg/m^3.

Sonebi et al. (2003) described the developing and evaluating methods for SCC by incorporation of pulverized fuel ash (PFA). The four key mix constituents used in the models included superplasticizer, cement and PFA filler contents and water/powder ratio. Responses included slump flow, rheological parameters, V-funnel flow, L-box, J-ring + Orimet test, settlement segregation column test and the compressive strengths at 7 and 28 days. The results showed that a low cost SCC can be achieved with compressive strength at 28 days of 30 MPa by using up to 210 kg/m^3 of PFA.

Barbhuiya (2005) has developed SCC by utilizing fly ash and dolomite powder for enhancing viscosity properties of SCC application. Fly ash and dolomite powder were used as replacement of viscosity modifying chemical admixture for producing low cost SCC. The results showed slump flow in the range of 550 to 650 mm, flow time ranging from 5 to 8 sec and L-box ratio ranging from 0.65 to 0.8. The mix containing fly ash and dolomite powder in the ratio 3:1 was found to satisfy the requirements suggested by EFNARC (EFNARC 2002). The cost of ingredients of SCC (containing fly ash and dolomite powder in the ratio 3:1) was 28.36 percent less than the control concrete, both having approximate compressive strength of 35 MPa. However, it should be noted that the properties of such low cost SCC might not be as good as that of control concrete.

Chapter 3

EXPERIMENTAL INVESTIGATION

3.1 MATERIALS

The materials along with specifications, which were used for this experimental program, are summarized below.

3.1.1 Cement

Ordinary Portland Cement (OPC), Type I conforming to ASTM C150-04, was used for the experimental work.

3.1.2 Fine Aggregate

Natural sand (quarry site at Nazampur, Khairabad) was used for mixing all samples. The sieve analysis was performed in accordance with ASTM C136-01. The specific gravity and the percentage absorption were determined in accordance with ASTM C128-01.

The results of sieve analysis of fine aggregate as compared with the requirement of ASTM C33-03 are summarized in Appendix I (Table 3.1). The physical properties of fine aggregate are summarized in Appendix I (Table 3.2). The detailed calculations involved are shown in Appendix II.

3.1.3 Coarse Aggregate

Crushed limestone (quarry site at Bassay, Peshawar) having maximum size of 20 mm was used as coarse aggregate. Two different nominal sizes were mixed, namely, 10 mm and 20 mm. The mixing ratio of 10 mm to 20 mm aggregates was 1:1 by weight. The sieve analysis was determined in accordance with ASTM C136-01. The specific gravity and the percentage absorption were determined in accordance with ASTM C127-01.

The results of sieve analysis of coarse aggregate as compared with the requirement of ASTM C33-03 are summarized in Appendix I (Table 3.3). The physical properties of coarse aggregate are summarized in Appendix I (Table 3.4). The detailed calculations involved are shown in Appendix II.

3.1.4 Superplasticizers

To achieve superior workability and placeability over conventional high range water reducing admixtures, Sikament NN was used. The dosage of superplasticizer was varied from 2 to 4 percent by weight of binder content.

The superplasticizer for viscosity is commercially branded as Sika Viscocrete 1 and was used for making the control concrete. The dosage of superplasticizer was kept as 2 percent by weight of binder for all control concretes.

3.1.5 Bagasse Ash

Bagasse is a waste material of sugarcane industry and the ash produced by burning it is termed as bagasse ash. For this study, bagasse ash was obtained from Premier Sugar Mill, Mardan. Los Angles Abrasion machine was used for the grinding purpose. Bagasse ash was ground by giving 2500 revolutions. The resulting ash was then sieved through sieve no. 100. Retained ash was discarded and ash passing through this sieve was again ground for 500 revolutions. The ash was further sieved through sieve no. 200 and the passing ash was used for experimental purpose. The ash was tightly packed in the polythene bag and was stored in dry place before use.

Bagasse ash was used as 5, 10, 15 and 20 percent by weight of cement. Each percentage was further combined with the varying quantity of superplasticizer for flowability.

3.1.6 Physical and Chemical Properties of OPC and Bagasse Ash

The physical and chemical properties of OPC and bagasse ash are illustrated in Appendix I (Table 3.5 and Table 3.6).

3.1.7 Mixing Water

Ordinary tap water from Nowshera was used for the entire experimental work.

3.2 DESIGNATION OF THE SPECIMENS

The various mixes used in this experimental program are abbreviated in two different forms, namely CC2SP and 5B2SP. In case of CC2SP, CC refers to the Control Concrete mix made by incorporating viscosity modifying admixture and 2SP refers to the amount of Superplasticizer in percent by weight of binder content. This particular designation represents Control Concrete mix having 2 percent of Superplasticizer by weight of binder content.

Similarly, in 5B2SP, 5B refers to the percentage of the Bagasse Ash by weight of binder content and 2SP refers to the amount of Superplasticizer in percent by weight of binder content. This particular designation represents mix having 5 percent of Bagasse Ash with 2 percent of Superplasticizer by weight of binder content.

3.3 MIX PROPORTIONS

For the entire experiment work, twenty five different mixes were prepared. These include five control concrete mixes and twenty mixes with different proportions of bagasse ash and superplasticizer for flowability. The experimental matrix for the mix design is summarized in Appendix I (Table 3.7).

3.4 PREPARATION AND CASTING OF SPECIMENS

From each concrete mix, six 150 mm x 300 mm cylinders were casted. These cylinders were used for the determination of compressive strengths at 7 and 28 days and were casted without vibration. After casting, all the moulded specimens were covered with plastic sheets and kept in casting room for 24 ± 8 hours. These were then demoulded and were transferred to the moist curing room at 23 ± 2 ^{0}C and 100 percent relative humidity until required for testing.

3.5 TESTING OF SPECIMENS

It is important to appreciate that none of the test method for SCC has yet been standardized and the tests described are not yet perfected or definitive. The methods presented here are descriptive rather than fully detailed procedures. They are mainly ad-hoc methods, which have been devised specifically for SCC (EFNARC 2002).

In considering these tests, there are a number of points which should be taken into account:-

- One principal difficulty in devising such tests is that they have to assess three distinct properties of fresh SCC i.e. filling ability, passing ability and resistance to segregation. So far, no single test can measure all the three properties.
- There is no clear relation between test results and performance on site.
- There is little precise data, therefore no clear guidance on compliance ranges.
- Duplicate tests are advised.
- The test methods and values are stated for maximum aggregate size of up to 20 mm.

3.5.1 Slump Flow Test

It is the most commonly used test and gives a good assessment of filling ability. The apparatus is shown in Fig. 3.1. However, it can be argued that the completely free flow, unrestrained by any boundaries, is not representative of what happens in practice in concrete construction, but the test can be profitably used to assess the consistency of supply of ready-mixed concrete to a site from load to load.

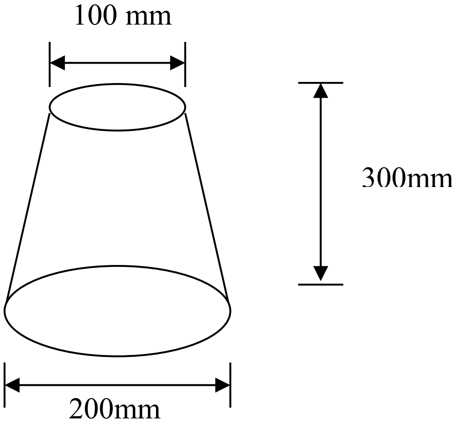

Fig. 3.1. Slump flow apparatus

3.5.1.1 Procedure

About 6 litre of concrete is needed to perform the test. At first, the inside of slump cone and the smooth leveled surface of floor on which the slump cone is to be placed are moistened. The slump cone is held down firmly. The cone is then filled with concrete. No tamping is done. Any surplus concrete is removed from and around the base of the cone. After this, the cone is raised vertically and the concrete is allowed to flow out freely. The diameter of the concrete in two perpendicular directions is measured. The average of the two measured diameters is calculated. This is the slump flow in mm.

3.5.1.2 Interpretation of Result

The higher the slump flow value, the greater its ability to fill formwork under its own weight. A value of at least 650 mm is required for SCC. As per EFNARC guide (EFNARC 2005), the range is from 650 mm to 800 mm. At more than 700 mm the concrete might segregate, and at less than 500 mm the concrete is considered to have insufficient flow to pass through highly congested reinforcement.

3.5.2 L - Box Test

It assesses filling and passing ability of SCC and significant lack of stability (segregation) can be detected visually. The apparatus is shown in Fig. 3.2. The apparatus consists of a rectangular-section box in the shape of an ‘L’, with a vertical and horizontal section, separated by a movable gate, in front of which vertical lengths of reinforcement bar are fitted. The vertical section is filled with concrete, and then gate lifted to let the concrete flow into the horizontal section. When the flow has stopped, the height of the concrete at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section. It indicates the slope of the concrete when at rest. This is an indication of passing ability or the degree to which passage of concrete through the bars is restricted.

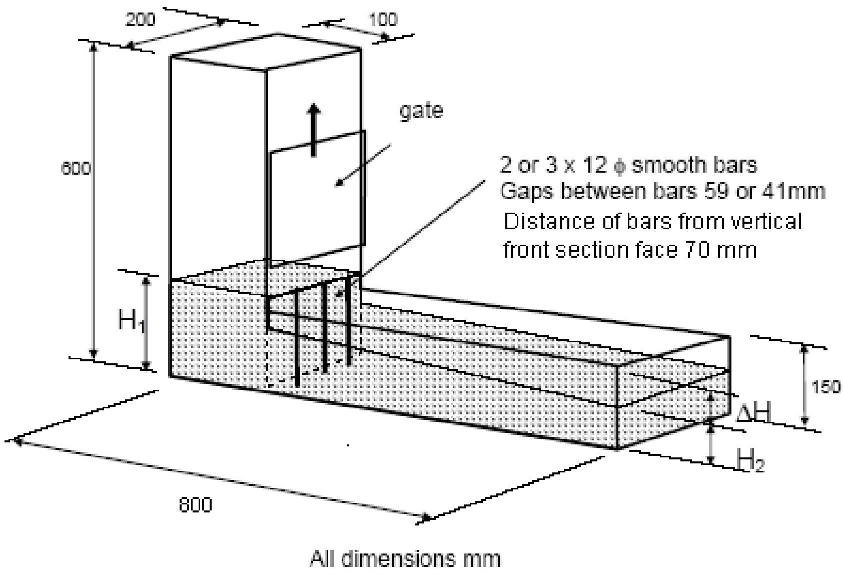

Fig. 3.2. L - box apparatus

3.5.2.1 Procedure

About 14 litre of concrete is needed to perform the test. The apparatus is set on a leveled firm ground and it is ensured that the sliding gate can be opened and closed freely. The inside surfaces of the apparatus is moistened. The vertical section of the apparatus is filled with concrete and is left for 1 minute. Then the sliding gate is lifted and the concrete is allowed to flow out into the horizontal section. When the concrete stops flowing, the distance 'H_1' and 'H_2' are measured. The 'H_2/H_1' is the blocking ratio. The whole test has to be performed within 5 minutes.

3.5.2.2 Interpretation of Result

If the concrete flows as freely as water, at rest it will be horizontal, so ratio H_2/H_1 will be equal to one. Therefore, closer to unity value of ratio H_2/H_1 indicates better flow of concrete. The EFNARC guide (EFNARC 2005) gives a range of 0.8 to 1.0 for this ratio. Moreover, obvious blocking of coarse aggregate behind the reinforcing bars can be detected visually.

3.5.3 V-Funnel Test at $T_{5minutes}$

The test is designed to measure flowability and segregation resistance. The apparatus is shown in Fig. 3.3. The test was developed in Japan. Though the test is designed to measure flowability, the result is affected by concrete properties other than flow. The apparatus is simple, but the effect of the angle of the funnel and the wall effect on the flow of concrete are not clear.

3.5.3.1 Procedure

About 12 litre of concrete is needed to perform the test. The V-funnel is set firmly on the ground and the inside surfaces are moistened. The trap door is closed and a bucket is placed underneath. The apparatus is completely filled with concrete without compacting or tamping. After filling the concrete, the trap door is opened within 10 seconds and the concrete is allowed to flow out under gravity. Stopwatch is started when the trap door is opened and the time for the discharge to complete is recorded. The complete test is to be performed within 5 minutes. To measure the flow time at $T_{5minutes}$, the trap door is closed, V-funnel is refilled immediately after measuring the flow time. The apparatus is completely filled with concrete without compacting or tamping. The trap door is opened 5 minutes after the second fill of the funnel and the concrete is allowed to flow out under gravity. The stopwatch is started when the trap door is opened and the time for the discharge to complete is recorded. This is the flow time at $T_{5minutes}$.

3.5.3.2 Interpretation of Result

Shorter flow time indicates greater flowability. For SCC a flow of 10 seconds is considered appropriate. As per EFNARC guide (EFNARC 2005), the minimum and maximum time of flow are 6 and 12 seconds respectively and the time increase in V-funnel at T $_{5minutes}$ is 3 seconds (maximum). However, according to Khayat and Manai, a funnel test flow time less than 6 seconds is recommended for a concrete to qualify as SCC.

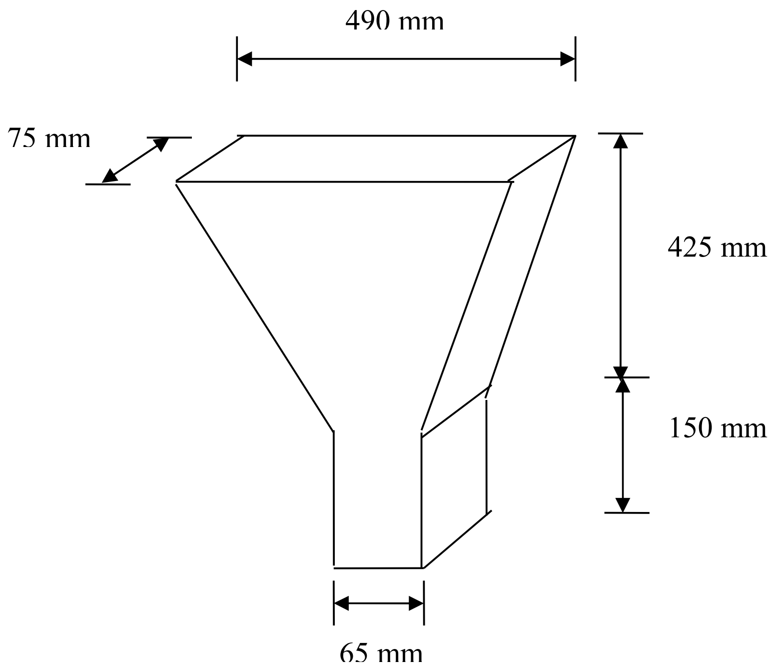

Fig. 3.3. Apparatus for V-funnel test at T $_{5minutes}$

Chapter 4

TEST RESULTS AND DISCUSSION

4.1 ANALYSIS OF PROPERTIES OF FRESH SCC

Properties of freshly mixed concrete were tested for qualifying within the specified EFNARC range of SCC (EFNARC 2002). The results obtained from different tests are summarized in Appendix III (Table 4.1).

4.1.1 Slump Flow Test Analysis

The slump flow for all control concrete mixes were within the ranges of SCC, whereas, for all other SCC mixes, the slump flow was between 333 mm to 815 mm, which have exceeded both the minimum and maximum range. The results of slump flow show that the flow increased with the increase in the quantity of superplasticizer used for flowability. Proportionally, the flow decreased with the increased quantity of bagasse ash. Slump flow results are shown in Appendix III (Fig. 4.1 to Fig. 4.5). The dosage of superplasticizer was constant in each figure.

4.1.2 L - Box Test Analysis

While testing the concrete for passing ability, few of the mixes were so viscous that they could not even reach the other end of the horizontal section of the L – box, whereas, majority of the mixes passed through the bars very easily and without any blockage. The experimental readings achieved in the L - box test were from 0 to 1. L - box test results are shown in Appendix III (Fig. 4.6 to Fig. 4.10). The dosage of superplasticizer was constant in each figure.

4.1.3 V - Funnel Test Analysis

As far as filling ability of the mixes was concerned, most of the results of V - funnel tests remained more towards the minimum range or even lesser. This showed more filling ability but less viscous mix. But as the quantity of bagasse ash was increased, the viscosity of the mix started increasing. V - funnel test results are shown in Appendix III (Fig. 4.11 to Fig. 4.15). The dosage of superplasticizer was constant in each figure.

4.1.4 V - Funnel at $T_{5minutes}$ Test Analysis

V - funnel at $T_{5minutes}$ test shows the potential to segregation resistance. The results of this test remained very encouraging and within the EFNARC range. V - funnel at $T_{5minutes}$ test results are shown in Appendix III (Fig. 4.16 to Fig. 4.20). The dosage of superplasticizer was constant in each figure.

Properties of freshly mixed concrete, which qualified all the four tests range limits, were five in numbers. Among them were 10B2.5SP, 15B2.5SP, 15B3SP, 20B3.5SP and 20B4SP. The concrete mixes which remained very close to the EFNARC range were also five. They were CC2SP, 5B2.5SP, 5B3SP, 10B3SP and 10B3.5SP. Four mixes were totally out of the range of all four tests. They were 10B2SP, 15B2SP, 20B2SP and 20B2.5SP.

4.2 COMPRESSIVE STRENGTH OF SCC

The compressive strengths of twenty five mixes for 7 and 28 days are summarized in Appendix IV (Table 4.2 and Table 4.3) respectively. The results are also shown graphically in Appendix IV (Fig. 4.21 to Fig. 4.25). The compressive strength is also shown graphically in Appendix IV (Fig. 4.26 to Fig. 4.30).

Among the five control concrete mixes, the control concrete CC2SP developed highest compressive strength of 37.71 MPa after 28 days. As compared with the mixes which contained bagasse ash, two mixes showed higher strengths than that of control concrete. They were 15B2SP and 20B2SP having 39.59 and 37.93 MPa respectively. Both these mixes have higher proportion of bagasse ash and lower dosage of superplasticizer. More quantity of bagasse ash causes a reaction between calcium hydroxide generated from the hydration of OPC, which leads to the formation of additional C-S-H gel and results in higher density and strength. 20B4SP mix had shown the lowest strength of 19.03 MPa, although it had a higher quantity of bagasse ash. The only difference was of the dosage of superplasticizer. More the dosage of superplasticizer than the required quantity, lesser the strength would be. Mixes with lesser dosage of superplasticizer showed more compressive strength after 7 and 28 days both in control concrete and other mixes irrespective of the fact that the mix was within the range of fresh SCC tests or not.

4.3 DENSITY OF HARDENED SCC

Densities of all the mixes are also shown in Appendix IV (Table 4.2 and Table 4.3). The results are shown graphically in Appendix IV (Fig. 4.26 to Fig. 4.30). Control concrete achieved maximum density of 2388.9 kg/m^3 with 2 percent of superplasticizer for flowability. The density increased with the increase in the content of bagasse ash and reached the maximum value when 15 percent of bagasse ash was used. This is due to the fact that control concrete was having less powder content than the other mixes. Among the mixes, which contained 15 percent of bagasse ash, the maximum density achieved was the mix which contained 2 percent of dosage of superplasticizer.

The decrease in density of the mix when 20 percent of bagasse ash was used showed that the pores present in the concrete were completely filled by bagasse ash when 15 percent bagasse ash was used. This is due to the fact that the density is a function of specific gravity of bagasse ash when other parameters such as cement and water contents are kept constant. Since, the specific gravity of bagasse ash is less than that of cement therefore density of the mix decreased when bagasse ash took the place of cement after filling all the pores in the concrete.

4.4 COMPARISON OF COST ANALYSIS BETWEEN CONTROL CONCRETE AND OTHER CONCRETE MIXES

Cost analysis of the materials used, has been analyzed as per the purchased price from the market (as of February 2006). The control concrete and other mixes selected for calculation and analysis were those which could pass maximum properties of freshly mixed concrete and also had almost same and reasonable compressive strengths. Keeping these criteria, the mixes selected were CC2.5SP, among the control concrete mixes, and 15B2.5SP, among the other mixes. The detailed calculations are summarized in Appendix V (Table. 4.4).

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Analyzing the experimental results obtained from the fresh and hardened concrete tests carried out in this study, the following conclusions can be drawn:

- The possibility of developing low cost SCC using bagasse ash is feasible. Low cost SCC can be made, by incorporating some percentage of bagasse ash along with the main ingredients of concrete (cement, fine aggregate and coarse aggregate) and superplasticizer for flowability. Water to binder ratio has to be decreased while using bagasse ash as a viscosity enhancing material.
- By increasing different percentages of bagasse ash with the same content of cement, SCC achieved the slump flow values from 333 mm to 815 mm, L - box values from 0 to 1, V - funnel vales from 0 to 18 seconds and V - funnel at $T_{5minutes}$ values from 0 to 7.5 seconds. Some of the mix results values are out of the EFNARC range and therefore before casting the concrete, the properties of freshly mixed concrete must be checked for SCC.
- The mixes containing lesser dosage of superplasticizer have shown more compressive strength but can not be classified as SCC because they failed in the basic properties of SCC. The dosage of superplasticizer for flowability up to 3 percent, have shown better results both in the fresh and hardened state of concrete. The compressive strength of SCC using bagasse ash was even more than the control concrete. Reason is the better densification of the concrete mix.
- The mix containing 15 percent of bagasse ash and 2.5 to 3 percent of superplasticizer dosage proved to be the best SCC as compared

with the control concrete. The compressive strength achieved by these mixes was approximately 34 MPa.

- As far the cost analysis is concerned , it was found that the cost of ingredients of SCC containing bagasse ash is 37.72 percent less than the control concrete, both having approximate compressive strength of 34 MPa.
- The utilization of bagasse ash in SCC solves the problem of its disposal thus keeping the environment free from pollution.

5.2 RECOMMENDATIONS FOR FUTURE RESEARCH

Pakistan’s industrial, agricultural and mining sector produces enormous quantity of waste / by-product (fly-ash, slag, bagasse ash, rice husk ash, bentonite, dolomite, limestone), which possesses pozzolanic properties. The suitability regarding usage of these materials in SCC needs to be investigated.

Higher powder contents can be achieved by using bagasse ash more than 20 percent in the concrete mix. Upto 20 percent of bagasse ash has been tested in this study with the specified mix design. Properties of fresh and hardened concrete may be examined by including higher percentage of bagasse ash in a different mix design than the one used in this study.

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APPENDIX I

Table 3.1. Grading of Fine Aggregate

ASTM sieve No	Sieve size (mm)	Weight retained (gm)	Percentage retained	Cumulative percentage retained	Percentage passing	
					Actual	ASTM C 33-03
16	1.18	334.38	29.02	29.02	70.98	50 to 85
30	0.60	213.62	18.54	47.56	52.44	25 to 60
50	0.30	477.94	41.48	89.04	10.96	5 to 30
100	0.15	88.84	7.71	96.75	3.25	0 to 10
Pan	-	37.47	3.25	-	0	-
Total		1152.23		262.37		

Table 3.2. Physical Properties of Fine Aggregate

Dry rodded unit weight (kg/m^3)	Bulk specific gravity (SSD)[a]	Absorption (%)	Fineness modulus
1953.54	2.671	1.65	2.62

[a] SSD refers to saturated surface dry

Table 3.3. Grading of Coarse Aggregate

Sieve size (mm)	Weight retained (gm)	Percentage retained	Cumulative percentage retained	Percentage passing	
				Actual	ASTM C33-03
19.0	235	6	6	94	90 to 100
12.5	1143	29	35	65	-
9.5	482	12	47	53	20 to 55
4.75	1880	47	94	6	0 to 10
Pan	244	6	100	0	
Total	3984				

Table 3.4. Physical Properties of Coarse Aggregate

Dry rodded unit weight (kg/m^3)	Bulk specific gravity (SSD)	Absorption (%)
1529.28	2.678	1.07

Table 3.5. Physical Property of OPC and Bagasse Ash

Property	OPC	Bagasse ash
Specific gravity	3.15	2.12

Table 3.6. Chemical Properties of OPC and Bagasse Ash

Chemical composition	OPC (%)	Bagasse ash (%)
Silicon dioxide (SiO_2)	19.00	62.44
Aluminum oxide (Al_2O_3)	09.87	06.74
Ferric oxide (Fe_2O_3)	03.46	05.77
Calcium oxide (CaO)	60.00	06.16
Magnesium oxide (MgO)	01.63	02.97
Sulfur trioxide (SO_3)	02.63	00.72
Sodium oxide (Na_2O)	00.84	03.15
Potassium oxide (K_2O)	01.19	06.87

Table 3.7. Mix Design of Concrete Mixes

Mix design	W/B ratio	Water kg/m^3	Cement kg/m^3	Bagasse ash kg/m^3	Fine aggr-egate kg/m^3	Coarse aggre-gate kg/m^3	Sikament NN (% by weight of binder)	Viscocrete (% by weight of binder)
CC2SP	0.45	225	500	-	875	750	2	2
CC2.5SP	0.45	225	500	-	875	750	2.5	2
CC3SP	0.45	225	500	-	875	750	3	2
CC3.5SP	0.45	225	500	-	875	750	3.5	2
CC4SP	0.45	225	500	-	875	750	4	2
5B2SP	0.43	225	500	25	875	750	2	-
5B2.5SP	0.43	225	500	25	875	750	2.5	-
5B3SP	0.43	225	500	25	875	750	3	-
5B3.5SP	0.43	225	500	25	875	750	3.5	-
5B4SP	0.43	225	500	25	875	750	4	-
10B2SP	0.41	225	500	50	875	750	2	-
10B2.5SP	0.41	225	500	50	875	750	2.5	-
10B3SP	0.41	225	500	50	875	750	3	-
10B3.5SP	0.41	225	500	50	875	750	3.5	-
10B4SP	0.41	225	500	50	875	750	4	-
15B2SP	0.39	225	500	75	875	750	2	-
15B2.5SP	0.39	225	500	75	875	750	2.5	-
15B3SP	0.39	225	500	75	875	750	3	-
15B3.5SP	0.39	225	500	75	875	750	3.5	-
15B4SP	0.39	225	500	75	875	750	4	-
20B2SP	0.37	225	500	100	875	750	2	-
20B2.5SP	0.37	225	500	100	875	750	2.5	-
20B3SP	0.37	225	500	100	875	750	3	-
20B3.5SP	0.37	225	500	100	875	750	3.5	-
20B4SP	0.37	225	500	100	875	750	4	-

APPENDIX II

Physical Properties of Fine Aggregate

- **Specific Gravity**

	Specimen A	Specimen B
A= Weight of oven-dry specimen in air (gm)	492.5	491.9
B= Weight of pycnometer filled with water (gm)	673.4	673.4
S= Weight of saturated surface dry specimen (gm)	500.5	500.2
C= Weight of pycnometer with specimen and water to calibration mark (gms)	986.5	986.3

Bulk Specific Gravity, 23/23 ^{o}C of Specimen A:

= A / (B + S – C)

= 492.5 / (673.4 + 500.5 – 986.5)

= 2.628

Bulk Specific Gravity, 23/23 ^{o}C of Specimen B:

= 491.9 / (673.4 + 500.2 – 986.3)

= 2.626

Average Bulk Specific Gravity, 23/23 ^{o}C:

= 2.627

Bulk Specific Gravity (Saturated Surface – Dry Basis) of Specimen A:

= S / (B + S – C)

= 500.5 / (673.4 + 500.5 – 986.5)

= 2.671

Bulk Specific Gravity (Saturated Surface – Dry Basis) of Specimen B:

= 500.2 / (673.4 + 500.2 – 986.3)

= 2.671

Average Bulk Specific Gravity (Saturated Surface – Dry Basis):

= 2.671

- **Absorption**

Absorption of Specimen A:

= [(S – A) / A] x 100

= [(500.5 – 492.5) / 492.5] x 100

= 1.62 percent

Absorption of Specimen B:

= [(500.2 – 491.9) / 491.9] x 100

= 1.69 percent

Average Absorption:

= 1.65 percent

- **Unit Weight**

G = Mass of the sand plus the measure (kg)	8.2
	8.1
	8.3
Average G	8.2
T = Mass of the measure (kg)	2.710
V= Volume of the measure (cum)	0.00282

Unit Weight of Fine Aggregate:

= (G – T) / V

= (8.2 – 2.710) / 0.00282

= 1953.54 kg/m^3

Physical Properties of Coarse Aggregate

- **Specific Gravity**

A = Weight of oven-dry specimen in air (gm)	4942
B = Weight of saturated surface dry sample in air (gm)	4995
C = Weight of saturated sample in water (gm)	3130

Bulk Specific Gravity, 23/23 ºC:

= A / (B – C)

= 4942 / (4995 – 3130)

= 2.649

Bulk Specific Gravity (Saturated Surface – Dry Basis):

= B / (B – C)

= 4995 / (4995 – 3130)

= 2.678

- **Absorption**

= [(B – A)/A] x 100

= [(4995 – 4942) / 4942] x 100

= 1.07 percent

- **Unit Weight**

G = Mass of the coarse aggaregte plus the measure (kg)	22.5
	36.0
	38.7
Average G	32.4
T = Mass of the measure (kg)	10.99
V = Volume of the measure (cum)	0.014

Unit Weight of Coarse Aggregate

$= (G - T) / V$

$= (32.4 - 10.99) / 0.014$

$= 1529.28 \text{ kg/m}^3$

APPENDIX III

Table 4.1. Test Results of Properties of Fresh SCC

Mix design	Average slump (650–800 mm)	L - box H_2/H_1 (0.8–1)	V - funnel (6–12 sec)	V - funnel at $T_{5\ min.}$ (0– +3 sec)
CC2SP	685	0.8	5.3	0.3
CC2.5SP	720	0.85	4	0.1
CC3SP	745	0.98	2.2	0
CC3.5SP	770	1	2.2	0
CC4SP	780	1	2.1	0
5B2SP	620	0.7	7	1.2
5B2.5SP	765	0.82	5.5	0.4
5B3SP	770	0.97	5	0
5B3.5SP	815	1	1.8	0
5B4SP	815	1	1.8	0
10B2SP	495	0	14	6
10B2.5SP	760	0.8	7	1
10B3SP	765	0.82	5	3
10B3.5SP	775	0.97	5	0
10B4SP	785	1	2.3	0.5
15B2SP	430	0	18	stucked
15B2.5SP	730	0.81	11	3
15B3SP	755	0.8	6	1
15B3.5SP	765	0.87	3	0.2
15B4SP	770	0.93	2.2	0.3
20B2SP	333	0	stucked	stucked
20B2.5SP	590	0.68	16	7.5
20B3SP	669	0.76	9	6
20B3.5SP	665	0.82	7	0.1
20B4SP	670	0.85	6	0

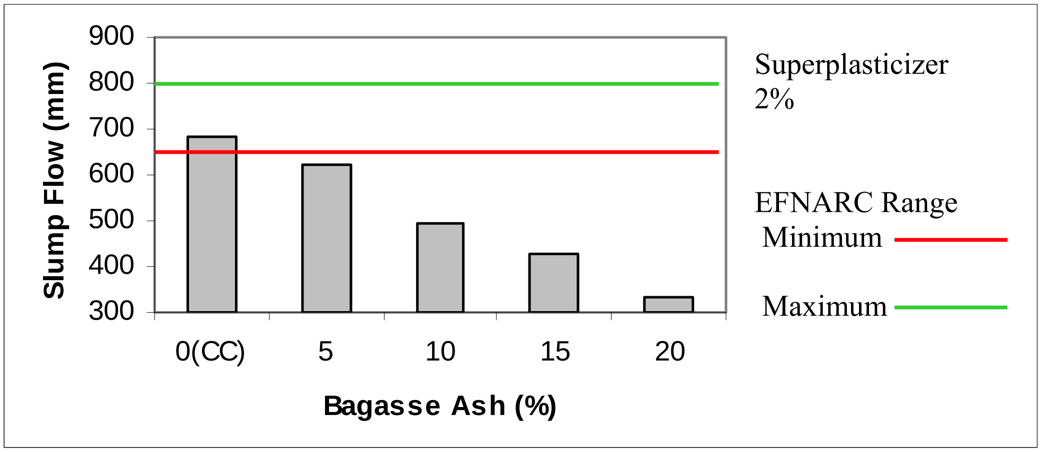

Fig. 4.1. Trend of slump flow-to-quantity of bagasse ash with 2% dosage of superplasticizer

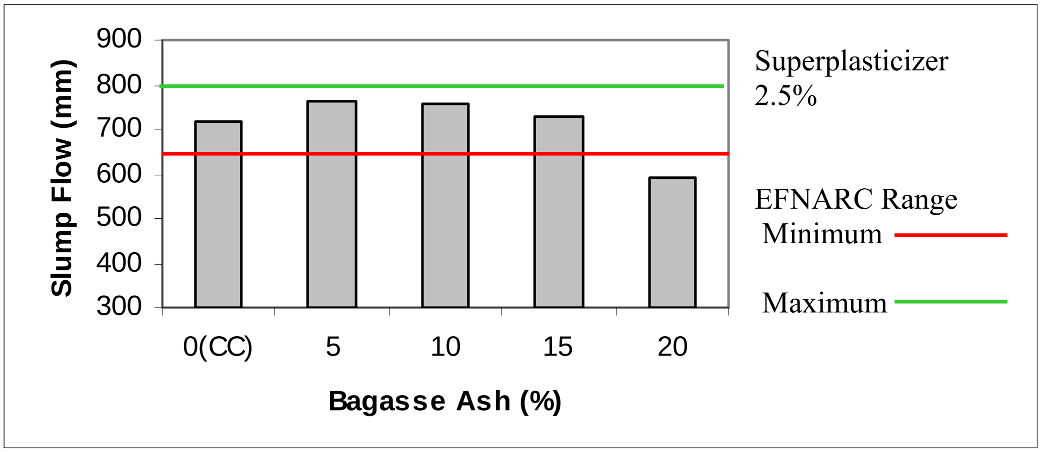

Fig. 4.2. Trend of slump flow-to-quantity of bagasse ash with 2.5% dosage of superplasticizer

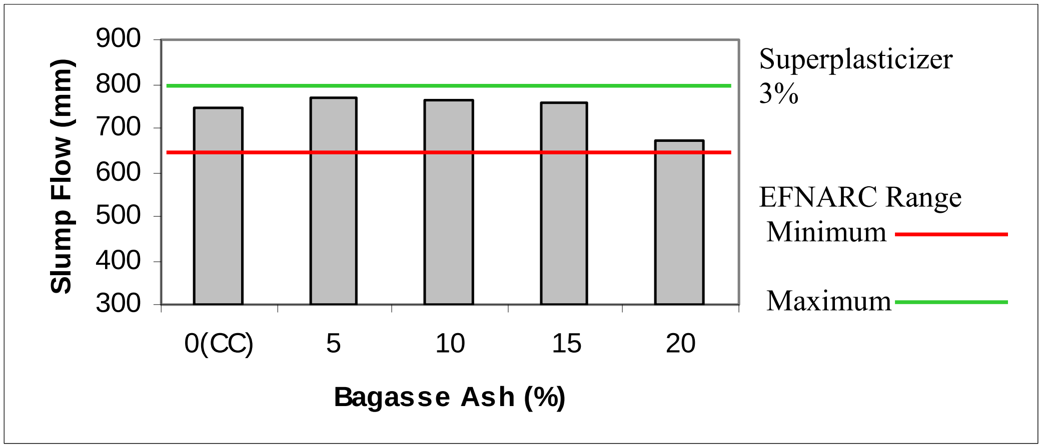

Fig. 4.3. Trend of slump flow-to-quantity of bagasse ash with 3% dosage of superplasticizer

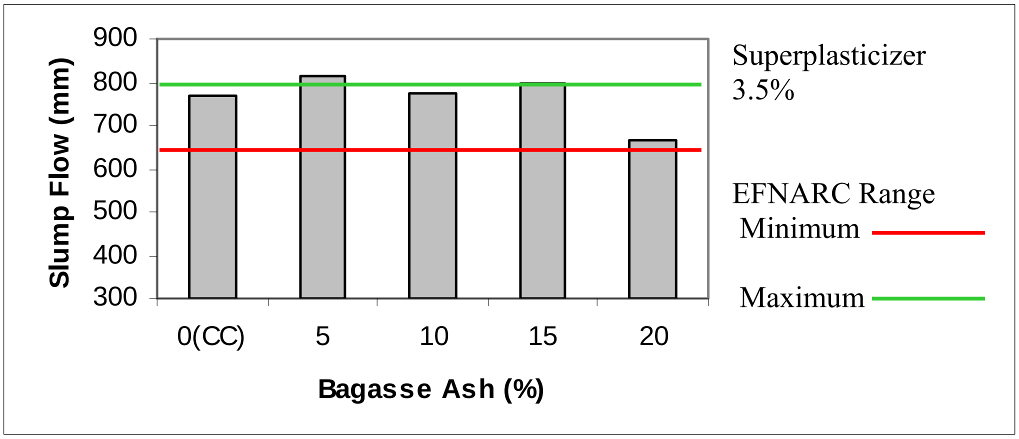

Fig. 4.4. Trend of slump flow-to-quantity of bagasse ash with 3.5% dosage of superplasticizer

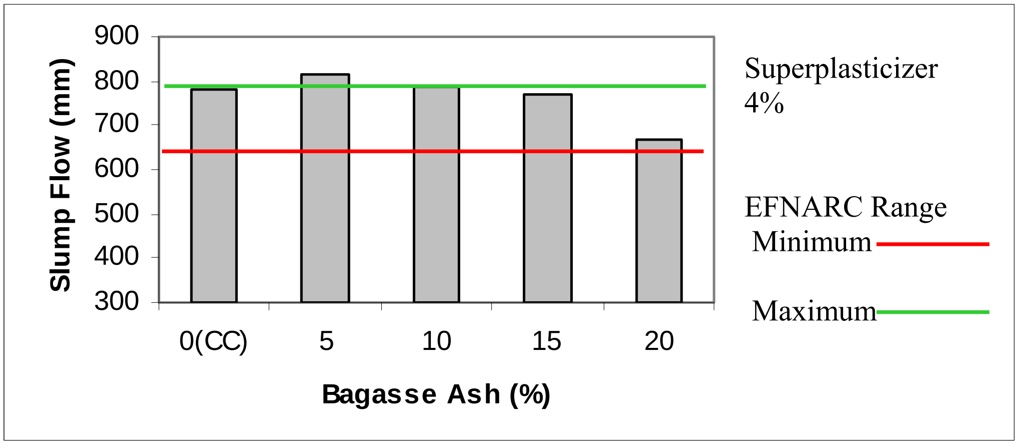

Fig. 4.5. Trend of slump flow-to-quantity of bagasse ash with 4% dosage of superplasticizer

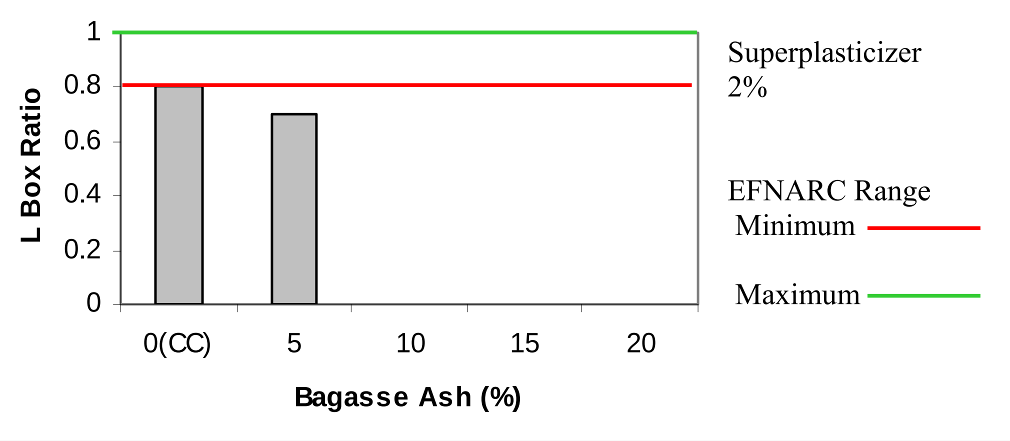

Fig. 4.6. Trend of L – box flow-to-quantity of bagasse ash with 2% dosage of superplasticizer

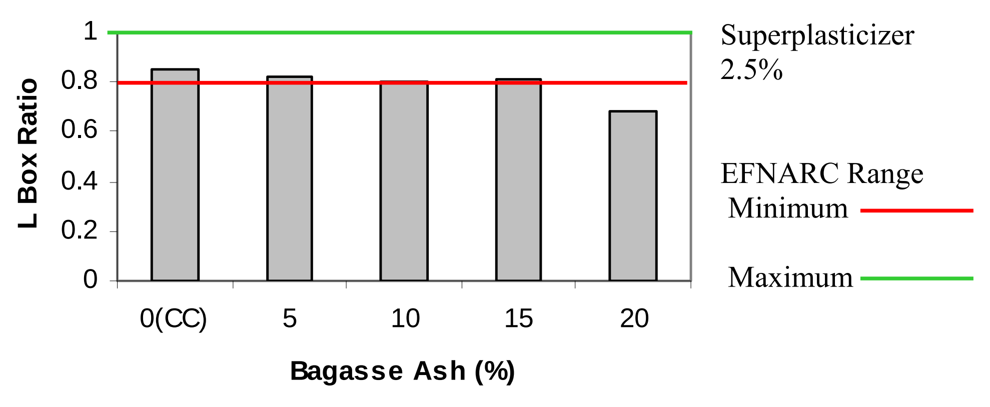

Fig. 4.7. Trend of L – box flow-to-quantity of bagasse ash with 2.5% dosage of superplasticizer

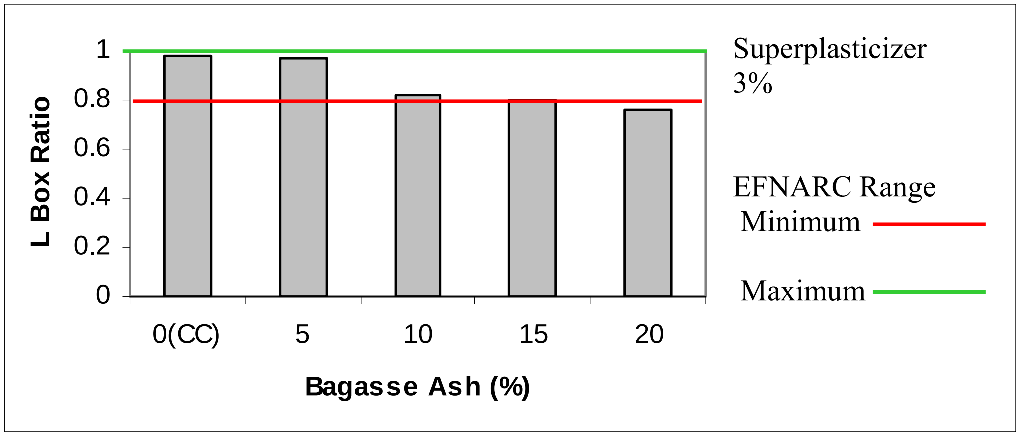

Fig. 4.8. Trend of L – box flow-to-quantity of bagasse ash with 3% dosage of superplasticizer

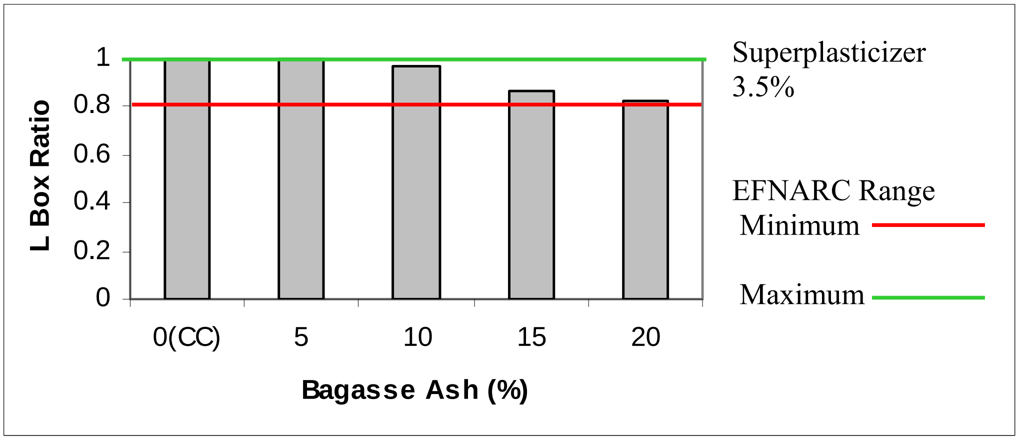

Fig. 4.9. Trend of L – box flow-to-quantity of bagasse ash with 3.5% dosage of superplasticizer

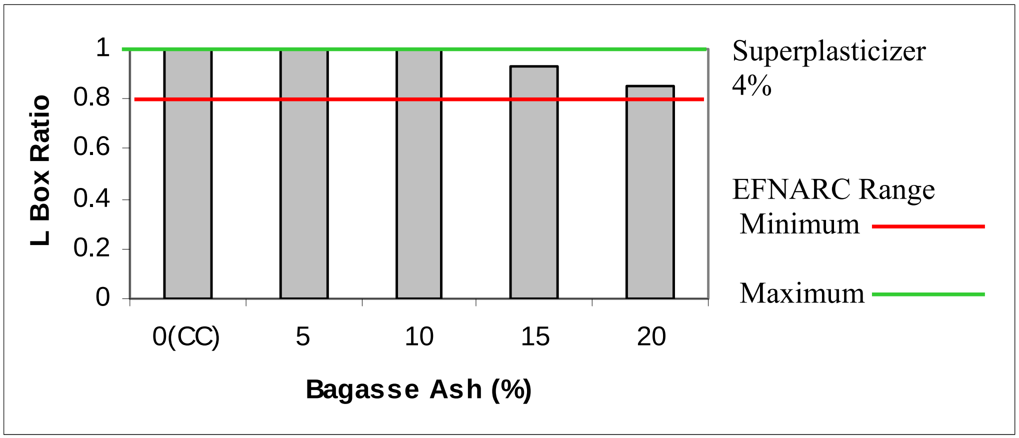

Fig. 4.10. Trend of L – box flow-to-quantity of bagasse ash with 4% dosage of superplasticizer

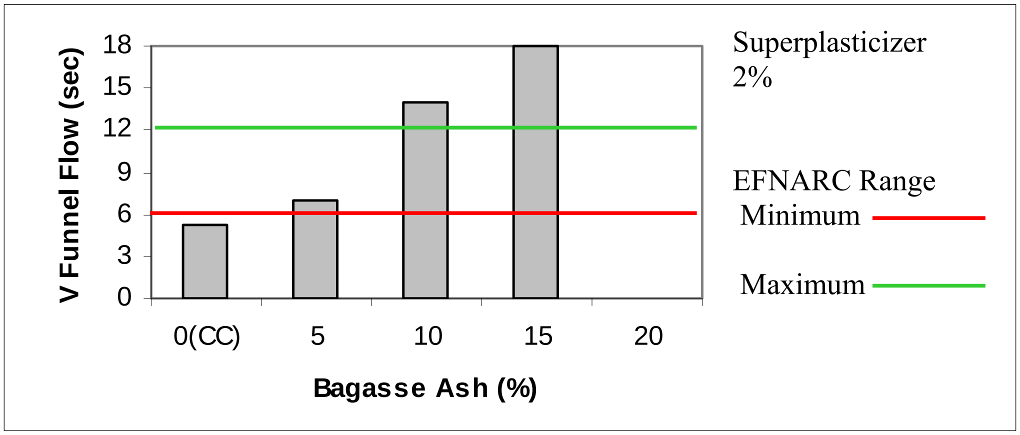

Fig. 4.11. Trend of V - funnel flow-to-quantity of bagasse ash with 2% dosage of superplasticizer

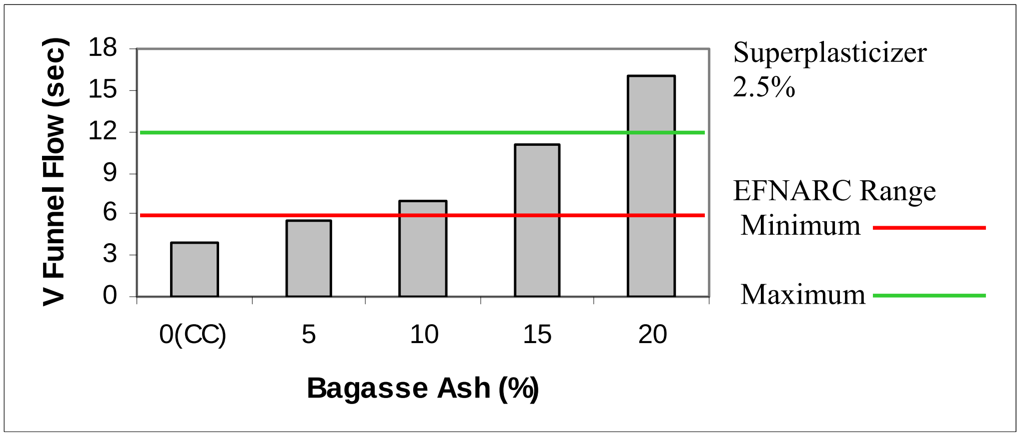

Fig. 4.12. Trend of V - funnel flow-to-quantity of bagasse ash with 2.5% dosage of superplasticizer

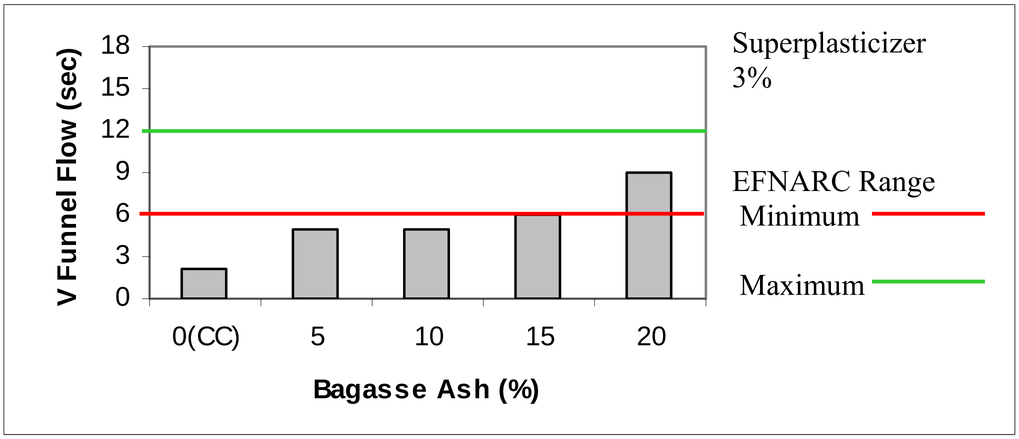

Fig. 4.13. Trend of V - funnel flow-to-quantity of bagasse ash with 3% dosage of superplasticizer

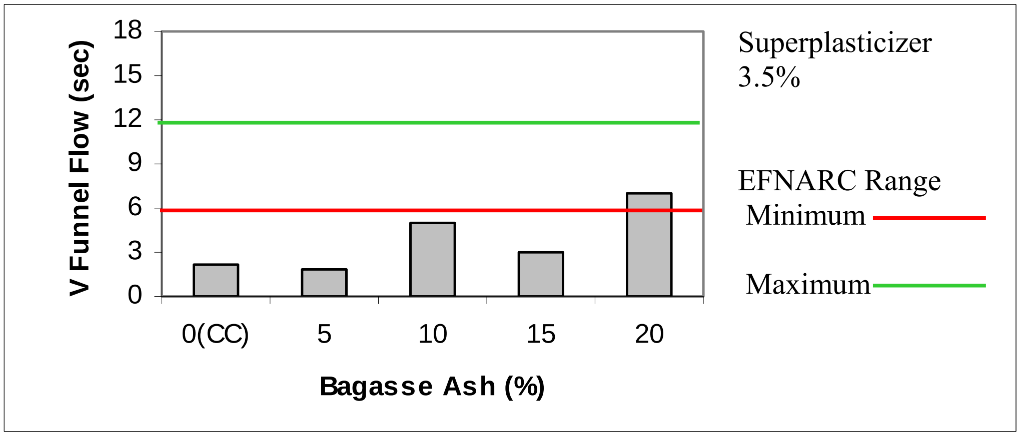

Fig. 4.14. Trend of V - funnel flow-to-quantity of bagasse ash with 3.5% dosage of superplasticizer

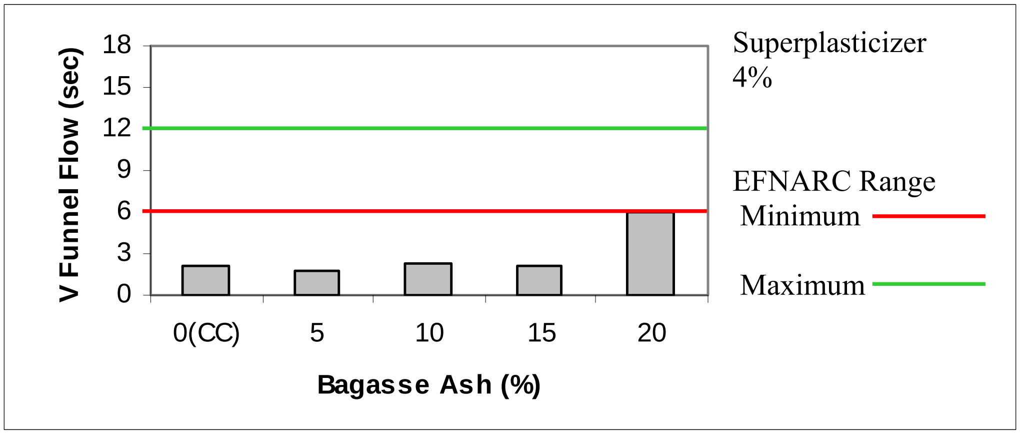

Fig. 4.15. Trend of V - funnel flow-to-quantity of bagasse ash with 4% dosage of superplasticizer

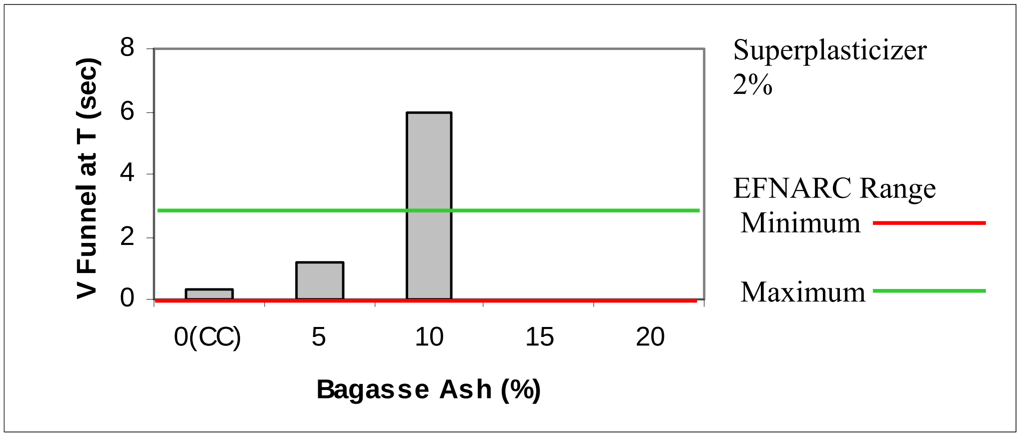

Fig. 4.16. Trend of V - funnel at T 5 min flow-to-quantity of bagasse ash with 2% dosage of superplasticizer

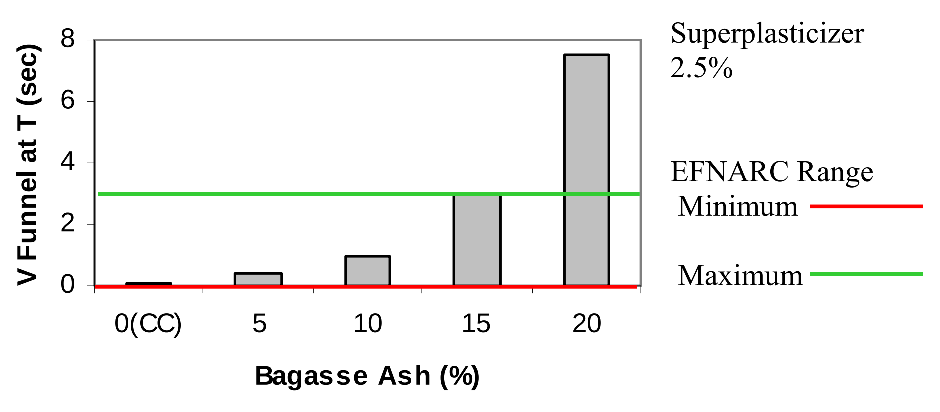

Fig. 4.17. Trend of V - funnel at T 5 min flow-to-quantity of bagasse ash with 2.5% dosage of superplasticizer

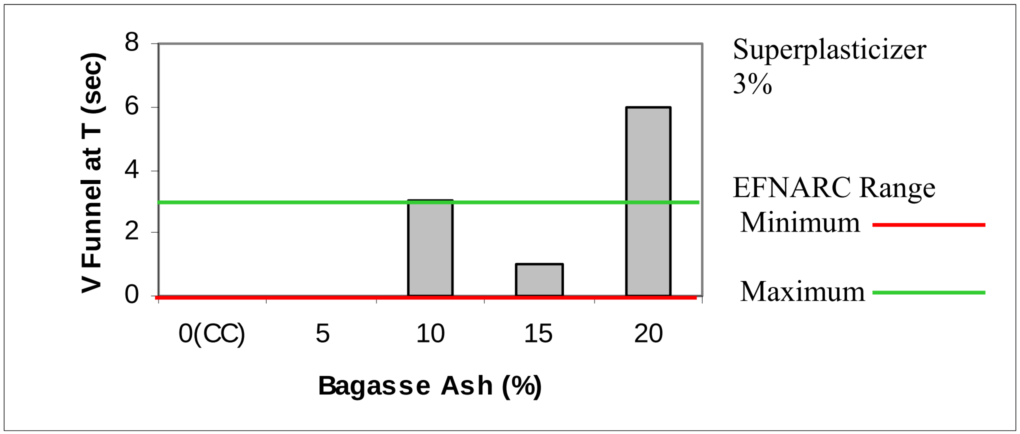

Fig. 4.18. Trend of V - funnel at T $_{5\ min}$ flow-to-quantity of bagasse ash with 3% dosage of superplasticizer

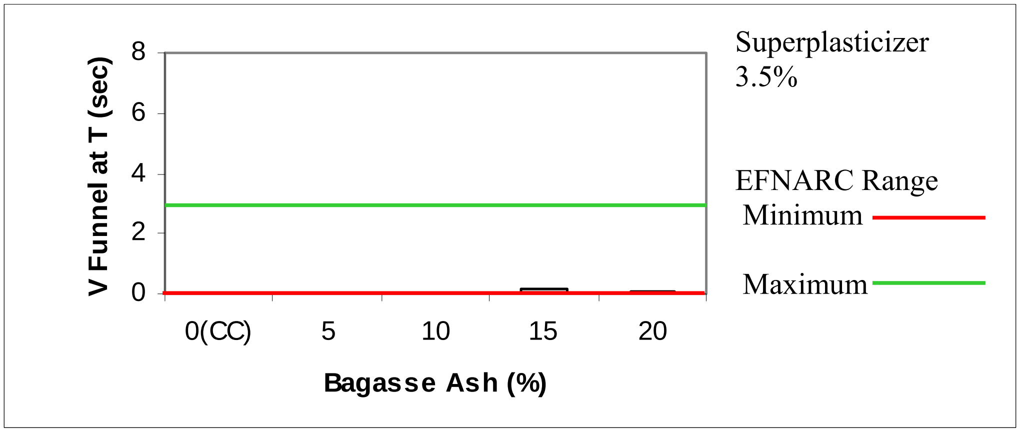

Fig. 4.19. Trend of V - funnel at T $_{5\ min}$ flow-to-quantity of bagasse ash with 3.5% dosage of superplasticizer

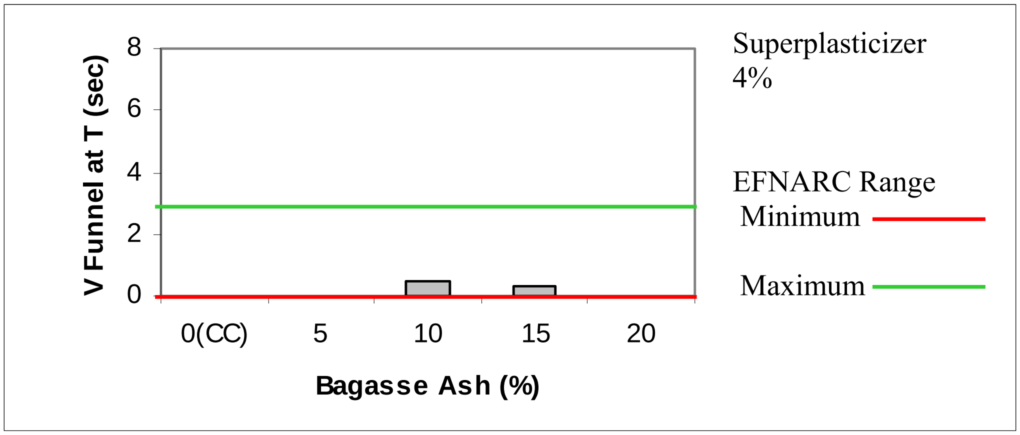

Fig. 4.20. Trend of V - funnel at T $_{5\ min}$ flow-to-quantity of bagasse ash with 4% dosage of superplasticizer

APPENDIX IV

Table 4.2. Compressive Strength of Cylinders at 7 Days

Specimen	Dia (mm)	Length (mm)	C/S area (mm²)	Weight (kg)	Density at 1 day (kg/m³)	Average density (kg/m³)	Load (kN)	Stress (N/mm²)	Average stress (N/mm²)
CC2SP	151.0	301.5	17898.8	13.1	2427.5	2388.9	615	34.36	34.20
CC2SP	151.4	300.0	17993.7	12.8	2371.2		639	35.51	
CC2SP	151.0	302.0	17898.8	12.8	2368.0		586	32.74	
CC2.5SP	151.0	301.5	17898.8	12.8	2371.9	2380.2	400	22.35	24.07
CC2.5SP	150.2	300.0	17709.6	12.7	2390.4		410	23.15	
CC2.5SP	151.3	299.5	17970.0	12.8	2378.3		480	26.71	
CC3SP	150.0	300.5	17662.5	12.7	2392.8	2363.4	230	13.02	17.73
CC3SP	152.0	301.2	18136.6	12.8	2343.1		410	22.61	
CC3SP	149.9	301.0	17639.0	12.5	2354.3		310	17.57	
CC3.5SP	152.0	302.0	18136.6	12.7	2318.7	2343.4	242	13.34	16.36
CC3.5SP	151.8	302.2	18088.9	12.8	2341.5		360	19.90	
CC3.5SP	150.6	301.0	17804.1	12.7	2369.8		282	15.84	
CC4SP	150.4	302.0	17756.8	12.2	2275.0	2327.9	290	16.33	15.31
CC4SP	151.0	301.9	17898.8	12.9	2387.3		232	12.96	
CC4SP	150.0	300.0	17662.5	12.3	2321.3		294	16.65	
5B2SP	149.8	300.4	17615.4	12.8	2418.9	2423.7	510	28.95	32.16
5B2SP	150.8	300.2	17851.4	13.0	2425.8		610	34.17	
5B2SP	150.1	300.6	17686.1	12.9	2426.4		590	33.36	
5B2.5SP	150.6	301.5	17804.1	13.0	2421.8	2394.0	346	19.43	19.70
5B2.5SP	152.0	301.8	18136.6	12.8	2338.5		306	16.87	
5B2.5SP	150.4	300.0	17756.8	12.9	2421.6		405	22.81	
5B3SP	151.0	302.4	17898.8	11.0	2032.3	2387.5	255	14.25	14.95
5B3SP	150.0	299.0	17662.5	10.8	2045.0		245	13.87	
5B3SP	149.8	202.4	17615.4	11.0	3085.2		295	16.75	
5B3.5SP	150.8	299.5	17851.4	12.4	2319.3	2364.4	200	11.20	12.32
5B3.5SP	150.1	280.5	17686.1	12.5	2519.7		225	12.72	
5B3.5SP	150.6	299.0	17804.1	12.0	2254.2		232	13.03	
5B4SP	150.4	301.0	17756.8	12.6	2357.4	2356.5	122	6.87	9.13
5B4SP	151.0	300.1	17898.8	12.8	2383.0		180	10.06	
5B4SP	150.0	299.0	17662.5	12.3	2329.1		185	10.47	

Table 4.2. (Continued)

Specimen	Dia (mm)	Length (mm)	C/S area (mm²)	Weight (kg)	Density at 1 day (kg/m³)	Average density (kg/m³)	Load (kN)	Stress (N/mm²)	Average stress (N/mm²)
10B2SP	149.8	300.0	17615.4	12.2	2308.6	2483.2	610	34.63	35.10
10B2SP	150.4	299.9	17756.8	13.5	2535.1		620	34.92	
10B2SP	151.0	298.0	17898.8	13.9	2606.0		640	35.76	
10B2.5SP	150.0	302.0	17662.5	13.4	2512.2	2464.0	400	22.65	20.14
10B2.5SP	149.8	302.2	17615.4	12.9	2423.3		320	18.17	
10B2.5SP	150.8	301.0	17851.4	13.2	2456.6		350	19.61	
10B3SP	150.1	302.0	17686.1	12.8	2396.5	2412.2	280	15.83	20.27
10B3SP	150.6	301.9	17804.1	13.0	2418.6		430	24.15	
10B3SP	150.4	300.0	17756.8	12.9	2421.6		370	20.84	
10B3.5SP	151.0	300.4	17898.8	12.7	2362.0	2378.9	325	18.16	16.54
10B3.5SP	150.0	300.2	17662.5	12.5	2357.5		255	14.44	
10B3.5SP	149.8	300.6	17615.4	12.8	2417.3		300	17.03	
10B4SP	150.8	301.5	17851.4	12.7	2359.6	2359.7	180	10.08	12.00
10B4SP	150.1	301.8	17686.1	12.7	2379.3		200	11.31	
10B4SP	150.6	300.0	17804.1	12.5	2340.3		260	14.60	
15B2SP	150.1	302.4	17686.1	11.5	2150.2	2506.7	670	37.88	35.12
15B2SP	150.6	299.0	17804.1	11.7	2197.8		610	34.26	
15B2SP	150.4	202.4	17756.8	11.4	3172.0		590	33.23	
15B2.5SP	151.0	299.5	17898.8	12.8	2387.8	2480.6	300	16.76	22.78
15B2.5SP	150.0	280.5	17662.5	13.0	2624.0		450	25.48	
15B2.5SP	149.8	299.0	17615.4	12.8	2430.2		460	26.11	
15B3SP	150.8	301.0	17851.4	13.0	2419.4	2420.6	360	20.17	19.88
15B3SP	150.1	300.1	17686.1	12.9	2430.5		450	25.44	
15B3SP	150.6	300.4	17804.1	12.9	2412.0		250	14.04	
15B3.5SP	149.8	300.2	17615.4	12.8	2420.5	2402.1	335	19.02	15.99
15B3.5SP	150.8	300.6	17851.4	12.7	2366.7		295	16.53	
15B3.5SP	150.1	301.5	17686.1	12.9	2419.2		220	12.44	
15B4SP	150.6	301.8	17804.1	12.8	2382.2	2378.2	260	14.60	12.75
15B4SP	150.1	300.0	17686.1	12.7	2393.6		180	10.18	
15B4SP	150.6	302.4	17804.1	12.7	2358.9		240	13.48	

Table 4.2. (Continued)

Specimen	Dia (mm)	Length (mm)	C/S area (mm²)	Weight (kg)	Density at 1 day (kg/m³)	Average density (kg/m³)	Load (kN)	Stress (N/mm²)	Average stress (N/mm²)
20B2SP	150.4	299.0	17756.8	13.3	2505.0	2493.8	554	31.20	31.03
20B2SP	151.0	302.0	17898.8	13.5	2497.5		510	28.49	
20B2SP	150.0	301.5	17662.5	13.2	2478.8		590	33.40	
20B2.5SP	149.8	300.0	17615.4	13.3	2516.7	2473.8	400	22.71	22.43
20B2.5SP	151.0	299.5	17898.8	13.9	2593.0		370	20.67	
20B2.5SP	151.4	300.5	17993.7	12.5	2311.8		430	23.90	
20B3SP	151.0	301.2	17898.8	12.9	2392.8	2418.3	300	16.76	16.26
20B3SP	151.0	301.0	17898.8	13.1	2431.5		280	15.64	
20B3SP	150.2	302.0	17709.6	13.0	2430.7		290	16.38	
20B3.5SP	151.3	302.2	17970.0	12.9	2375.5	2392.0	120	6.68	9.02
20B3.5SP	150.0	301.0	17662.5	13.0	2445.3		180	10.19	
20B3.5SP	152.0	302.0	18136.6	12.9	2355.2		185	10.20	
20B4SP	149.9	301.9	17639.0	12.7	2384.9	2352.0	220	12.47	12.25
20B4SP	152.0	300.0	18136.6	12.9	2370.9		220	12.13	
20B4SP	151.8	300.4	18088.9	12.5	2300.4		220	12.16	

Table 4.3. Compressive Strength of Cylinders at 28 Days

Specimen	Dia (mm)	Length (mm)	C/S area (mm^2)	Wei-ght (kg)	Density at 1 day (kg/m^3)	Aver-age density (kgm^3)	Load (kN)	Stress (N/mm^2)	Average stress (N/mm^2)
CC2SP	151.0	301.5	17898.8	13.1	2427.5	2388.9	640	35.76	37.37
CC2SP	151.4	300.0	17993.7	12.8	2371.2		620	34.46	
CC2SP	151.0	302.0	17898.8	12.8	2368.0		750	41.90	
CC2.5SP	151.0	301.5	17898.8	12.8	2371.9	2380.2	630	35.20	34.14
CC2.5SP	150.2	300.0	17709.6	12.7	2390.4		560	31.62	
CC2.5SP	151.3	299.5	17970.0	12.8	2378.3		640	35.61	
CC3SP	150.0	300.5	17662.5	12.7	2392.8	2363.4	610	34.54	31.24
CC3SP	152.0	301.2	18136.6	12.8	2343.1		590	32.53	
CC3SP	149.9	301.0	17639.0	12.5	2354.3		470	26.65	
CC3.5SP	152.0	302.0	18136.6	12.7	2318.7	2343.4	510	28.12	24.25
CC3.5SP	151.8	302.2	18088.9	12.8	2341.5		340	18.80	
CC3.5SP	150.6	301.0	17804.1	12.7	2369.8		460	25.84	
CC4SP	150.4	302.0	17756.8	12.2	2275.0	2327.9	480	27.03	23.10
CC4SP	151.0	301.9	17898.8	12.9	2387.3		420	23.47	
CC4SP	150.0	300.0	17662.5	12.3	2321.3		332	18.80	
5B2SP	149.8	300.4	17615.4	12.8	2418.9	2423.7	640	36.33	37.44
5B2SP	150.8	300.2	17851.4	13.0	2425.8		640	35.85	
5B2SP	150.1	300.6	17686.1	12.9	2426.4		710	40.14	
5B2.5SP	150.6	301.5	17804.1	13.0	2421.8	2394.0	660	37.07	29.98
5B2.5SP	152.0	301.8	18136.6	12.8	2338.5		540	29.77	
5B2.5SP	150.4	300.0	17756.8	12.9	2421.6		410	23.09	
5B3SP	151.0	302.4	17898.8	11.0	2032.3	2387.5	540	30.17	28.77
5B3SP	150.0	299.0	17662.5	10.8	2045.0		490	27.74	
5B3SP	149.8	202.4	17615.4	11.0	3085.2		500	28.38	
5B3.5SP	150.8	299.5	17851.4	12.4	2319.3	2364.4	320	17.93	21.76
5B3.5SP	150.1	280.5	17686.1	12.5	2519.7		470	26.57	
5B3.5SP	150.6	299.0	17804.1	12.0	2254.2		370	20.78	
5B4SP	150.4	301.0	17756.8	12.6	2357.4	2356.5	390	21.96	20.81
5B4SP	151.0	300.1	17898.8	12.8	2383.0		390	21.79	
5B4SP	150.0	299.0	17662.5	12.3	2329.1		330	18.68	

Table 4.3. (Continued)

Specimen	Dia (mm)	Length (mm)	C/S area (mm^2)	Weight (kg)	Density at 1 day (kg/m^3)	Average density (kg/m^3)	Load (kN)	Stress (N/mm^2)	Average stress (N/mm^2)
10B2SP	149.8	300.0	17615.4	12.2	2308.6	2483.2	750	42.58	37.38
10B2SP	150.4	299.9	17756.8	13.5	2535.1		610	34.35	
10B2SP	151.0	298.0	17898.8	13.9	2606.0		630	35.20	
10B2.5SP	150.0	302.0	17662.5	13.4	2512.2	2464.0	570	32.27	31.81
10B2.5SP	149.8	302.2	17615.4	12.9	2423.3		560	31.79	
10B2.5SP	150.8	301.0	17851.4	13.2	2456.6		560	31.37	
10B3SP	150.1	302.0	17686.1	12.8	2396.5	2412.2	620	35.06	31.94
10B3SP	150.6	301.9	17804.1	13.0	2418.6		480	26.96	
10B3SP	150.4	300.0	17756.8	12.9	2421.6		600	33.79	
10B3.5SP	151.0	300.4	17898.8	12.7	2362.0	2378.9	420	23.47	24.83
10B3.5SP	150.0	300.2	17662.5	12.5	2357.5		440	24.91	
10B3.5SP	149.8	300.6	17615.4	12.8	2417.3		460	26.11	
10B4SP	150.8	301.5	17851.4	12.7	2359.6	2359.7	410	22.97	21.55
10B4SP	150.1	301.8	17686.1	12.7	2379.3		300	16.96	
10B4SP	150.6	300.0	17804.1	12.5	2340.3		440	24.71	
15B2SP	150.1	302.4	17686.1	11.5	2150.2	2506.7	690	39.01	39.44
15B2SP	150.6	299.0	17804.1	11.7	2197.8		720	40.44	
15B2SP	150.4	202.4	17756.8	11.4	3172.0		690	38.86	
15B2.5SP	151.0	299.5	17898.8	12.8	2387.8	2480.6	600	33.52	34.61
15B2.5SP	150.0	280.5	17662.5	13.0	2624.0		580	32.84	
15B2.5SP	149.8	299.0	17615.4	12.8	2430.2		660	37.47	
15B3SP	150.8	301.0	17851.4	13.0	2419.4	2420.6	620	34.73	34.12
15B3SP	150.1	300.1	17686.1	12.9	2430.5		600	33.93	
15B3SP	150.6	300.4	17804.1	12.9	2412.0		600	33.70	
15B3.5SP	149.8	300.2	17615.4	12.8	2420.5	2402.1	430	24.41	24.65
15B3.5SP	150.8	300.6	17851.4	12.7	2366.7		410	22.97	
15B3.5SP	150.1	301.5	17686.1	12.9	2419.2		470	26.57	
15B4SP	150.6	301.8	17804.1	12.8	2382.2	2378.2	470	26.40	23.45
15B4SP	150.1	300.0	17686.1	12.7	2393.6		360	20.36	
15B4SP	150.6	302.4	17804.1	12.7	2358.9		420	23.59	

Table 4.3. (Continued)

Specimen	Dia (mm)	Length (mm)	C/S area (mm²)	Wei-ght (kg)	Density at 1 day (kg/m³)	Aver-age density (kg/m³)	Load (kN)	Stress (N/mm²)	Average stress (N/mm²)
20B2SP	150.4	299.0	17756.8	13.3	2505.0	2493.8	678	38.18	38.19
20B2SP	151.0	302.0	17898.8	13.5	2497.5		610	34.08	
20B2SP	150.0	301.5	17662.5	13.2	2478.8		747	42.29	
20B2.5SP	149.8	300.0	17615.4	13.3	2516.7	2380.5	660	37.47	34.78
20B2.5SP	151.0	299.5	17898.8	12.4	2313.1		610	34.08	
20B2.5SP	151.4	300.5	17993.7	12.5	2311.8		590	32.79	
20B3SP	151.0	301.2	17898.8	12.9	2392.8	2418.3	480	26.82	25.79
20B3SP	151.0	301.0	17898.8	13.1	2431.5		440	24.58	
20B3SP	150.2	302.0	17709.6	13.0	2430.7		460	25.97	
20B3.5SP	151.3	302.2	17970.0	12.9	2375.5	2392.0	450	25.04	23.84
20B3.5SP	150.0	301.0	17662.5	13.0	2445.3		480	27.18	
20B3.5SP	152.0	302.0	18136.6	12.9	2355.2		350	19.30	
20B4SP	149.9	301.9	17639.0	12.7	2384.9	2352.0	280	15.87	18.82
20B4SP	152.0	300.0	18136.6	12.9	2370.9		370	20.40	
20B4SP	151.8	300.4	18088.9	12.5	2300.4		365	20.18	

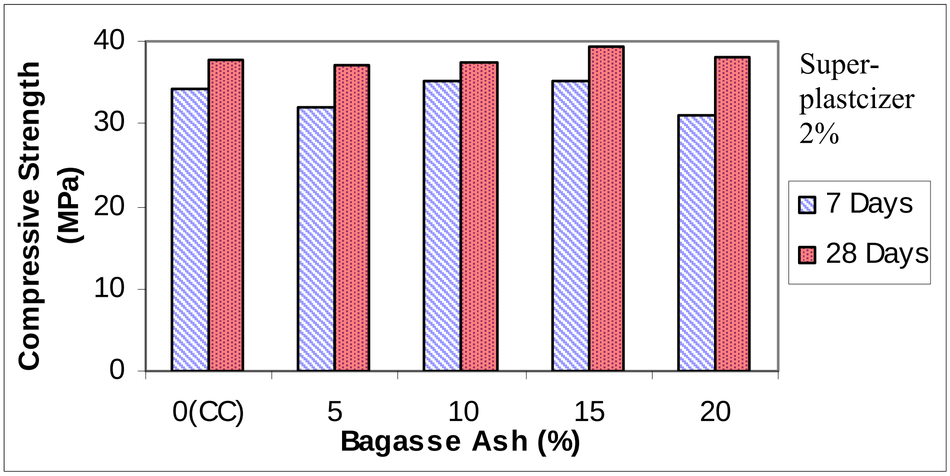

Fig. 4.21. Variation of compressive strength-to-quantity of bagasse ash with 2% dosage of superplasticizer

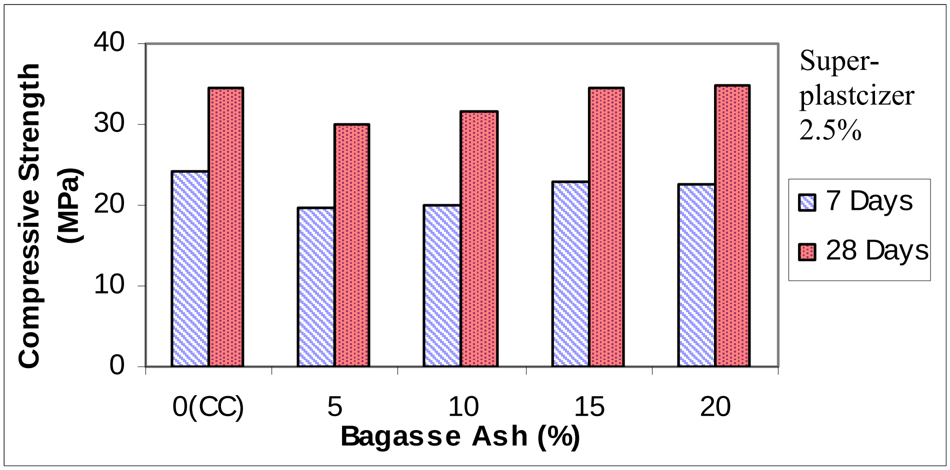

Fig. 4.22. Variation of compressive strength-to-quantity of bagasse ash with 2.5% dosage of superplasticizer

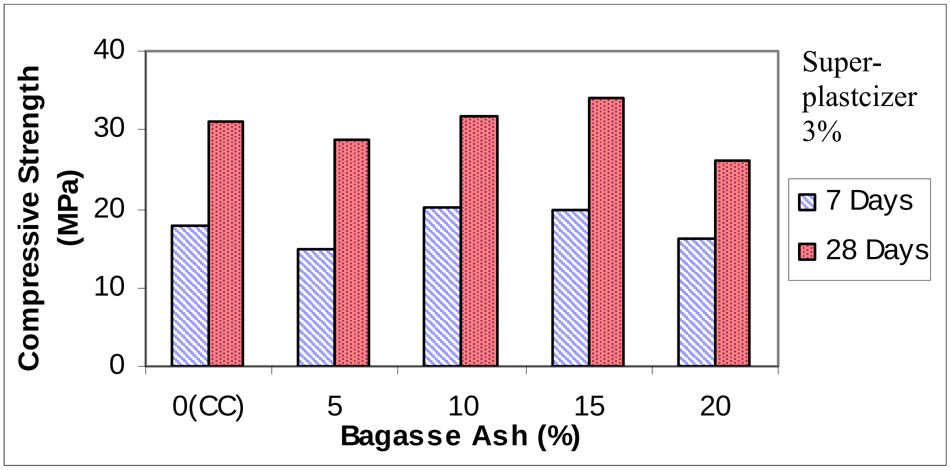

Fig. 4.23. Variation of compressive strength-to-quantity of bagasse ash with 3% dosage of superplasticizer

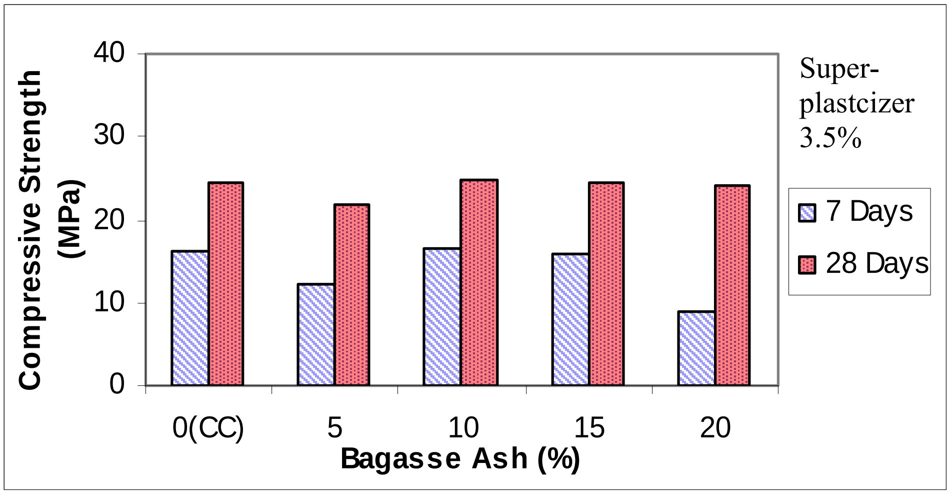

Fig. 4.24. Variation of compressive strength-to-quantity of bagasse ash with 3.5% dosage of superplasticizer

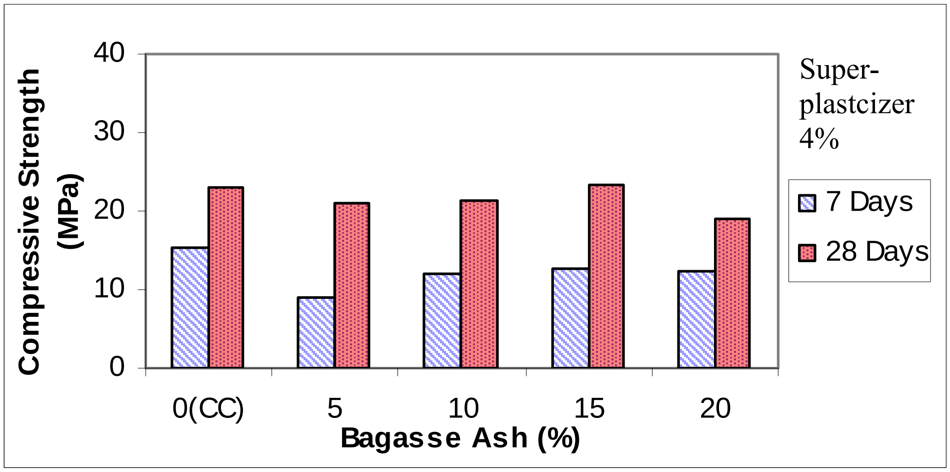

Fig. 4.25. Variation of compressive strength-to-quantity of bagasse ash with 4% dosage of superplasticizer

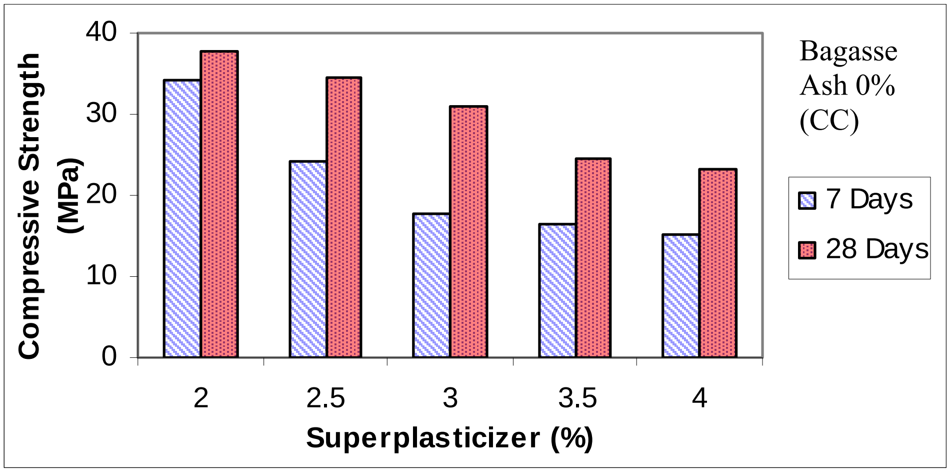

Fig. 4.26. Variation of compressive strength-to-dosage of superplasticizer with 0% quantity of bagasse ash (control concrete)

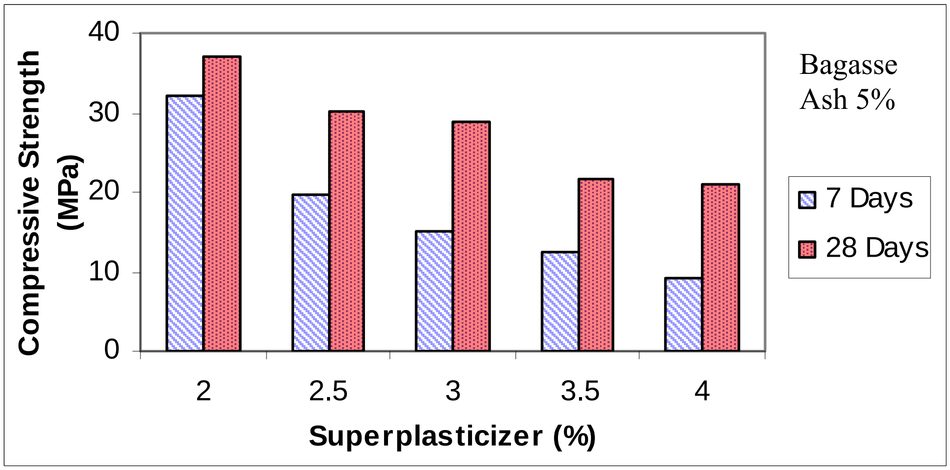

Fig. 4.27. Variation of compressive strength-to-dosage of superplasticizer with 5% quantity of bagasse ash

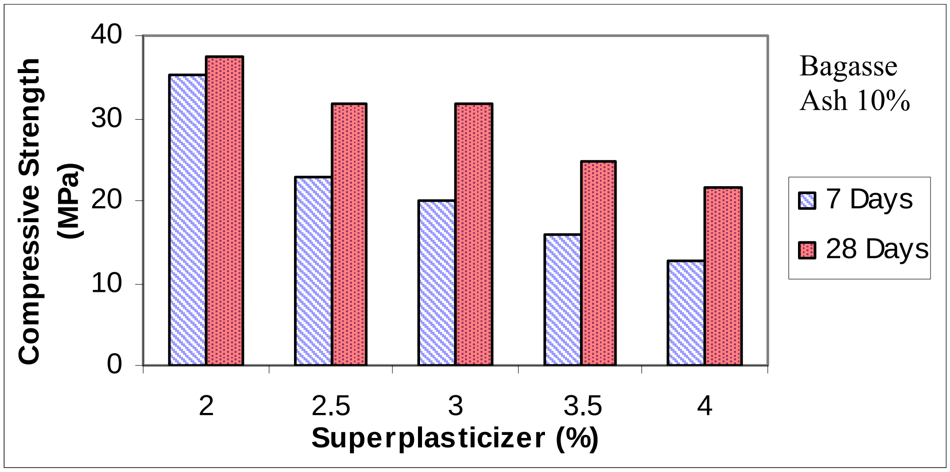

Fig. 4.28. Variation of compressive strength-to-dosage of superplasticizer with 10% quantity of bagasse ash

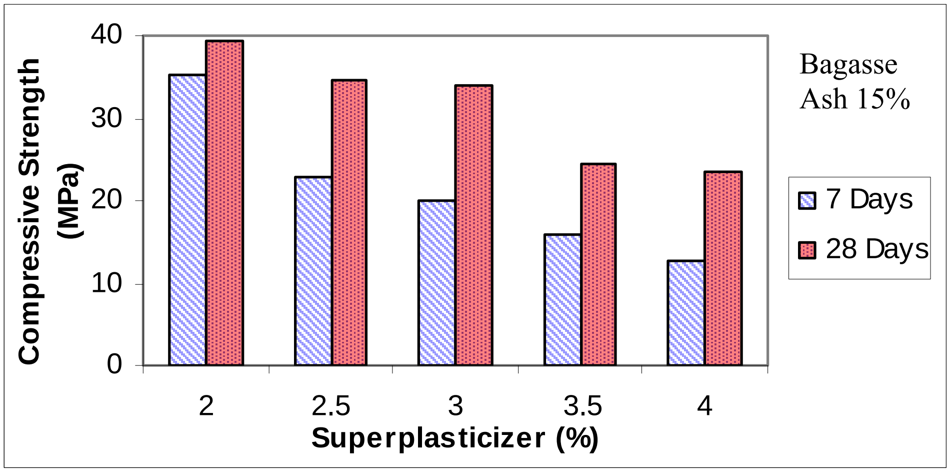

Fig. 4.29. Variation of compressive strength-to-dosage of superplasticizer with 15% quantity of bagasse ash

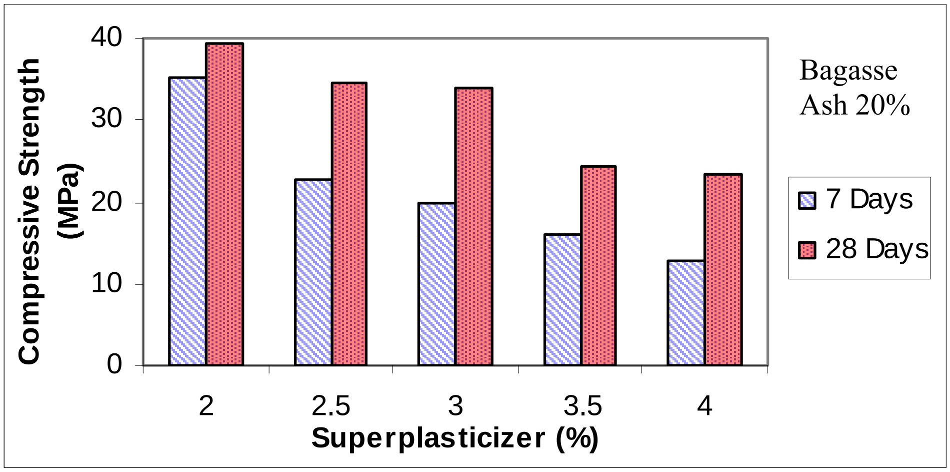

Fig. 4.30. Variation of compressive strength-to-dosage of superplasticizer with 20% quantity of bagasse ash

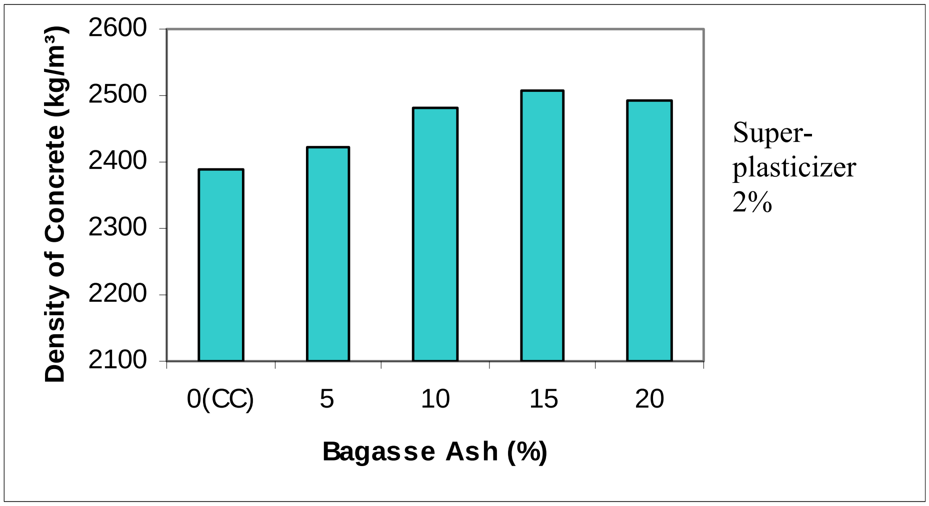

Fig. 4.31. Variation of density of hardened concrete at 1 day-to-quantity of bagasse ash with 2% dosage of superplasticizer

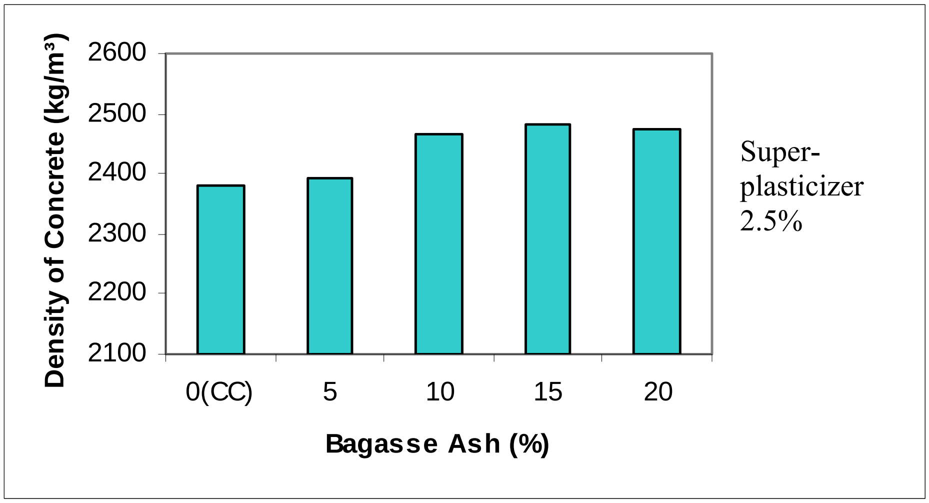

Fig. 4.32. Variation of density of hardened concrete at 1 day-to-quantity of bagasse ash with 2.5% dosage of superplasticizer

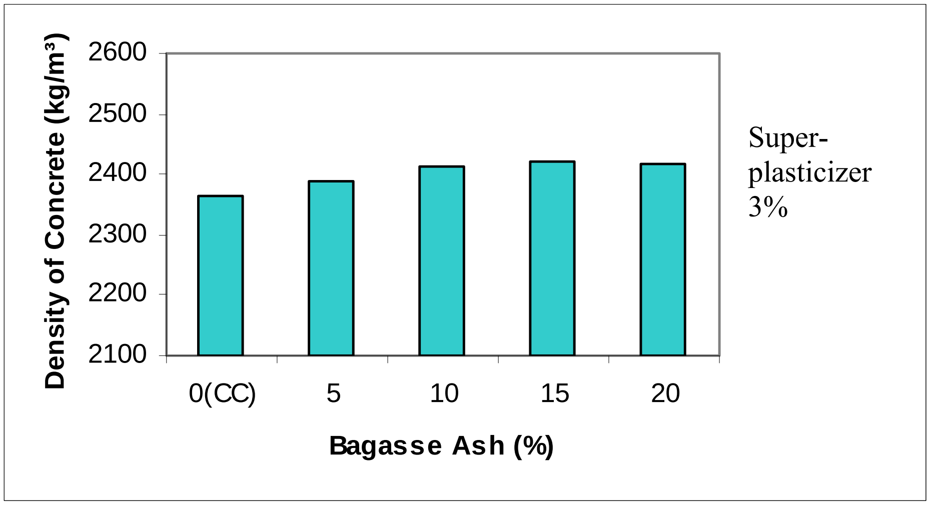

Fig. 4.33. Variation of density of hardened concrete at 1 day-to-quantity of bagasse ash with 3% dosage of superplasticizer

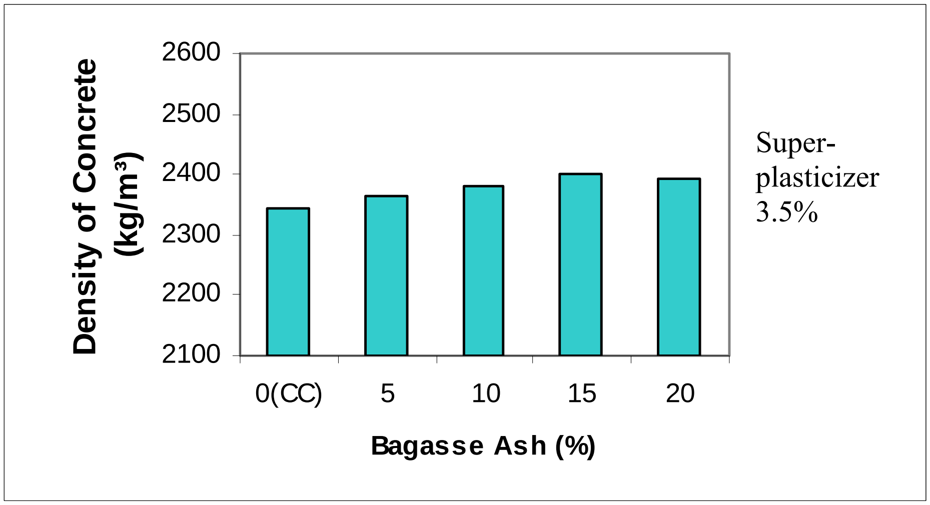

Fig. 4.34. Variation of density of hardened concrete at 1 day-to-quantity of bagasse ash with 3.5% dosage of superplasticizer

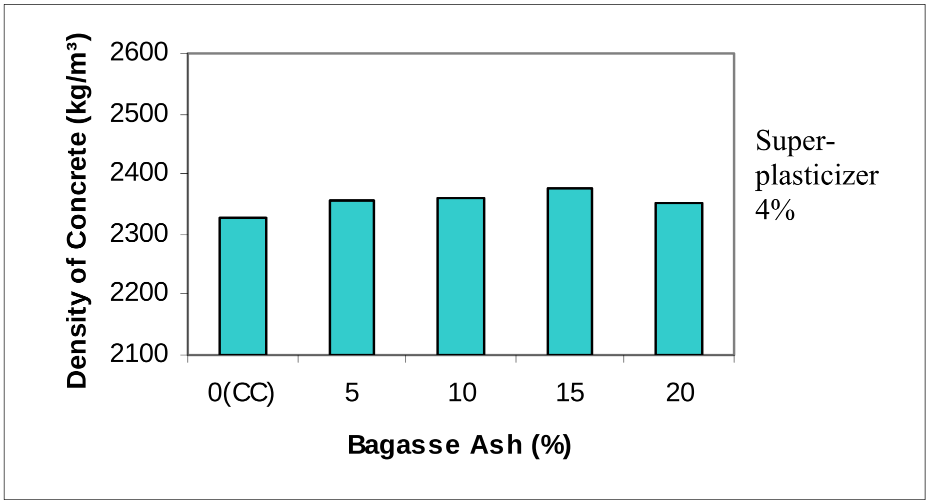

Fig. 4.35. Variation of density of hardened concrete at 1 day-to-quantity of bagasse ash with 4% dosage of superplasticizer

APPENDIX V

Table. 4.4. Comparison of the cost analysis

Material	Rate per kg (rupees)	Control Concrete (CC2.5SP)		SCC with bagasse ash (15B2.5SP)	
		Quantity (kg)	Amount (rupees)	Quantity (kg)	Amount (rupees)
Cement	6	500	3000	500	3000
Coarse aggregate	0.198	750	148.5	750	148.5
Sand	0.105	875	91.87	875	91.87
Superplasticizer (Sikament NN)	69	12.5	862.5	13.125	905.62
Superplasticizer (Sika viscocrete 1)	247.25	10	2472.5	-	-
Bagasse ash	Free of cost	75	-	75	-
Total	-	-	6441.37	-	4012
Percent reduction in cost = 37.72					