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Compressive Strength and Durability Properties of Bagasse ash and Fly Ash based Mortars

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Abstract

Compressive strength and RCPT properties of mortars containing bagasses ash and fly ash were analysed. Mortar mixtures were prepared with a water-to-cementitious materials ratio of 0.65 and a cementitious/sand ratio of 1:3. The usage of 10% and 20% untreated sugarcane bagasse ash (SCBA) and 10% and 20% untreated fly ash (FA) as partial replacements for Ordinary Portland Cement (OPC) was employed as obtained from the factory. The SCBA and FA were sieved through 75 micron and 150 micron sieves, respectively. Cylindrical specimens were prepared for compression strength (CS) and rapid chloride permeability (RCPT) tests on mortars with 10% and 20% replaced with SCBA and FA. The addition of 10% and 20% of SCBA and 10% and 20% FA to the mortars had the following effects: the CS decreased generally for all the mortars at early ages but at 28 days showed slight increase; results of RCPT for varying proportion of mortars shows decreased values for increasing percentages of SCBA. Correlations between the results of the different tests evidence the need for further investigation of the influence of additives in mortar mixtures in order to develop more reliable predictions on the behaviour of the properties of cementitious materials.

1.1 Introduction

The use of pozzolanic materials as a partial replacement for cement in concrete or mortar mixtures provides a reasonable answer to environmental problems as well as the loss of durability that some reinforced concrete constructions suffer from. Pozzolanic materials feature a significant percentage of amorphous silica in their chemical composition, according to studies. When pozzolanic elements are added to cement, the silica ($SiO2$) combines with the free lime left over from cement hydration, forming new silicate hydrate products that improve the concrete's mechanical and durability properties [1].

The utilisation of industrial waste as pozzolanic additives in concrete or mortar mixtures, particularly fly ash (FA), has received a lot of attention. FA is a by-product of the burning of pulverised coal in thermal power plants, and it is collected from the combustion gases by electrostatic precipitators before they are released into the atmosphere. The precipitators are only attracted to flying particles created by coal combustion.

As a result, silica and alumina-rich particles make up the majority of FA, with just a minor quantity of unburned coal particles. As a result, FA reacts well with hydration products to generate more dense and resistant cementitious products, enhancing the mechanical and durability qualities of concrete over time.

Concrete's impermeability and durability are improved with FA. Some researchers have found that the replacement of 20% of cement with FA in concrete mixtures improved compressive strength and significantly delayed the corrosion initiation period due to the decreased permeability to chloride ions [2,3].

The chemical properties of FA vary substantially as a result of variability of both the coal composition and the burning conditions, and this variability has a significant impact on the qualities of the cementitious materials where FA is used.

Grinding the FA and curing at high temperatures have been reported to reduce mortar variability and increase mechanical characteristics [4]. Its pozzolanic activity can also be improved by recalcination. Finally, the addition of Calcium Hydroxide and Sodium Silicate to accelerate the cement early hydration and promote setting and hardening of mortars has been investigated [5]. There is an extensive developing body of knowledge on the effects of post-treated FA on alkali-silica reaction resistance, permeability modification, and corrosion resistance of Portland cement based concretes.

Recent studies of agricultural waste materials have shown to improve the mechanical and durability properties of reinforced concrete and mortar.

Some authors have reported that Sugar Cane Bagasse Ash (SCBA) has substantial amounts of Silica (SiO_2), Alumina (Al_2O_3) and Ferric Oxide(Fe_2O_3) [1,6,7] and that these account for over 70% of the constituents of SCBA, indicating that SCBA can also be used as a mineral admixture.

According to Frias et al. [9], the chemical and mineralogical composition, as well as the pozzolanic material qualities, are influenced by the method of capturing the SCBA and the conditions under which it is calcinated.

Cordeiro et al. [8] found that at $800^{o}C$ Cristobalite and Calcium were formed. The production of SCBA under controlled conditions helps to prevent the formation of crystalline phases and in this way increases its pozzolanic activity.

Some researchers have shown that a high percentage of the loss on ignition (LOI) of the SCBA has a negative effect on its pozzolanic activity. For example, the development of the compressive strength of mortars with an addition of SCBA with a high LOI value was less than for SCBA mortars with low LOI values [9].

Cordeiro et al. [10] analysed the influence of the particle size of the SCBA on the density and compressive strength and found that the reduction in the particle size of the SCBA resulted in an improvement in the pozzolanic activity.

It has been reported that an increase in the compressive strength of concrete and mortar mixtures with an addition of SCBA and it has been also demonstrated that the optimal percentage of cement replacement is 20% [1]. On the other hand, Hernandez et al. [7] observed that a poor curing time of mortar specimens with an addition of SCBA had a negative effect on the compressive strength.

The effect of the addition of SCBA on the properties that determine the durability of mortar and concrete mixtures has received attention in recent research. Ganesan et al. [1] found that the replacement of 20% of cement with SCBA decreased permeability and penetration of chloride ions. Meanwhile, Hernandez et al. [7] found that the higher the content of the SCBA, the higher the content of chlorides in surface layers of mortar specimens, which led them to conclude that the addition of 10% and 20% of SCBA reduced the diffusion coefficient by about 50%.

According to the findings of several researchers, SCBA and FA exhibit high pozzolanic activity when post-treated and can be utilised as additives in concrete and mortar mixes to increase mechanical and durability properties.

Unfortunately, all the methods used to activate FA and SCBA demand a lot of energy, necessitating to investigate whether or not the impairment of the properties of mortars or concretes caused by the use of untreated, ‘‘practically as received” ashes, is tolerable.

Therefore, this research proposes to evaluate the mechanical and durability properties of minimally treated SCBA and FA as a partial replacement for cement in mortar mixtures. Compressive Strength (CS) and Rapid Chloride Permeability (RCPT) tests were carried out. The correlations between mechanical and durability testing results were analysed as well.

2. Experimental

2.1. Experimental design

To evaluate the effects of sugarcane bagasse ash (SCBA) and fly ash (FA), mortars were prepared containing these materials at three levels. Tests of these mortars in fresh and hardened states were carried out. Details of the experimental design and experimental procedures for results in the hardened state are summarized in Table 1.

2.2. Materials

The materials used in this research consisted of Ordinary Portland Cement 53 grade (OPC) in accordance with the IS 4031. The density of the cement was 3.14 g/cm3. The SCBA was collected from a sugar mill located at sugar factory in Mandya district, Karnataka, India. This ash is generated as combustion by-product of sugar cane bagasse at temperatures between 600^0 and 750^0 C and recovered by sprinkling water during sugar production. The collected ash was homogenised and dried for 24 h in an electric oven at 105^0C. In previous research, sieving and grinding were evaluated in order to select the appropriate low-energy input post-treatment [7,11]. In accordance with the findings of the evaluations of low-level treatments sieving the ash through the 90 micron sieve for five minutes was chosen for future research. The density of the SCBA used was 2.1 g/cm3.

The flyash is produced in a thermal plant located at Raichur, Karnataka, India and sieved through 150 micron for five minutes. The density of the FA was 1.98 g/cm3. Manufactured sand was used as a fine aggregate, and its density was 2.65 g/cm3 and its fineness modulus of 2.78. This sand fulfils the recommendations for the use of fine aggregate according to the IS 383-1970. Distilled water was used to prepare all the specimens. Mixtures with 10% and 20% of SCBA had workability problems; therefore, the use of a superplasticizer was required. The polycarboxilates based high-range water reducer PlastolViscoCrete (ASTM C494 Type A and F) was used to improve the workability of these mixtures (see Table 2 for proportions).

2.3. Methods

2.3.1. Characterization of materials and mixture proportioning

The chemical composition of Bagasse ash, Fly Ash and OPC were determined by XR florescence spectrometer.

Finally, scanning electron microscopy was used to study the morphology, size and superficial characteristics of the particles of the materials.

The fine aggregate was characterised for gradation, volumetric weight, density and absorption according to the ASTM C136, ASTM C29/C29M and ASTM C128 standards, respectively.

Mortar mixtures had a water/cementitious materials ratio of 0.65 and a cementitious materials/fine aggregate ratio of 1:3. To keep these ratios constant in 10SBCA and 20SBCA, the addition of a superplasticizer (SP) was needed. All mixtures were designed to achieve a flow of 110 ± 5% mm according to the ASTM C1329 Standard. A summary of the mixture proportions is shown in Table 2.

Table 1
Experimental design and details of experimental procedures

Factor	Level of replacement, %, (name)	Response	Type of specimen	Replicates per mixture	Age of testing	Total number of specimens
Bagasse ash (SCBA)	0 (OPC), 10 (10BA), 20 (20BA),	CS	15/ 20 cm mortar cylinders	3 per each testing age	7, 14, 28 days	60
Fly ash (FA)	0 (OPC), 10 (10FA), 20 (20FA),	RCPT	10 5 cm disks from 10/20 cm mortar cylinders	6 for testing at all ages	7, 14, 28 days	162 disks

Table 2
Mortar Proportions (1 m^3)

Mixture	Cement (kg)	SCBA (kg)	FA (kg)	Water (kg)	Fine aggregate (kg)
OPC	419.8	-	-	250.2	1543.5
10% SBCA	378.5	42.4		250.7	1539.4
20% SBCA	347.2	84.3		251.4	1547.6
10% FA	387.5		42.2	251.9	1555.2
20% FA	351.7		84.1	253.6	1541.2

Table 3
Chemical compositions of OPC, SCBA and FA

Element/compound	OPC %	UtSCBA %	UtFA %	Element/compound	OPC %	UtSCBA %	UtFA %
Na_2O	0.86	0.54	0.43	CuO	n.d	0.01	0.004
MgO	1.16	1.19	0.60	ZnO	0.04	0.02	0.01
Al_2O_3	3.97	14.99	24.83	Ga_2O_3	n.d	n.d	0.005
SiO_2	16.70	66.12	64.45	Rb_2O	0.003	0.007	0.005
P_2O_5	0.72	1.14	0.15	SrO	0.07	0.04	0.04
SO_3	5.46	0.26	0.39	Y_2O_3	n.d	n.d	0.01
K_2O	0.80	3.52	1.04	ZrO_2	n.d	0.03	0.05
CaO	66.4	2.57	1.68	Nb_2O_5	n.d	n.d	0.004
TiO_2	0.25	1.13	1.08	BaO	n.d	n.d	0.04
Cr_2O_3	0.02	0.02	0.01	WO_3	n.d	0.04	n.d
MnO	0.07	0.22	0.02	LOI	4.12	9.34	2.98
Fe_2O_3	2.46	7.16	4.67	$SiO_2 + Al_2O_3 + Fe_2O_3$	-	88.27	93.95

3. Analysis and discussion of results

3.1. Characterization of cement and pozzolanic materials

3.1.1. Chemical analysis

Table 3 presents the major oxides for OPC, SCBA and FA. The ASTM 618 establishes that for Class N and F pozzolans, the minimum value of the sum of SiO should be higher than 70% and for pozzolans Class C higher than 50%. For the SCBA and FA under study the sums are 81.38% and 91.89%, respectively, which are higher than the value recommended by the Standard to consider the materials as pozzolans. The results are consistent with those from the literature which have been reported to be between 73.91% and 90.5% for SCBA [1,12,10,13].

Values in Table 3 also suggest that the SCBA, used to prepare the mortar mixtures, has a lower pozzolanic potential than FA. The CaO values for SCBA and FA were found to be less than 10%, therefore SCBA can be classified as a Class N (calcined natural) pozzolan and FA as Class F pozzolan.

The SCBA used in this study showed a high LOI, whereas, for the FA used in this study the LOI was significantly lower. The ASTM C618 sets the LOI value for Class F pozzolans at less than 6%. In spite of the high LOI content found in the SCBA in the present study, research was interested in investigating the influence of SCBA on some mechanical and durability properties of mortars.

It was decided to use the untreated SBCA because the implementation of a high energy demanding post-treatment of the ash, such as thermal activation and grinding, would result in the emission of additional pollutants to the atmosphere.

3.2. Properties of mortar in fresh and hardened states

All mortars achieved a flow value of 110 ± 5% mm which helps to assure that the mixtures were cohesive, workable and with no segregation (Table 4). The control and the FA mixtures did not demand the superplasticizer to reach the target value. FA usually improves the workability of mixtures because the spherical particles act as a lubricant between cement particles. The 10BA mixture required the addition of the superplasticizer in order to be workable.

When the amount of SCBA was increased to 20%, the dosage of SP also needed to be augmented. This is the result of several factors. First, the prismatic shape of the SCBA particles increases the friction between the cement particles and allows a large percentage of voids which should be filled with water prior to the flow of the mixture [7]; second, the SCBA particles are porous and absorb some of the mixing water; and third, the high LOI value of SCBA increases the water demand in fresh concrete [9]. A reduction of the volumetric weights of the mortars occurs when the cement replacement increases. This reduction is caused by the lower densities of the ashes and the shape of the particles. The air content results confirm this reduction because the addition of 10% and 20% of SCBA increased the air content values by 10.5% and 26.3%, respectively; whereas, the addition of 10% and 20% of FA decreased the air content values by 26.3% and 15.7% when they were added to the mortar mixture. The addition of SP contributes to the reduction because it increases the air content.

3.2.2. Compressive strength (CS)

The results in Fig. 3a reveal that adding 10% SCBA to the mortar mixture has a modest negative impact on the compressive strength of the mortar (reductions of 7.9 %, 5.3 %and 3.5 %at 7, 14 and 28 days, respectively). When 20 percent SCBA is added to the mixture, a similar effect is found (reductions of 9.5 %, 9.4 %, and 3.6 %at 7, 14 and 28 days, respectively).

Despite the use of a low-energy demand post-treatment for the conditioning of the SCBA, the results obtained in this study are consistent with those described in the literature [12,1].

The compressive strength of the mortars containing 10% FA was comparable to the compressive strength of mortars containing 10% SCBA. When the amount of FA in the mixture was increased from 10% to 20%, the compressive strengths fell. The mortar with 20% FA had the lowest compressive strength of the other mortars after 56 days, after which it regained strength comparable to the control.

According to certain research, increasing the amount of SCBA used to replace cement by more than 10% can reduce the compressive strength of mortars and concretes [1,7,8,11,16]. The presence of high carbon content in the SCBA is blamed for this impact. This effect can be seen in the current study, but only at young ages. It is not visible at later ages. At 90 and 180 days, there was no discernible difference between mixes containing SCBA (10BA and 20BA) and FA (10FA and 20FA) and the control.

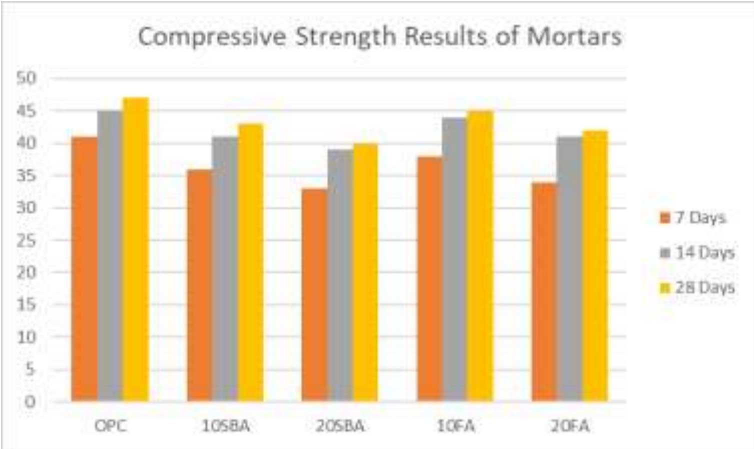

Fig 3a - Compressive strength results

3.2.3. Rapid Chloride Permeability Test (RCPT)

Fig. 3d shows the results for the RCPT. Mortars at early ages were highly permeable. Because of the ratio of relatively high water-to-cementitious materials, some tests could not be performed. As a consequence, only RCPT results for 28, 56, 90 and 180 days are reported. In order to attempt a comparison between OPC and mortars with pozzolans the rating of chloride permeability for concrete proposed by the ASTM C1202 was implemented. Readings indicate that the total current passed decreases with age because the connection between pores in the cementitious matrix diminishes as a result of the hydration and pozzolanic reactions. Results show that the addition of SCBA positively influences the impermeability of the mortars at all ages when they are compared to the OPC mixture, especially when 20% of the ash is incorporated into the mixture. With the addition of 10% and 20% of SCBA, the mortars can be considered as moderate and low permeability, respectively.

The addition of 10% of FA helps to improve the impermeability of mortars as well at the majority of the tested ages, when compared to the OPC mixture; however, when 20% of FA is added the impermeablity is lower than the OPC mixture, and only after 90 days this effect is reversed.

however, Shi et al. [17] demonstrated that the reduction of the current passed values of concrete with FA and natural pozzolans in fact caused a reduction in the alkalinity of the pore solution rather than a reduction in the permeability of concrete. They concluded that the electrical conductivity of the obtained values from the RCPT decreased when the alkalinity of the pore solution was reduced.

Based on the above discussion, it can be concluded that the reduction of the current passed is the result of two things: first, the densification of the cementitious matrix which causes a decrease of the mobility of ions inside the mortar because of the reduction of the connectivity of the pore system; and second, the change in the ionic concentration by the inclusion of pozzolanic materials.

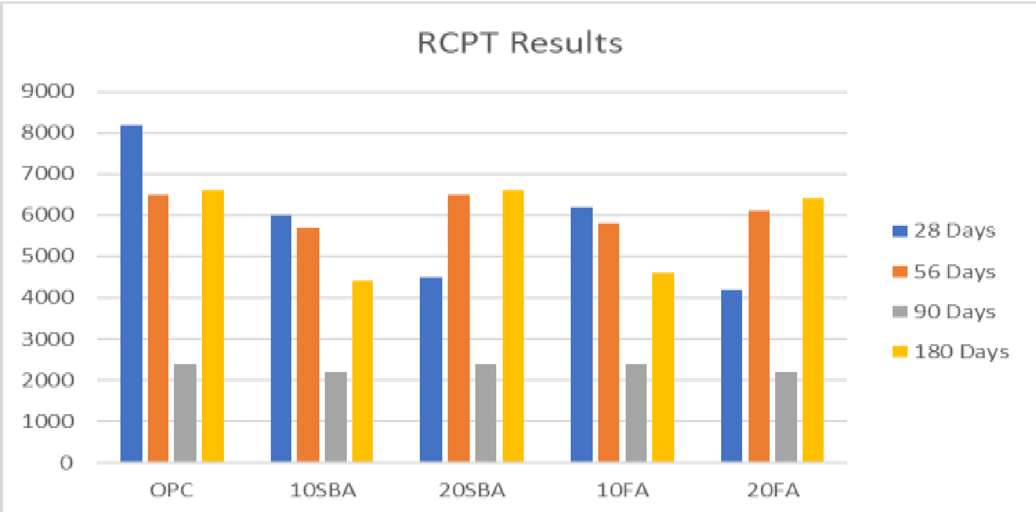

Fig 3b - RCPT results

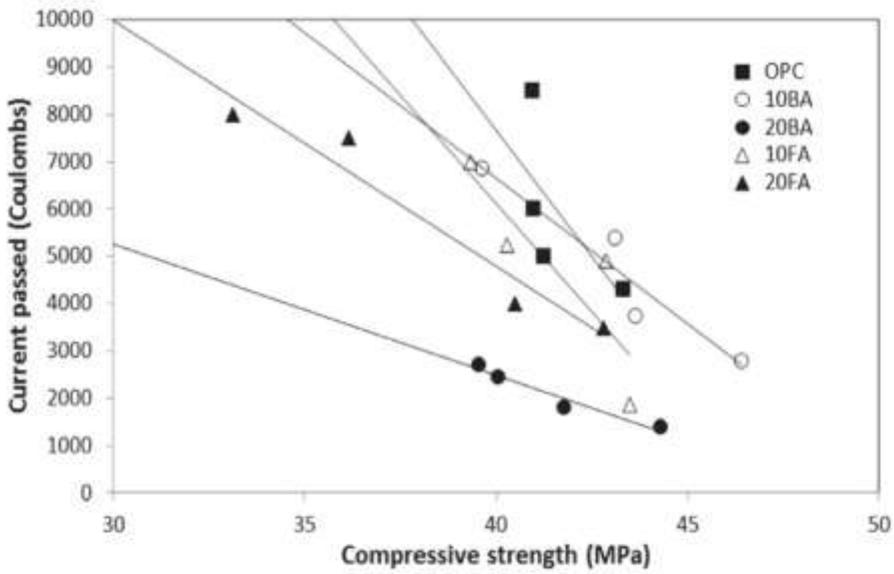

Fig 3c - Correlation between Compressive strength and RCPT

4. Conclusions and recommendations

Based on the results of the tests the following conclusions can be drawn:

1. The addition of 10% untreated SCBA had the following effects on the properties of the mortars: a decrease in the Compressive Strength at early ages but an increase in strength at later ages to a level similar or higher than the control
2. The addition of 20% untreated SCBA had the following effects on the properties of the mortars: a decrease in the Compressive Strength at 7, 14 and 28 days, but this effect was not significant at 56, 90 and 180 days when compared with the control; and a significant decrease in the Rapid Chloride Permeability Test of all the mortars.
3. The addition of 10% untreated FA had the following effects on the properties of the mortars: a decreased Compressive Strength of the mortars at early ages but a decrease in the Rapid Chloride Permeability Test was also observed, but only at 180 days.
4. The addition of 20% untreated FA had the following effects on the properties of mortars: a decreased Compressive Strength and not until 90 days did the strength equal that of the control; and the Rapid Chloride Permeability Test was lower than the control, but higher than the other mortars containing ashes.
5. The properties of Portland cement-based mortars fabricated with FA and SCBA with a low-energy demanding posttreatment correlate well; in some cases the coefficients of determination of these mortars were higher than for the control.
6. This research evidences the necessity for further investigation into the influence of additives in mortar mixtures in order to develop a comprehensive body of knowledge and develop more reliable predictions on the behaviours of the properties of cementitious materials.
7. The results obtained from the experiments lead the researchers in this study to recommend that an analysis of pore solutions should be carried out in order to understand the significant increase in the electrical resistivity and the significant decrease in the permeability of mixtures containing 20% of SCBA. The hypothesis that unburned matter can bond chlorides has to be addressed in more detail in those experiments.

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