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Determination of Pozzolanic Activity of Buffalo Dung Ash to Utilize as Cement Replacement Material in Concrete

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ABSTRACT

Increasing construction activity around the globe has raised the demand for cement to 4.4 giga-tonnes/year, making it costlier, and its consumption second to water. Meanwhile, a tonne of clinker produces a tonne of CO_2 on a large consumption of natural resources of raw materials and energy of 10–11 EJ/year, which is why an affordable and environmentally sustainable substitute for cement is needed today. Pakistan possesses more than 30 million buffalos. Each can produce up to 15 kg of dung per day, resulting in 450 million kg of dung produced in Pakistan alone. This research aims to investigate the pozzolanic activity of Buffalo dung ash and determine the optimum conditions for developing the ash, along with the optimum dosage as cement replacing material in Normal concrete. For this purpose, five buffalo dung ash samples were prepared by calcining the dung in a muffle furnace for a 1-hour duration at 400°C, 500°C, 600°C, 700°C, and 800°C, and after cooling, sieving through a No. 100 sieve. The Strength Activity Index was determined as per ASTM C311. The results showed that developed ash at 600°C has a maximum Strength Activity Index of 94.2%, meeting the ASTM C618 standards for pozzolanic material, which was further confirmed by X-ray Fluorescence analysis. Furthermore, when 5%, 10%, 15%, and 20% of this ash were used as cement substitutes in concrete, the compressive strength increased by 11.2% on 10% substitution compared to the control mix. Based on the parameters investigated, it was found optimal to replace 10% of the cement in the concrete with buffalo dung calcined at 600°C for 1 hour.

Keywords: Buffalo Dung ash; Pozzolanic activity; XRF; cement replacement material

INTRODUCTION

Concrete is the most widely used man-made construction material due to its various advantages. The main ingredient of concrete is Portland cement, which is used as a binder. The increase in construction activity around the globe has raised the demand for cement to 4.4 giga-tonnes per year, making it costlier, and its consumption second to water. Meanwhile, a tonne of clinker produces a tonne of CO_2 (Mehta 2001). The cement industry is thought to be responsible for about 10% of total CO_2 gas emissions, during the manufacturing of cement, resulting in global warming (Suhendro 2014). The demand for energy to reach a high temperature of around 1400°C to 1500°C during the manufacturing of cement has also increased to 10–11 EJ annually, which is approximately 2–3% of global primary energy use (Mehwish Asad et al. 2013). Another drawback of cement is that it depletes natural resources like clay and limestone at an alarming rate because of the building industry's constant need for cement as the main binder ingredient (Bux 2020). Therefore, researchers around the world attempt to determine the potential of various affordable and environmentally sustainable substitutes for cement that can replace Portland cement in concrete partially or completely, to decrease the consumption of cement.

By primarily generating milk, buffalos are contributing significantly to Pakistan's national economy. Around 68% of the nation's total milk production comes from buffalo (M Q Bilal 2006). Pakistan possesses more than 30 million heads of buffalos only for milking. Each can produce up to 15 kg of dung per day, resulting in 450 million kg of dung produced in Pakistan alone (BETA PAK). In Pakistan, Buffalo dung has not any major use. Massive amounts of air-polluting gases including ammonia, nitrous oxide, hydrogen sulphide, and most critically, carbon dioxide and methane, are produced when fresh buffalo excrement and oxygen in the air mix. Studies have shown that people who live close to factory farms are more likely to have chronic asthma, lung inflammation, immune system suppression, and even mental problems. Significant concentrations of these toxic gases can be lethal. The problem of global warming due to these gases is another matter of concern. The livestock sector contributes 14.5% to global GHG emissions (FAO).

Therefore, in this research, to determine the possible usage of B.D.A in concrete, cleansing the environment due to the generation of the large quantity of B.D.A, to improve the properties of concrete economically, and to decrease CO_2 content to some extent, an attempt is made to investigate the Pozzolanic activity of B.D.A and determine the optimum conditions for developing the ash, along with the optimum dosage as cement replacing material in Normal concrete.

Different research has been conducted previously on the usage of different types of industrial, agricultural ashes in concrete, but no research has been conducted to investigate the cementitious properties of B.D.A and optimum conditions to develop it. Some of the research on cattle manure mainly, cow dung ash, are discussed here, which is used as a reference.

B. Veera Narayana et al. (2020) analyzed CDA's pozzolanic activity and identified the strength characteristics of cow dung ash concrete. The compressive strength of concrete cubes and tensile strength of cylinders rose by 16.33% and 17%, respectively, at 15% replacement, and concrete behaved well against sulphate and acid assaults, in comparison to control mix, when cement replacement was made at 5%, 10%, 15%, and 20% by weight. Consequently, it was advised to replace cement in concrete with 15% CDA. P. Thej Kumar et al. (2015) determined the pozzolanic activity of CDA using the strength activity index using CDA and observed SAI of 78.21% at 7 days of curing, which was higher than the minimum requirement of 75%, and thus conclusions were made that CDA is pozzolanic. Vasu.K (2019) attempted to determine the usage of cow dung ash in concrete. The CDA burned at 450°C to 500°C, and the ash was sieved through a 300-micron sieve (#50) and used to cement in concrete by 5%, 10%, 15%, and 20% by weight of cement. The cubical strength of concrete showed that it increased by 12% on 10% replacement. Based on these results, a 10% replacement of cement with CDA was recommended. Inderveer Singh Gurjar et al. (2015) in their research analyzed the performance of concrete when cement is replaced partially by dried Rise husk ash burned at 450°C – 500°C and cow dung ash burned at 450°C – 600°C in equal proportions. Both ashes were sieved through a 150-micron (#100) sieve and used in a proportion of 5% to 25% as partial replacement of cement in concrete and observed the enhanced compressive strength by 30% at 5% replacement. Thus, 5% of #100 sieved CDA burned at 400 to 600°C was found to be optimum. C Venkatasubramanian et al. (2017) attempted to utilize cow dung ash and coconut fibers in the concrete. Cow dung ash was used to replace cement, whereas coconut fibers were used to improve the strength of concrete. The cow dung ash was obtained by burning dried cow dung cakes at 450°C to 500°C and sieved through a 150-micron (#100) sieve. The finely chopped coconut fibers were obtained from the local market with a size of less than 1 cm. The 150 mm cubes and 150 mm x 300 mm cylinders were cast for 7, 14, and 28 days of curing at 2.5%, 3%, and 3.5% of CDA replacing cement by weight of cement, with 1% of coconut fibers. The results of the modified concrete were compared with the Normal cement concrete M-25. According to the findings of compressive strength and indirect tensile strength tests, the replacement of 3.5% of CDA enhanced the modified concrete's compressive strength by about 77.2% and 75.5%, and its tensile strength by approximately 46%. Thus, it was concluded that 3.5% of CDA with 1% of coconut fibers have a positive effect on the properties of concrete.

MATERIALS AND METHODS

MATERIALS

Ordinary Portland Cement (OPC), Lucky Brand, is used in this research project and is claimed by the company to confirm to ASTM C150 type I. Various physical properties of OPC are shown in Tale 1. The fine aggregates for concrete were obtained from Bolar, a place in Thatha Sindh, and the coarse aggregates were obtained from Nooriabad crushing plant with a Nominal maximum size of 19.5mm, conforming to ASTM C33. The physical properties of aggregates are shown in Table 2. Clean natural sand that had gone through sieve number 30 and been retained on sieve number 60 was utilised in the mortar, as per ASTM C311. Buffalo dung used is of a single buffalo and a single source and is obtained from a cattle farm in Qasimabad, Hyderabad, Sindh. The chemical composition of optimized buffalo dung ash is shown in Table 5 presented in the result and discussion section. Ordinary drinking water is used throughout experimental work

TABLE 1. Physical Properties of Ordinary Portland Cement

Properties	Results
Fineness	94%
Consistency	0.32
IST	50 minutes
FST	7 hours and 50 minutes
Soundness	5 mm
Sp. gravity	3.15

TABLE 2. Physical Properties of Aggregates

Properties	Fine-Aggregates	Coarse-Aggregates
Fineness Modulus	3.08	-
Sp. gravity	2.65	2.58
Loose Bulk-density (Kg/m^3)	1833	1447
Compacted Bulk-density (Kg/m^3)	1942	1646
Water Absorption (%)	2.04	1.17

RESEARCH METHODOLOGY

For this research, first of all, five buffalo dung ash samples were prepared by calcining dried and crushed buffalo dung in a muffle furnace at various temperatures of 400^{o}C, 500 ^{o}C, 600 ^{o}C, 700 ^{o}C, and 800 ^{o}C for 1 hour, respectively, as shown in Figure 1. These five different buffalo dung ash samples, after cooling for 24 hours, were sieved through #100 (150 microns) and stored in air-tight containers.

Afterwards, mortar specimens of 2 in. (50 mm) were prepared, as shown in figure 2, for the control mix as well as by replacing 20% of the cement with all B.D.A sample was burned earlier at five different temperatures, by weight, according to ASTM C 311. The mortar mixes were developed with a sand-to-binding material ratio (S/B) of 2.75:1 and a water-to-binding material ratio (W/B) of 0.485. Clean natural sand that had gone through sieve number 30 and been retained on sieve number 60 was the sand that was utilized to make the mortar cubes. Mix details are shown in Table 3. ASTM C305, ASTM C10, and ASTM C109 were used for mixing,

compaction, and molding, respectively. Three specimens were cast and tested for Compressive strength for each curing age (i.e. 7 and 28 days) and replacement (i.e. 20%).

FIGURE 1. Preparation of Buffalo Dung ash in Muffle Furnace

TABLE 3. Mix Proportion for Mortar Cubes for Compressive strength and SAI test

Mix ID	Binder Content (%)		Amount of Material required for Six cubes				
	Cement	B.D.A	Cement	B.D.A	Sand	W/B ratio	Water
C.M	100 %	0%	500 g	0 g	1375 g	0.485	242 g
M-400	80 %	20%	400 g	100 g	1375 g	0.485	242 g
M-500	80 %	20%	400 g	100 g	1375 g	0.485	242 g
M-600	80 %	20%	400 g	100 g	1375 g	0.485	242 g
M-700	80 %	20%	400 g	100 g	1375 g	0.485	242 g
M-800	80 %	20%	400 g	100 g	1375 g	0.485	242 g

FIGURE 2. Preparation of Mortar Specimen

On the 7 and 28 days of curing, the compressive strength of mortar cubes and the Strength Activity Index (S.A.I.) which is the percentage ratio of the strength of mortar cubes prepared with 20 percent replacement of cement by weight with B.D.A to the strength of control-mix, were performed. The S.A.I test was carried out according to ASTM C311/C311M – 18.

$$S.A.I = \frac{M}{C.M} \times 100$$

Where, M = modified mix Compressive strength and C.M is Control mix compressive strength, at 7 or 28 curing days respectively.

The strength activity index test is performed to assess whether the cement replacing the material is pozzolanic or not, or to determine whether the pozzolana will result in an acceptable degree of strength development when used in concrete or not. Based on the results of S.A.I, the pozzolanic properties were confirmed, as per ASTM C618, and optimum burning conditions for preparation of B.D.A were chosen and corresponding sample was called as Optimized Buffalo Dung ash, whose composition is also confirmed by XRF test.

The optimized B.D.A is than utilized to prepare the 100mm x 100mm x 100mm concrete cubes, as cement replacement material in the dosage of 5, 10, 15, and 20% by weight of total binder content, to determine its effect in Concrete. The mix design of the concrete is shown in Table 4.

RESULTS AND DISCUSSION

COMPRESSIVE STRENGTH OF MORTAR CUBES

Compressive strength tests on mortar cubes were performed to examine the reactivity of BDA, as shown in figure 3. Testing was done on the samples following wet curing, at the ages of 7 and 28 days, according to ASTM C109. The results are shown in Figure 4. The results show that the compressive strength of all mortar cubes containing B.D.A was lowered as compared to the control mix, due to the higher content of B.D.A replacement, but strength is being increased with the burning temperature up to 600^{o}C, which is attributed to the pozzolanic reaction caused by the presence of reactive silica in amorphous in B.D.A. The results show that the pozzolanic reaction is increased with temperature, but there is a sudden decline in strength on the further increasing temperature of burning which can be attributed to the presence of crystalline silica on burning temperatures of 700°C and 800°C which decreases the pozzolanic reaction (Suhail Zaffar et. al.). It is clear from experimental results of the compressive strength of mortar cubes that BDA calcinated at 600°C for 1 hr has maximum compressive strength as compared to other samples containing BDA

TABLE 4. Mix Proportions for Concrete

Mix ID	Binder Content (%)		Quantity				
	Cement	B.D.A	Cement	B.D.A	F.A	C.A	Water
M-0	100 %	0%	366 Kg/m³	0 Kg/m³	734.5 Kg/m³	1101. Kg/m³	197.7 Kg/m³
M-5	95 %	5%	347.7 Kg/m³	18.3 Kg/m³	734.5 Kg/m³	1101. Kg/m³	197.7 Kg/m³
M-10	90 %	10%	329.4 Kg/m³	36.6 Kg/m³	734.5 Kg/m³	1101. Kg/m³	197.7 Kg/m³
M-15	85 %	15%	311.1 Kg/m³	54.9 Kg/m³	734.5 Kg/m³	1101. Kg/m³	197.7 Kg/m³
M-20	80 %	20%	292.8 Kg/m³	73.2 Kg/m³	734.5 Kg/m³	1101. Kg/m³	197.7 Kg/m³

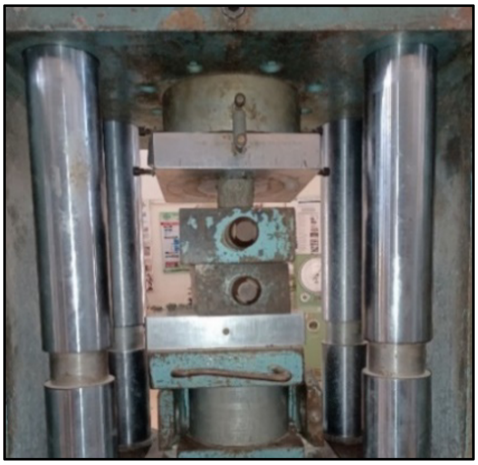

FIGURE 3. Experimental Setup for Compressive Strength of Mortar Cubes

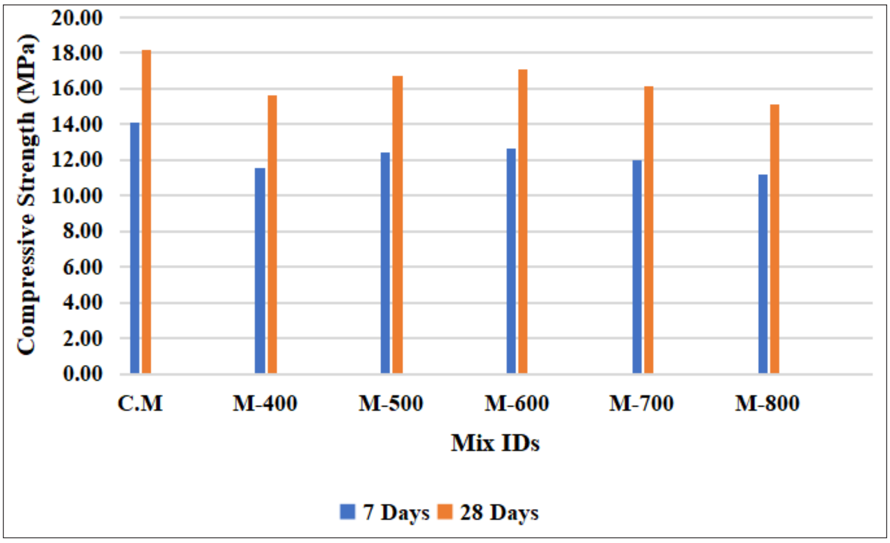

FIGURE 4. Compressive Strength of Mortar Cubes at 7 and 28 Days

STRENGTH ACTIVITY INDEX (SAI)

The results of SAI as presented in figure 5, clearly indicates that BDA the SAI is increasing up to 600°C due to pozzolanic reaction with reactive amorphous silica present in the B.D.A, which is increasing with burning temperature. The SAI then drops on further increase in temperature due to the presence of silica in Crystalline form which is decreasing the pozzolanic reaction (Suhail Zaffar et. al.). The S.A.I presented figure 5, which clearly shows that for all mortar mix, the S.A.I is greater than 75 %, i.e. minimum to be used as pozzolanic material in concrete, as per ASTM C 618, but for M-600 mix, that is prepared with replacing cement with B.D.A (600 °C @ 1hr), the S.A.I am 89.7% and 94.2%, which is much higher than 75% and S.A.I of all other mixes (other than C.M.), which shows the presence of the highest amount of reactive silica at this burning temperature (Suhail Zaffar et. al.). Thus, it is concluded that B.D.A produced by burning B.D.A at 600 °C for 1hr, termed as optimized buffalo dung ash, has higher pozzolanic activity than other samples.

CHEMICAL ANALYSIS OF OPTIMIZED B.D.A

The chemical analysis of buffalo dung ash calcinated at 600°C for 1 hour is also performed to confirm its pozzolanic properties, as shown below in table 5. According to ASTM C 618, a pozzolanic material must include at least 70% of $SiO_2 + Al2O_3 + Fe_2O_3$. Here the XRF study of Buffalo dung ash produced at 600°C showed that it has $SiO_2 + Al2O_3 + Fe_2O_3$ equal to 71.61%, as shown in Table 5. As a result, BDA's chemical composition justifies its usage in concrete per ASTM C-618 because it meets the requirements for pozzolanic material.

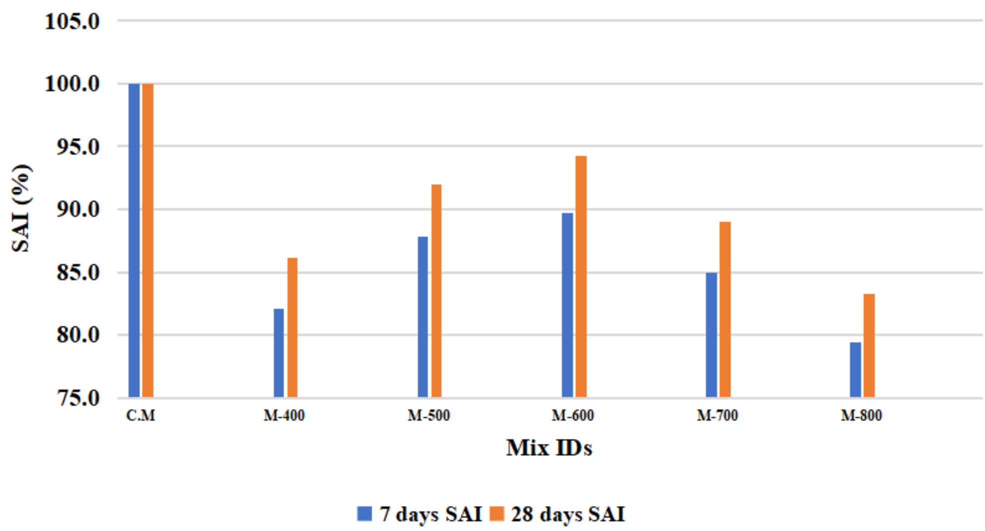

FIGURE 5. SAI of Specimen at 7 and 28 days of curing

TABLE 5. Chemical Analysis of Optimized Buffalo Dung ash using XRF test

Constituents	% Wt. Chemical Composition
SiO_2	58.72
CaO	7.53
Fe_2O_3	3.32
MgO	5.05
Al_2O_3	9.57
Na_2O	0.67
K_2O	1.2
P_2O_5	6.59
TiO_2	0.28

COMPRESSIVE STRENGTH OF CONCRETE CUBES

The results of the compressive strength of concrete cubed investigated at 7 and 28 days of curing as presented below in Figure 6, which indicates that the optimized buffalo dung ash is also useful in improving the compressive strength of concrete maximum by 11.2% at 10% replacement in concrete. The increasing trend up to 10% replacement is due to an increase in the content of secondary CSH gel, due to a pozzolanic reaction caused by B.D.A, but a decline in strength on a further increase of B.D.A in concrete is caused by a decrease of CSH get produced from the hydration of cement which pozzolanic reaction of B.D.A could not be compensated.

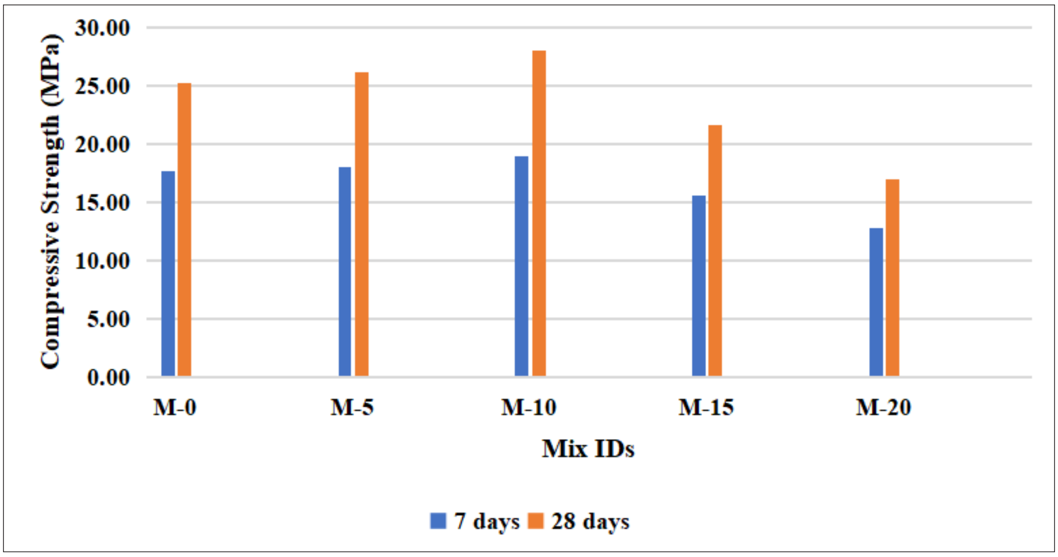

FIGURE 6. Compressive Strength of Concrete Cubes at 7 and 28 Days

CONCLUSIONS

Based on the outcomes obtained from experimental work, the following conclusions can be made:

1. The S.A.I test showed that all samples of Buffalo dung calcinated from 400°C to 800°C, at an interval of 100°C, has S.A.I greater than 75%, indicating that it can be used in concrete as a pozzolana, as per ASTM C618.

2. The buffalo dung ash calcinated at 600°C for 1 hour has a maximum Strength activity index, thus burning temperature of 600°C with a burning duration of 1 hr are optimum conditions to produce highly pozzolanic (Optimized) BDA.

3. The chemical analysis of optimized buffalo dung ash also suggests that it is a pozzolanic material, as per ASTM C618.

4. Optimized buffalo dung ash in concrete as a 10% replacement of cement improves the compressive strength of concrete by 11.2%.

5. Conclusively, Buffalo dung ash developed at 600°C with a heating duration of 1 hr is recommended to replace the 10% cement in Normal concrete.

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DECLARATION OF COMPETING INTEREST

None

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