APPLICATION OF SUGARCANE BAGASSE ASH AS A PARTIAL CEMENT REPLACEMENT MATERIAL

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ABSTRACT

Sugarcane bagasse ash is a byproduct of sugar factories found after burning sugarcane bagasse which itself is found after the extraction of all economical sugar from sugarcane. The disposal of this material is already causing environmental problems around the sugar factories. On the other hand, the boost in construction activities in the country created shortage in most of concrete making materials especially cement, resulting in an increase in price. This study examined the potential use of sugarcane bagasse ash as a partial cement replacement material.

In this study, bagasse ash sample was collected from Wonji sugar factory and its chemical properties were investigated. The bagasse ash was then ground until the particles passing the 63μm sieve size reach about 85% and the specific surface area about 4716 cm^2/gm. Ordinary Portland cement and Portland Pozzolana cement were replaced by ground bagasse ash at different percentage ratios. Normal consistency and setting time of the pastes containing Ordinary Portland cement and bagasse ash from 5% to 30% replacement were investigated. The compressive strengths of different mortars with bagasse ash addition were also investigated. Four different C-35 concrete mixes with bagasse ash replacements of 0%, 5%, 15% and 25% of the Ordinary Portland cement were prepared with water to cement ratio of 0.55 and cement content of 350kg/m^3 for the control mix.

The test results indicated that up to 10% replacement of cement by bagasse ash results in better or similar concrete properties and further environmental and economical advantages can also be exploited by using bagasse ash as a partial cement replacement material.

Keywords: *Bagasse ash, Pozzolanic material, Normal consistency, Setting time, Compressive strength, Water penetration depth.*

INTRODUCTION

Concrete is one of the most commonly used construction material in the world. It is basically composed of three components: cement, water and aggregates. Cement plays a great role in the production of concrete and is the most expensive of all other concrete making materials. In addition, there is environmental concern in the production of cement. Due to this, requirements for more economical and environmental-friendly cementing materials have extended interest in partial cement replacement materials. Ground granulated blast furnace slag, pulverized fly ash and silica fume, have been successfully used for this purpose.

Bagasse is a by-product from sugar industries which is burnt to generate power required for different activities in the factory. The burning of bagasse leaves bagasse ash as a waste, which has a pozzolanic property that would potentially be used as a cement replacement material. It has been known that the worldwide total production of sugarcane is over 1500 million tons [1]. Literatures indicate that currently there is about 300,000 tons of sugar production in Ethiopia. Sugarcane consists about 30% bagasse whereas the sugar recovered is about 10%, and the bagasse leaves about 8% bagasse ash (this figure depend on the quality and type of the boiler, modern boiler release lower amount of bagasse ash) as a waste [1, 2]. With the country's plan to boost the sugar production to over 3 million tons by the end of 2015, the disposal of the bagasse ash will be of a serious concern [3].

Sugarcane bagasse ash has recently been tested in some parts of the world for its use as a partial cement replacement material. The bagasse ash was found to improve some properties of the paste, mortar and concrete including compressive strength and water tightness in certain replacement percentages and fineness [1,2,4,5]. The higher silica content in the bagasse ash was suggested to be the main cause for these improvements. Although the silicate content may vary from ash to ash depending on the burning conditions and other properties of the raw materials including the soil on which the sugarcane is grown, it has been reported that the silicate undergoes a pozzolanic reaction

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with the hydration products of the cement and results in a reduction of the free lime in the concrete [2].

The main objective of this study is, therefore, to study the suitability of bagasse ash produced in Wonji Sugar factory, Ethiopia, as a pozzolanic material to partially replace cement in mortar and concrete production. Towards this, experimental investigations were carried out to examine the impact of adding bagasse ash on the mechanical and physical properties of pastes, mortars and concretes.

MATERIALS

Sugarcane Bagasse Ash

The sugarcane bagasse ash used for the study was collected from Wonji sugar factory located in Oromiya Regional State - North Eastern Ethiopia. The original ash was ground in a small mill to reduce its particle sizes until the particles passing the 63μm reaches about 85%. The specific gravity of the cement (Messebo OPC) and the bagasse ash were tested in the laboratory and it was found to be 3.15 and 2.16, respectively. The physical properties test results of the cement and bagasse ash are shown in Table 1 and the particle size distribution is also shown in Fig 1.

Table 1: Physical property of Messebo OPC and bagasse ash (as tested in the laboratory.)

Material	Messebo OPC	Bagasse Ash
Density (g/cm^3)	3.15	2.16
Specific surface area (cm^2/gm)	2910	4716
Average size(μm) (where 50% of the particle passes)	43.4	40.1

Cement and Aggregate

Messebo OPC, PPC and aggregates (both fine and coarse) conforming to Ethiopian standard ES C.D5 201 and ES C.D3.201, respectively, were used for the preparation of the test specimens [6]. The oxide composition of the bagasse ash and Messebo OPC are as shown in Table 2.

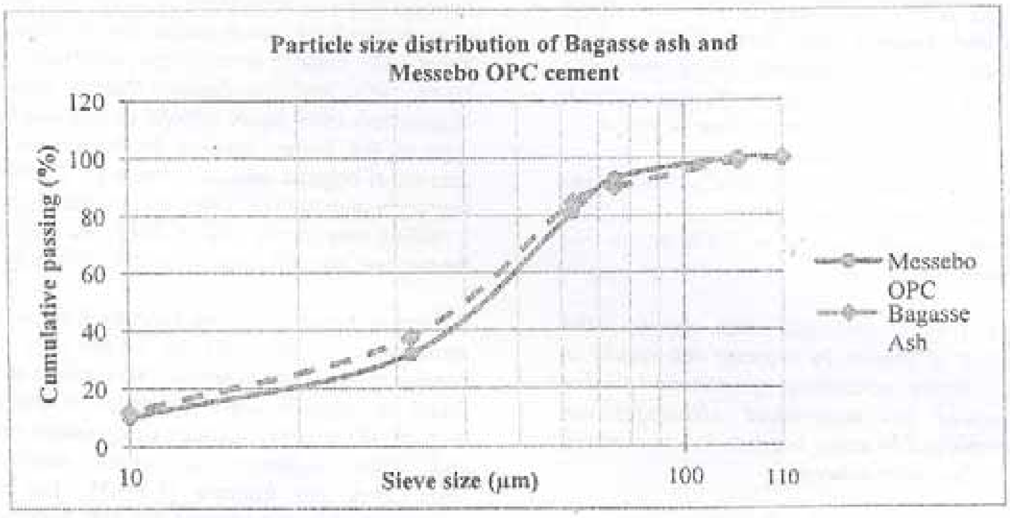

Figure 1: Particle size distribution of bagasse ash and cement

Table 2: Oxide composition Messebo OPC [7] and bagasse ash as tested in Geological Survey center of Ethiopia.

Oxide Composition (%)		Sugarcane Bagasse Ash	Oxide composition of Messebo OPC [7]
SiO_2		65.58	20.50
Al_2O_3		5.87	4.75
Fe_2O_3		4.32	3.70
CaO		1.78	63.40
MgO		1.23	1.31
Alkalies	Na_2O	1.02	-
	K_2O	6.41	
MnO		0.05	-
TiO_2		0.25	-
P_2O_5		1.35	-
H_2O		0.20	-
SO_3		0.18	2.41
LOI		10.48	-
Cl		< 0.1	-
SiO_2+ Al_2O_3+ Fe_2O_3		75.77	-

EXPERIMENTAL PROGRAM

Mortar cubes of size 50x50x50mm were prepared and placed in a curing pond until the test date. Seven different mortar samples containing 5, 10, 15, 20, 25 and 30 % bagasse ash replacement along with the control mix (0% bagasse ash) were prepared for both OPC and PPC replacements. The mix proportion used in the preparation of the control mortar specimens was: 1000g cement; 1500g sand and 450g water. The blended mortar specimens were prepared by volume replacement) of the cement and keeping water and sand constant. Here it should be noted that all the measurements for the preparation of test specimens were made by weighting. For each substitution ratio, 3 sets (3 x 3 = 9) of mortar specimens were prepared for compressive strength tests conducted at the age of 3, 7, and 28 days. Mix proportions used in the preparation of OPC-BA and PPC-BA mortar specimens are as shown in Table 3 below.

(The term 'volume replacement' is to imply that instead of 1:1 by weight replacements, 1:1 by volume replacements were used to keep similar paste content between the different mixes. 1:1 by weight replacements were also tested, but in this case the mortars with bagasse ash were found to have higher amount of paste (due to lower specific gravity of bagasse ash) which results in unfair comparison between the control mix and the other mixes.

Table 3: OPC-BA and PPC-BA mortar mixes

Test No	Mix Designation	Cement type	Cement (gm)	Bagasse ash(gm)	W/B	Water (gm)	Sand (gm)
1	BAM 0	OPC	1000	0	0.450	450	1500
2	BAM 5	OPC	950	34.5	0.457	450	1500
3	BAM 10	OPC	900	68.5	0.465	450	1500
4	BAM 15	OPC	850	103.0	0.472	450	1500
5	BAM 20	OPC	800	137.0	0.480	450	1500
6	BAM 25	OPC	750	171.5	0.488	450	1500
7	BAM 30	OPC	700	206.0	0.497	450	1500
8	BAMP 0	PPC	1000	0	0.450	450	1500
9	BAMP 5	PPC	950	39.0	0.455	450	1500
10	BAMP 10	PPC	900	78.5	0.460	450	1500
11	BAMP 15	PPC	850	118.0	0.465	450	1500
12	BAMP 20	PPC	800	157.0	0.470	450	1500
13	BAMP 25	PPC	750	196.5	0.475	450	1500
14	BAMP 30	PPC	700	236.0	0.481	450	1500

N.B – BAM stands for OPC-BA mortars while BAMP is for PPC-BA mortars and the number refers to the volume percentage of OPC or PPC replaced by bagasse ash.

In order to investigate whether bagasse ash can be activated by the addition of calcium hydroxide ($Ca(OH)_2$) or not, other mortar specimens were prepared by mixing OPC, bagasse ash and $Ca(OH)_2$. The specimens prepared included a control mortar cube with no cement replacement, a mortar with 15% cement replacement by bagasse ash and the same mortar with the latter with the only difference of 3% and 6% replacement of the replacing bagasse ash by $Ca(OH)_2$ for 7 and 28 days test. Mix proportions used in the preparation OPC-BA-$Ca(OH)_2$ mortar specimens are as shown in Table 4 below.

Table 4: OPC-BA-$Ca(OH)_2$ mortar mixes

Test No	Mix Designation	Cement type	Cement (gm)	Bagasse ash(gm)	$Ca(OH)_2$ (gm)	W/B	Water (gm)	Sand (gm)
1	BAMA 0	OPC	700	0	0	0.450	315	1050
2	BAMA 15	OPC	595	72	0	0.472	315	1050
3	BAMA 15-3	OPC	595	69.8	2.2	0.474	315	1050
4	BAMA 15-6	OPC	595	67.7	4.3	0.475	315	1050

N.B – BAMA stands for OPC-BA-$Ca(OH)_2$ mortars, the first number refers to the volume of OPC replaced and the second the volume of bagasse ash replaced by $Ca(OH)_2$.

Concrete cubes of size 150x150x150mm were prepared and placed in a curing pond for a maximum of 14 days. Four different concrete samples containing 5, 15 and 25 % bagasse ash along with the control mix were prepared for OPC replacements. The control concrete mix had a mix proportion of 350 kg/m^3 cement, 192.5 kg/m^3 water, 650 kg/m^3 sand and 1205 kg/m^3 coarse aggregate. The blended concrete specimens were prepared by volume replacement of the cement with bagasse ash and keeping the other ingredients constant. For each substitution ratio, 3 sets of concrete specimens were prepared for compressive strength tests conducted at the age of 7, 28 and 56 days. Water penetration depth tests were also conducted at the age of 56 days for each replacement ratio. The final mix proportions for 1m^3 of the control and OPC-BA concrete mixes are as shown in Table 5 below.

TEST RESULTS AND DISCUSSIONS

Physical and Chemical Properties

The test results indicated that the sugarcane bagasse ash had a low density (2.16g/cm^3) and higher specific surface area (4716cm^2/g) when compared with that of the Messebo OPC. Particle size analysis of ash samples (Fig. 1) indicates that 50% of the ash particles passed through 40.1μm and 90% were of size less than 76.1μm, whereas the analysis for the cement indicated that 50% of the particles passed through 43.4μm which is slightly greater than the bagasse ash and 90% of the particles were less than 72μm which is less than the ash. The fineness was determined using blain air permeability method and the results are tabulated as shown in Table 6.

The chemical composition shown in Table 2, revealed that the bagasse ash can be assigned as a class N pozzolan, as per ASTM C618 classification since the sum of SiO_2, Al_2O_3, and Fe_2O_3 content is greater than 70%. The loss on ignition (LOI) value was found to be 10.48% which is slightly higher than that specified by the same standard, which is 10%.

Table 5: Mix proportion for the concrete mixes

Test No	Mix Designation	Cement type	Cement quantity (kg/m^3)	Bagasse ash (kg/m^3)	W/B	Water (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	FA (%)	CA (%)
1	BA 0	Messebo OPC	350	0	0.55	192.5	650	1205	35	65
2	BA 5	Messebo OPC	332.5	12	0.56	192.5	650	1205	35	65
3	BA 15	Messebo OPC	297.5	36	0.58	192.5	650	1205	35	65
4	BA 25	Messebo OPC	262.5	60	0.60	192.5	650	1205	35	65

N.B – BA stands for OPC-BA concretes and the number refers to the volume of OPC replaced by bagasse ash.

Normal Consistency and Setting Time

The results of setting time tests shown in Table 6 indicate that the addition of bagasse ash retarded the setting time of the paste; however this retardation was within limits as specified by the Ethiopian standard which is not less than 45 minutes for initial setting time and not greater than 10 hours for final setting time. It could have been caused by the adsorption of water at the surface of bagasse ash. Further, Goyal A. et al suggested the reduction in the amount of calcium hydroxide and also the development of films of silica gel around cement grains, and a mutual coagulation of components within the paste may have caused the retardation of setting time [1]. The finding on the consistency of the blended pastes conformed to previous research findings [1, 5].

The mortar with 5% and 10 % replacement of OPC by sugarcane bagasse ash have shown a higher compressive strength value than the control throughout the test periods as shown in Fig. 2a. However, Fig. 2b. shows that the mortars with PPC didn't show any improvement on the compressive strength at any replacement percentage. Rather they showed a reduction in compressive strength. A similar trend was found by undergraduate research project on self-compacting concrete by using bagasse ash [9].

Table 6: Specific surface area, Normal consistency and Setting time

Mix Designation	Specific surface area (cm^2/g)	Consistency (%) (ASTM C 187)	Initial setting time (minutes)	Final setting time (minutes)
BAP 0	2910	32.5	176	280
BAP 5	2929	32.5	195	316
BAP 10	2948	32.5	203	324
BAP 15	3085	33.0	200	327
BAP 20	3214	33.5	205	325
BAP 25	3359	34.0	216	327
BAP 30	3497	34.8	232	333

N.B – BAP stands for bagasse ash powder or paste as applicable and the number refers to the volume of OPC replaced by bagasse ash.

Compressive Strength of the Test Mortars

The compressive strength of both OPC-BA and PPC-BA mortars were tested and the average results are as shown in Table 7 below.

Table 7: Compressive strength of OPC-BA and PPC-BA mortars

Test No	Mix Designation	Average compressive strength					
		3 days		7 days		28 days	
		Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)
1	BAM 0	54.6	21.85	89.6	35.85	134.6	53.86
2	BAM 5	57.6	23.05	93.4	37.36	140.1	56.01
3	BAM 10	55.9	22.35	90.6	36.24	138.5	55.42
4	BAM 15	47.5	18.98	82.7	33.09	134.1	53.64
5	BAM 20	45.0	18.00	77.5	31.01	126.7	50.68
6	BAM 25	43.8	17.53	71.6	28.64	114.8	45.95
7	BAM 30	42.7	17.09	68.9	27.57	109.3	43.74
8	BAMP 0	31.8	12.74	57.3	22.90	109.3	43.71
9	BAMP 5	30.3	12.11	53.5	21.39	94.1	37.62
10	BAMP 10	28.8	11.53	51.6	20.66	93.3	37.33
11	BAMP 15	27.5	11.01	50.0	19.99	91.0	36.41
12	BAMP 20	26.3	10.54	43.7	17.50	88.2	35.27
13	BAMP 25	23.1	9.25	40.5	16.21	79.8	31.91
14	BAMP 30	22.4	8.96	37.5	14.98	69.8	27.93

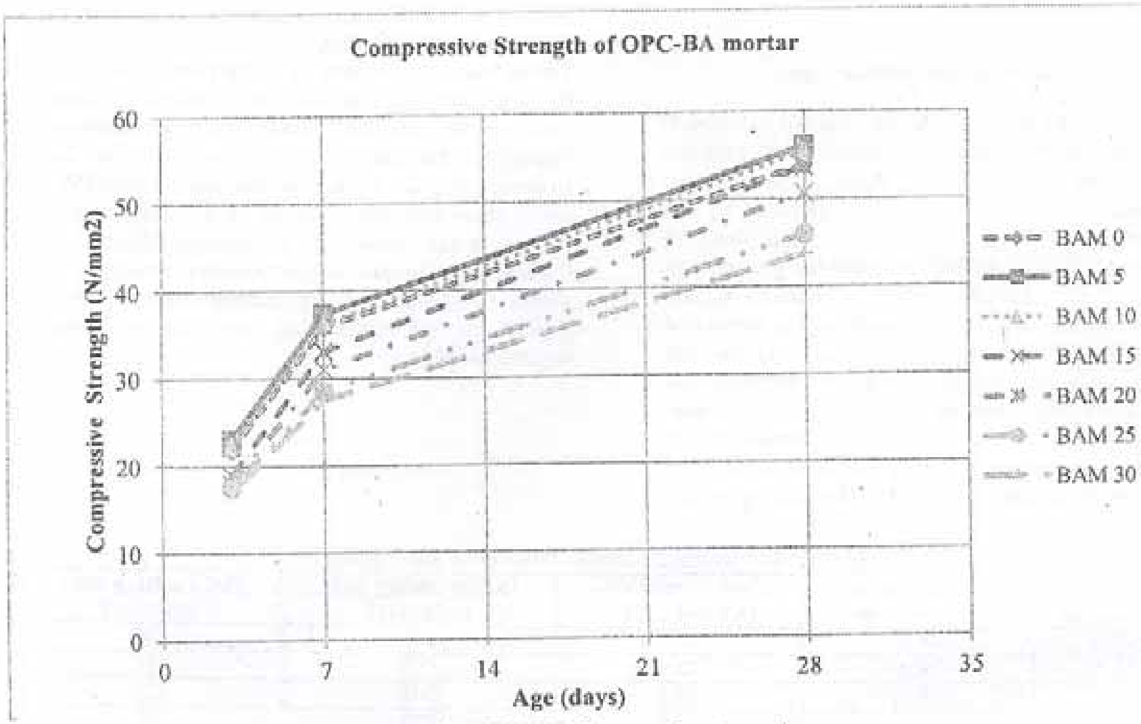

Figure 2a OPC-BA Compressive strength

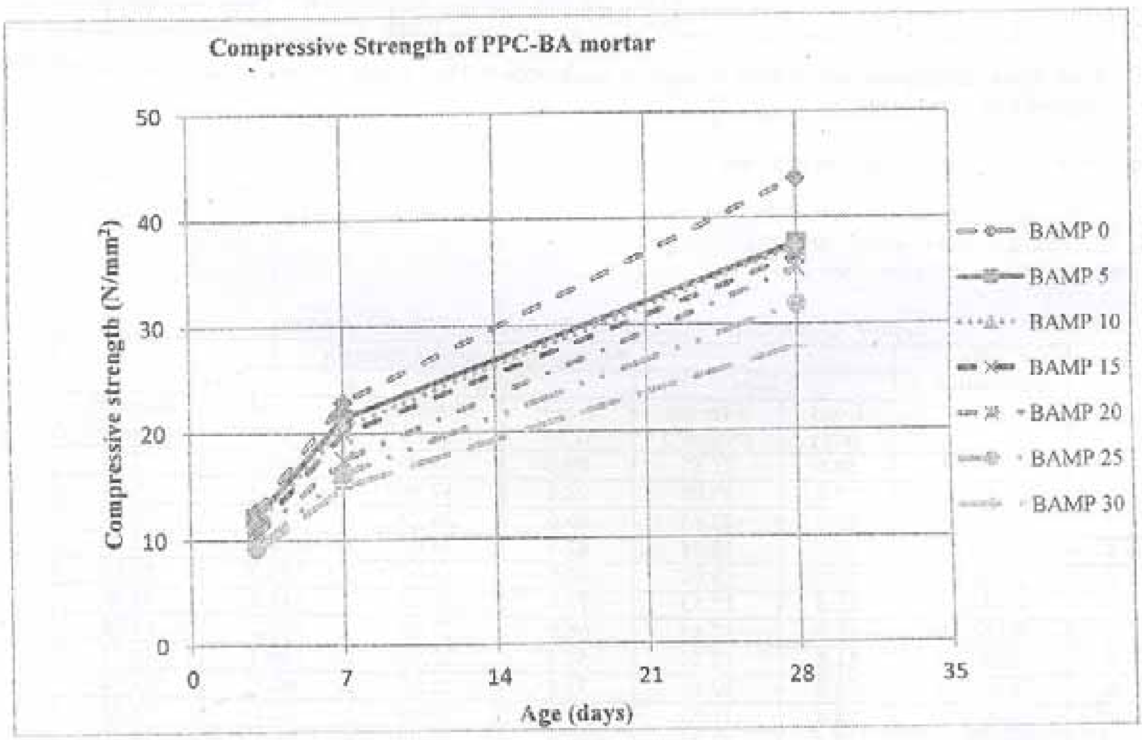

Figure 2b PPC-BA Compressive strength

Figure 2 Compressive strength of OPC-BA and PPC-BA mortars

The bagasse ash acts in different ways when it partially replaces OPC and PPC. The substitution of PPC with bagasse ash did not result in compressive strength improvement probably due to the high amount of unhydrated silica from the cement and the bagasse ash. As a result of this, all the PPC-BA mortars have shown a lower compressive strength than the control mortar.

OPC on the other hand, which contains smaller amount of silica by itself, resulted in a higher compressive strength for 5% and 10% replacements. This is probably due to the pozzolanic reaction between the bagasse ash and the $Ca(OH)_2$ from the cement hydration. Different researchers have also proved the existence of pozzolanic reaction using alternative test methods. It has been reported by Goyal A. et al, that the intensity of $Ca(OH)_2$ in the 91 days cured sample significantly reduced with corresponding increase in the intensity of C-S-H [1].

As a measure of pozzolanic activity, strength activity indices (the percentage ratio of compressive strength of the blended mortars with the control mix mortar) were calculated at the ages of 3, 7, and 28 days, as per ASTM C 618 definition. As can be seen from Table 8, strength activity index for all OPC-BA blended mortars at 3, 7 and 28 days were higher than the minimum requirement of 75% specified in ASTM C 618.

Table 8: Strength activity index of OPC-BA and PPC-BA mortars

Mix Designation	Age of specimen		
	3 days	7 days	28 days
BAM 0	100	100	100
BAM 5	105.5	104.2	104
BAM 10	102.3	101.1	102.9
BAM 15	86.9	92.3	99.6
BAM 20	82.4	86.5	94.1
BAM 25	80.2	79.9	85.3
BAM 30	78.2	76.9	81.2
BAMP 0	100	100	100
BAMP 5	95.1	93.4	86.1
BAMP 10	90.5	90.2	85.4
BAMP 15	86.4	87.3	83.3
BAMP 20	82.7	76.4	80.7
BAMP 25	72.6	70.8	73.0
BAMP 30	70.3	65.4	63.9

The result indicates that increasing the percentage replacement of cement by bagasse ash over a certain percentage has resulted in reduction of compressive strength, which conformed to other findings [9]. This is due to the fact that high replacement of cement by bagasse ash reduces cement content of the mixture which in turn causes a reduction in the hydration reaction. The strength activity index has also shown a general pattern of increasing with age for most of the specimens with OPC. For example, BAM 15 has a strength activity index of 86.9, 92.3 and 99.6% at the ages of 3, 7 and 28 days, respectively. The increase with age of the strength activity index can also partly prove the pozzolanic nature of the bagasse ash i.e. since pozzolanic reactions are slower and dependant on the hydration of the cement. Nuntachai C. et al, also reported that the strength activity index increases as the age of the test specimen increases [5]. The presence of pozzolanic reactions between the bagasse ash and the cement on the other hand, will have a positive effect on the long-term behavior of mortars especially on durability. The consumption of calcium hydroxide, the product of cement hydration, by the silicate from the bagasse ash will reduce the permeability of the mortar and result in a better durability.

On the other hand as in the case of OPC-BA mortar, increasing the replacement of bagasse ash resulted in a reduction of the strength activity index of the PPC-BA mortar. Interestingly, most of the PPC-BA blended mortars showed a decrease in strength activity index as the age of the specimen increased which is different from that of OPC-BA blended mortar. Moreover, none of the PPC-BA mortars have shown improvement over the control mortar which is not the case for OPC-BA mortars. However, the main requirement set by ASTM C 618 has been fulfilled up to 20% replacement of PPC by BA.

The compressive strength of OPC-BA with $Ca(OH)_2$ are shown in Table 9 and Figure 3 below.

Table 9: Compressive strength of OPC-BA-$Ca(OH)_2$ mortars

Test No	Mix Designation	Average compressive strength			
		7 days		28 days	
		Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)
1	BAMA 0	85.7	34.30	131.4	52.57
2	BAMA 15	75.9	30.35	129.0	51.62
3	BAMA 15-3	77.5	30.99	129.4	51.78
4	BAMA 15-6	77.5	31.02	129.5	51.80

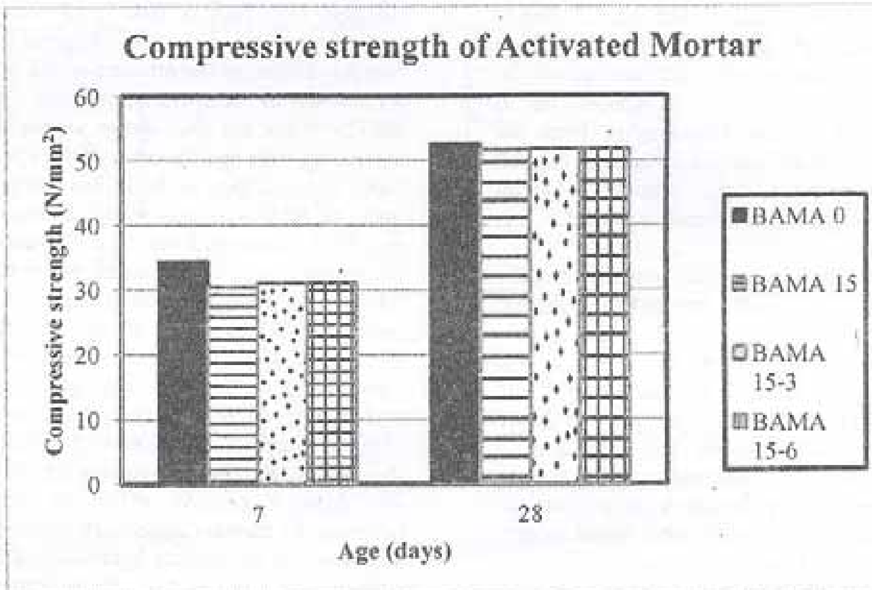

Figure 3 Compressive strength of OPC-BA-$Ca(OH)_2$ mortars

At both test days all mortars containing bagasse ash have shown a lower compressive strength than that of the control mortar. However, mortars containing 3% and 6% $Ca(OH)_2$ have shown a slight improvement over the mortar containing 15% bagasse ash with no $Ca(OH)_2$. This strength difference between the OPC-BA mortar and OPC-BA-$Ca(OH)_2$ mortar was more visible at the early days. The probable reason for this can be that the OPC-BA mortar without $Ca(OH)_2$ is much slower in reaction than all other mortars since it has to wait the hydration reaction of the cement in order to have its pozzolanic reaction, where as the OPC-BA-$Ca(OH)_2$ mortar at 3% and 6% $Ca(OH)_2$ is faster than the OPC-BA mortar since it contains some free $Ca(OH)_2$ which are available to react with the silica present in the bagasse ash. However, at latter days both the OPC-BA mortar and OPC-BA-$Ca(OH)_2$ mortar showed competitive compressive strength values, which show that as the hydration of OPC proceeds the bagasse ash in OPC-BA mortar have found free $Ca(OH)_2$ which is similar to the one observed in OPC-BA-$Ca(OH)_2$ mortar. Since the strength difference between OPC-BA and OPC-BA-$Ca(OH)_2$ is very small, at this percentage replacement of bagasse ash i.e. 15%, the addition of $Ca(OH)_2$ has very minor effect on the reactivity of bagasse ash and makes practically no difference especially at latter days.

Workability of concrete

Workability test results indicate that the slumps of the concrete containing sugarcane bagasse ash have shown a slight reduction as the bagasse ash content increases (see Table 10). On the other hand, Table 6 shows that the normal consistency of the blended pastes increase with increase of the bagasse ash. This can be an indication that in order to get a certain slump, OPC-BA blended concrete needs higher water content than a concrete with no bagasse ash. The probable reason for this may be the higher specific surface area of the bagasse ash and its lower density resulting in a higher porosity, which requires higher water demand. In order to get similar slump for the control and OPC-BA concretes, the water content can be increased as the bagasse ash content increases.

Table 10: Slump test results

Test No	Mix Designation	Replaced OPC (%)	W/B	Observed Slump (mm)
1	BA 0	0	0.55	35
2	BA 5	5	0.56	35
3	BA 15	15	0.58	33
4	BA 25	25	0.60	32

Compressive and Flexural Strength of Concrete

The compressive strength of the concrete with 5% bagasse ash have shown improvement over the control concrete by about 5% at 28 days (see Table 11 and Fig 4). On the other hand BA 15 and BA 25, have shown a strength reduction by about 3.4% and 12.6%, respectively at the age of 28 days.

As can be seen from Table 11, the compressive strength of the OPC-BA blended concretes decreases with an increase in the bagasse ash content after 5% replacement. The probable reason for this is due to the high replacement of cement by bagasse ash, thus reducing cement content of the mixture which in turn results in reduction of the hydration reaction. In addition to this the high content of bagasse ash resulted in a higher water requirement, making the water unavailable for the hydration of the cement and thus reducing hydration and compressive strength development.

Table 11: Average compressive strength values of concrete

Test No	Mix Designation	Average compressive strength					
		7 days		28 days		56 days	
		Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)
1	BA 0	551.9	24.53	960.1	42.67	1034.5	45.98
2	BA 5	580.0	25.78	1008.0	44.80	1101.9	48.97
3	BA 15	484.0	21.51	927.5	41.22	1006.6	44.74
4	BA 25	433.8	19.28	839.0	37.29	922.7	41.01

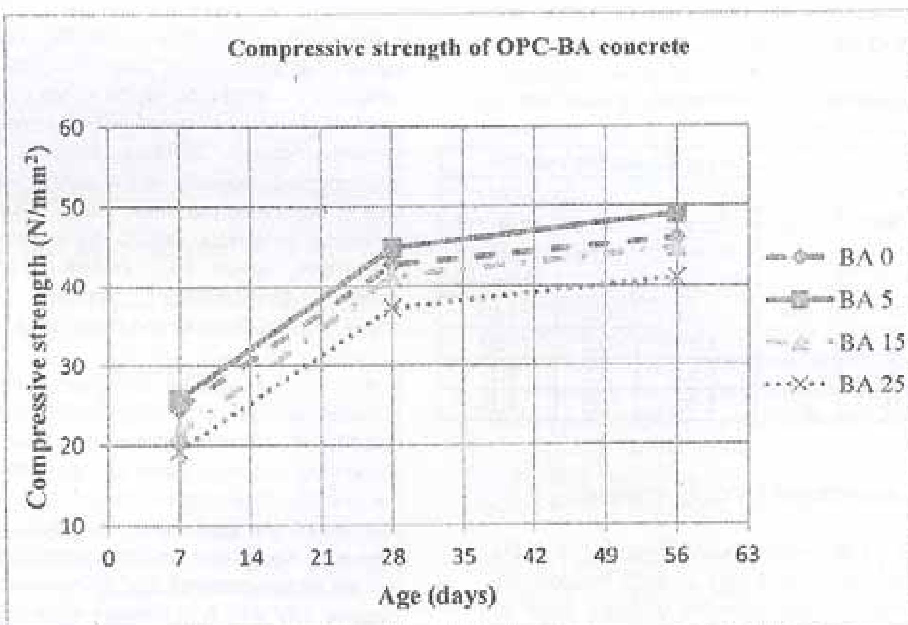

Figure 4 Compressive strength of OPC-BA concrete

As in the case of the mortar mix, the strength of the OPC-BA concretes have also shown increase in activity index for most of the mixes as the age of the specimen increased. For example the concrete BA 15 (i.e. the concrete with 15% bagasse ash), had a strength activity index of 87.7% at 7 days which increase to 96.6% at 28 days and 97.3% at 56 days. The increase in strength can be attributed partly to the presence of pozzolanic reaction between the bagasse ash and the cement. Table 12 below shows the strength activity index for all concrete test specimens.

Table 12: Strength activity index of OPC-BA concretes

Test No	Mix Designation	Age of specimen		
		7 days	28 days	56 days
1	BA 0	100.0	100.0	100.0
2	BA 5	105.1	105.0	106.5
3	BA 15	87.7	96.6	97.3
4	BA 25	78.6	87.4	89.2

The flexural strength has shown a reduction pattern as the bagasse ash content of the concrete increases. The average flexural strengths are summarized in Table 13 below.

Table 13: Average flexural strength value of the concretes

Test No	Mix Designation	Average flexural strength			
		7 days		28 days	
		Load (kN)	Flexural Strength (N/mm^2)	Load (kN)	Flexural Strength (N/mm^2)
1	BA 0	5.8	4.35	6.2	4.68
2	BA 5	5.8	4.33	6.2	4.68
3	BA 15	5.1	3.83	5.6	4.23
4	BA 25	4.7	3.50	5.5	4.10

Water Permeability of OPC-BA Concrete

The results of the water penetration test, i.e. the average and maximum depths of water penetration, showed some variation over the different types of concrete specimens with different percentages of bagasse ash. The average and maximum depth of water penetration for each of the mixes are summarized and shown in Table 14.

Table 14: Results of the water penetration depth test

Test No	Mix Designation	Penetration depth (mm)	
		Average	Maximum
1	BA 0	22.7	27.4
2	BA 5	20.7	27.6
3	BA 15	23.5	29.2
4	BA 25	24.8	34.8

The average depth of water penetration varied from 20.7 to 24.8 mm for BA 5 and BA 25 mixes, respectively. The concrete with 5% bagasse ash (BA 5) has shown some reduction on the average depth of penetration over the control concrete. However, the maximum depth of penetration for this concrete is about the same with that of the control mix (BA 0) and as the permeability of a concrete is not better than the weakest part of the concrete, none of the concretes with bagasse ash showed improvement on permeability. Since permeability is not so far a big concern for most parts of Ethiopia, such a slight increment in permeability values will not be a serious concern to use sugarcane bagasse ash as a cement replacement material.

Environmental Analysis

It has been said earlier that the production of cement has serious environmental and economical concerns as compared to the other constituents of concrete. In order to alleviate these problems of the cement industry different methods have been implemented specially in the developed countries. One of these methods is the use of different cement replacing materials which have lower cost of production, lower CO_2 emission, and reduced energy consumption implying a more environmental friendly and economical material.

Researches reveal that about one ton of CO_2 is released for every ton of Portland cement produced. In addition to this, concrete consumes vast amount of natural resources such as aggregate. Replacing the portion of Portland cement with bagasse ash can reduce the environmental impact of concrete. The most significant environmental factors are the use of virgin material and CO_2 emissions. Using bagasse ash, which is a waste material, will save a great deal of virgin material usage. Therefore, as the production of bagasse ash requires only transportation and grinding, environmental as well as economical benefits can be exploited by using it especially in countries like Ethiopia, where expanding sugar production capacity is one of the government major agenda.

CONCLUSIONS

Based on the research work the following conclusions are drawn:

1. The oxide composition test indicates that, the bagasse ash from Wonji sugar factory can be classified as class N pozzolana as prescribed by ASTM C 618.

2. The replacement of OPC by bagasse ash up to 10% resulted in a better compressive strength than the control mortar with 100% OPC. However, the replacement of PPC with bagasse ash resulted in a lower compressive strength than the control mortar even at lower replacement. Moreover, all of the mortars containing OPC and bagasse ash satisfy the ASTM C 618 minimum pozzolanic activity index requirement i.e. 75%.

3. Higher replacements of cement by bagasse ash resulted in higher normal consistency and longer setting time. The workability of the concrete has also shown a slight reduction as the bagasse ash content increase.

4. The difference in the trend of strength development of OPC-BA mortars (increasing with age for most of the mixes and having improvement up to 10% replacement) and PPC-BA mortars (decreasing with age for most of the mixes and having a lower compressive strength than the control for all blended mixes) proved the presence of pozzolanic reaction.

5. The compressive strength results of the concrete with 5% ordinary Portland cement replacement by bagasse ash have shown a 5% compressive strength improvement at 28 days over the control concrete mix, whereas the 15% and 25% replacements have shown 3.4% and 12.6% reduction, respectively.

6. The water penetration depth increases as the bagasse ash content of the concrete increases and all the concretes with bagasse ash have a maximum penetration depth greater than the control specimen.

7. Since bagasse ash is a waste material, its use as a cement replacing material reduces the levels of CO_2 emission by the cement industry and also saves a great deal of virgin materials.

RECOMMENDATIONS

In Ethiopia, even though the current construction activity is significantly expanding, it is still in its infant stage and needs much more effort in understanding the use of alternative construction materials. Therefore based on the findings of this research, the following recommendations are forwarded:

1. It has been shown in this study that sugarcane bagasse ash can be used as a partial cement replacement material with technical and environmental benefits. Concerned stakeholder, such as sugar industries, cement industries and relevant government institutions, should be made aware about this potential cement replacement material and promote its standardized production and usage.

2. The sugar and cement factories in collaboration with higher education institutions in the country should work together and establish a research team to study further the use of bagasse ash as a cement replacement material.

3. This research focused on some of the basic physical and chemical properties of Wonji sugar factory bagasse ash as a cement replacement material. However, further studies are required on the following issues:
   - Effects of controlled burning of the bagasse at different temperature and holding time.
   - Effects of different fineness of the bagasse ash.
   - Bagasse ash from different sources like, Metahara, Finchaa and the upcoming new sugar factories.
   - Determining the pozzolanic reaction of the bagasse ash using more advanced methods such as X-ray Diffraction (XRD) Analysis, Thermal Analysis (TGA) and Scanning Electron Microscopy (SEM).

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