POSSIBLE USES OF BAGASSE ASH

AS AN ALTERNATIVE CEMENT

BY

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THESIS DECLARATION

I hereby declare that this thesis has been composed by myself, and that it is a record of my own research work. It has not been accepted in any previous publication for a higher degree.

All quotations are distinguished by quotation marks, and the sources of information are specifically acknowledged by means of references.



OGBONYOMI TADE DANIEL

OCTOBER, 1998.

DEDICATION

This work is affectionately dedicated to HP who has consistently loved me with heart and hand.

CERTIFICATION

This thesis entitled "Possible Uses of Bagasse Ash as an Alternative Cement" by Ogbonyomi Tade Daniel meets the regulations governing the award of the degree of Master of Science (Structural Engineering) in Civil Engineering Department of the Ahmadu Bello University, and is approved for its contribution to Knowledge.

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ABSTRACT

This study is an investigation into the possible use of bagasse ash, SCBA, as an alternative cementing material. The SCBA was used in conjunction with lime (i.e. as a pozzolana) to produce lime-pozzolana cement, and with ordinary portland cement, OPC (as a partial replacement) to produce blended pozzolanic cement.

Bagasse is the fibrous residue of sugar cane after crushing and extraction of juice. SCBA is the resulting waste product obtained from the combustion of bagasse. The SCBA was obtained by burning bagasse in a furnace at a temperature of 400°c.

preliminary investigation was initiated to ascertain the composition and properties of the SCBA. A desk, top chemical investigation carried out on the SCBA, revealed the presence of silica (SiO_2) in a large amount (about 58.65%). The combined ratio of silica, alumina and ferrous oxide was determined as 70.86%, indicative of a good pozzolana. The reactivity of the SCBA was measured through its pozzolanic activity index (PAI). The PAI with cement and with lime were found to be 91% and 4.88Mpa respectively, and these together suggest a reactive pozzolana.

Trial compressive strength tests were carried out on various mixes of the 5CBA with lime and OPC to produce masonry units of constant cement - sand ratio of 113. The results of the initial tests, revealed the best performances of lime - SCBA as 25 175, and OPC-SCBA as 75:25 mixtures. These results were further substantiated with compressive strength tests carried

out on a population of 86 test specimens.

The lime - SCBA (25:75) mixture was found to have a strength property of 6.27MPa and 7.48MPa at ages of 7 and 28 days respectively. These values clearly meets the requirements of ASTM for non-load bearing masonry units. For the OPC-SCBA mixes, an optimum evaluation of strength vis-a-vis replacement of OPC made, showed that a maximum of 25% replacement can be made without adverse loss in compressive strength value. The compressive strength value was measured as 20.3MPa at 28 days which is 85.98% of result obtained with control test specimens. Generally, increases in the substitution of OPC with SCBA gave progressively lower compressive strength values, in all a total of 171 test specimens were prepared and tested.

A cost evaluation of the prepared units revealed that pozzolanic cements are cheaper than pure OPC. A savings of 13.25% and 15.74% were recorded for the 75:25 (OPC + SCBA) and 25:75 (LIME + SCBA) cement mixtures respectively.

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ABBREVIATIONS

BS	-	British Standard
NIS	-	Nigerian Industrial Standard
ASTM	-	American Society for Testing Materials
C_3S	-	Tricalcium Silicate
C_2S	-	Dicalcium silicate
C_3A	-	Tricalcium Aluminate
C_4AF	-	Tetracalcium alumino ferrite
^oC	-	Degrees Centigrade
%	-	Percentage
SO_3	-	Sulphur trioxide
CaO(c)	-	Calcium oxide
SiO_2(S)	-	Silicon oxide
Al_2O_3 (A)	-	Aluminium oxide
Fe_2O_3 (F)	-	Iron oxide
MgO	-	Magnesium oxide
K_2O	-	Potassium oxide
Na_2O	-	Sodium oxide
$Ca(OH)_2$	-	Calcium hydroxide
$C_3S_2H_3$	-	Calcium silicate hydrates
LOI	-	Loss on Ignition
SCBA	-	Sugar cane Bagasse Ash
OPC	-	Ordinary Portland Cement
PAI	-	Pozzolanic Activity Index
Pfa	-	Pulverized fuel ash or fly ash
rha	-	rice husk ash
W/C	-	Water-Cement ratio

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND

The need for locally manufactured building materials in developing countries is increasing due to greater demand for housing, mainly as a consequence of uncontrolled population growth, and the pursuit after technological expansion. Also in countries like Indonesia, there is the depletion of the traditional building materials (David et al, 1977), or the inaccessibility of required standard materials to the average citizen. Thus, the development of locally manufactured building materials is advantageous, because it attempts to meet the staggering need for housing, increases on-going manufacturing activity, and reduces the need for imported materials. This latter aspect is particularly significant, as importation of goods into developing countries is generally undesirable, as it reduces the foreign currency reserves and raises the external debt level.

In the construction of building, cement is one of the principal ingredients required to construct a firm, stable and durable structure. Cements work by filling the spaces between solid fragments, binding them together into a compact whole. The commonest type of cement used worldwide for constructional purposes today is the ordinary portland cement (OPC). (Lea, 1970).

OPC is produced in large plants, which are usually capital intensive and consumes large amount of fuel. The installation and operation of these plants require

imported equipment and expertise. Thus, coupled with high demand for cement, and factors of transportation, the eventual cost of the finished product becomes high.

As a means of obviating these problems in developing countries, various possible alternatives to OPC ought to be considered, and the benefits which might accrue from their use examined. Several materials such as lime, volcanic ash, burnt clay (pellets), pulverized fuel ash (pfa), rice husk ash (rha), sugarcane bagasse ash (SCBA) are in use in Thailand, Malawi, India, Indonesia, Sudan, Germany, France, USA as possible alternatives and additives to OPC. (Neville, 1981; Smith, 1992).

1.2 SCOPE OF WORK

This research aimed to investigate principally, the possible uses the sugar cane bagasse ash, SCBA, can be put into use as an alternative cement material. This comprised investigating the behaviour of pure lime - SCBA mixtures of varying mix composition of lime and SCBA; and OPC-SCBA mixtures, where the OPC is replaced with SCBA in certain quantities.

The cost evaluation of masonry units prepared with the best mixes of lime - SCBA and OPC - SCBA cements were made and compared with control values obtained with pure OPC mixture.

The results obtained from this work revealed that SCBA contain silica in a large amount (about 58.65%). The reactivity of the SCBA measured through its pozzolanic activity index (PAI), shows a PAI with cement and lime as 91% and 4.88MPa respectively. The results of the compressive strength tests carried out on various

mixtures of lime - SCBA and OPC-SCBA, indicate that the best performances were obtained from the 25:75 lime-SCBA and 75:25 OPC-SCBA mixtures. The lime-SCBA (25:75) mixture was found to have a strength property of 5.04MPa, 6.27MPa, and 7.48MPa at ages of 3,7 and 28 days respectively. The strength of the OPC-SCBA (75:25) mixture at 28 days was found to be 20.3MPa, which is 85.98% of results obtained with control test specimens. Either in blended form with lime, or OPC, the SCBA-cements were found to be cheaper than pure OPC.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 HISTORICAL DEVELOPMENT OF CEMENT

The use of cementing materials generally in construction, is almost as old as when the building construction itself began (Smith, 1992). Early structures were made of ordinary earth by ramming successive layers together, or of stone blocks secured together by special arrangement, with or without the aid of any cementing material (Lea, 1970). Natural gypsum was one of the earliest materials used as cement, some 4,000 years ago (Smith, 1992).

Lime sometimes modified by the addition of a pozzolana has had a history of use as cement, for well over 2,000 years ago, and is still in use as a reliable cementing material (Smith, 1992: David et al. 1977). The Egyptian builders used moist layer of mud chopped with straw, while the Kuwaitis used bitumen to cement their bricks together. In India, finely ground brick (Surki) and lime were used together. The Greeks and Romans used burnt lime and sand with other materials of volcanic origin, such as trass, turfs and Santorin earth. The material of the Roman builder, which was found to be superior was the red or purple volcanic turf found near the bay of Naples. The best variety was obtained within the neighbourhood of pozzoli, and thus acquired the name pozzolana (Lea, 1970). These materials exhibit properties of hydraulicity, not in themselves, but when mixed together with lime.

The invention of OPC must be attributed, at least partially to John Smeaton (1756) who discovered the hydraulicity of lime,

to Joseph Aspdin (1824) who first patented OPC, and to Isaac Johnson (1845) who improved on the process of manufacture (Chong, 1977, Jackson and Dhir, 1988). Aspdin, crushed and calcined limestone, grinding together with sand to a fine slurry. The resulting lumps, he fed into a furnace, and then ground the burnt stones into powder as cement. Production of OPC today is done in large manufacturing plants to exacting standards. The choice of raw material and the control of the OPC production processes require care and skill to ensure a satisfactory product.

2.2 CEMENT USAGE IN MASONRY CONSTRUCTIONS

Ordinary portland cement (OPC) is a well known and versatile material, used extensively for the production of mortars, renderings, and concrete. Mortars made solely from OPC and sand give a rather harsh mix, which is difficult to work with (Smith, 1992). Lime mortars have the peculiar property of 'fattiness' or 'butteriness', which makes them easier to work with, and does not adhere to the trowel (Denzil, 1968).

Straight OPC/sand mixes have been favoured in the past, but as cement becomes stronger, renderings made solely of OPC/sand mixes have tended to develop cracks. The strength developed is excessive, and not required for plastering purposes.

In unfavourable high temperature atmosphere conditions, OPC exhibits a high thermal shrinkage because the rate of evaporation becomes higher than the rate of the hydration process. Mixtures of lime, sand, pozzolana reduces shrinkages tendencies, by retaining the moisture needed for the full setting of the cement. Though strength developed is lower than OPC mortars, it is however adequate for masonry purposes. (Denzil, 1968; Mehta, 1977).

The calcium hydroxide liberated in the making of opc mortars or concrete is generally readily subject to chemical attack, especially forms associated with leaching, carbonation, chlorides,

sulphates and acids. The reaction of these chemical agents over time weakens the strength, porosity and permeability of the OPC mixtures (Lea, 1970; Jackson and Dhir, 1988). For this reason in Italy, France and Germany, lime-pozzolana mortars, and pozzolanic cements are recommended for all sea-water works, in place of OPC.

2.3 POZZOLANAS

The name pozzolana derived its source from a volcanic ash that was used by ancient Roman builders in combination with lime to form a cementing compound. The best variety was first discovered around the village of Pozzuoli, near Vesuvius in Italy (Neville, 1981; Lea, 1970). Pozzolanas are natural or artificial materials which contain silica in a reactive form. A more formal definition of ASTM C618-78 describes pozzolana as a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value, but will in finely divided form, and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

Gypsum and lime were early materials used by Egyptian, Roman and Greek builders over 2000 years ago (Smith, 1992; Lea, 1970). Ordinary earth, mud bricks, burnt clay (pellets) called surki together with lime were used by Kuwaitis and Indian builders. With the advent of OPC in 1824 attention generally shifted to the use of OPC as an effective cementing material for constructional purposes. However, these older pozzolanas - volcanic ash, turfs, pumicide, opaline shales and

cherts, fly ash, basalt stone are still in use in Kenya, India and Guyana (Lea, 1970; Smith, 1992).

More recent development have also shown the large possibility of the use of agricultural wastes for producing cementitious compounds in conjunction with lime. Many plants, during their growth pick up silica from the ground, into the structure of their leaves, stalks and other parts. When plants residue are burnt, organic material which is the largest proportion is broken down and disappears as carbon dioxide, water vapour, etc. The ash remaining contains mostly inorganic residues, notably silica. This silica in its reactive form can combine with lime to form insoluble, cementitious compound (Smith, 1992).

Pulverized fuel ash (pfa), trass and volcanic ash have found acceptance in their usage for blending with OPC during the manufacturing stage or as a partial replacement of OPC at the construction sites in Germany, France and USA (Lea, 1970). Cements produced by the intergrounding of pozzolanas with the clinker are termed portland-pozzolana cements, or blended pozzolanic cements. ASTM standard C595-79 describes portland-pozzolana cement as Type IP for general concrete construction, and Type P when high early strengths are not required, the pozzolana content is limited to between 15 and 40% of the portland-pozzolana cement. (Neville, 1981).

The specific gravity of most pozzolanas is about 2.0 - 2.6 as against 3.1 for OPC. Thus the absolute solid volume of a pozzolana is about 15% to 35% greater than that of an equal weight of OPC. A substitution of 40%

by weight of cement by a pozzolana increases their combined solid volume by about 6 - 14%. Generally, the substitutions are done by weight, but atimes it is suggested that it be made on the basis of equal volumes (Lea, 1970).

Lime-pozzolana mortars enjoy a good reputation for its use in building mortar in many parts of Europe. They have been shown practically by experience of 2,000 years to possess the requisite durability claimed for them by Vitruvious in his Treatise on Architecture, where he says that when pozzolanas are mixed with rich lime and stone, it sets solidly, not only in all kinds of structures but particularly those built on the sea. Roman monuments such as the bridges of Fabricus, Aemilius, the arches of Calndius and Trajam at Osita which are still in use today, all stand as a tribute to the performance of lime-pozzolana mortars. (Lea, 1970).

Pozzolanas can be broadly divided into two groups, containing the natural and artificial products respectively.

2.3.1 NATURAL POZZOLANAS

The natural pozzolanas are for the most part materials of volcanic origin, but also include certain diatomaceous earth.

a) Volcanic Tuffs - These originate from the deposition of volcanic dust and ash. These are materials that have been thrown out by volcanoes in recent time or long ago which contain finely divided material, high in silica or alumina content. In Europe, the most exploited materials are the Italian pozzolanas, santorin earth, and the German trass found at Goblenz on the Rhine in

Bavana (Lea, 1970). Trass deposits are also found in Romania and Russia; no tangible, suitable ash has been discovered in Britain. Other forms are tuffs, trass or pumice used in Italy.

For a suitably reactive ash, one part by weight of lime might be added to two parts of the ash to make a so-called pozzolanic cement. For an unreactive ash, the ratio of ash in the mix will be higher. Volcanic ash may also be blended with OPC to produce blended pozzolanic cement, and up to 30% replacement have been proved adequate and feasible by cement manufacturers in Italy, Germany and USA (Lea, 1970; Smith, 1992).

Analysis of some volcanic ash carried out by Lea are shown in Table 1. (see page 10).

b) Diatomaceous Earths - These are composed of the siliceous skeletons of diatoms deposited from either fresh or sea-water. In many cases the deposits are mixed with sand or clay. The largest known deposits are those occurring in California, Canada, Algeria, Denmark and Germany (Lea, 1970).

Within the British Isles there are small deposits in Scotland, Western Isles and Northern Ireland. In their raw condition, many diatomaceous earth have little value as pozzolanas, for although they combine actively with lime, their physical state is such requiring large quantity of water to render their mixes plastic, and thus their cementing value (strength) becomes poor. Their main constituent is opal, an amorphous form of hydrous silica, containing up to 10% water.

TABLE 1 : PERCENTAGE COMPOSITION OF VOLCANIC ASH POZZOLANAS

pozzolanas	Ignition Loss	SiO_2	AI_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	SO_3
1. Rhemish Trass	10.1	54.6	16.4	3.8	0.6	3.8	1.9	5.1	3.9	0.4
2. Rhemish Trass	8.5	54.8	17.2	4.4	0.6	2.3	0.9	7.0	3.8	0.1
3. Bavarian Trass	14.5	57.0	10.9	5.6	0.5	6.0	2.2	1.8	1.5	0.2
4. Santorin Earth	4.9	63.2	13.2	4.9	1.0	4.0	2.1	3.9	2.6	0.7
5. Santorin Earth	3.1	65.2	12.9	6.3	-	3.2	1.9	2.6	4.2	-
6. Rome: Segni	9.6	44.1	17.3	10.7	-	12.0	2.0	1.4	3.1	-
7. Naples: Bacoli	4.8	55.7	19.0	4.6	-	5.0	1.3	3.4	3.9	-
8. Crimean Tuff	11.7	70.1	10.7	1.0	-	2.5	0.3	3.7	3.7	-
9. U.S.A. Pumicite	4.2	72.3	13.3	1.4	-	0.7	0.4	1.6	5.4	Trace

2.3.2 ARTIFICIAL POZZOLANAS

The chief artificial pozzolanas are burnt clays and shales, pulverized fuel ash, pfa; recent discoveries are calcined basalt stone, rice husk ash (rha), and bagasse ash (SCBA). The latter two are derivatives of agricultural wastes.

a) Burnt Clays and Shales - Burnt clay pozzolanas are produced by burning suitable clays or shales at a temperature of between 600°c to 900°c, depending upon the nature of the clay, the conditions of burning (Lea, 1970). The value of burnt clay as an addition to fat lime mortars has long been known in India and Egypt, where it passes under the names 'Surkhi' and 'homra'. A pozzolanic cement consisting of ground burnt clay and OPC was described in 1909 by potter who stated that 5000 tons of it were used in fresh water, and sea-water construction in Great Britain. In the building of the Sennar Dam on the Blue Nile in Egypt, between 1919 - 1925, the masonry was set in a cement having 70% OPC and 30% burnt clay.

Raw clays consist essentially a group of hydrated alumino silicates, with a three broad groups of Kaolinites, montmorillonites and illites.

b) pulverized fuel ash (pfa) - This is obtained when pulverized coal is burnt in boilers, and approximates to a burnt clay high in alumina and iron oxide in composition. The particles are roughly spherical in shape, and in finely divided form with a specific surface of 2000cm^2/gm to 5000 cm^2/gm.

Its pozzolanic activity is in no doubt, but may vary with material from different power stations. Combustibles are always present, but in well burnt materials, it is below 10%. BS 3892; 1965 specifies a maximum loss on ignition of 7%. It is not yet clear why carbon may be harmful, but since it is not pozzolanic, it may therefore be no more than a filler (Neville, 1981; Lea, 1970). ASTM C618-78 specifies a minimum content of 70% for silica, alumina and ferric oxides; maximum sulphate of 5%, maximum loss on ignition of 12%.

c) Calcined basalt stone - Research has shown that basalts treated to a temperature range of 500-800^{o}c exhibits pozzolanic activity. The optimum temperature will differ from one stone source to another. When ground into powder, research in Vietnam shows that this powder mixed with lime in proportions 70:30, give a very satisfactory cement. (Smith, 1992). Alternatively, up to 30% replacement of OPC by the basalt stone may be made. A replacement of 15% of the OPC with basalt stone gave higher 28 day strength than does OPC alone.

d) Rice husk ash (rha) - Approximately 20% of the weight of rice paddy processed in rice mills is discarded as husk. The rha remaining after the burning of the husks constitutes about 20% of the weight of the husks. Burning of husks in heap gives no particular control over the burning conditions, though it may produce an ash with good pozzolanic properties. To curtail the risk of producing less reactive ash, it is best to burn the husks

in a purpose made incinerator, having temperature restriction of a maximum of 750°c (Smith, 1992).

Laboratory tests have shown that if the burning temperature exceeds 750°c, a crystalline, less reactive form of silica is produced; instead of the highly amorphous, non-crystalline type. Series of researches carried out on rha as a partial replacement for OPC, have shown its adequacy and suitability in concrete and masonry production, Mehta (1977) and Loo et al (1984).

e) Bagasse ash (SCBA) - After the extraction of the sugar juice from sugar cane, there remains a fibrous waste known as bagasse, and this material usually poses a disposal problem in sugar factories particularly in developing countries. Some bagasse is burnt to generate steam at the factories for the production processes, but this still leaves the problem of disposing the bagasse ash (SCBA). Though the silica is only about 60%-70% (less than 80% - 90% in rha), there is also 9% alumina, and 3% iron oxide; and these in their reactive form can take part in cement-like setting reactions with lime or OPC. Bagasse can also be specially burnt in purpose-made furnaces to produce SCBA for making cements. (Meade, 1963; Smith, 1992).

In Mauritius research has shown that a 20% - 30% replacement of OPC with SCBA gives a useful cement-strength value which at upwards of 4 months compare favourably with OPC mixes (Smith, 1992).

Other uses of bagasse generally are for paper production, ceilings, wall boards, alpha cellulose, plastics, agricultural mulch and cattle bedding. The various component present in sugar cane is shown in Table 2. (Meade, 1963).

TABLE 2: COMPOSITION OF SUGAR CANE AND JUICE SOLIDS

No.	Constituent	Percent (%)
1.	Water Content	73 - 76
2.	Solids	24 - 27
	(i) Dry fibre	11 - 16
	(ii) Soluble solids	10 - 16
3.	Bagasse bulk weight	
	(i) When stacked	1.964kN/m^3
	(ii) When loosed	1.178kN/m^3

2.4 PROPERTIES OF POZZOLANAS AND POZZOLANIC CEMENTS

2.4.1 Oxide Composition: Pozzolanas by definition are siliceous materials, and this implies that they contain silica in a large quantity. Other necessary oxides for a reactive pozzolana are alumina and iron oxides. The insitu silica is expected to be in the amorphous state, which is more reactive than the crystalline silica, this is the basis for temperature regulation during the burning of agricultural waste pozzolanas (Smith, 1992). The ASTM specification for pozzolanas is shown in Table 3.

TABLE 3: ASTM C618-78 FOR POZZOLANAS

Property	Pozzolanas		
	(N)	(F)	(C)
Chemical properties			
$SiO_2 + Al_2O_3 + Fe_2O_3$ (%)	70	70	50
SO_3 (max %)	4.0	5.0	5.0
MgO (max %)	5	5	5
Loss on Ignition	10	2	6
Physical properties			
Moisture content (%)	3	3	3
Fineness (%) on sieve No. 200 (min %)	85	85	85
Pozzolanic Activity Index with OPC at 28 days (%)	75	75	75
Pozzolanic Activity Index with lime at 7 days (MPa)	5.5	5.5	5.5

2.1.2 Hydration and Setting Times - Pozzolanas have been found to generally reduce slightly the rate of setting of OPC, but accelerates the rate of setting of lime (Lea, 1970; Smith, 1992). Pozzolanic mixes usually require much longer time before they achieve their maximum strength values. The rate of reaction and strength development of lime-pozzolana mixes increases with rise in atmospheric temperatures. Pozzolanic mixes produces lower heat of hydration during their reaction, and the heat evolution at 28 days may be taken as half the percentage of substitution made (Lea, 1970).

2.4.3 Durability of hydration products: Durability is the property of the hardened mortar paste or concrete, which defines its ability to withstand stresses and conditions for which it has been designed, without deterioration, over a period of time. Pozzolanas have the characteristic of combining with the free lime liberated during the hydration process of OPC to produce stable, insoluble calcium silicates. This tendency mops up calcium hydroxide quickly from the hydration products, and thus reduces the proneness of mortar or concrete to attacks from sulphates, salts and chlorides. Pozzolanas also inhibit expansion resulting from the alkali-aggregate reaction in concrete works (Lea, 1970).

2.4.4 Fineness: This is an essential physical property of cements, which affects the affinity it has for water, and always expressed as the total surface area. Cementing materials are expected to grade in particle size to fine dust, BS sieve No. 200 (75μm). The activities of pozzolanas are increased by fine grinding. Most pozzolanas after their calcination, need to be ground into powder and sieved before usage (the particles of pfa are already finer than OPC). ASTM specification requires that percentage passing sieve No. 200 $\geqslant$ 85%. (Lea, 1970; Smith, 1992).

2.4.5 Compressive Strength: Lime-pozzolana mixes are known not to possess the ultimate strength required for structural works. However, their strength values have been proved to be adequate for

masonry construction.

In blended pozzolanic cements, with partial replacement of OPC with pozzolana, very comparative strength values are only recorded after long ages of 4 months - 1 year. With about 30% OPC replacement with pfa, the compressive strength of concrete may not be adversely impaired (Smith, 1992). Mehta, 1977 reported strength values of 24.5MPa for lime-rha cement, greater than value measured for OPC-sand mortars.

2.4.6 Workability of mixes: Lime-pozzolana mortars are more plastic than OPC-sand mortars, and have greater ability to accommodate internal stresses within brickwork. Lime-surkhi mortars are also more workable and exhibit less shrinkage tendencies, because of the comparatively slower rate of the hydration process, generally for lime-pozzolana mixes (Denzil, 1968).

2.5 TESTS FOR POZZOLANA ACTIVITY

The evaluation of pozzolanas by chemical tests has long attracted attention. The testing of pozzolanas is complicated becuase they have no cementitious properties in themselves, and only develop them when mixed with lime or OPC. In pozzolanic cements used for concrete works, it is the properties contributed by the pozzolana at long ages that are important, at short ages, the influence of OPC is very dominant especially in determining strength. In masonry construction however, the properties contributed by the pozzolanas at early ages can be easily assessed - workability, plasticity, slight reduction in compressive strength.

Tests on pozzolana and pozzolanic cements can be broadly divided into four groups - analytical composition, Vicat absorption, extraction tests and strength tests.

2.5.1 Analytical Composition: This is essentially a desk top, laboratory investigation in which the predominant oxides present in a pozzolana are evaluated based on their percentage composition. The relevant oxides which enhances a good pozzolanic activity are the silica, alumina and iron oxide . ASTM C618-78 specifies a minimum content of 70% for these combined oxides in a good pozzolana. This investigation is only an initial sorting test when considering a limited class of pozzolanas. A quantitative chemical analysis is carried out, which involves selective separation and determination of oxides present in the pozzolana (Vogel, 1989).

2.5.2 Vicat Absorption test: This is the oldest test for pozzolanas, in which the rate of absorption of lime from a calcium hydroxide solution is measured. According to BS 4550, 1970, the underlying principle is that the pozzolanic activity consists of fixing of $Ca(OH)_2$ by the pozzolana, so that the lower the resulting quantity of $Ca(OH)_2$ in the solution, the higher the pozzolanicity. (Neville, 1981). This test gives some limited value in distinguishing pozzolanas, but does not give adequate guide to the practical value of a pozzolana in use.

2.5.3 Extraction tests: Extraction with hydrochloric, nitric or sulphuric acid, or alkali hydroxide and carbonate solution have all failed to give results that showed any relation between the contents of soluble constituents and

the strength developed by the pozzolana in lime or cement mortars (Lea, 1970). Later attempts involving an initial acid attack followed by an alkali treatment have been more successful in seperating the active and the inert part of natural pozzolanas.

2.5.4 Strength tests: The best assessment of any pozzolana is the useful strength it develops in blended pozzolanic cements, or lime-pozzolana cements (Lea, 1970). Feret at the Brussels meeting of the International Association for Testing materials in 1906, put forward a cement/sand ratio of 1:3; with cement comprising of 1 part lime to 4 parts pozzolana.

Two pozzolanic activity indices are defined by ASTM standard C618-78 for the measurement of the activity of a pozzolana - activity with cement and activity with lime. The activity with cement requires comparative compressive strengths on 50mm cubes of a 1:2.75 (OPC: graded sand) mortar of standard consistency; and of a $1:{}^{1}/_{4}:2{,}5$ (OPC: pozzolana: graded sand) mortar. The ratio of the strength of the second to the first mortar after 28 days is the pozzolanic activity index (PAI) with cement. For pfa, the PAI with cement $\geqslant$ 85%.

The PAI with lime is the compressive strength of mortar cube prepared with standard consistency and a cement composition of 1:4 (lime-pozzolana), and cement: sand ratio (1:3) evaluated at 7 days (Syed and Zaheerudein, 1992). General strength tests require the evaluation of masonry units of same cement/sand ratio, but varying composition of cement content (Lea, 1970).

2.6 RECENT WORKS ON POZZOLANAS

One of the foremost works on pozzolanas was by Mehta, 1977, who investigated the properties of cements made with rha in two forms - lime-rha contents and OPC-rha cements. He obtained his ash from an industrial furnace, ground in a ball-mill and used for the experiment. The results shows that the strength characteristics of OPC-rha cement were adequate for masonry works; while lime-rha cements developed lower strength values. (Table 4 and Table 5). His work also revealed the excellent resistance of pozzolanic cements to dilute organic and mineral acids.

TABLE 4 : STRENGTH OF MORTAR CUBES MADE FROM LIME-RHA CEMENTS (ASTM C109)

Cement Composition			Compressive Strength (MPa)	
Ash	: Lime (by weight)	W/C ratio	3 days	7 days
80	: 20 (grounded)	0.50	10.30	24.03
70	: 30 (grounded)	0.65	4.71	14.03
70	: 30 (grounded)	0.70	2.45	8.34
75	: 25 (grounded)	0.50	7.55	1.96
70	: 30 (grounded)	0.57	4.51	16.48
70	: 30 (blended)	0.77	3.43	12.75

TABLE 5 : STRENGTH OF MORTAR CUBES MADE FROM OPC-RHA CEMENTS (ASTM C109)

	Compressive Strength (MPa)	
Cement type	3 days	7 days
B-30	32.27	45.91
B-50	26.39	39.44
B 70	24.23	35.81
OPC (Control)	22.56	32.86

Torii and Kawamura, 1994, confirmed some of Mehta's discoveries. They investigated the effects of fly ash and silica fume on the resistance of mortars to acid and sulphate attack. The long term exposure test data, revealed that the replacements of OPC by pozzolanas effectively improved the resistance of the mortars to the attack. Djurie et al, 1996 contributed to the sulphate resisting ability of pozzolanas. They used a low quality fly ash to blend OPC (up to 30%), and prepared mortar prisms with the pozzolanic cement and control cement. The blended cement was found to have superior resistance when exposed to aggressive environment of sulphate and ammonium ions.

David et al, 1977, evaluated masonry units made with rha cements in Thailand, adding reactive alumina to enhance early development of compressive strength. Their results show that rha could constitute up to 60% of the total cement in the mix, to produce units that satisfy the requirements for non-load bearing masonry (Table 6). They postulated that to obtain load-bearing strength values, the specimens would need to be cured for more than 3 days. Their cost evaluation shows a savings of 34% for the cement having 60% rha.

In blended pozzolanic cement, the amount of replacement of OPC made with pozzolana is limited, because excessive amount will reduce the useful strength adversely, and increase the porosity of the mixes. Malami et al, 1994 proved this in a work carried out involving the use of pfa, santorin earth and slag as substitutes for OPC.

TABLE 6 : COMPRESSIVE STRENGTH OF CEMENT + LIME + RHA MORTARS (David et al, 1977)

Mix proportion Cement + Lime + rha : sand	% of sodium aluminate	W/C ratio	Saturated density (kg/m^3)	Compressive Strength (MPa)		
				7 days	28 days	30 days
(0,05+0,317+0,623) : 2.75	1.25	0.624	1970		0.27	0.65
	2.50	0.644	1986		1.05	1.85
(0,10+0,30+0,60) : 2.75	1.25	0.644	1970	1.64	3.82	4.65
	2.50	0.675	1922	1.92	3.97	4.68
(0,15+0,283+0,567) : 2.75	1.25	0.561	2034	1.80	4.06	5.49
	2.50	0.605	2018	1.98	4.57	5.63
(0,50+0+0,50) : 2.75	1.00	0.560	1970	1.90	4.65	6.18
	2.00	0.580	1970	2.00	4.90	6.04
(0,60+0+0,40) : 2.75	1.00	0.623	1986	2.59	5.31	6.69
	2.00	0.644	2018	3.26	5.47	6.72

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Their results show addition of 4% pozzolana, 4% and 15% pfa, 4% and 15% slag did not influence the porosity; but higher additions did. Day and Shi, 1994 investigated the influence of the fineness of a Bolivian pozzolana on the strength of lime-pozzolana mixes. The results show that there is a good linear relationship between the Blaine fineness of the pozzolana and the strength developed at all ages. Fineness of a pozzolana was discovered to have its most significant effect on early strength gain.

Not much traceable work on SCBA is available, but guides can be drawn from the extensive work on rha, and other pozzolanas. Smith, 1992 reported from investigations carried out on masonry units made with OPC+SCBA cement, that a substitution of 20% - 30% pozzolana produces units that compare favourably in strength with that of control mixes. For lime-SCBA mixes, he suggests trial mixes of 1:2 and 1:3 for such cements to be investigated. Lime-SCBA mixes are expected to produce units that could meet the requirements of ASTM standards, particularly for non-load bearing units. (Table 7).

TABLE 7 : ASTM REQUIREMENTS FOR LOAD-BEARING AND NON-LOAD BEARING BLOCK (ASTM C90-75, ASTM C129-75)

Compressive Strength	ASTM Requirements (MPa)
1. Non-load bearing - individual unit	3.45
average of 3 units	4.14
2. Load bearing	
i) Grade N - individual unit	5.50
average of 3 units	6.90
ii) Grade S - individual unit	4.10
average of 3 units	4.80

Baguant and Mohammedbhai, 1990, investigated the technical feasibility of using SCBA as a partial replacement for OPC in concrete. They carried out 3 series of experiments with the ash collected - series 1 were control, series 2 involve total replacement of sand with SCBA, while series 3 was an addition of a super plasticizer to series 2 mixes. The PAI of the ash was measured as 68%, lower than 75% specified in ASTM C618-78. The 28 day strength of the ash concrete varies from half to one third of equivalent control mix. With the addition of a super plasticizer, the concrete strength became thrice of unplasticized concrete. (Table 8). Evaluation of the strength results over a period of 1 year revealed the strength of the SCBA concrete comparing favourably with that of the control mix.

TABLE 8 : COMPRESSIVE STRENGTH RESULTS OF MIXES IN THE THREE SERIES (Baguant and Mohammedbhai 1990)

Mix (For Control)	28 day cube Strength (MPa)		
	Series 1 (Standard basalt sand)	Series 2 (SCBA)	Series 3 (SCBA + Plasticizer
1:1.33:1.63	62 (0.41)•	33 (0.41)•	70 (0.29)•
1:1.66:1.95	53 (0.48)	48 (0.48)	65 (0.24)
1:2.25:2.44	42 (0.59)	21 (0.59)	55 (0.41)
1:2.74:2.74	34 (0.67)	14 (0.67)	45 (0.47)
1:3.76:3.34	24 (0.84)	8 (0.84)	35 (0.58)

• Values in bracket represent the W/C ratios.

Syed and Zaheerudin, 1992) also carried out an investigation to assess the quality of blended pozzolanic cements made with OPC + SCBA, and OPC + SCBA + lime. Their samples were collected from the boiler houses of two different sugar mills. The oxide composition and combined silica, alumina and ferric oxides met the requirements of ASTM C618-78 for class N pozzolanas (Table 9) . Blended cements were produced by inter blending OPC + SCBA and OPC + SCBA + lime, and used to prepare 50mm mortar cubes of standard cement: sand ratio of 1:3. Their mix schedule is laid out in Tables **10** and **11**. The resistance of the mortar cubes to sulphate attack was also studied, by visual observation on deterioration of specimens immersed for a period of 1 year in a corrosive medium.

From their results, they saw that pozzolanic reactions made less contributions to strength at early ages, but at later ages (28 - 365 days) their contributions are pronounced. The cement having 30% substitution with SCBA gave strengths almost equal to that of control specimens. For the OPC-SCBA-lime blend, the best performance was the blend having 40% replacement giving strength values comparable with control values. The sulphate resisting ability of mixes containing SCBA were found superior to that of their control counterparts.

TABLE 9 : PHYSICAL AND CHEMICAL PROPERTIES OF SUGARCANE BAGASSE ASH (SCBA) SAMPLES M & F AND OTHERS IN RELATION WITH THE REQUIREMENTS OF ASTM C618-78.

Property	ASTM C618-78 classes of pozzolana (N)	(F)	(C)	SCBA Sample-M	SCBA Sample-F
Chemical properties					
$SiO_2+Al_2O_3+Fe_2O_3$	70.0	70.0	50.0	71.29	76.33
SO_3 (max %)	4.0	5.0	5.0	1.01	0.28
MgO (max %)	5.0	5.0	5.0	2.40	3.03
Loss on ignition	10.0	2.0	6.0	5.11	2.52
Physical properties					
Moisture content(%)	3.0	3.0	3.0	0.86	0.58
Fineness % retained on sieve No. 200	15.0	15.0	15.0	4.00	12.00
Pozzolanic activity index with OPC at 28(days (% of Control)	75	75	75	84	84
Pozzolanic activity index with lime at 7 days, psi (MPa)	800(5.5)	800(5.5)	800 (5.5)	650(4.5)	650 (4.5)

TABLE 10 : SCHEDULE OF BATCHES USING OPC AND SCBA (Syed and Zaheerudin, 1992)

Batch title	Proportion OPC: SCBA % by weight	No. of specimens tested at each age (Nos.)	Ages of specimens tested (days)	Total specimens tested (Nos.)
	I. Sample-M			
MA	90.10	03	1, 3, 7, 14, 28	30
MB	85:15	03	28, 56, 90, 140	30
MC	80:20	03	224 and 365	30
MD	75:25	03	(10 different	30
ME	70:30	03	ages)	30
	II. Sample-F			
FA	90:10	03		30
FB	85:15	03		30
FC	80:20	03		30
FD	75:25	03		30
FE	70:30	03		30
	III. Control batch			
C	100:00	03		30

TABLE 11.: SCHEDULE OF BATCHES USING OPC WITH SCBA AND LIME (Syed and Zaheerudin, 1992)

Batch title	Proportion OPC:SCBA:LIME % by weight	No. of Specimens tested at each age (Nos.)	Ages of specimens tested (days)	Total specimens tested (Nos.)
	I. Sample-M			
MF	90: 5: 5	03	1, 3, 7, 14, 28	30
MG	80:10:10	03	28, 56, 90, 140	30
MH	70:15:15	03	224 and 365	30
MI	60:20:20	03	(10 different	30
MJ	50:25:25	03	ages)	30
	II. Sample-F			
FF	90: 5: 5	03		30
FG	80:10:10	03		30
FH	70:15:15	03		30
FI	60:20:20	03		30
FJ	50:25:25	03		30

CHAPTER THREE

3.0 EXPERIMENTATION

In ascertaining the pozzolanic activity of sugar cane bagasse ash (SCBA), various trial tests were initiated according to the specifications of ASTM C618-78 on pozzolanas. Guidelines laid out in similar previous works, especially of Baguant and Mohammedbhai (1990), Syed and Zaheerudin (1992) and Smith (1992) were also adopted. Basic standard testing procedures for sand and cement as specified in NIS 11 (1974) and BS 12 (1978) were also used for this work.

The investigation was essentially in two stages, with the first being a broad preliminary test on bagasse when ground into powder, and when burnt into ashes. The second stage was exclusively based on results from the first and centered on the evaluation of the average compressive strength of the best mixes at ages of 3, 7, 14, 21, 28 and 60 days, with a testing of a total of 96 prepared specimens. The programme of work is shown in a flow chart in Figure 1 on page 30.

3.1 SITE SURVEY AND COLLECTION OF BAGASSE

Bagasse is a bulky material, and is estimated as 25% of all sugar cane crushed in sugar factories (Meades, 1963). In Mauritius, a small Indian ocean island, whose economy is solely dependent on the cultivation of cane, the average annual yield is 5.6×10^6 tonnes. (Baguant and Mohammedbhai, 1990). In Nigeria, cane is only one of numerous agricultural products being cultivated to enhance a productive economy; the amount

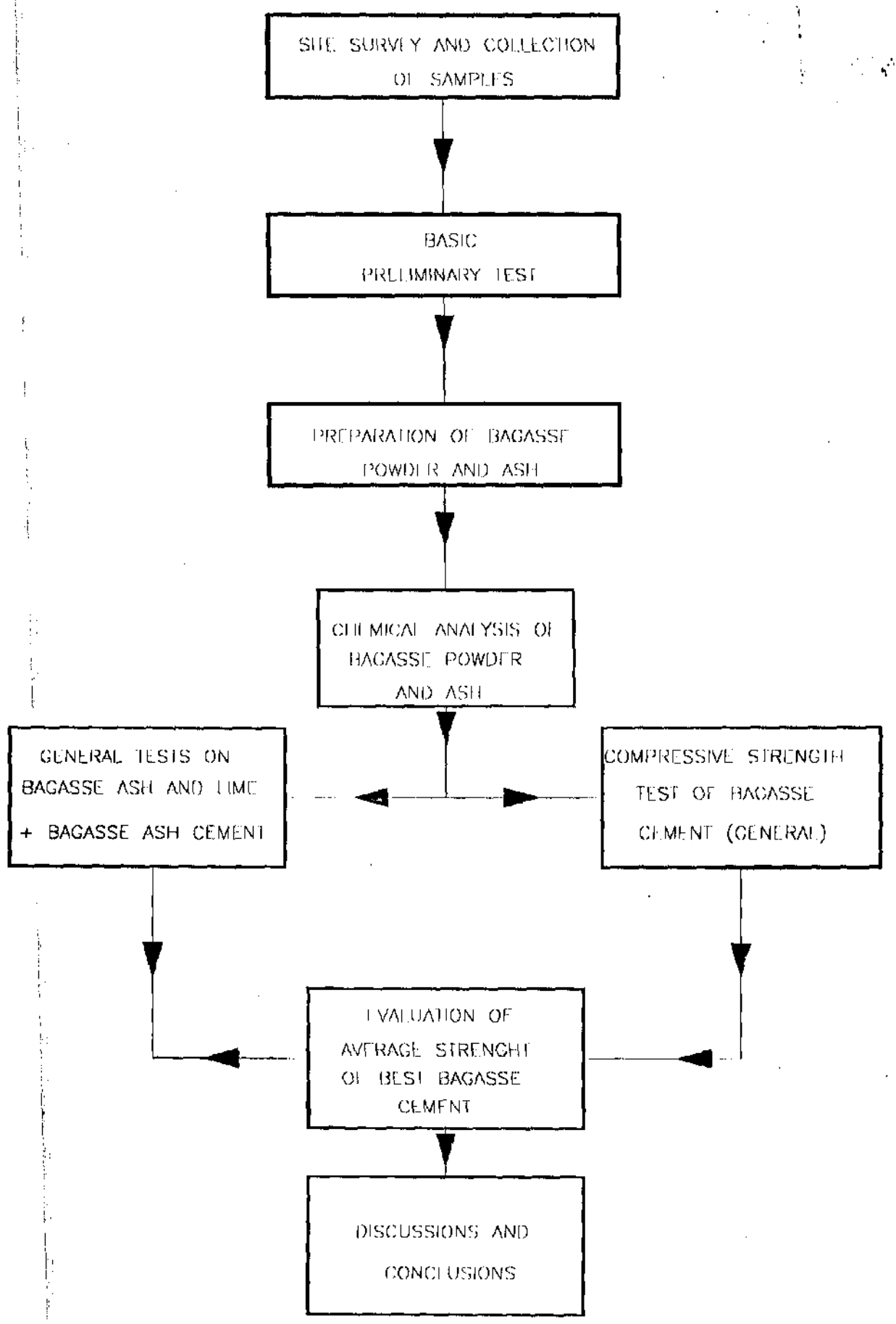


FIGURE 1: PROGRAMME OF WORK

of crushed cane yearly at the two factories at Bacita and Numan is put at 60,000 tonnes. The full operation of these factories is on a seasonal basis at the peak of the harvest of sugar cane.

Bagasse is used as fuel to raise steam at the sugar factories. The resulting ash is used by the Nigerian local farmers for mulching their cultivated ridges; the larger amount is discarded as a waste product. Some quantity of ash was collected at the Bacita factory, and tested in this work. In developed countries, bagasse has found extensive use for paper production, ceiling boards, alpha cellulose and cattle bedding. Attempt is currently being made in Nigeria to see how bagasse can be used for making ceiling boards and paper pulp.

The bagasse for this work was sourced within Zaria in Kaduna State. Collection spots were opened in four different centres where cane was available in large quantities. These are Samaru market, near Petrol Station called point 1; near JAWOM Church close to the railway line called point 2; Hanwa near Kano road junction called point 3 and Sabo market near garage called point 4. These points are marked out in Figure 2 shown on page 32.

3.2 BASIC PRELIMINARY TESTS

These tests were conducted on the sand and cement used in this work to ensure compliance with standard requirements as laid out in NIS 11; 1974 and BS 12; 1978. The bagasse content in sugar cane was also measured, and the

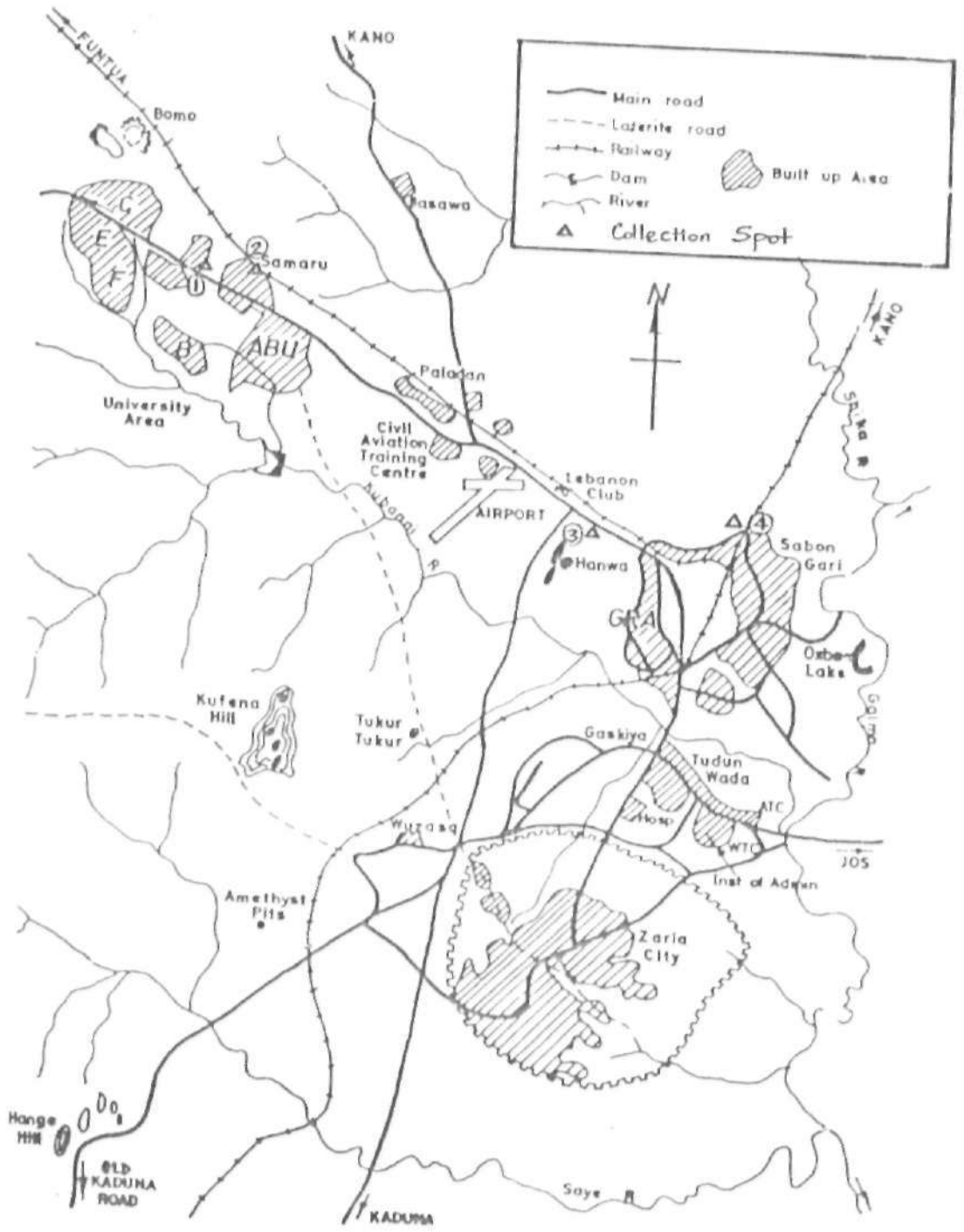


FIGURE 2: SAMARU-ZARIA URBAN AREA

pozzolanic activity of the factory ash examined.

3.2.1 Sand:

The sand was tested according to the specification of NIS 11, 1974, Appendix **D2** . It was washed, dried and sieved. The clay content present in the prepared sand was measured as 3%. The specified maximum allowable value is 6%.

3.2.2 Cement:

The ordinary portland cement (OPC) for this work was produced by Ashaka Cement Company, Bauchi.

a) Consistency of paste: The measured water-cement ratio which gave a consistent paste was 0.32.

b) Setting times: The procedure for this test is described in NIS 11, 1974. Appendix B. The results obtained for both the initial and final setting times are shown below:

Initial setting time = 1 hour 46 minutes.

Final setting time = 3 hours 04 minutes.

The prescribed minimum initial setting time for OPC is 45 minutes, and the maximum final setting time is $<$ 10 hours. The experimental data are presented in Appendix A1.

c) Soundness of cement: The procedure for this test is covered by the 'Le Chatalier Method', and is described in NIS 11, 1974, Appendix C and BS 12, 1978.

The result of the test, indicate an expansion of 3mm, against the maximum specified value of 10mm. The raw data are presented in Appendix A2.

d) Strength of Cement: The procedure for this test is laid out in NIS 11, 1974, Appendix D and BS 12, 1978. Mortar cubes of cement-sand ratio of 1:3 were prepared and their compressive strength measured at 3, 7 and 28 days. The results are shown in Table 12 while the raw data are presented in Appendix A3.

TABLE 12: COMPRESSIVE STRENGTH OF STANDARD MORTAR CUBES

Cement sand ratio	1 : 3		
Age (days)	3	7	28
Average Compressive Strength (MPa)	16,15	21,53	23,54

3.2.3 Bagasse ash content:

A laboratory investigation was carried out to estimate the bagasse content from sugar cane; and the ash content from bagasse. There was no available code which describes the procedure for such an investigation.

3 Samples of cut out cane of weights 138g, 150g and 147g were crushed, and the soluble sugar juice extracted. The bagasse was then burnt to ashes in an oven set at $400^{o}c$. The weights of the bagasse before burning and the resulting ash were recorded.

The results are shown in Table 13 . The average estimate of bagasse from cane is 30%, while the ash content from bagasse is 2.48%. The experimental data are presented in Appendix A4.

TABLE 13 : BAGASSE ASH CONTENT

Descriptions	Samples		
	1	2	3
Weight of cane (g)	138,333	150,000	146,667
Weight of bagasse (g)	44,000	42,000	43,334
Weight of ash (g)	1,000	1,167	1,034
percentage of bagasse in cane	31.81	28.00	29.55
percentage of ash in bagasse	2.27	2.78	2.38

3.2.4 Test on Factory ash: The qualitative pozzolanic activity of the ash was evaluated by compressive strength test of mortar cubes prepared with a cement-sand ratio of 1:3. The cement was composed of a mixture of lime + ash in ratios of 20;80 and 25:75. (Smith, 1992; Lea, 1970).

The results of the average compressive strength at 3, 7 and 28 days are presented in Table 14 shown below:

TABLE 14 : AVERAGE COMPRESSIVE STRENGTH OF MORTAR CUBES MADE WITH FACTORY SCBA

Mix Description	Cement Consumption Lime + SCBA	Water/ Cement Ratio	Ages of Specimen (days)	Average Strength of 3 test Specimens (MPa)
Lime+factory SCBA	20 + 80	0.46	3	0.50
			7	0.64
			28	0.67
	25 + 75	0.44	3	0.53
			7	0.67
			28	0.73

The raw experimental data are presented in Appendix A5.

3.3 BAGASSE PREPARATION

3.3.1 Bagasse powder: Attempt made into literature revealed that there is little work carried out in this area. A simple mortar and pestel was used for pounding the dried bagasse into powder form. A salient observation made during this operation was the sensing of choking fumes, thus requiring the covering of one's nasal area. The resulting mass was then sieved out using the 75μm sieve (BS sieve No. 200).

3.3.2 Bagasse ash: A furnace with a regulated temperature device was used for this operation. The furnace dimensions are 1.2m x 1.2m x 1.7m, having a chimney at the top. It is a multilayered structure made of refractory bricks.

The chamber was stacked with bagasse, and the firing operation begins. It takes about 40 minutes to fire up 300°c, and 70 minutes to fire up to 400°c. The ash was collected after cooling and ground using the mortar and pestel. The ash was then sieved using the 75μm sieve.

3.3.3 Trial tests on bagasse ash: Trial compressive strength tests were performed on the ash obtained at 300°c and 400°c. Mortar cubes of cement-sand ratio of 1:3 were prepared, with a substitution of 20% of OPC made with the prepared ash (David et al, 1977). The tests were according to description of NIS 11, 1974, Appendix D.

The results are presented in Table 15 ; all cubes were tested at 3 days.

TABLE 15: COMPRESSIVE STRENGTH OF MORTAR CUBES MADE WITH SCBA BURNT AT 300°c AND 400°c.

SCBA-type	Cement/ sand ratio	Cement Composition SCBA:OPC	Water/ Cement Ratio	Age (days)	Average Strength of Specimens (MPa)
Burnt @ 300°c	1:3	20:80	0.41	3	4.41
Burnt @ 400°c	1:3	20:80	0.41	3	9.60

The experimental data are presented in Appendix A6.

3.4 CHEMICAL COMPOSITION OF BAGASSE

3.4.1 Oxide Composition: This involved the use of chemical compounds to determine in a quantitative manner the main oxides present in the bagasse powder and ash. The description for this analysis is as laid out by Vogel (1989). The oxide composition of the powder and ash (SCBA) are presented in Table 16 and Table 17 .

TABLE 16: OXIDE COMPOSITION OF BAGASSE POWDER

Composition	% of oxide		
	1	2	Mean
Silicon dioxide (SiO_2)	23.70	25.36	24.53
Aluminium oxide (Al_2O_3)	4.52	4.18	4.35
Iron oxide (Fe_2O_3)	1.85	2.11	1.98
Calcium oxide (CaO)	2.78	2.64	2.71
Magnesium oxide (MgO)	1.50	1.78	1.64
Sulphate (SO_3)	0.65	0.75	0.70

TABLE 17: OXIDE COMPOSITION OF BAGASSE ASH (SCBA)

Composition	% of oxide		
	1	2	Mean
Silicon dioxide (SiO_2)	58.20	59.10	58.65
Aluminium oxide (Al_2O_3)	8.25	7.64	7.95
Iron oxide (Fe_2O_3)	4.57	3.96	4.27
Calcium oxide (CaO)	6.30	6.64	6.47
Magnesium oxide (MgO)	3.77	3.95	3.86
Sulphate (SO_3)	1.25	1.52	1.39
Loss on ignition	5.25	5.16	5.21

For reactive pozzolanas like rice husk ash (rha) and pulverized fuel ash (pfa), a minimum content of reactive silica of 55% is expected (Smith, 1992). The ASTM C618-78 specify the combined weight of silica, alumina and ferrous oxides as 70% for classes N, F and C pozzolanas.

A desk top assessment of the oxide composition shown in Tables 16 and 17 revealed a combined value of SiO_2, Al_2O_3 and Fe_2O_3

- For powder = 24.53 + 4.35 + 1.98 = 30.86%
- For SCBA = 58.65 + 7.95 + 4.27 = 70.87%

3.4.2 Bogue's equations composition: Bogue's equations give an estimate of the potential principal compounds present in cement. These compounds are tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium

aluminate (C_3A) and tetracalcium alumino ferrite (C_4AF). The equations state:

$$C_3S = 4.07\,(CaO) - 7.60\,(SiO_2) - 6.72\,(Al_2O_3) - 1.48\,(Fe_2O_3) - 2.85\,(SO_3)$$

$$C_2S = 2.87\,(SiO_2) - 0.754\,(C_3S)$$

$$C_3A = 2.65\,(Al_2O_3) - 1.69\,(Fe_2O_3)$$

$$C_4AF = 3.04\,(Fe_2O_3)$$

substituting the results obtained for the powder and ash in these equations and evaluating; the potential compound composition compared with standard OPC is shown in Table 18.

TABLE 18: BOGUE'S ANALYSIS OF BAGASSE POWDER, SCBA AND STANDARD OPC

Cementitious compound	Computed values %		
	Bagasse Powder	SCBA	Standard OPC
C_3S	-209.46 *	-482.85 *	50.70
C_2S	228.33**	168.33**	22.50
C_3A	8.18	13.85	8.60
C_4AF	6.02	12.97	9.40

* does not exist, implies CaO is low or non-existence.

** absence of C_3S, affects presence of C_2S.

3.5 GENERAL TESTS ON BAGASSE POWDER, SCBA, LIME+SCBA AND OPC+SCBA MIXTURES

3.5.1 Fineness of powder and SCBA: The ground bagasse powder and SCBA were sieved out using the BS Sieve No. 200. The results of this test is shown in Table 19.

TABLE 19: FINENESS TEST ON BAGASSE POWDER AND SCBA

Description	Bagasse Powder			SCBA		
	1	2	3	1	2	3
Percentage retained on sieve No. 200 (%)	11.30	10.27	10.60	5.85	6.12	5.30
Percentage passing sieve No. 200 (%)	88.70	89.73	89.40	94.15	93.88	94.70
Average percentage passing sieve No. 200	89.28			94.24		

The experimental data are presented in Appendix A7. ASTM C618-78 specifies for classes N, F and C pozzolanas, a minimum percentage passing sieve No. 200 of 85% .

3.5.2 Specific gravity of SCBA: The specific gravity of the SCBA was measured as described in BS4550: part 3, 1978. The results are presented in Table 20 below:

TABLE 20: SPECIFIC GRAVITY OF SCBA

Samples	1	2	3
Specific gravity	2.00	1.79	1.98
Average value	1.92		

The raw data represented in Appendix A8. The average specific gravity of most pozzolanas lies between 1.9 - 2.4 (Neville, 1981).

3.5.3 Pozzolanic Activity Index (PAI): There are two pozzolanic Activity Indices defined for a pozzolana - the PAI with cement, and the PAI with lime, for the assessment of the qualitative activity of the pozzolana. The PAI with cement (OPC) is defined by ASTM C618-78 as the ratio of the compressive strength of the test specimen; to that of the control specimen measured at 28 days, and expressed as a percentage. The PAI with lime is defined as the compressive strength of test specimen measured at 7 days.

The procedure for these tests is described by ASTM C618-78. The results of the test are presented in Table 21 .

TABLE 21 : POZZOLANIC ACTIVITY INDICES TESTS

Average Strength of control specimens @ 28 days (MPa)	Average Strength of test specimens (OPC+SCBA) at 28 days (MPa)	PAI with Cement	Average Strength of specimens (LIME+SCBA) at 7 days (MPa)	PAI with Lime (MPa)
23.07	21.00	91%	4.88	4.88

The experimental data are presented in Appendix A9. The ASTM specifies a PAI with cement of minimum of 75%, and PAI with lime of 5.5MPa for classes N, F and C pozzolanas.

3.5.4 Setting times of Lime + SCBA Mix: This experiment was carried out as described in Appendix B of NIS 11, 1974, as for standard OPC. The measured times are stated below:

Initial setting time = 3 hours 55 minutes

Final setting time = 7 hours 05 minutes

For pure OPC, the prescribed minimum initial setting time is 45 minutes; while the maximum final setting time is 10 hours. The experimental data are presented in Appendix A10.

3.5.5 Soundness of Lime + SCBA Mix: The Le Chatelier apparatus was used for the evaluation of the soundness of the lime + SCBA (0.25 + 0.75) mix as laid out in Appendix D of NIS 11, 1974. The results indicate an average expansion value of 3mm for the lime + SCBA mix. The specified maximum expansion for pure OPC is 10mm.

The raw data are presented in Appendix A11.

3.6: COMPRESSIVE STRENGTH TESTS ON BAGASSE POWDER AND ASH (SCBA)

i) Batching of materials: The batching of all mix constituents including cement (OPC), bagasse powder, SCBA, sand and water was done by weight. A weighing scale was employed for this operation (Lea, 1970 and David et al, 1977). All mix ratios and proportions, percentage replacements and substitutions refer to weight measurements.

ii) Layout of mixes: The layout of mixes tried in this work are shown in Table 22 and Table 23. The former is for the preliminary works, while the latter refer to final strength measurements of best mixes of lime + bagasse, and OPC + bagasse. Tables 22 and 23 are as shown on pages 44 and 45.

TABLE **22:** Layout of Mixes for Stage One Work (Preliminary)

Group	Batch Title	Mix Proportion % by weight	Ages of Specimens (days)	No of Specimens tested at each age	Total No. of Specimens tested
G1		Cement:Bagasse			
	A	100 : 0	3	3	3
	B	100 : 0	7	3	3
	C	100 : 0	28	3	3
G2	A	80 : 20	3	9	9
	B	70 : 30	3	9	9
G3		Lime :Bagasse			
	A	40 : 60	3	9	9
	B	33 : 67	3	9	9
G4		Cement:Bagasse			
	A	90 : 10	3, 7, 28	3	9
	B	80 : 20	"	3	9
	C	70 : 30	"	3	9
	D	75 : 25	"	3	9
	E	60 : 40	"	3	9
	F	50 : 50	"	3	9
G5		Lime :Bagasse			
	A	40 : 60	3, 7, 28	3	9
	B	33 : 67	"	3	9
	C	25 : 75	"	3	9
	D	20 : 80	"	3	9

G1 Control cubes made of standard OPC + sand
G2 Cubes made of standard OPC + raw bagasse powder + sand
G3 Cubes made of lime + raw bagasse powder + sand
G4 Cubes made of standard OPC + bagasse ash + sand
G5 Cubes made of lime + bagasse ash + sand

TABLE 23 : LAYOUT OF MIXES FOR STAGE TWO WORK

Group	Batch Title	Mix Proportion % By weight	Ages of Specimens (days)	No. of Specimens tested at each age	Total No. of Specimens tested
		Cement:Bagasse			
G4	D	75 : 25	3, 7, 14, 21, 28, 60	8	48
		Lime :Bagasse			
G5	C	25 : 75	3, 7, 14, 28, 60	8	48

iii) Consistency of mixes: The water-cement ratio required to make a consistent cement paste for the various mix proportions of OPC + bagasse, and lime + bagasse cements were determined. The results of the OPC + SCBA mixes are shown in Table 24 (See page 47).

iv) Curing media: The test specimens prepared were initially cured in water, moist polythene and damped cloth at the preliminary stage. Subsequently, all test specimens were cured in water, as the best compressive strength results were obtained for cubes cured in water, over the other media. Works by David et al (1970) and Syed and Zaheerudin (1992) attest to the superiority of water for curing pozzolanic cements.

v) Density of test specimens: The mass per unit volume of all tested units were measured. The results (Table 25) show that specimens made with the bagasse powder, weighed lesser than those of the ash (SCBA). Table 25.

vi) Compressive Strength measurements: The compressive strength of the masonry units prepared, were measured according to the specifications laid out in NIS 11, 1974, Appendix D. The units were 70.6mm x 70.6mm x 70.6mm mortar cubes and the cement:sand ratio was 1:3. The cement composition of the various mixes vary as shown in Table 22 , both for the OPC + bagasse cement, and lime + bagasse cements. The OPC + bagasse

TABLE 24 : NORMAL CONSISTENCY OF PASTES CONTAINING OPC + SCBA CEMENT

Mix Proportion (OPC:SCBA)	1:0	0.90:0.10	0.80:0.20	0.75:0.25	0.70:0.30	0.60:0.40	0.50:0.50
Water-Cement ratio	0.40	0.41	0.41	0.42	0.42	0.43	0.44

TABLE 25 : DENSITIES OF TESTED SPECIMENS

Description of Group	Batch Title	Cement Composition (%) (OPC+Lime+Bagasse)	Average density (KN/m^3)
Control	1	100 + 0 + 0	21.26
OPC + raw bagasse powder	2A	80 + 0 + 20	14.56
	2B	70 + 0 + 30	14.95
Lime + raw bagasse powder	3A	0 + 40 + 60	18.28
	3B	0 + 33 + 67	18.16
OPC + bagasse ash (SCBA)	4A	90 + 0 + 10	21.83
	4B	80 + 0 + 20	21.68
	4C	70 + 0 + 30	21.88
	4D	75 + 0 + 25	21.79
	4E	60 + 0 + 40	21.72
	4F	50 + 0 + 50	20.63
Lime + bagasse ash (SCBA)	5A	0 + 40 + 60	21.45
	5B	0 + 33 + 67	20.57
	5C	0 + 25 + 75	20.70
	5D	0 + 20 + 80	20.73

cement was obtained by substituting some proportion of OPC with the prepared bagasse, to obtain a blended portland-pozzolana cement; while the lime + bagasse cement was a direct blend giving a lime-pozzolana cement.

The final evaluation of the best mixes of the portland-pozzolana cement, and lime-pozzolana cement at 3, 7, 14, 21, 28 and 60 days was then carried out. This involved the preparation of 96 test specimens, and the testing of 8 specimens at each corresponding age. Results from the preliminary and final works are presented in Tables 26 and 27.

TABLE 26 AVERAGE COMPRESSIVE STRENGTH OF TEST SPECIMENS FOR STAGE ONE WORK (PRELIMINARY)

Mix Description	Group/ Batch Title	Cement Composition (%) OPC+Lime+Bagasse	W/C Ratio	Age of (days) Specimens	Average Compressive Strength from 3 test Specimen (Mpa)
Control	1A	100 + 0 + 0	0.40	3	16.15
	1B	100 + 0 + 0		7	21.53
	1C	100 + 0 + 0		28	23.54
OPC + raw bagasse powder	2A	80 + 0 + 20	0.62	3	0.17
	2B	70 + 0 + 30	0.67	3	0.18
Lime + raw bagasse powder	3A	0 + 40 + 60	0.78	3	0.16
	3B	0 + 33 + 67	0.85	3	0.11
OPC + bagasse ash (SCBA)	4A	90 + 0 + 10	0.41	3	14.78
				7	19.59
				28	21.53
	4B	80 + 0 + 20	0.41	3	10.43
				7	13.78
				28	20.33
	4C	70 + 0 + 30	0.42	3	7.69
				7	11.43
				28	18.93
	4D	75 + 0 + 25	0.42	3	8.49
				7	12.10
				28	20.26
	4E	60 + 0 + 40	0.43	3	6.69
				7	10.83
				28	14.98
	4F	50 + 0 + 50	0.44	3	6.02
				7	9.70
				28	12.44
	5A	0 + 40 + 60	0.41	3	1.47
				7	1.74
				28	1.94
	5B	0 + 33 + 67	0.42	3	1.54
				7	1.88
				28	2.14
Lime + Bagasse (SCBA)	5C	0 + 25 + 75	0.44	3	4.68
				7	4.48
				28	6.29
	5D	0 + 20 + 80	0.46	3	4.08
				7	4.14
				28	5.02

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TABLE 27 : AVERAGE COMPRESSIVE STRENGTH OF TEST SPECIMENS FOR STAGE TWO WORK (FINAL)

Mix Description	Group/ Batch Title	Cement Composition (%) OPC+Lime+Bagasse	W/C Ratio	Age of (days) Specimens	Average Compressive Strength from 8 test Specimens (MPa)
OPC + Bagasse ash (SCBA)	4D	75 + 0 + 25	0.42	3	7.07
				7	12.04
				14	12.82
				21	15.08
				28	19.01
				60	22.57
Lime + Bagasse ash (SCBA)	5C	0 + 25 + 75	0.44	3	5.04
				7	6.27
				14	6.97
				21	7.20
				28	7.48
				60	7.96

CHAPTER FOUR

4.0 DISCUSSION OF RESULTS

4.1 PHYSICAL PROPERTIES OF SCBA

4.1.1 Fineness of SCBA: The percentage of SCBA passing sieve No. 200 (75um aperture) was measured as 94% (Appendix A7). ASTM C618-78 specifies minimun percentage passing sieve No. 200 as 85%.

The finer the particles of a pozzolana, the more the available surface area with lime or OPC, and the more reactive it will be. It is required that pozzolanas be ground to at least cement fineness (75um) or even finer (approaching 50um), when used in blended cement mixes. (Barkakati et al, 1994; Lea, 1970).

4.1.2 Specific gravity of SCBA: The measured specific gravity of SCBA is 1.92 (Appendix A8). The specific gravity of most pozzolanas is between 1.90 to 2.40, as against 3.1 for OPC. (Neville, 1981). This result for the SCBA shows that it has an absolute solid volume of about 38% greater than that of an equal weight of OPC.

It is generally agreeable among researchers (Lea, 1970; smith, 1992; Syed and Zaheerudin, 1992; David et al, 1970) that in measuring out pozzolanas for use in portland-pozzolana cements or lime-pozzolana cements, the weights of the material be taken instead of the volume, ASTM C311-54T, C109-54 and C340-55T also agree with this.

Thus, it implies that the increased solid volume due to pozzolana light weight, does not have any significant effect on the compressive strength developed.

4.1.3 Consistency of mixes: The results of the consistency test for all mixes is shown by their water-cement ratio in Table 26. The normal pattern of behaviour of pozzolanas was observed; as the pozzolana content increased, the required amount of water to make a consistent paste increased. The water-cement ratio ranged from 0.40 for the control, to 0.445 for the replacement of 50% OPC with SCBA. Graphs of water-cement ratio against mix proportions for the OPC+SCBA cements and lime+SCBA cements is shown in Figure 3 and 4 respectively.

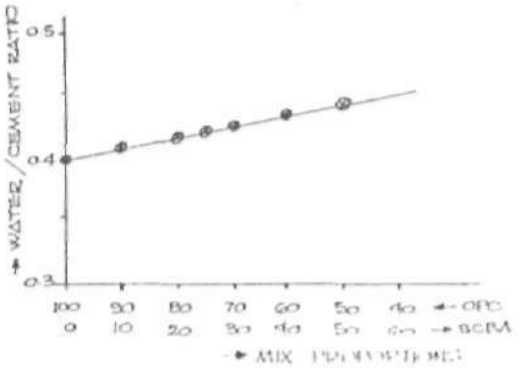


FIGURE 3 — CONSISTENCY OF OPC + SCBA MIXTURES

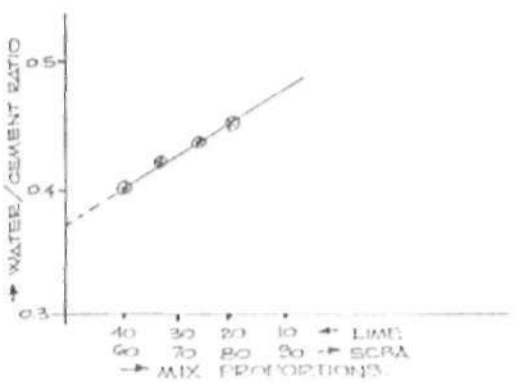


FIGURE 4 — CONSISTENCY OF LIME + SCBA MIXTURES

4.1.4 Setting times of lime + SCBA cement: The setting times of the best mix of lime + SCBA cements was measured as: Initial setting time = 3 hrs. 55 minutes

Final setting time = 7 hrs 05 minutes

These values are within stipulated standards for pure OPC in NIS 11, 1974. The specified times are 45 minutes (minimum) for initial set, and 10 hours (maximum) for final set. Pozzolanic hydration reactions are slower, and there is need for ample initial time and medium for the development of the cementitious compounds.

4.1.5 Soundness of Lime + SCBA cement: The measured expansion of the best lime + SCBA cement was 3mm (Appendix A11), which is less than the prescribed maximum of 10mm for pure OPC. Excessive expansion of cement usually leads to the development of cracks on rendered surfaces, and this is undesirable in masonry works. The low expansion can also be attributed to the complete absence of gypsum, which is usually responsible for the flash setting in OPC.

4.2 CHEMICAL PROPERTIES OF BAGASSE POWDER AND SCBA

4.2.1 Oxide Composition: The silica content of the bagasse powder (24.53%) and its combined silica, alumina and ferrous oxides of 30.86% are much lower than the specifications of ASTM C618-78 for pozzolanas, given as 55% for silica and 70% for combined silica, alumina and ferrous oxides. These suggest a likely unreactive pozzolana in the bagasse powder.

The insitu silica of the SCBA of 58.56% is greater than specified value of 55% by Smith, 1992; and its combined silica, alumina and ferrous oxides of 70.87% is above the specified value of 70% by ASTM C618-78. A comparison of the physical and chemical properties of the SCBA with ASTM standards is made in Table 28.

TABLE 28: COMPARISON OF SCBA PROPERTIES WITH ASTM C618-78

Property	ASTM C618-78 classes of Pozzolanas (N)	(F)	(C)	Prepared Bagasse ash (SCBA)
Oxides (%)				
$SiO_2+Al_2O_3+Fe_2O_3$ (Min)	70	70	70	70.87
SO_3 (max)	4.0	5.0	5.0	1.39
MgO (max)	5.0	5.0	5.0	3.86
Loss on ignition (max)	10.0	2.0	6.0	5.21
Physical property				
Fineness % passing sieve No. 200 (min)	85	85	85	94
Pozzolanic Activities				
With OPC at 28 days (%)	75	75	75	91
With lime at 7 days (MPa)	5.5	5.5	5.5	4.88

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The sulphate content (SO_3) of 1.39% is lower than 5% specified. The magnesium oxide of 3.86%, which is higher than the sulphate is lower than specified value of 5%. The loss on ignition, which is indicative of total carbon content was measured as 5.21% is lower

than 10% and 6% specified for classes N and C pozzolanas. Syed and Zaheerudin (1992), obtained a loss of ignition of 5.11% and 2.52% for SCBA. Thus the tested SCBA can be classified as ither a class N or C pozzolana. The low sulphur content implies a good soundness (low expansion) for the pozzolana mixes. The loss on ignition is a measure of adulteration of cement (i.e. the cement reacting with moisture in the air) or unburnt carbon present. A value of 5.21% obtained for the SCBA though somewhat high (may be attributed to some little untidiness during the burning operation, and exposure of burnt material to air) clearly meets the ASTM class N requirements.

A comparison of oxide composition of SCBA, bagasse powder and typical OPC is made in Table 29.

TABLE 29: COMPARISON OF OXIDE COMPOSITION OF SCBA, BAGGASE POWDER AND OPC.

Composition	SCBA	Bagasse Powder	OPC
SiO_2	58.65	24.53	23.90
Al_2O_3	7.95	4.35	1.50
Fe_2O_3	4.27	1.98	3.11
CaO	6.47	2.71	64.10
MgO	3.86	1.64	0.79
SO_3	1.39	0.70	2.37

This table clearly shows the low content of calcium oxide in the pozzolana (against the abundant presence in OPC) which makes it difficult for the pozzolana to develop cementitious compound on its own. The need for lime or its compound to go into reaction with the pozzolana is herein buttressed.

4.2.2 Bogue's Analysis: Analysing the oxide composition using the Bogue's empirical equations gave the results shown in Table 18 with a tricalcium silicate (C_3S) valuesof -209.46% and -482.85% for the bagasse powder and SCBA respectively. The computed value of dicalcium silicate (C_2S) was 228.33% and 168.33% for the bagasse powder and SCBA.

This analysis reveals the absence of tricalcium silicate (C_3S) both for the bagasse powder and SCBA. This implies that these materials on their own are incapable of developing any cementitious property, which confirms the ASTM definition for pozzolanas. This explains also the need for the pozzolanas to be added to lime compounds. The early strength developed by OPC is entirely due to the presence of C_3S, and its absence means no tangible strength value can be obtained (Chong, 1977). The absence of C_3S will likely affect the functional presence of C_2S (dicalcium silicate), because they are related in the equations.

The last two compounds tricalcium aluminate (C_3A) and tetracalcium alumino ferrite (C_4AF) are not known to produce high strength value in cements (<10%)

4.2.3 Pozzolanic Activity Indices: The Pozzolanic Activity Index (PAI) is a measure of the potential activity of any suspected pozzolana. The PAI of the SCBA was measured with cement and with lime. The PAI with cement obtained was 91% greater than 75%

specified by ASTM C618-78 for classes N, F and C pozzolanas. BS 3892, 1965 specifies a PAI value of 85% for pulverized fuel ash (pfa) for use in concrete. The PAI with cement of 91% for the SCBA shows that the material is very active and can effectively be used as a replacement for OPC in masonry or concrete construction.

The PAI with lime is a much more relevant property of any pozzolana for use in load bearing or non-load bearing blocks. The measured value of 4.88 MPa is slightly lower than the specified value of 5.5MPa. This value however meet the requirement of ASTM for non-load bearing units and load bearing grade 'S' units. (ASTM C90-75 and ASTM C129-75). It may be added here, however that according to ASTM C311-77, neither the PAI with OPC or the PAI with lime should be taken exclusively as a measure of the quality of the pozzolana, hence the need for compressive strength tests of mortar cubes. Again, it is the property contributed by the pozzolanas at longer ages that are most desirable, particularly its resistance to salts, acids and sulphates (Mehta, 1977; Djuric et al, 1996; Torii and Kawamura, 1994).

4.3 COMPRESSIVE STRENGTH TEST

The compressive strength of tested mortar cubes is the final indicator of the quality of any cement. The strength of mortar depends on the cohesion of the cement

paste, its adhesion to the aggregate particles, strength of the aggregate itself and to some extent on the water-cement ratio.

The results of strength development for all mixes tried, from tested mortar cubes are given in Table 26 (Chapter three).

The Compressive strength of the ground bagasse mortar cubes measured, were extremely low, and do not in any way show any trace of good pozzolanic properties. Either when the powder was substituted as a replacement for OPC, or when used directly with lime, the compressive strenth obtained was generally lower than 0.25 MPa (far cry from ASTM C90-75 specification for non-load bearing units of 3.45MPa). This is essentially because the particles are in the unburnt form, containing organic materials.

Thus, it can be conclusively stated that heat treatment plays a vital role in the production of viable and useful pozzolanas from agricultural wastes, as already postulated by Smith (1992). Raw powder contains excessive organic material that would require a lot of water to form a consistent paste, and also inhibit the development of a good cementitious compound. Heat action breaks down the organic materials, liberating carbon dioxide and water, leaving only the inorganic residues. The ash left behind has

been proved in reactive pozzolanas like rice husk ash and SCBA to contain silica in a large quantity (David et al, 1977; Baguant and Mohammedbhai, 1990).

The results of the compressive strength test on the factory SCBA is presented in Appendix A5. The strength values obtained for the mixes tried (20/80 and 25/75 lime + SCBA cements of 0.67MPa and 0.73MPa) even at 28 days were generally lower than 1MPa.

According to Smith (1992) the main reason for poor activity of agricultural waste pozzolanas is overburning, into the temperature range that favours the development of crystalline (less reactive) particles. This is probably responsible for the behaviour of the factory SCBA, as it is not known the temperature at which the bagasse was burnt to raise steam. At the time of visit, the factory was on production recess, and the thin staff present, could not give a sure answer on the burning temperature within their combustion chamber.

The compressive strength of the prepared SCBA mixes measured are presented in Tables 26 and 27 (Appendices 12 and 13). During the crushing operation the following observations were made:

a) Failure pattern of specimens - Failure of a specimen when loaded can occur in different forms, depending on the type of load applied to it. Observations made show higher shearing angles for the OPC + SCBA cements, over the lime + SCBA cements. This is probably due to the strength property of the cements being examined.

b) Densities of specimens - From the computed densities of tested specimens (Table 25.) there seems to be an indication that heavier specimens give higher strength values for both the OPC + SCBA and lime + SCBA cements. However, the slope of the density graphs plotted (Figure 5 and Figure 6) is very small, showing that there is not much variation in the densities of the tested specimens of the OPC + SCBA and lime + SCBA cements. The lime + SCBA cements shows a slight increase in densities with increasing quantity of SCBA.

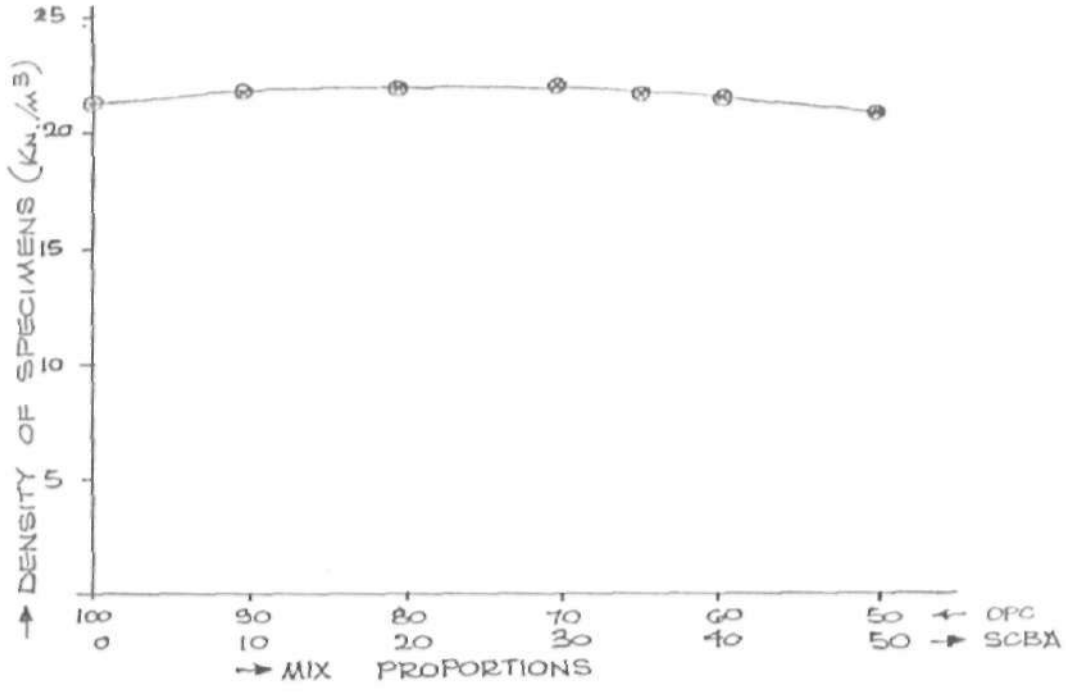


FIGURE 5 - DENSITIES OF OPC + SCBA CEMENTS

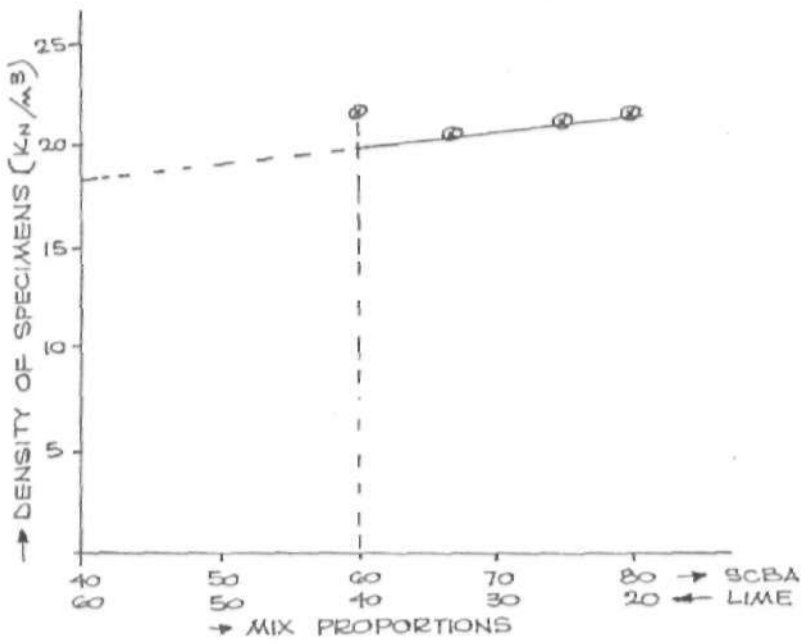


FIGURE 6 – DENSITIES OF LIME + SCBA CEMENTS

c) Specimen Colour - The control specimens, exhibited distinctly their traditional colour of light grey. The OPC + SCBA cement specimens showed a dark grey colour, probably indicative of high carbon content. Thelime + SCBA specimens showed a similar colour as that of OPC + SCBA specimens, however there appeared to be a slight improvement from dark to lighter grey as from ages of 28 days. This can be attributed to the fact that the pozzolana hydration reactions are slower, and takes a much longer time for the pozzolanic effects to become pronounced.

4.3.1 . Strength of OPC + SCBA Cements: The results of the strength tests on the OPC + SCBA cements (Table 26 - group 4) indicate a good performance of the cements, where amount of substitution made is less or equals 30%, and as from 28 days. The rate of strength development of the cements is shown in Figure 7 . Beyond the 30% sbustitution, the strength of mixes fall appreciably below the control values.

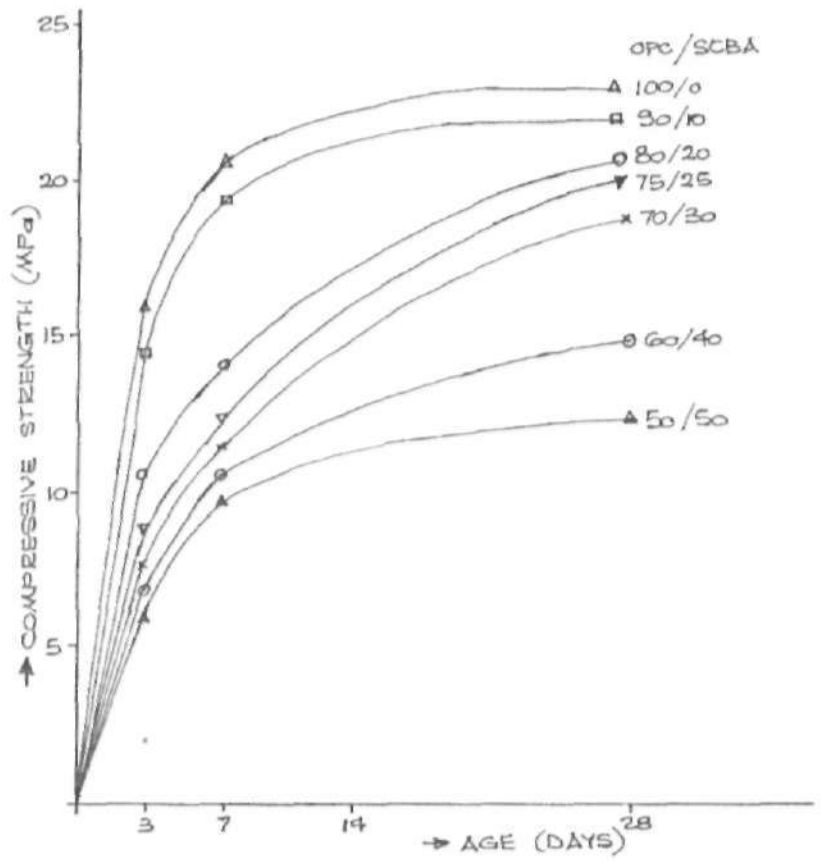


FIGURE 7 – COMPRESSIVE STRENGTH OF VARYING MIXES OF OPC + SCBA AGAINST AGES OF SPECIMEN.

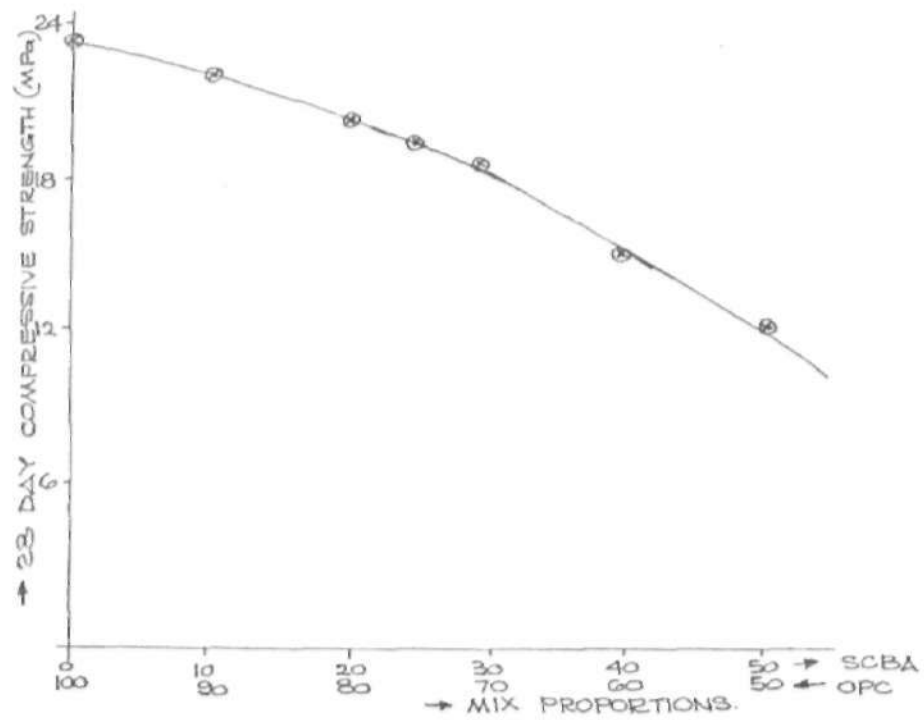


FIGURE 8 – 28 DAY COMPRESSIVE STRENGTH AGAINST VARYING MIXES OF OPC + SCBA.

The 28 day compressive strength of the cement is shown in Figure 8. The best cement according to David et al (1977) and Smith (1992) is that in which the amount of replacement of OPC made with SCBA, does not suffer adverse loss of strength values. A maximum loss in strength of 10% - 15% (maximum) may be considered, as OPC+SCBA cements having these strength values at 28 days have been proved to have about the same strength as control specimens at age of 1 year (Syed and Zaheerudin, 1992).

A check on the 28-day strength of the OPC + SCBA (70/30) with strength of 18.93MPa showed a loss of 20%, when compared with control value of 23.61MPa. Similarly for the OPC+SCBA cements (of 75/25 and 80/20) computed strength losses with the 28 day strength are 14.02% and 6.99% respectively. Thus, the OPC + SCBA cement with 25% replacement has the best performance.

Evaluation of the strength characteristics of this cement at 60 days, showed that it can achieve up to 96% of the 28-day strength of control specimens. (Table 27 , Figure 9) - the average strength of the OPC+SCBA cement of 22.66MPa against 23.61MPa for pure OPC cements. It is obvious thus, that the rate of strength development of the OPC + SCBA cement is slower, this is the traditional behaviour of pozzolanas, mainly due to a slower rate of hydration reactions taking place (Lea, 1970).

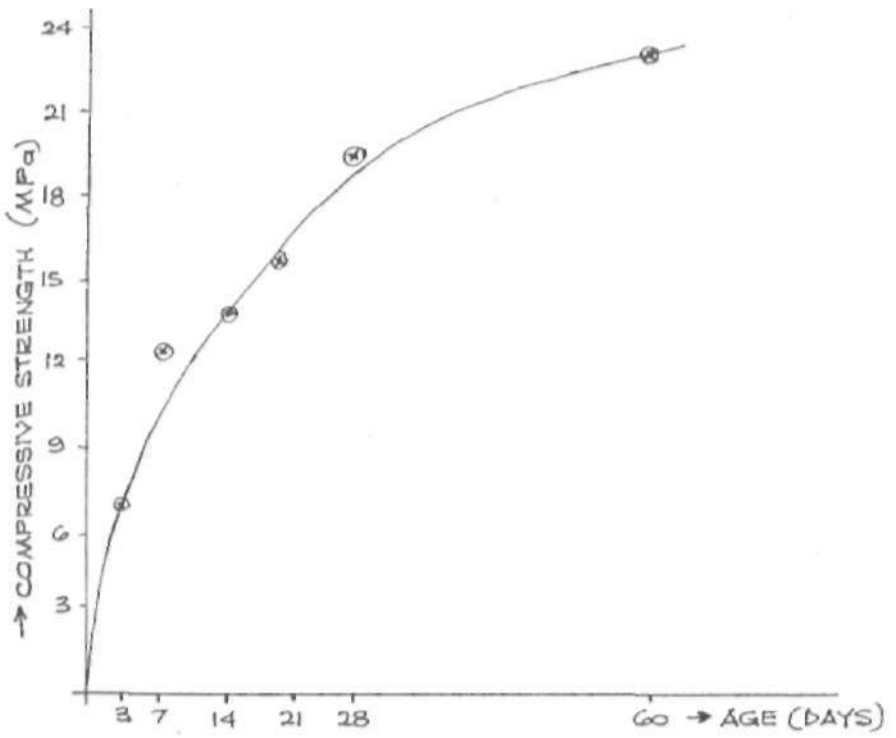


FIGURE 9 – COMPRESSIVE STRENGTH OF 75/25 OPC + SCBA MIX AGAINST AGES OF SPECIMEN.

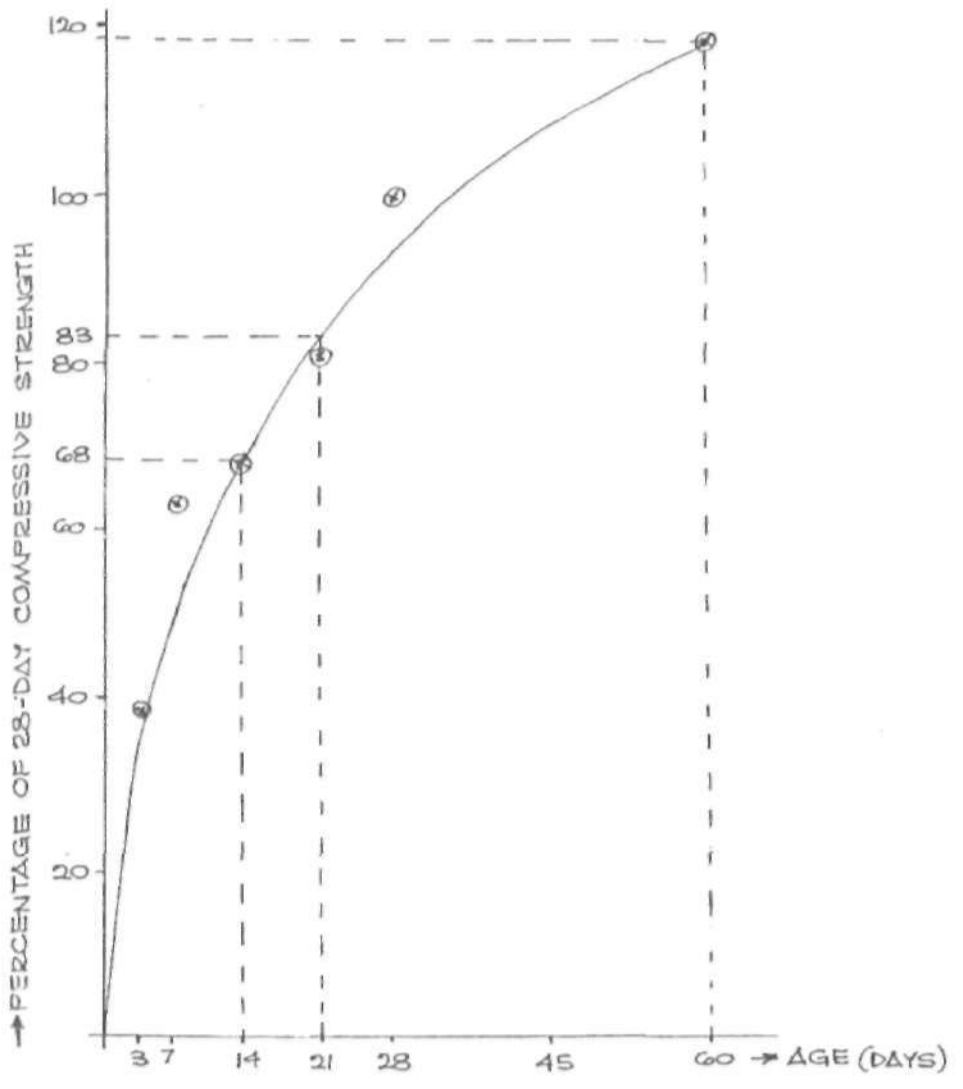


FIGURE 10 – STRENGTH DEVELOPMENT OF 75/25 OPC + SCBA AS A PERCENTAGE OF 28-DAY STRENGTH.

The strength development of the OPC +SCBA cement (75/25), as a percentage of its 28-day strength, shows a slightly steep formation (Figure 10). At 14 days, about 68% of the 28-day strength has been developed, at 21 days the value has moved up to 83%, while at 60 days almost 120% of the 28 day strength is developed.

4.3.2 Strength of Lime + SCBA Cements: The results of the strength tests on the lime+SCBA cements is shown in Table 26 (group 5). The rate of strength development of all mixes tried (Figure 11) revealed a better performance of the 25/75 and 20/80 lime + SCBA cements.

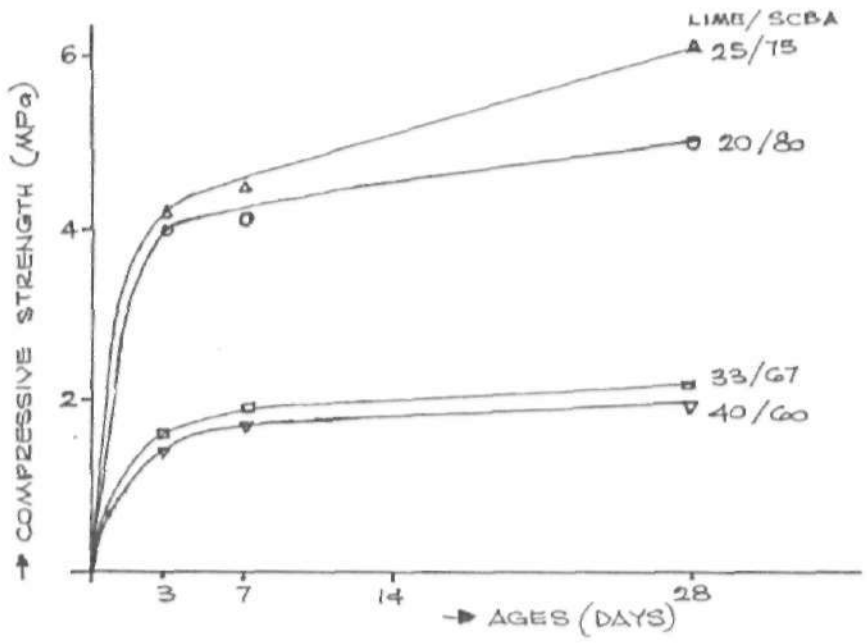


FIGURE 11 - COMPRESSIVE STRENGTH OF VARYING MIXES OF LIME + SCBA AGAINST AGES OF SPECIMEN

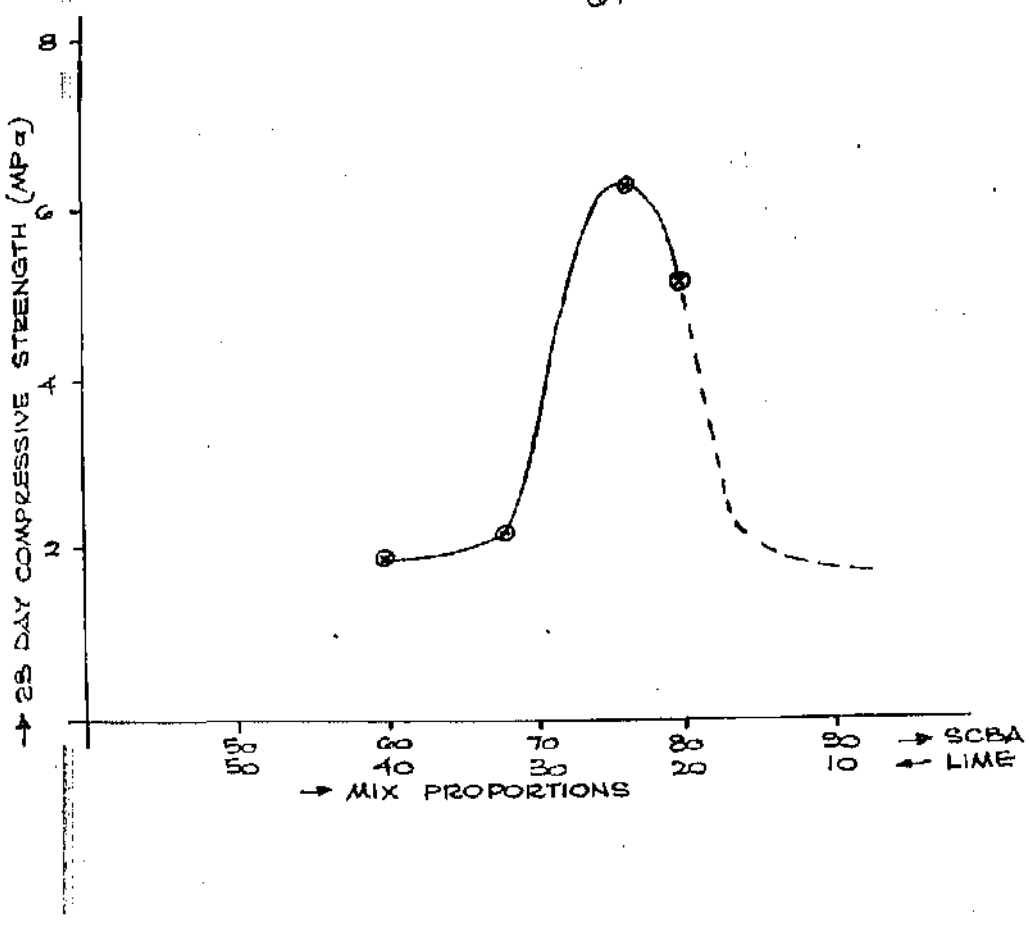


FIGURE 12 - 28 DAY COMPRESSIVE STRENGTH AGAINST VARYING MIXES OF LIME + SCBA

The 28-day compressive strength plot for all mixes showed that only the 25/75 and 20/80 lime+SCBA cements have strength values above 4MPa. (Figure, 12). The best mix of the lime+SCBA cements is clearly seen from Figure 12 i.e. the mix having the highest compressive strength value, found to be 25/75 mix. At younger ages of 3 and 7 days, there seems to be little difference between the strength of the 25/75 and 20/80 lime+SCBA cements, but at older ages of 28 days the 25/75 lime+SCBA cement gave higher strength values.

The development of strength the lime+SCBA cement follows a clearly defined gentle smooth curve with all points falling appropriately on the line (Figure 13). The strength development as a

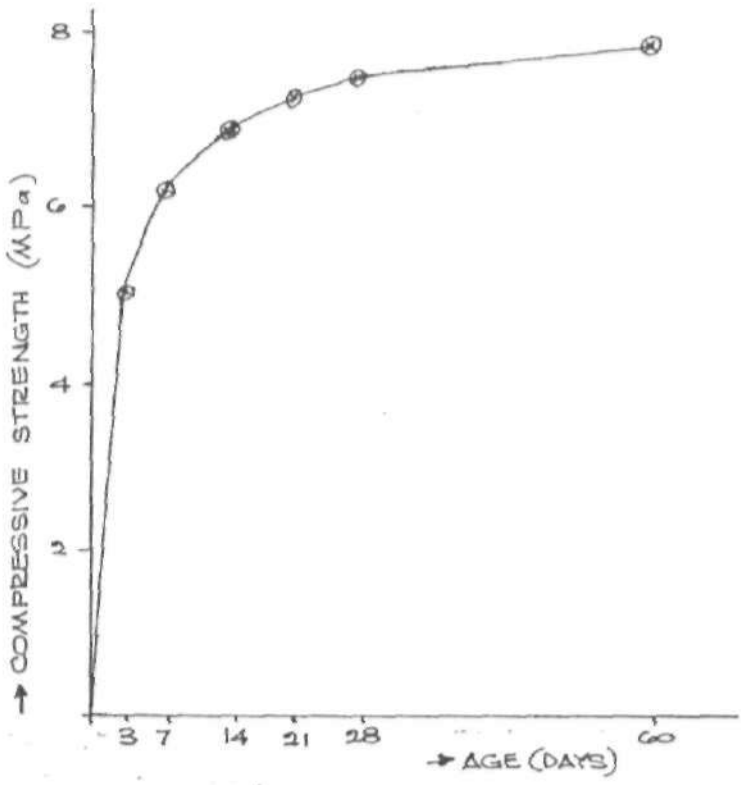


FIGURE 13 – COMPRESSIVE STRENGTH OF 25/75 LIME + SCBA MIX AGAINST AGES OF SPECIMEN

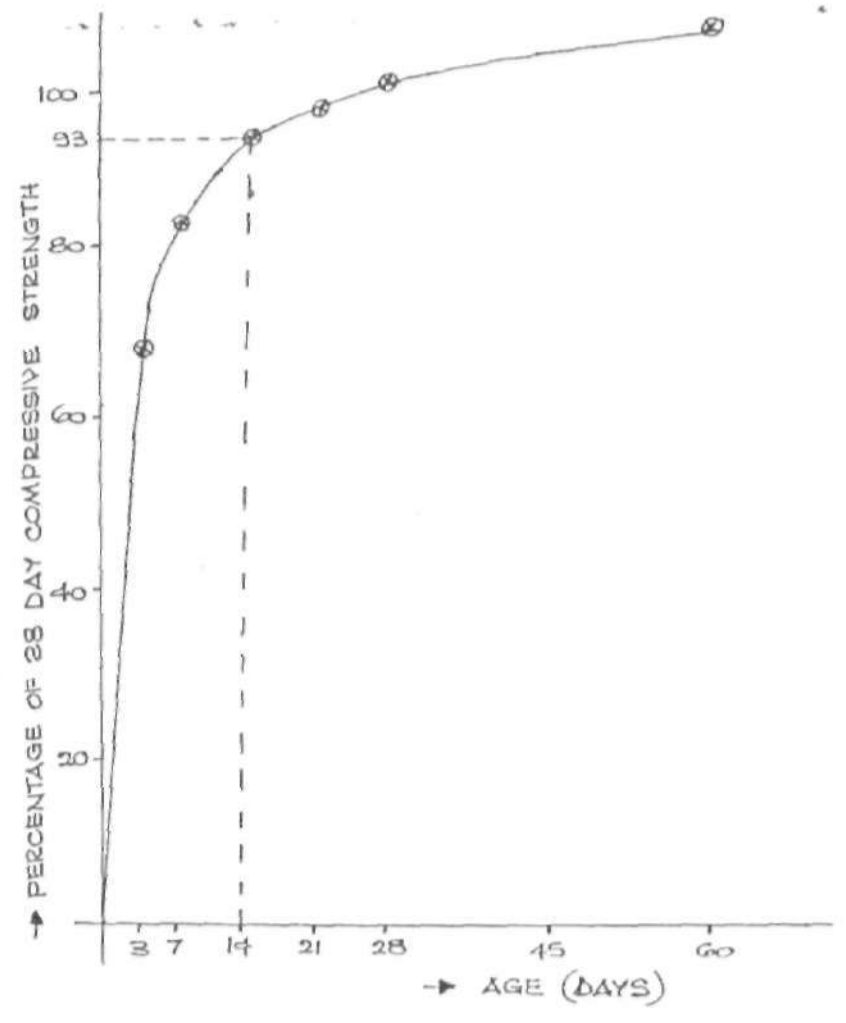


FIGURE 14 – STRENGTH DEVELOPMENT OF 25/75 LIME + SCBA MIX AS A PERCENTAGE OF 28 DAY STRENGTH

percentage of 28 day strength (Figure 14) shows that at 14 days, the cement already has achieved about 93% of its 28 day value. The increase or gain of strength as from 21 days is very gentle.

The average measured strength of 7.5MPa at 28 days (Table 27) is much higher than the ASTM C90-75 and ASTM C125-75 values for non-load bearing and load-bearing masonry units (Table 7). This again shows that at longer ages lime-pozzolana cements develop strength values sufficiently high enough to serve load-bearing purposes, and thus require more curing time. (David et al, 1977).

4.4 COST EVALUATION OF MIXES

The relative costs of the various mixes used for the production of the tested specimens were evaluated. The aim is to estimate and confirm the costs of such units, and compare with the cost of control specimens.

The rates used for costing the materials were collated locally from dealers on the materials. It was only the rates for the SCBA that was obtained from a liason office of the Numan plant at Kano. The evaluation of the units is presented comprehensively in Table 30 .

As expected, the control mix of 100% OPC with no substitution has the highest cost of 24.080 units. The mix having a 25% replacement of OPC with SCBA, has a savings of 15.74% with a cost of 20.289 units.

TABLE 30: RELATIVE COST EVALUATION OF TESTED MASONRY UNITS

			Mix Proportion - (OPC + Lime + SCBA) : Sand									
	Relative Cost Per Kg (₦)		(1+0+0): 3		(0.75+0+0.25):3		(0.5+0+0.5):3		(0+0.25+0.75):3		(0+0.2+0.8):3	
Mix Component	Actual	Relative	Qty	Relative Cost	Qty	Relative Cost	Qty	Relative Cost	Qty	Relative Cost	Qty	Relative Cost
Sand	0.200	1.000	1.680	1.680	1.680	1.680	1.680	1.680	1.680	1.680	1.680	1.680
Cement	8.000	40.000	0.560	22.400	0.420	16.800	0.280	11.200				
Lime	19.700	98.500	-	-	-	-	-	-	0.140	13.790	0.112	11.032
SCBA	2.580	12.900	-	-	0.140	1.806	0.280	3.612	0.420	5.420	0.448	5.779
Relative Total Cost				24.080		20.289		16.492		20.890		18.491

The 50% replacement of OPC with SCBA, has the lowest cost of 16.492 units, i.e. savings of 31.51%.

The lime-SCBA best mix of 25/75 has a cost of 20.890 units which is about 13.25% savings or 86.75% of control cost per unit. The 20/80, lime-SCBA whose strength values compare favourably with standard values for non-load bearing masonry has a savings of 23.21% with a cost of 18.491 units.

With these figures the savings made by substituting SCBA for OPC for use in structural masonry construction of 16% approximately is commendable and can be improved upon by intending users of the blended OPC+SCBA cement. Greater savings can be made by sourcing for cheap er sources of SCBA which is a bit expensive locally.

The lime-SCBA mix giving a savings of 13.25% (25/75 mix) can also be improved upon economically. The cost of each unit can be brought down, if the cost of the lime is reduced - thus intending users and producers of lime-SCBA cement have to source for cheap lime, probably directly from the lime manufacturers. This will automatically bring down the cost of the cement and encourage builders to buy the cement.

From this work, the savings made have not been so conspicuously large, but are nonetheless pointers, that cheap er cements can be made by using pozzolanas in blended pozzolanic cements or lime-pozzolana mixes. Savings of 13.25% and 15.74% are good enough, considering

several units of blocks that are usually required for large projects.

4.5 AVAILABILITY OF BAGASSE AS RAW MATERIAL FOR POZZOLANA CEMENT

The bagasse content obtainable from cane in this work is 30%, and the amount of SCBA from bagasse is 2.48% (Appendix A4). In Mauritius, a small Indian ocean country whose economy depends solely on sugar cane, it is estimated that about 20,000 tonnes of SCBA is produced every year. This represents about 0.3% of cane crushed, or about 2.8% of the dry weight of bagasse (Baguant and Mohammedbhai, 1990).

Thus, it can be stated that even though there is large quantity of bagasse, the obtainable SCBA is small. However, the available SCBA cannot be looked at in isolation, but in conjunction with its performance in pozzolana cements produced from it, either portland-pozzolana cements or lime-pozzolana blend. Results from this work shown in Table 26 (Appendix A12) has proved that SCBA is a good replacement for OPC in blended pozzolanic cements. When the percentage substitution is $\leq$ 25%, the resulting cement gave masonry units of comparable strength values with control specimens (maximum loss $<$ 15%). Similar results were obtained by Syed and Zaheerudin, 1992.

For lime-pozzolana mixes, with a ratio of 25:75, strength of masonry units tested are clearly satisfactory for non-load bearing blocks. The compressive strength

at 3 days of 5.04Mpa, is higher than 3.45MPa specified by ASTM C90-75 and ASTM C129-75 for non-load bearing blocks, and 4.80MPa specified for grade 'S' load bearing blocks (Table 31).

TABLE 31 COMPARISON OF STRENGTHS OF TESTED MASONRY UNITS OF LIME+SCBA

Average strength of test specimens at 3 days (MPa)	ASTM requirements	
	Non-load bearing blocks	Grade 'S' load-bearing block
5.04	Individual unit - 3.45MPa Average of 3 units - 4.14MPa	Individual unit - 4.10MPa Average of 3 units - 4.80MPa

For prospective manufacturers within Nigeria, the present cultivation of cane seems to favour a seasonal production for a start. As the cements find wider acceptance, there will be an expansion in the cultivation of cane and thus more available SCBA as raw material for the cement production.

CHAPTER FIVE

5.1 CONCLUSIONS

The following conclusions can be drawn from the results of this investigation on the possible uses of sugar cane bagasse ash (SCBA) in blended cements having various proportions of OPC + SCBA, and in conjunction with lime as a lime-pozzolana cement mix:

1. The physical and chemical properties of SCBA are satisfactory and conform to the requirements of ASTM C618-78, class N pozzolanas in fineness, specific gravity and oxide composition.
2. The Pozzolanic Activity Index (PAI) with OPC, determined as 91% is greater than 75% prescribed for ASTM class N pozzolanas. This is also indicative of a good pozzolanic activity. However, the PAI with lime of 4.88MPa, is slightly lower than the 5.5MPa value stipulated by ASTM standard.
3. The strength development characteristics of the SCBA pozzolana when used in blended cement with OPC, indicate that during the first 21 days of hydration, pozzolanic reactions did not make much contributions to the strength. The compressive strength values of the tested specimens of the various replacements of OPC with SCBA, showed differing strength values at early ages. However, the evidence of pozzolanic activity is more pronounced as from 28 days when all the mixes containing $\leq$ 30% SCBA gave strength values which compare favourably with control specimens. Thus, it can be stated

that blended mixes of OPC + SCBA (having OPC content ≥ 70%) can be used for load bearing constructional purposes.

4. Generally, for both the blended cement mixes of OPC+SCBA, and the lime-pozzolana mix, the initial rate of strength development during the first 14 days was high and very noticeable. Subsequently, as from ages of 28 days, the rate of strength gain became low, and not very noticeable, particularly in the lime-pozzolana mixes. This seem to conform with the traditional behaviour of cements.
5. For the OPC + SCBA cements, there is a direct relationship between the compressive strength (especially at early ages) and the amount of the OPC, with increasing replacement of OPC with SCBA, lower strength values were recorded.
6. The blended pozzolanic cements of OPC+SCBA, and the lime-SCBA mixes require a slightly higher amount of water to produce pastes of standard cement consistency.

   Generally, as the pozzolana content increases, more water is required to achieve a paste of standard consistency.

   This is indicative of the pozzolanic mixes requiring more moist condition for effective strength development. (David et al, 1970).
7. Lime+SCBA (25/75) cement gave masonry units having compressive strength values ≥ 5.04MPa as from 3 days, which clearly meets the conditions of ASTM standards for non-load bearing units (3.45MPa and 4.14MPa), and even grade 'S' load bearing values

of 4.10MPa and 4.80MPa.

8. The best curing medium for pozzolanic cements containing SCBA is in water. All tested specimens cured in water gave better results compared with those of same mix proportions cured in other mediums. This confirms early assertion by Lea (1970).

9. Pretrial experiments on temperature of burning bagasse in a furnace, shows that temperature of 400°c gave good SCBA, used for this work. Lower burning temperature of 300°c gave SCBA which exhibited poor activity.

10. The need for burning agricultural wastes to produce reactive pozzolana is established. Powder obtained from the unburnt ground bagasse exhibited no cementitous property either in the blended form with OPC, or in lime-pozzolana mix. Thus it can be stated that, there is need for heat application on plant residues, which breaks down the hydrocarbon materials, expelling carbon dioxide and water. The ash residue left behind is what should be investigated for the presence of amorphous silica. (Smith, 1992).

11. The measured specific gravity of prepared SCBA and that obtained from the sugar factory gave similar values of 1.92 and 1.94 respectively. However, the latter showed very poor pozzolanic action. (Baguant and Mohammedbhai, 1990).

12. The relative cost evaluation of the prepared masonry units show that pozzolanic cements are cheaper than

OPC. For the OPC + SCBA (75/25) and lime + SCBA (25/75) cements, a savings of 15.74% and 13.25% were recorded respectively.

13. There is a dire need for more cultivation of cane within the local environment, to produce SCBA cements. The present production level favours a seasonal production of the SCBA cements. The obtainable SCBA from the crushed cane and bagasse is very small (less than 3%). Apart from increasing the available SCBA by more planned cultivation, the cost of the SCBA cement will be brought further down.

5.2 RECOMMENDATIONS

Based on the results obtained from this work and the experience acquired, the following suggestions are put forward:

1. Obtain SCBA burnt at temperature range of $400^{o}c$ - $650^{o}c$. Then test the activity of each sample, to obtain a probable peak temperature for the best pozzolanic action.
2. Make the lime-SCBA cement into a slurry, and burn at $1450^{o}c$ into clinkers. Grind the clinkers into cement fineness with and without gypsum. Investigate the properties of the resulting cement.
3. Investigate the resistance of the SCBA cements to salts, chlorides and sulphates.
4. The possible uses of SCBA (especially factory SCBA) as a filler (replacement for sand) in structural concrete should be investigated. Also the possible uses of OPC + SCBA cement in structural concrete

should be examined.

5. The use of accelerators, plasticizers such as calcium chloride, and Melment L10 (condensate product of melamine and formal dehyde) on the rate of strength development of SCBA cements be investigated.

All these investigations put together, will form the basis of a broader and more acceptable judgement and possibility of using SCBA as an alternative cement. At the moment the use of SCBA cements in masonry construction and especially for non-load bearing blocks is established.

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APPENDIX A1: NORMAL CONSISTENCY, INITIAL AND FINAL SETTING TIMES OF STANDARD OPC PASTE

Paste	1	2
Room temperature °C	27	27
Weight of cement, g	400	400
Start of operation (time)	9.05 a.m	9.20 a.m
Water-Cement ratio (%)	32	32
Plunger penetration (mm)	5.7	5.9
Starting time (to)	9.05 a.m	9.20 a.m
Initial setting (t1)	10.45 a.m	11.12 a.m
Initial setting time ($t_1 - t_o$)	1 hr. 40 mins.	1 hr. 52 mins.
Mean time	1 hr. 46 mins	
Final setting (t_2)	12:10 p.m	12:23 p.m
Final setting time ($t_2 - t_o$)	3 hrs. 05 mins.	3 hrs. 03 mins.
Mean time	3 hrs. 04 mins.	

APPENDIX A2: SOUNDNESS OF STANDARD OPC PASTE

Paste	1	2
Initial measurement (mm)	18.60	18.20
Final measurement (mm)	21.60	21.19
Expansion (mm)	3.00	2.99
Specification	≤ 10mm	

APPENDIX A3: COMPRESSIVE STRENGTH OF CUBES MADE WITH STANDARD OPC AND STANDARD SAND

Mix composition OPC: Sand	Ages of Specimen (days)	Curing medium	Weight of cubes (g)	Appea-rance	Water/ cement ratio	Failure load (KN)	Compre-ssive strength (MPa)
Standard: Standard OPC sand 1 : 3	3	Water	700	light grey	0.40	81	16.25
			710			80	16.05
			705			81	16.25
	7		710			102	20.46
			715			110	22.07
			720			110	22.07
	28		720			115	23.07
			715			120	24.08
			715			117	23.47

APPENDIX A4: ESTIMATE CONTENT OF ASH FROM LABORATORY CRUSHED CANE

Descriptions	Samples		
	1	2	3
Weight of empty pan (g)	75.652	72.212	74.254
Weight of pan + cane (g)	213.985	222.212	220.921
Weight of pan + bagasse (g)	119.652	114.212	117.587
Weight of pan + ash (g)	76.652	73.379	75.287
Weight of cane (g)	138.333	150.000	146.667
Weight of bagasse (g)	44.000	42.000	43.334
Weight of ash (g)	1.000	1.167	1.034
Percentage of bagasse in cane (%)	31.81	28.00	29.55
Percentage of ash in bagasse (%)	2.27	2.278	2.38

APPENDIX A5: COMPRESSIVE STRENGTH OF FACTORY SCBA MIXES

Group Title	Mix Constituents Cement Composition OPC + lime + pozzolana	Mix ratio Cement:sand	Water-Cement ratio	Specimen colour	Days of curing	Curing medium	Weight of specimen (g)	Failure load (KN)	Compressive strength (MPa)
6A	0+0, 25 + 0.75	1 : 3	0.44	dark grey	3	Water	660	2.0	0.40
							670	3.0	0.60
							680	3.0	0.60
					7		690	3.0	0.60
							680	4.0	0.80
							680	3.0	0.60
					28		680	4.0	0.80
							680	3.0	0.60
							700	4.0	0.80
6B	0+0, 20+0,80	1 : 3	0.46	dark grey	3	Water	680	2.8	0.55
							660	2.5	0.50
							680	2.3	0.45
					7		680	3.4	0.67
							670	3.0	0.60
							680	3.3	0.65
					28		680	3.5	0.70
							680	3.4	0.67
							700	3.2	0.64

APPENDIX A6: TRIAL COMPRESSIVE STRENTH TEST ON BAGASSE BURNT AT 300°C AND 400°C

Description of bagasse ash (SCBA)	SCBA:OPC Cement	Cement: sand ratio	Water-Cement ratio	Ages of specimen (days)	Specimen colour	Weight of specimens (g)	Failure load (KN)	Compressive strength (MPa)
Bagasse burnt at 300°C	20:80	1:3	0.41	3	dark grey	740	22	4.41
						730	23	4.61
						735	23	4.61
						740	22	4.41
						735	23	4.61
						740	20	4.01
						735	21	4.21
						730	22	4.41
Bagasse burnt at 400°C	20:80	1:3	0.41	3	dark grey	750	49	9.83
						760	49	9.83
						755	50	10.03
						755	47	9.43
						760	47	9.43
						750	46	9.43
						760	48	9.60
						755	48	9.60

APPENDIX A7: FINENESS TEST ON BAGASSE POWDER AND SCBA

Description	Bagasse Powder			SCBA		
	1	2	3	1	2	3
Weight of sample (g) before sieving (sieve No. 200)	320.15	332.50	315.22	345.70	330.55	338.20
Weight retained after sieving (g)	36.18	34.15	33.41	20.22	20.23	17.92
Percentage retained on sieve No. 200 (%)	11.30	10.27	10.60	5.85	6.12	5.30
Percentage passing sieve No. 200 (%)	88.70	89.73	89.40	94.15	93.88	94.70
Average percentage passing sieve No. 200 (%)	89.28			94.24		

APPENDIX A8: SPECIFIC GRAVITY DETERMINATION OF SCBA

Descriptions	Samples		
	1	2	3
Weight of pycnometer, W_1 (g)	556	556	556
Weight of pycnometer + sample, W_2 (g)	644	624	635
Weight of pycnometer + sample, W_3 (g)	1644	1630	1639
Weight of pycnometer + water, W4 (g)	1600	1600	1600
Specific gravity = $\frac{(W2 - W1)}{(W_4 - W_1) - (W_3 - W_2)}$	2.0	1.79	1.98

APPENDIX A9: POZZOLANIC ACTIVITY INDICES DETERMINATION

Mix description	28 days compressive strength (MPa)	Average strength (MPa)	PAI with cement
OPC:SCBA: sand	23.07		
1 : 0 : 3	23.48	23.07	
(control)	22.66		
1 : 0.25 : 2.5	22.07		
	21.07	21.00	91%
(test specimen)	19.86		
(lime + SCBA) : sand	7 days compressive strenth (MPa)	Average strength (MPa)	PAI with lime
(0.20 + 0.80) : 3	4.61		
	5.02	4.88	4.88
	5.02		

APPENDIX A10: SETTING TIMES OF LIME + SCBA (25+75) CEMENT

Paste	1	2
Room temperature °C	27	27
Weight of lime, 9	100	100
Weight of SCBA, 9	300	300
Start of operation (time)	8.40 am	9.10 am
Water-cement ratio (%)	44	44
Plunger penetration (mm)	5.6	5.8
Starting time (to)	8.40 a.m	9.10 a.m
Initial setting (t_1)	12.33 p.m	1.07 p.m
Initial setting time (t_1 - to)	3 hrs 53 mins	3 hrs 57 mins
Mean time	3 hrs 55 mins.	
Final setting (t_2)	3.40 p.m	4.20 p.m
Final setting time (t_2 - to)	7 hrs. 00 mins	7 hrs. 10 mins
Mean time	7 hrs. 05 mins	

APPENDIX A11: SOUNDNESS OF LIME + SCBA (25 + 75) CEMENT

Paste	1	2	3
Initial measurement (mm)	20.50	20.70	19.60
Final measurement (mm)	23.50	23.68	22.60
Expansion (mm)	3.00	2.98	3.00
Specification for OPC	$\leq$ 10 mm		

APPENDIX A12: COMPRESSIVE STRENTH RESULTS OF TEST SPECIMENS

STAGE ONE - PRELIMINARY

Group/Batch title	Mix constituents: Cement composition OPC + lime + pozz.	Mix constituents: mix ratio Cement:sand	Water Cement ratio	Specimen colour	Days of curing	Curing medium	Weight of Specimen (g)	Failure load (KN)	Compressive Strenth (MPa)
1A	1 + 0 + 0	1 : 3	0.40	light grey	3	Water	730 735 725	81 80 81	16.25 16.05 16.25
1B	1 + 0 + 0	1 : 3	0.40	light grey	7	Water	750 740 760	102 110 110	20.46 22.07 22.07
1C	1 + 0 + 0	1 : 3	0.40	light grey	28	Water	750 780 760	115 120 118	23.07 24.08 23.68
2A	0.8 + 0 + 0.2	1 : 3	0.62	light greenish grey		Water	540 520 530	1.1 0.7 0.8	0.22 0.14 0.16
						Water proof membrane	495 510 490	0.5 0.3 0.3	0.10 0.06 0.06
						Damp cloth	500 515 500	0.7 0.9 0.8	0.14 0.18 0.16
2B	0.7 + 0 + 0.3	1 : 3	0.67	light greenish grey		Water	530 550 540	1.0 1.0 0.7	0.20 0.20 0.14
						Waterproof membrane	510 520 515	0.6 0.3 0.3	0.12 0.06 0.06
						Damp cloth	520 525 525	0.8 0.9 1.0	0.16 0.18 0.20
3A	0 + 0.40 + 0.60	1 : 3	0.78	light greenish grey		Water	650 660 650	1.0 0.7 0.7	0.20 0.14 0.14

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Group title	Batch	Mix constituents: Cement composition OPC + lime + pozz.	Mix constituents: mix ratio Cement:sand	Water Cement ratio	Specimen colour	Days of curing	Curing medium	Weight of Specimen (g)	Failure load (KN)	Compressive Strenth (MPa)
	3A						Water proof membrane	640 630 625	0.2 0.4 0.3	0.04 0.08 0.06
							Damp cloth	640 650 645	0.7 0.6 0.7	0.14 0.12 0.14
	3B	0+0.33+0.67	1 : 3	0.85	light greenish grey	3	Water	640 650 650	0.5 0.6 0.6	0.10 0.12 0.12
							Waterproof membrane	635 630 630	0.3 0.2 0.3	0.06 0.04 0.06
							Damp cloth	640 640 635	0.4 0.3 0.4	0.08 0.06 0.08
	4A	0.90+0+0.10	1 : 3	0.41	dark grey	3	Water	760 760 770	80 65 76	16.05 13.04 15.25
						7	Water	770 760 765	95 100 98	19.06 20.07 19.66
						28	Water	780 780 770	102 110 110	20.46 22.07 22.07
	4B	0.80 + 0 + 0.20	1 : 3	0.41	dark grey	3	Water	760 750 755	50 47 59	10.03 9.43 11.84
						7	Water	760 760 765	70 72 64	14.04 14.45 12.84
						28	Water	770 765 780	110 95 99	22.07 19.06 19.86

APPENDIX A12: CONTINUED

Group/Batch title	Mix constituents: Cement composition OPC + lime + pozz.	Mix constituents: mix ratio Cement:sand	Water Cement ratio	Specimen colour	Days of curing	Curing medium	Weight of Specimen (g)	Failure load (KN)	Compressive Strenth (MPa)
C	0.70+0+0.30	1 : 3	0.42	dark grey	3	Water	760	34	6.82
							760	45	9.03
							765	36	7.22
					7	Water	770	64	12.84
							770	52	10.43
							775	55	11.03
					28	Water	780	95	19.06
							780	92	18.46
							770	96	19.26
D	0.75+0+0.25	1 : 3	0.42	dark grey	3		750	49	9.83
							760	38	7.62
							760	40	8.03
					7	Water	765	68	13.64
							760	55	11.03
							770	58	11.64
					28		780	100	20.06
							780	98	19.66
							775	105	21.07
E	0.60+0+0.40	1 : 3	0.43	dark grey	3		760	38	7.62
							760	29	5.82
							765	33	6.62
					7	Water	770	62	12.44
							760	53	10.63
							765	47	9.43
					28		765	80	16.05
							770	70	14.04
							765	74	14.85
F	0.50+0+0.50	1 : 3	0.44	dark grey	3		720	33	6.62
							725	29	5.82
							740	28	5.62
					7	Water	740	52	10.43
							725	42	8.43
							730	51	10.23
					28		720	62	12.44
							715	70	14.04
							720	54	10.83

APPENDIX A12: CONTINUED

Group/Batch title	Mix constituents: Cement composition OPC + lime + pozz.	Mix constituents: mix ratio Cement:sand	Water Cement ratio	Specimen colour	Days of curing	Curing medium	Weight of Specimen (g)	Failure load (KN)	Compressive Strenth (MPa)
							740	10	2.01
				dark grey	3		750	6	1.20
							745	6	1.20
5A	0+0.40+0.60	1 : 3	0.41				740	8	1.61
					7	Water	755	9	1.81
							770	9	1.81
							770	10	2.01
				lighter grey	28		765	9	1.81
							760	10	2.01
							720	9	1.81
				dark grey	3		715	8	1.61
						Water	720	6	1.20
							725	8	1.61
5B	0+0.25+0.75	1 : 3	0.42		7		730	10	2.01
							730	12	2.41
				lighter grey	28		725	9	1.81
							720	11	2.21
							720	28	5.62
				dark grey	3		725	20	4.01
							720	22	4.41
5C	0 + 0.25 + 0.75	1 : 3	0.44		7	Water	730	20	4.01
							730	24	4.82
							725	23	4.61
				lighter grey	28		740	37	7.42
							735	28	5.62
							730	29	5.82
							725	22	4.41
				dark grey	3		720	20	4.01
							720	19	3.81
5D	0+0.20+0.80	1 : 3	0.46				725	20	4.01
					7	Water	730	22	4.41
							730	20	4.01
				lighter grey	28		750	25	5.02
							730	24	4.82

APPENDIX A13 CONTINUED

Group/Batch title	Mix constituents: Cement composition OPC + lime + pozz.	Mix constituents: mix ratio Cement:sand	Water Cement ratio	Specimen colour	Days of curing	Curing medium	Weight of Specimen (g)	Failure load (KN)	Compressive Strenth (MPa)
							730	34	6.82
							725	36	7.22
							725	33	6.62
					14	Water	730	37	7.42
							730	32	6.42
							725	36	7.22
							720	30	6.02
							725	40	8.03
							720	36	7.22
							720	31	6.22
5C	0 + 0.25 + 0.75	1 : 3	0.44				730	38	7.62
							730	38	8.43
					21		735	45	7.02
							730	30	6.02
							730	37	7.42
							725	38	7.62
							735	39	7.82
							740	31	7.62
							720	33	6.62
							740	25	5.02
					28		740	38	5.02
							730	42	8.43
							730	40	8.03
				lighter grey			735	38	7.62
							740	37	7.42
							735	42	8.43
							730	40	8.03
							740	44	8.83
					60		745	43	8.63
							730	39	7.82
							730	39	7.82
							740	34	6.82