Development of Local Bagasse Ash as Pozzolanic Material for Use in Concrete

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Abstract

Concrete is one of the extensively used materials in construction industry. General construction uses ordinary Portland cement, however for specialized projects specific properties of concrete are tailored using different pozzolans. Sugarcane bagasse ash is abundantly available in Pakistan as being obtained from sugar mills which uses sugarcane bagasse as fuel. This research is focused to determine the maximum pozzolanic activity of sugarcane bagasse ash. Raw bagasse ash was calcined at temperatures of 500, 600 and 700 degree Celsius for 1, 2 and 3 hours heating duration. ASTM C 618 and C 311 were used to determine the suitability of sugarcane bagasse ash for its pozzolanic activity. It was found that maximum pozzolanic activity is achieved at a temperature of 500 degree Celsius for 1 hour heating duration and same was verified by X-ray diffraction analysis of calcined sugarcane bagasse ash.

Key Words: Bagasse ash; Strength activity index; X-ray diffraction analysis

1. Introduction

Pozzolans are the mineral admixtures which are employed in development of high performance and more durable concrete. Pozzolans are either natural or artificial containing silica in amorphous form. The pozzolans have little or no cementitious value by itself however they react chemically with alkalis present in presence of water thus contributing to improvement in strength and other properties of concrete [1].Production of cement is energy extensive process which consumes natural resources and causes global warming. Silica fume, fly ash and rice husk ash are popular mineral admixtures which are by-products of industrial and agro-industrial processes. Research works have indicated that inclusion of these pozzolanic materials not only improves the strength and durability of concrete but are also helpful in reducing global warming through disposal of waste material [2].

Pakistan is an agricultural country and its economy is dependent on agriculture. It is considered among those countries which are largest producer of sugarcane in terms of acreage [3]. Sugar industries operate their boiler by burning sugarcane bagasse at uncontrolled temperature. Sugarcane bagasse ash (SCBA) is obtained after using sugarcane bagasse as a fuel, resulting into non-usable material that is dumped in landfills and open streams thus causing environmental pollution. The use of sugarcane bagasse ash as partial replacement of cement not only improves the compressive strength of concrete but also improves the durability of concrete by reducing shrinkage and permeability [4].

Sugarcane bagasse is burnt at temperature range of 1000 - 1200°C which produces raw bagasse ash. However bagasse ashes obtained from different sources have influence on the optimum calcination temperature and heating duration regime to obtain ash of maximum reactivity [4]. Bagasse ash produced by calcinating raw bagasse ash at fixed temperature of 650°C for one hour improves the durability of concrete when replaced with cement and is also beneficial to protect the rebar from corrosion [5,6]. High amorphous silica contents are obtained when raw bagasse ash is air calcined at 600 °C for 3 hours with a rate of heating of 10 °C/min [7]. Inclusion of bagasse ash as cement replacement also helps in increasing the setting time, lowering the heat evolved during hydration and improving the ductility of concrete [8, 9, 10].

The literature review indicates that production of bagasse ash for its maximum pozzolanic activity depends on calcination temperature and heating duration. The different sources of bagasse has influence on calcination temperature and heating duration. In this study a single source of bagasse ash is used in order to determine its maximum pozzolanic activity.

2. Materials and Methods

The physical and chemical properties of materials used in this study are as follows,

2.1 Cement

Ordinary Portland cement conforming ASTM C 150 Type – I was used in the study. The physical properties of cement are given in Table 1.

Table 1 Physical Properties of Cement

Property	Cement
Density	3.14
Fineness	330 m^2/kg
Initial Setting Time	125 min
Final Setting Time	170 min
Water required for standard Consistency	25.4 %

Source: Researcher Laboratory Experiment, Civil Engineering Department, U.E.T Lahore.

2.2 Raw Bagasse Ash

The raw bagasse ash obtained from Patoki sugar mill Punjab province of Pakistan, was dry and black in color with average silica contents of 54.3%. Gravimetric wet chemistry analysis was used to determine the chemical composition of cement and raw bagasse ash is as given in Table 2. The chemical composition of raw bagasse ash conforms to ASTM C 618.

2.3 Fine Aggregates

Standard graded natural silica sand was used as fine aggregate conforming ASTM C 33. Fineness modulus of fine aggregates was 2.42, with water absorption of 0.79%.

Table 2 Chemical Composition of Cement and Raw Bagasse Ash

Compound	Cement (%)	Raw SCBA (%)
SiO_2	19.19	54.3
Al_2O_3	5.16	3.31
Fe_2O_3	3.32	1.2
CaO	62.1	4.87
MgO	2.1	2.98
SO_3	2.14	0.99
LOI	3.94	15.71

Source: Courtesy of Technology Upgradation and Skill Development Company (TUSDEC) for Chemical analysis of samples provided by the Researcher.

2.4 Test Procedure

The procedure for determination of maximum pozzolanic activity is given by ASTM C 618 and ASTM C 311. ASTM C 618 contains both chemical and physical requirements for any material to be used as a pozzolans. The chemical analysis of raw bagasse ash categories it into Class N pozzolan as per Table 1 of ASTM C 618. The physical requirements contains number of tests for qualification of material to be used as pozzolan.

Strength activity index (SAI) is the main consideration among physical tests. The qualification of this test can be followed by other physical tests specially autoclave expansion test for suitability of any material to be used as pozzolan. To determine the strength activity index ASTM C 311 procedure was followed. Bagasse ash was burnt in a temperature and duration controlled digital electric furnace for three temperature ranges (500, 600 and 700°C) at three durations (1, 2 and 3 hours) for each temperature range. Temperature and duration for thermal incineration process was selected on the bases of literature review. Samples of raw bagasse ash was placed inside the furnace in a mud bowl to resist the high temperature without breaking. After cooling the bagasse ash samples to room temperature, specimens were passed through sieve No. 200 and sealed in air tight moisture repellent polythene bags with labels. The complete detail of experimentation is given in Table 3.

Table 3 Mortar Mixture Proportion for determination of SAI

Mixture ID	CT (°C)	HD (Hrs)	Cement (gms)	SCBA (gms)	W/B	Sand (gms)
A	--	--	500	--	0.49	1375
B	500	1	400	100	0.49	1375
C	500	2	400	100	0.49	1375
D	500	3	400	100	0.49	1375
E	600	1	400	100	0.49	1375
F	600	2	400	100	0.49	1375
G	600	3	400	100	0.49	1375
H	700	1	400	100	0.49	1375
I	700	2	400	100	0.49	1375
J	700	3	400	100	0.49	1375
K	--	--	400	--	0.49	1475*

Source: Researcher Laboratory Experiment, Civil Engineering Department, U.E.T Lahore.

*To makeup filler effect of bagasse ash, CT = Calcination Temperature, HD = Heating Duration, SCBA = Sugarcane Bagasse Ash

Six mortar cubes of size 50 mm were cast for each set of mixture. Based on compressive strength of mortar mixtures with respect to control mixture strength activity index (SAI) of each mixture was determined at age of 7 and 28 days in accordance with ASTM C 311. The normal consistency of neat cement paste was obtained at 25.4% while normal consistency of cement with 20% replacement of bagasse ash was obtained at 33.0% in accordance with ASTM C 187.

Mortar cube samples were de-molded after 24 hours of casting and were water cured till the testing date at a temperature of 23 ± 2°C. Compressive strength of mortar cube samples was determined after 7 and 28 days under uni-axial compression testing machine of 300 tons capacity. Average of three specimens was taken for determination of strength activity index. X-ray diffraction (XRD) analysis was carried on fine powdered bagasse ash samples to observe the peaks of various constituent materials.

3. Results and Discussion

The results are discussed as follows,

3.1 Strength Activity Index (SAI)

Strength activity index is an effective tool for measurement of pozzolanic activity of any pozzolan. It is ratio of average compressive strength of test specimen to average compressive strength of control specimen at same age. The strength activity index

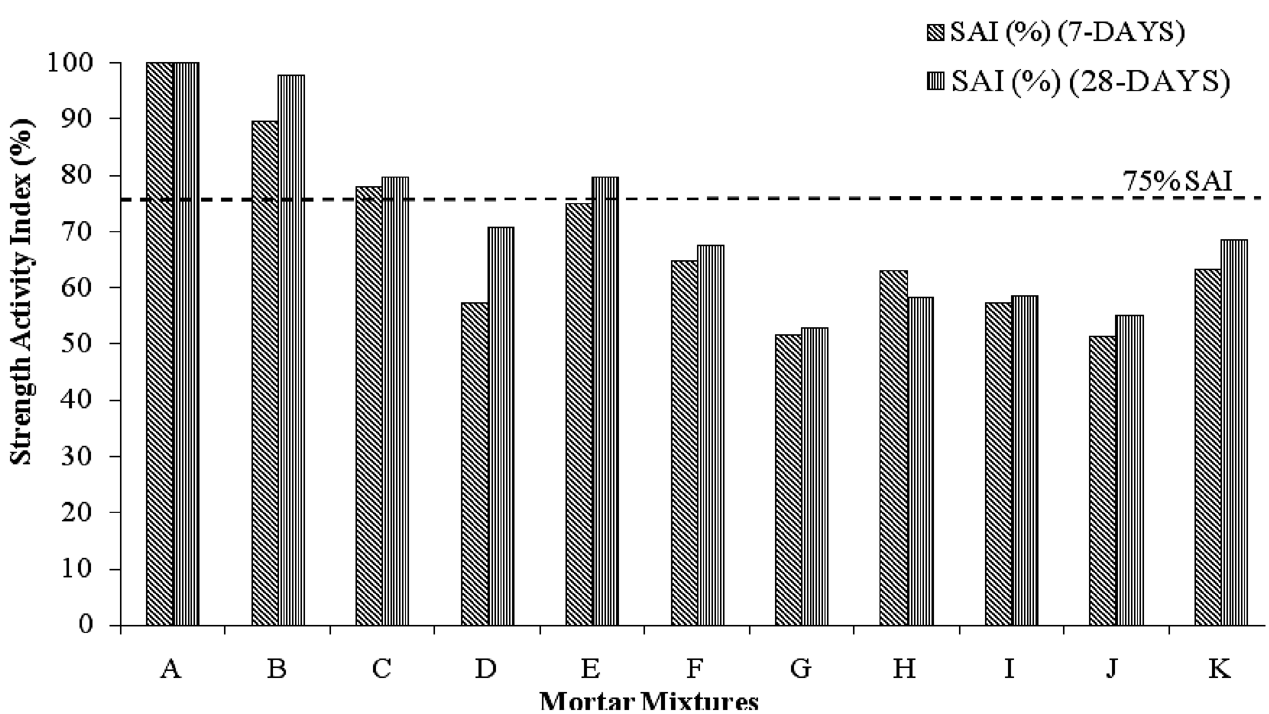

Fig 1 Strength activity index (%) for mortar mixtures at 7 and 28 days

was determined based on 7 and 28 days compressive strength results obtained as per ASTM C 109. Figure 1 graphically presents the strength activity index at 7 and 28 days age. Highest strength activity index is observed for sample “B” containing bagasse ash burnt at 500°C for 1 hour heating duration at both 7 and 28 days age. Mixture “C” and “E” also attained the minimum requirement of 75 % SAI as per ASTM C 618, while other samples showed poor results. Mixtures “G”, “H”, “I” and “J” exhibited lower SAI value compared with mortar mixture “K” containing sand as cement replacement, which indicates that in mixture G, H, I and J contains silica in crystalline state and hence acting as filler material.

3.2 Confirmation by X-Ray Diffraction Analysis

X-ray diffraction analysis was carried out on the samples of fine powdered bagasse ash samples and peaks of various constituent materials were observed. Results of XRD analysis were used to verify the results of strength activity index. Silica peak pattern was observed in XRD results for bagasse ash calcined at different temperatures and durations. Figure 2 – 4 presents the peak count for bagasse ash burnt at 500°C, 600°C and 700°C for 1, 2 and 3 hours respectively. **S**ilica is the main constituent imparting the pozzolanic activity in all pozzolanic materials. Round peaks of silica were observed for samples calcined at 500°C thus representing the amorphous state of bagasse ash; however, sharp peak of quartz were observed for bagasse ash samples calcined at 600 & 700°C indicating crystallization of bagasse ash. Hence X-ray diffraction analysis results also corroborate the findings of experimental work.

3.3 Chemical Properties of Calcined Bagasse Ash

Based on the experimental results, the chemical analysis of bagasse ash calcined at 500°C for 1 hour

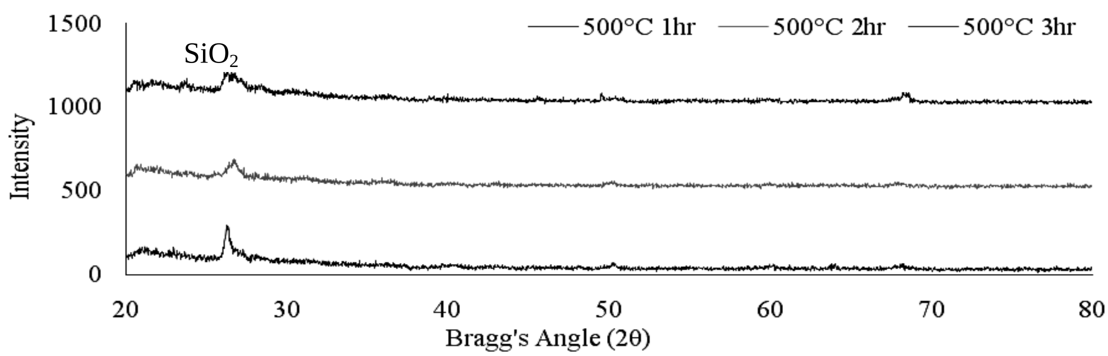

Fig 2 XRD analysis for thermally activated bagasse ash at 500°C for 1, 2, 3 hours

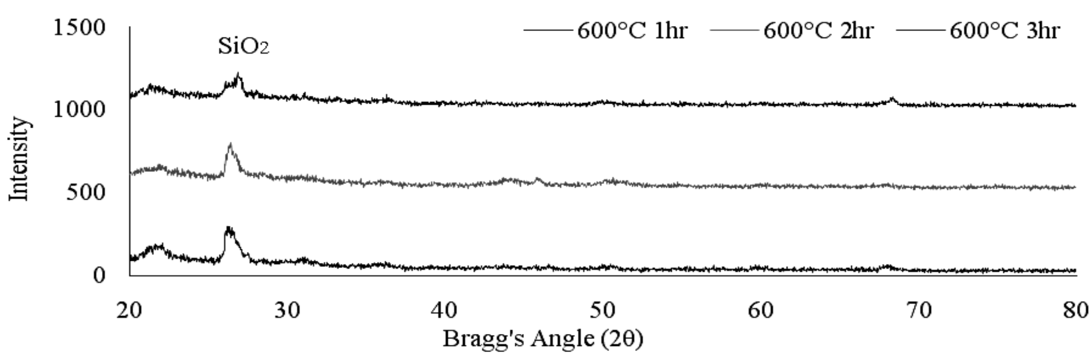

Fig 3 XRD analysis for thermally activated bagasse ash at 600°C for 1, 2, 3 hours

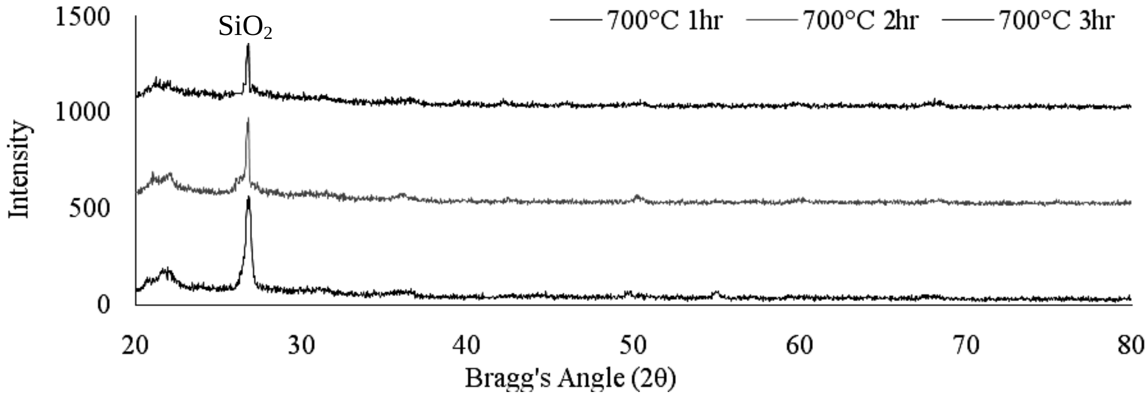

Fig 4 XRD analysis for thermally activated bagasse ash at 700°C for 1, 2, 3 hours

Table 4 Chemical Composition of Sugarcane Bagasse Ash burnt at 500°C for 1 hour

Compound	SCBA Burnt at 500°C for 1 hour (%)
SiO_2	67.82
Al_2O_3	1.72
Fe_2O_3	1.07
CaO	4.14
MgO	2.08
SO_3	0.51
LOI	6.32

Source: Courtesy of Technology Upgradation and Skill Development Company (TUSDEC) for Chemical analysis of samples provided by the Researcher.

The addition of SiO_2, Al_2O_3, and Fe_2O_3 is more than 70%, thus conforming to Class N pozzolan as per ASTM C 618 requirement. Results of chemical analysis are presented in Table 4.

3.4 Fineness, Water Requirement and Density

Fineness, water requirement, density and other physical properties of bagasse ash sample burnt at 500°C for 1 hour heating duration was determined in accordance with ASTM C 311 and are given in Table 5. Fineness, water demand and density are found to be within specified limits as mentioned in Table 2 of ASTM C 618.

Table 5 Physical Properties Bagasse Ash burnt at 500°C for 1 hour

Property	SCBA Burnt at 500°C for 1 hour (%)
Density	2.75
Color	Grey
Fineness	Residue on Sieve No. 325 (45μm) = 13.3 % Residue on Sieve No. 170 (90μm) = 9.36 %
Moisture Content	2.7 %
Initial Setting Time	150 min
Final Setting Time	245 min
Water Requirement, percent of control	115.7 %

Source: Researcher Laboratory Experiment, Civil Engineering Department, U.E.T Lahore.

3.5 Autoclave Expansion Test

The ability of the hardened paste to retain its volume is called soundness. Excessive amount of hard burned lime and magnesia causes the delayed destructive expansion or lack of soundness. ASTM C 151 provides standard test method for determination of autoclave expansion of Portland cement. Autoclave expansion test was performed on bagasse ash cement paste sample and by replacing cement with 20% bagasse ash. For control specimen autoclave expansion value was 0.1850% while for sample containing 20% bagasse ash the value decreased by 53.1%. The net value for both the samples is well below the upper limit of ASTM C 618.

Table 6 Autoclave expansion test results

Mixture Detail	Average Autoclave Expansion (%)
Control Sample	0.1850
Cement + 20% Bagasse ash	0.0869

4. Conclusions

Based on the experimental results following conclusions have been drawn.

1. Bagasse ash obtained from Patoki sugar mill can be converted to highly reactive pozzolan by calcining it at 500°C for one hour.
2. The chemical analysis of bagasse ash calcined at 500°C for one hour categorizes it as class-N pozzolan.
3. Inclusion of reactive bagasse ash increases water demand of the mixture.
4. X-ray diffraction analysis clearly indicates that bagasse ash obtained from Patoki sugar mill crystallizes above 600°C.

5. Acknowledgements

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