# Chemical Activation of Bagasse Ash in Cementitious System and its Impact on Strength Development

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**Summary**: The production of bagasse ash from sugar mills in a great quantity has become one of the environmental problem, but its use in cement mortar that provided a satisfactory solution to problems that associated with waste management. In this study, the effect of industrially produced quicklime on the strength development and pozzolanic reaction rates of Bagasse ash/Cementitious systems was investigated. Strength development of the Quicklime-Bagasse ash-Cement (C-BA-QL) system was monitored and presented here. Moreover, new efficiency factors were calculated for the activated systems in an attempt to seek for the optimum quicklime addition in each case. The addition of quicklime increased both the early and later strengths of the cement-bagasse ash specimens. A 3% addition of quicklime was found to be the optimum dosage for both short and longer curing periods.

## Introduction

The use of different ashes in cement at various stages has become very common nowadays in the construction sector. The quantities produced, globally are steadily increasing, however, exceeding the utilization rates in most of the countries remain low. The amounts that remain unused obviously create acute environmental problems and inhibit the path towards sustainability [1, 2]. For increasing the utilization rate of this by-product (ashes), it is not sufficient to only explore its dynamic and pozzolanic potential by using in cement mortar and concrete, but also to come up with methods of enhancing its slow action. However, this task becomes very complicated when dealing with a very heterogeneous product, where all the streams are not chemically or physically similar and the effects of each of those parameters on the hydration of Ash/Cement systems has not been completely understood yet. Bagasse is a major by-product of sugar industry which finds a very useful utilization in the same industry as an energy source. Sugarcane consists of 25-30% bagasse whereas sugar recovered by the industry is about 10%. Bagasse is also used as a raw material for paper making due to its fibrous content and about 0.3 tons of paper can be made from one ton of bagasse.

It is a fact that cement is the major construction material [3, 4]. Industrial wastes like blast furnace slag, coal fly ash, silica fumes and hazel nutshells are being used as a supplementary cement replacement material and agricultural waste like rice husk ash, wheat straw ash and bagasse ash as pozzolanic materials [5, 6]. When pozzolanic materials are added to cement, the silica ($SiO_2$) that is present in these materials reacts with free lime released during the hydration of cement and forms additional calcium silicate hydrate (CSH) as new hydration products [7] hence improve the mechanical strength of the cement mortar and concrete. The ashes produced by the burning process at incinerating temperature transform silica into amorphous phase whose reactivity is directly proportional to the specific surface area [8]. The resulted ash after pulverizing is mixed with cement.

A number of activation techniques have been adopted by researchers to deal with ashes shortcomings including prolonged grinding [9], curing at elevated temperatures [10] and chemical activation [11, 12]. The principal aim of all these attempts was to enhance the reactivity of the pozzolan, to improve the mechanical and durability properties of the final product. However, the efficiency of some of these methods is debatable since others are too energy demanding, or failed because of a simple cost-benefit analysis.

The objective of the present work is to evaluate the bagasse ash as supplementary cementitious material and its activation by chemical method using industrially produced quicklime. The reactivity of the ash has been enhanced chemically way using quick lime in order to improve the mechanical and durability properties of the final product to recycle more bagasse ash in cement mortars and concrete.

**Results and Discussion**

(Fig. 1) shows the compressive strength of results of all constructed systems plotted against hydration time. It is clear from the figure that both a 3% and 6% bagasse ash replacement by quicklime slightly enhanced the compressive strength of the initial bagasse ash mortar, from the early period of hardening. However, the specimen with no cement replacement (control) outperformed all bagasse ash mortars (with or without activator) during the first week of hydration. It seems that the addition of lime in the matrix cannot compensate for the cement loss during that stage. From the first week to onwards, the bagasse ash specimens are approaching the value of the control and even exceed it (at 28 days), as a result of the evolution of their pozzolanic action. When bagasse ash replacement by quicklime increased to 6%, the strength of the activated mortar was higher than that of the control specimen at all ages, but slightly diminished compared to the values attained with less lime addition. This is an indication that addition of lime must be limited to 3% only. From the above results, it can be deduced that 3% lime is the optimum content both for short and longer curing periods. It is possible that a small offer of lime fully employed the available amorphous silica from the bagasse ash, to form additional cementitious compounds, prevailing pozzolanic C-S-H. It has been observed [13, 14], that in the presence of $Ca(OH)_2$, the solubility of $SiO_2$ increases notably, indicate that as the hydration progresses, greater quantities of soluble silica are released from the reacted bagasse ash particles into the matrix [15]. This accounts for the improved strengths of activated high-calcium ash observed at later ages. During the early stages of hydration, added lime works alternatively to enhance the strength of the system. Lime addition and its subsequent formation to $Ca(OH)_2$, results in a higher basicity inside the matrix. The increase in pH leads to the corrosion of the densified outer layer of bagasse ash particles [9], leaving more active cores exposed for reacting forming additional hydration products. An additional explanation for the improved early age strengths observed in lime-activated bagasse ash systems, is the formation of flocs inside the matrix due to lime hydration. It has been observed [13] that these flocs reduce the effective voids, and hence the interconnectivity of the pores, leading to a denser microstructure.

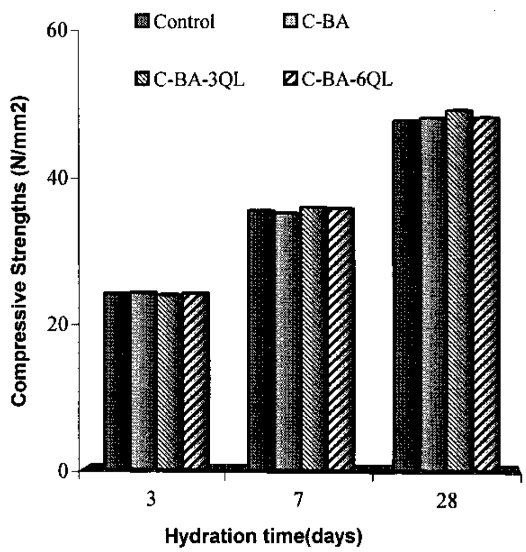


Fig. 1: Compressive strength of the Quicklime-activated Bagasse Ash mortars.

*Efficiency Factors*

Procedure described by Papadakis *et. al.*, [10] was followed for estimating the k-values. Briefly, in the case of mortars and concrete that incorporate supplementary cementing materials, the k-value derives from the following expression for the compressive strength (fc) measured for the constructed systems:

$$f_c = K\left(\frac{1}{W/(C+kP)}\right)$$

where, K is a parameter depending on the cement type (here 388 MPa),
C = cement contents in the mortar ($kg/m^3$)
P = bagasse ash contents in the mortar ($kg/m^3$),
W = water content ($Kg/m^3$)

In the frame of this study, where a small replacement of bagasse ash by quicklime took place, P was considered as the sum of bagasse ash and quicklime in each blend. Applying in the above equation the measured values of the compressive strength, the k-values for the activated systems were calculated and presented in Table-3. The k-values are below unity during the early ages and they progressively exceeds, as the hydration procedure evolved. This means that up to a certain level, those ashes could substitute for cement. For a similar pozzolan addition (20% by weight of cement), all samples with bagasse ash have a k-value less than 1 at 3 days, but afterwards as bagasse ash is involved in the pozzolanic reactions, they reach unity.

## Experimental

### *Materials*

The chemical composition of cement and bagasse ash used for blending is shown in Table-1 [16, 17]. Cement used for this purpose was high strength Portland cement meeting the Pakistan standard specification PS: 232-1983 (R). Commercial quicklime of high purity was used as the activator. The sand used in this study was 100% pass through 850 μm and 10% pass through 600 μm sieve, according to Pakistan standard specification.

Mill fired bagasse ash was collected from Premier Sugar Mill Mardan (PSM), Khazana Sugar Mill Peshawar (KSM) and Frontier Sugar Mill Thaktbhai Mardan (FSM). Parameters of the ash are represented in Table-2 [16, 17]. The samples were collected randomly from the heaps present in the yard of the sugar mills, and carried to the laboratory in polyethylene. Bagasse ash was black in color due to the high amount of carbon content. The mill fired bagasse ash was further burnt under controlled temperature at 65 °C for one hour. The burning process brought down the carbon content to 4.5%. After cooling the ash was ground before, it was used as a cement replacement material.

Table-1: Chemical Composition of Cement and Bagasse ash [16, 17].

| Material | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | $SO_3$ |
|---|---|---|---|---|---|---|---|---|
| Cement | 21.55 | 5.69 | 3.39 | 64.25 | 0.85 | 0.33 | 0.59 | 2.47 |
| Bagasse Ash | 87.40 | 3.60 | 4.90 | 2.56 | 0.69 | 0.15 | 0.47 | 0.11 |

Table-2: Physical parameters of Bagasse ash [16, 17].

| Moisture (%) | Ash (%) | Loss on Ignition (%) | Calorific value (kcal/kg) | Fineness passing 50μm sieve |
|---|---|---|---|---|
| 2.93 | 86.69 | 8.45 | 50 | 50 |

Table-3: Efficiency factors (k-values) for cement-bagasse ash and cement-activated bagasse ash mortars.

| Material | k-values | | |
|---|---|---|---|
| | 3 days | 7 days | 28 days |
| C-BA | 0.67 | 0.92 | 0.98 |
| C-BA-3QL | 0.69 | 0.97 | 1.00 |
| C-BA-6QL | 0.69 | 0.95 | 0.95 |

### *Blends Construction*

In order to incapacitate the effect of fineness on the performance of bagasse ash used, the raw ashes were ground before use in a lab mill, so as to obtain ashes of similar fineness. The particle size distribution of the ground bagasse ash determined by passing through sieves of different pore sizes is presented in (Fig. 2), which indicates the absence of any significant differences in their final granulometry. Equal amount of bagasse ash was replaced from the mix with the addition of quicklime. The activated blends were named according to the quantity of quick lime, for example C-BA-3QL and C-BA-6QL corresponds for the specimen containing 3% and 6% quick lime, respectively. One blend containing no bagasse ash was named as C-BA, and one without quick lime and bagasse ash as control.

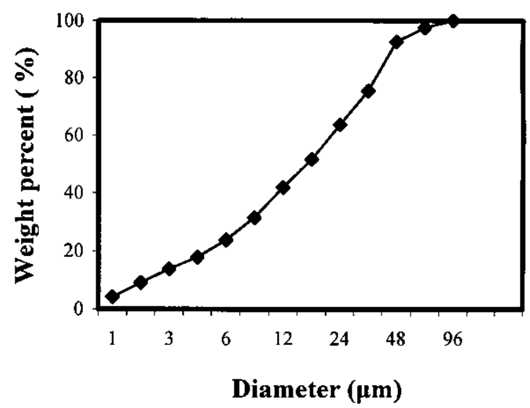


Fig. 2: Particle size distribution of ground bagasse ashes.

### *Determination of Compressive Strength*

For studying the effect of compressive strength of the blend mortar mixes were prepared by adopting a cementitious to sand ratio of 1:3. Blended cement containing bagasse ash was mixed with water at water to cement ratio of 0.45 (v/w). The constructed blends were used to substitute 20% by weight of cement in all mortars. For every blend, three moulds were made for triplicate reading and the mean value has been reported. Keeping the w/b ratio constant, cement mortar without any ash or quicklime was prepared as the control and one with ash but without bagasse (C-BA). The blends were sufficiently mixed in dry and wet condition for four minutes, and were cast in to mould of 40 mm x 40 mm x 40 mm using a vibrating machine with a normal speed 1200 round/minute for 120 seconds in order to get compact cubes. The temperature of the mixing room was kept at 20 ± 2 C° and relative humidity of 65%. The molded samples were placed in the moist curing chamber for 24 h at a temperature of 20 ± 1 C° and relative humidity of 90%. After 24 h the specimens were stripped from their moulds and were placed in water curing tank having a temperature of 20 ± 1 C° until testing. A Toni tecknik compressive strength machine with a load cell of 0-300 KN and a loading rate of 2.4 KN / sec was used for the compressive strength. The compressive strength of the specimens was measured according to British standard specifications BS 196-1 and Pakistan standard specification PS 232-1983 (R), after 3, 7 and 28 days from the mixing date. The corresponding pastes were prepared using a similar procedure, adopting the same w/b ratio and curing under water, in order to monitor the hydration process of the bagasse ash-cement-quicklime systems. For each age three specimens of every mixture were tested and the mean value of these measurements is reported.

*Efficiency Factors*

The concept of the efficiency factor or simpler k-value has been introduced as a way to predict the effect of bagasse ash on the compressive strength of Portland cement systems that incorporate them. In other words, the efficiency factor is defined as the part of the bagasse ash, which can be considered as equivalent to high strength Portland cement, having the same properties as the mortar without bagasse ash (obviously k = 1 for Portland cement) [18]. In this work, the efficiency factors were determined in order to draw conclusions regarding the effectiveness of each activation dosage applied.

## Conclusion

Addition of quicklime in Bagasse Ash-Cement systems is an effective, relatively cheap and environmental friendly way to accelerate the degree of bagasse ash reaction. Since, in this work quicklime actually replaced bagasse ash and was not additionally added in the mix, the loss of active silica due to bagasse ash replacement, was critical in the final performance of the newly constructed activated blends. Obviously, when quicklime is added separately in the mix, a more drastic effect is expected.

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