

OPTIMIZING COW DUNG ASH FOR USE AS A SUSTAINABLE
POZZOLAN IN CEMENTSuhail Zaffar^{*1}, Aneel Kumar², Abdullah Saand³, Naeem Aziz⁴

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Abstract

This study was conducted to determine the optimal conditions for producing pozzolanic ashes from cow dung for use as cement substitute materials. When the cow dung is turned into ash, it develops a pozzolanic character due to the presence of silica. However, the transformation of silica from amorphous to crystalline and its associated pozzolanic reactivity depends on the calcination temperature, duration, and grinding. In this research the Cow dung were calcined at three different calcination temperatures (300°C, 400°C, and 800°C) for 2-, 4-, 6- and 8-hours duration. The obtained ashes were ground for 30 minutes and replaced by 20% with cement. The samples containing ashes were tested for compressive strength, X-ray diffractometry (XRD), weight loss, and strength activity index (SAI). It was observed that the CDA, the most favorable calcination condition in terms of strength development was obtained at 600°C for 6 hours duration. The highest SAI was achieved for the mortar samples containing CDA calcinated at 600°C for 6 hours duration (CDA600-6H). The materials ground for the higher duration is recommended for higher SAI.

Introduction

Within the construction industry, concrete is consumed more than any other material, and its usage keeps growing steadily [1]. The main ingredient required in the production of concrete is cement. The production of cement clinker is responsible for the release of 8-10% of CO₂ in the environment [2], [3]. Overall, the construction industry is reported to be responsible for CO₂ emissions greater than 20% in the environment. Since the production of cement is an energy-intensive process, the substitution of supplementary cementitious material (SCM)

becomes a promising way to produce alternative binding material for the construction industry [4], [5]. In addition, the disposal of untreated waste materials from industries and agricultural lands in open-air landfills has always been an environmental concern [6]. Further, the availability of land for dumping waste is getting limited with time. This leads to the discharge of waste materials into rivers and lakes or burnt in the open air which causes air pollution as well as health hazards [2]. Utilizing such waste materials rich in silica extend the range of building materials

to be used as cement's substitute and can solve the ecological problems [6], [7].

In past, several studies have been conducted to investigate the use of industrial by-products and agricultural wastes as a partial alternative to cement [5], [8], [9]. The most used industrial by-products as an alternative to cement are reported to be fly ash, slag, and silica fume [10], [11]. In addition, different agricultural wastes in the form of ash are also widely used in concrete as CRM [12]-[14]. Generally, the common practice for the disposal of agricultural wastes is open-air burning [2]. This open-air burning process not only emits harmful gases but also fades cementitious properties which restrict its use as CRM in the production of cementitious material [6]. In this regard, incineration of agro-wastes in a controlled condition is a promising method to reduce environmental pollution and retain the material properties.

Sahan and Aydin [9] reported the highest strength up to 10 % substitution of RHA cement. Chandra et al., [5] also observed the highest strength development rate at 10% replacement. Overall, the optimum replacement of RHA is selected in the range of 10-20% [15]. The enhanced strength is due to the availability of amorphous silica which increase pozzolanic performance [16], [17].

In recent years, the utilization of CDA in concrete is also explored due to the presence of pozzolanic properties [23]. Sirri et al., [24] observed the increase in strength by utilizing CDA up to 15%. Ramachandran et al., [23] also reported the better strength and higher durability by utilizing CDA as cement's substitute. To the authors' best knowledge, limited studies are reported on CDA to be used as potential substitute to cement. Furthermore, the calcination temperature and the calcination duration for CDA containing highly reactive silica is still novel and yet to be explored.

Methodology

Materials

Type I ordinary Portland cement (OPC) conforming ASTM C150 [25] specifications were utilized in the research. the cement was obtained

from a locally available materials supplier in the vicinity of Jamshoro. Natural hill sand passing from the #30 sieve and retained at the #60 sieve was utilized for the preparation of mortar samples. Cow Dung was collected from cow farms located in the Jamshoro region. It was collected in dry form and crushed into a smaller size to obtain uniform calcination.

Calcination of Ashes

The cow dung used in the research were subjected to heat treatment, to convert into ashes. The heating was given in an electric muffle furnace. To obtain cow dung ash (CDA), the heating was performed at 300°C, 600°C, and 800°C for 2-, 4-, 6- and 8-hours durations. After heating required temperature and duration the sample was allowed to cool in the open air. All the obtained ashes were ground in the ball mill for 30 minutes and sieved from the #200 sieve.

Sample Preparation

The mortar samples of size 50 mm³ were prepared by substituting 20% of the activated ashes by weight of the cement. The sample was prepared using a cement to a sand ratio of 1:2.75 and the water-to-cement ratio was kept constant at 0.49 (ASTM C 311) [26]. The detail of mortar mixes is presented in Table 1. The nomenclature for mixes is adopted in such a way that it signifies the type of ash used in a mortar mix. For example, the control mix denotes a mix containing only cement without ashes. CDA300-2H, CDA300-4H, CDA300-6H, and CDA300-8H signify Cow dung ash calcinated at 300°C for 2, 4, 6, and 8 hours. CDA600-2H, CDA600-4H, CDA600-6H, and CDA600-8H signify cow dung ash calcinated at 600°C for 2, 4, 6, and 8 hours. CDA800-2H, CDA800-4H, CDA800-6H, and CDA800-8H signify cow dung ash calcinated at 800°C for 2, 4, 6, and 8 hours. The mixing, compaction, and molding of mortar specimens were performed following ASTM C305 [27] and ASTM C109 [28] guidelines. The samples were demolded after 24 hours and left for 28 days of water curing.

Table 1: Mix Details

Mix No.	Mix ID	Cement	Sand	CDA	w/b
A	Control (Cement)	1	2.75	-	0.49
B	CDA300-2H	0.80	2.75	0.20	0.49
C	CDA300-4H	0.80	2.75	0.20	0.49
D	CDA300-6H	0.80	2.75	0.20	0.49
E	CDA300-8H	0.80	2.75	0.20	0.49
F	CDA600-2H	0.80	2.75	0.20	0.49
G	CDA600-4H	0.80	2.75	0.20	0.49
H	CDA600-6H	0.80	2.75	0.20	0.49
I	CDA600-8H	0.80	2.75	0.20	0.49
J	CDA800-2H	0.80	2.75	0.20	0.49
K	CDA800-4H	0.80	2.75	0.20	0.49
L	CDA800-6H	0.80	2.75	0.20	0.49
M	CDA800-8H	0.80	2.75	0.20	0.49

Testing

X-ray diffraction analysis

Mineralogical analysis on CDA samples calcined at 300, 600, and 800 °C was performed by X-ray diffractometry with a copper tube and a nickel filter.

The compressive strength of the 50 mm mortar cube at 28 days of moist curing was determined following ASTM C109-21 standard [28]. The pozzolanic activity of the ash samples at different calcination temperatures was examined as per ASTM C618 specification [29].

The strength activity Index (SAI) was determined on cubes at 28 days of curing by replacing 20% cement with a weight of the ash. SAI was then calculated as per ASTM C311 [26] using the following formula: $SAI = (A/B) \times 100$, where A = average compressive strength of ash blended cubes, MPa (psi), and B = average compressive strength of control mix cubes, MPa (psi).

Results and Discussion

X-ray diffraction analysis of CDA at different duration and calcination temperatures

The XRD pattern of CDA at different calcination temperatures and duration is shown in Figure 1.

Figure 1a shows the calcination of CDA at 300°C for 2, 4, 6, and 8 hours. The sharp peaks of crystalline quartz were identified at $2\theta = 26^\circ$ and 45° . the increase in the burning duration increases the crystallinity in the material. The formation of a new crystalline quartz peak was observed at $2\theta = 21.6^\circ$ at 300°C calcination for 8 hours. In Figure 1b, the silica present is in an amorphous state. However, peaks at $2\theta = 26^\circ$ and 45° were identified which shows the presence of crystalline silica. Similarly, calcination at 800°C at different duration also showed the presence of strong peaks of crystalline silica in the CDA. This shows that at the higher temperature the material is transformed into a crystalline phase from the amorphous phase. The findings are consistent with Patel et al [31]. Based on the XRD patterns shown in Figure 1(a-c), the amorphous silica in CDA is identified at the 600°C calcination temperature for 6 hours.

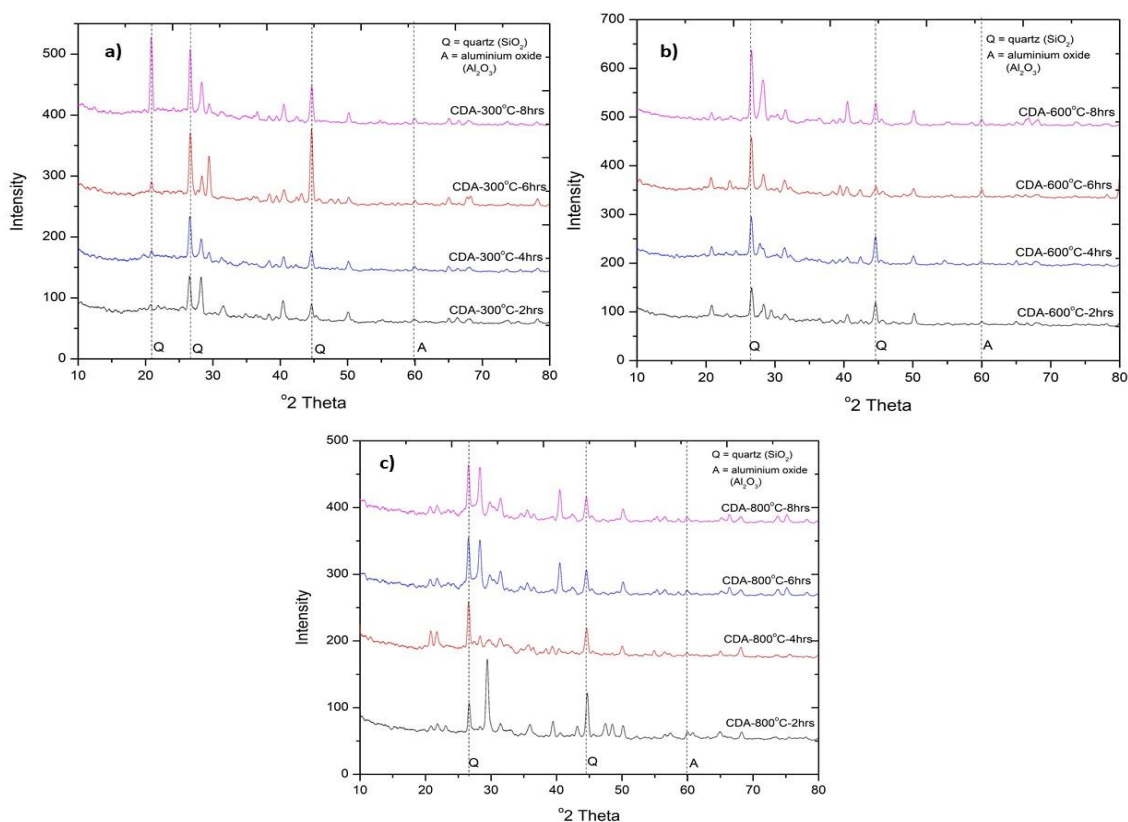


Figure 1: XRD pattern of rice CDA calcinated at a) 300°C b) 600°C and c) 800°C

Compressive Strength and Strength Activity Index

Compressive Strength CDA

The mortar samples containing 600oC calcinated CDA showed better strength development compared to other temperatures and duration. At this temperature, the strength gain was recorded up to 6 hours of calcination duration. The increase in strength was observed as 10%, and 15% compared to CDA600-2H. Further calcination caused a drop in strength up to 8% compared to mix CDA600-6H. The decline in strength was due to the phase transformation of silica elements present in the material. CDA calcinated at 600oC for 6 hours depicted the highest compressive strength compared to other calcination temperatures at different durations. The strength was recorded as 19.8 MPa which is 5% lower than the control mix.

CDA calcinated at 600°C and 800°C for 4 hours duration presented the identical compressive strength. Compared to RHA and WSA samples, the performance of CDA as cement replacement material in terms of compressive strength was exceptional. The significant rise in strength was due to higher pozzolanic reactivity, which is attributed to the presence of highly reactive silica. This is also evident from the XRD pattern shown in Figure 3b. Calcination of CDA at higher temperatures for higher duration results in lower compressive strength. The decline in compressive strength is attributed to the formation of crystalline silica at higher temperatures. It can be concluded that the optimum calcination temperature of 600°C is required to obtain high reactive CDA when calcinated for 6 hours.

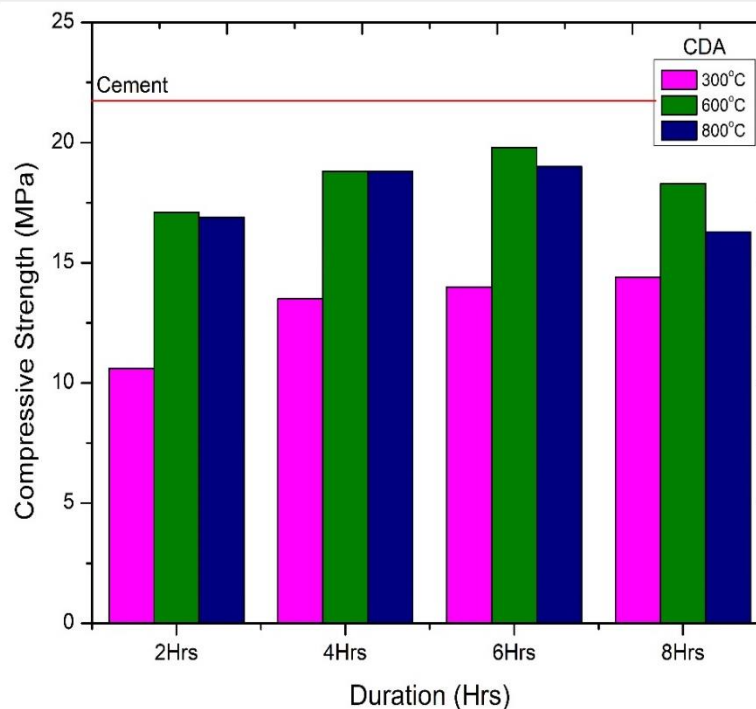


Figure 2: Compressive strength behavior of CDA paste at different incineration temperatures

Strength Activity Index

Strength activity index (SAI) or pozzolanic activity index (PAI) is one of the most important tests which measures the compressive strength development rate of mixtures containing pozzolans. Figure 3 shows the SAI of CDA calcined at different temperatures for different duration when used as a 20% substitute by weight of the cement. According to ASTM C618, the material can classify as pozzolan when its SAI is equal to or greater than 75%. This means that the

mortar mix containing pozzolan should have the compressive strength equal to or greater than 75% of the control mix at 28 days. It can be noted that all the mixes containing CDA calcinated at 600°C and 800°C for 2, 4, 6, and 8 hours qualified as pozzolanic material. The highest SAI was achieved for the mortar sample containing CDA calcinated at 600°C for 6 hours duration (CDA600-6H). This was due to the presence of reactive silica in the amorphous form.

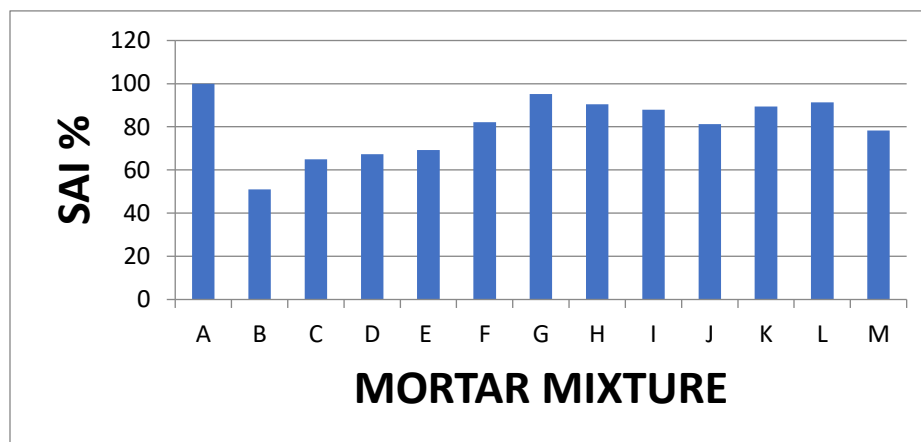


Figure 3: SAI of CDA at different incineration temperatures

Weight Loss

Weight loss is an important parameter in terms of obtained mass to be used as a substitute for cement after calcination. The weight loss of CDA subjected to different calcination temperatures

and durations are shown in Figure 8. The increase in weight loss was observed with the increase in calcination temperature. The highest weight loss 78% was obtained during Eight hours at 800°C calcination temperature for CDA.

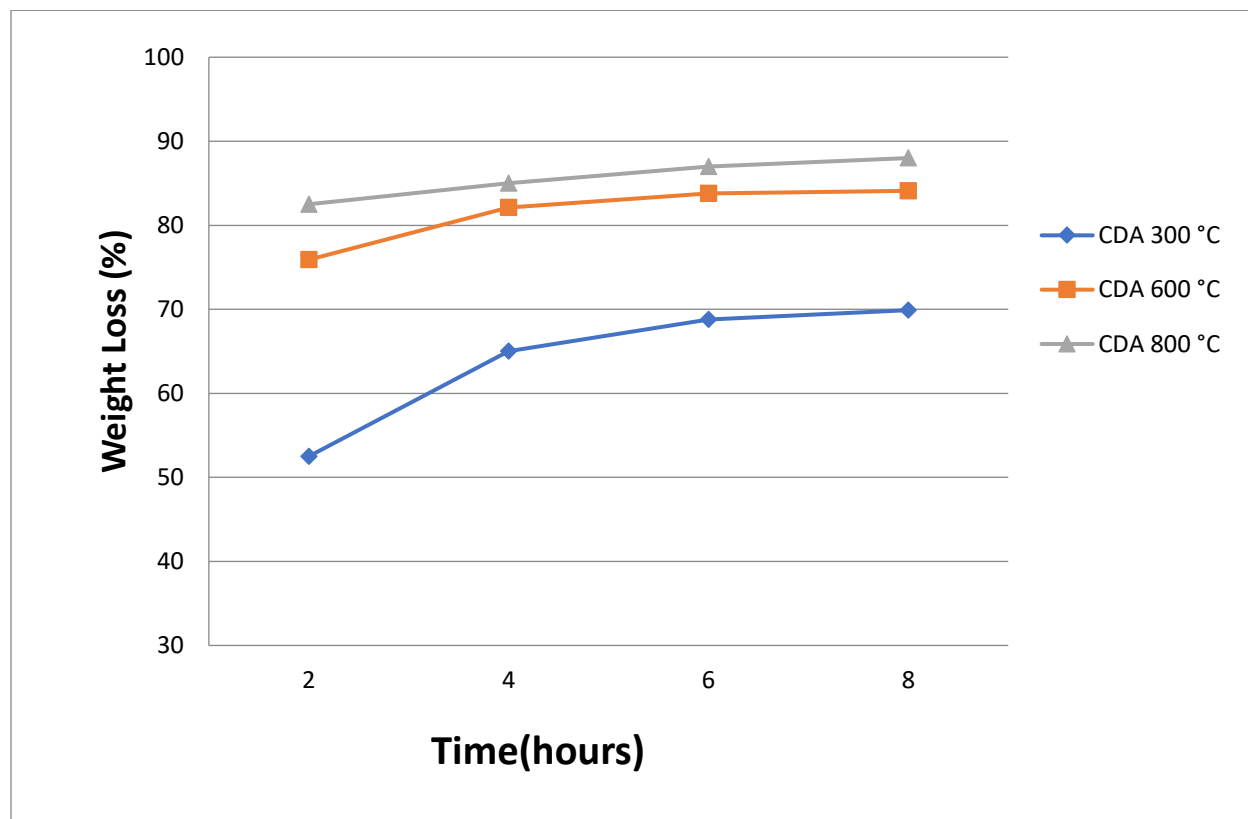


Figure 4: SAI of CDA at different incineration temperatures

Conclusion

This research was conducted to evaluate the optimum conditions for obtaining different ashes that can be used as a partial substitute to cement. In this research CDA were considered as potential partial cement replacing materials. The prime focus was to find the optimum calcination temperature and duration to obtain highly reactive CDA to be used in cement-based materials. The ashes were prepared at controlled burning temperatures of 300°C, 600°C, and 800°C for 2, 4, 6, and 8-hours duration. Based on the experimental results, the following findings are drawn.

- Based on the XRD patterns the silica was presented in the amorphous state when

CDA were calcinated at 600°C. The optimum calcination duration for producing good quality CDA was recorded as 6 hours.

- The highest compressive strength was obtained for mix (CDA600-6H) containing calcinated CDA at 600°C for 6 hours.
- The highest SAI was achieved for the mortar samples containing CDA calcinated at 600°C for 6 hours duration (CDA600-6H).
- The increase in weight loss was observed with the increase in a calcination temperature.

The highest weight loss 78% was obtained during Eight hours at 800°C calcination temperature for CDA.

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