

# Mechanical, Mineralogical and Durability Properties of Pulverized Pond Ash Based Concrete

Yuvaraj KANDASAMY<sup>1\*</sup>, Vidhya KUMARASAMY<sup>2</sup>, Pradeep THIRUMOORTHY<sup>3</sup>, Sakthivel MURUGAN<sup>4</sup>, Ramesh SUBRAMANI<sup>1</sup>

<sup>1</sup> Department of Civil Engineering, K.S. Rangasamy College of Technology, Tiruchengode, Namakkal, 637 215, India

<sup>2</sup> Department of Civil Engineering, Mahendra Engineering College, Mallasamudram, Namakkal, 637 503, India

<sup>3</sup> Department of Civil Engineering, Kongu Engineering College, Perundurai, Erode, 638 060, India

<sup>4</sup> Department of Civil Engineering, Kongunadu College of Engineering and Technology, Tholurpatti, Trichy, 621 215, India

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In recent decades, cement production and demand have significantly impacted the environment; enormous amounts of energy are required to produce cement. This led to a severe energy crisis in our country. In order to minimize the usage of cement and energy consumption in an eco-friendly manner, industrial waste materials with cementitious characteristics are drawn to attention. Hence, the study deals with the use of pulverized pond ash as a partial replacement for cement in concrete. The mix design was carried out for M 25 grade concrete by IS 10262-2019. Two significant mix proportions were prepared, namely, Conventional Concrete (CC) (100 % cement), and Pulverized Pond Ash Concrete (PPAC) (90 % cement and 10% pulverized pond ash). In this study, cylinder compressive strength, mineralogical analysis, sulphate resistance tests, sorptivity, and water absorption, were examined. The PPAC mix outperformed CC in compressive strength by 10.74 %, 13.09 %, and 13.66 % at 28, 56, and 90 days, respectively. At 28 days, ettringite peaks are minor, with both intensity and quantity increasing significantly by 56 and 90 days. The PPAC also showed higher residual compressive strength (1.08 %, 1.65 %, 2.32 %) and lower sorptivity (8.93 %, 10.14 %, 12.5 %) than CC at all ages. From the results, PPAC showed superior properties than CC at all ages suggesting for replacement of 10 % of cement with pond ash.

**Keywords:** pulverized pond ash, hardened concrete, mineralogical studies, durability concrete.

## 1. INTRODUCTION

Concrete is the man-made and most popular artificial building material for constructing various types of buildings [1, 2]. The importance of concrete in the construction industry has grown consistently over the years [3]. An increase in concrete consumption leads to the depletion of its resources. i.e., cement and crushed stone. [4]. Besides, cement is an expensive component of concrete; its production leads to economic fall [5]. The cement industry also contributes significantly to CO<sub>2</sub> emissions in the environment [6–8]. CO<sub>2</sub> emissions negatively impact climate change and lead to global warming [9, 10]. For the production of high strength concrete, cement in large volume is required, which is an energy-intensive process in the concrete manufacturing industry [11, 12]. Hence, an alternative to cement ought to be proposed to minimize its production and, thereby the environment [13, 14].

Agricultural wastes, namely, rice husk ash [15], palm kernel shells [16], sugar cane bagasse ash, and rice husk ash [17], and industrial wastes such as fly ash [18], blast furnace slag, metakaolin [19] and coal bottom ash [20], Copper slag [21, 22], coal pond ash has been attempted as a partial replacement for cement [23]. The cement replaced materials were found to decrease the cost of concrete as well as environmental pollution [24, 25]. Fly ash is typically extracted from flue gases through electrostatic precipitation

or cyclone separation. It has been utilized as a source of valuable metals and in various applications, including as a mineral admixture in concrete, road pavement construction, and brick manufacturing. In this study, pond ash has been partially substituted for cement. Pond ash is composed of fly ash and bottom ash, or a mixture of both, which is usually blended with soil and re-vegetated once the pond is full. The amount of pond ash in landfills needs to be alleviated [26, 27]. The properties of pond ash vary depending on the coal type, burning conditions, and wet storage time conditions [28].

Fly ash and Bottom ash could also be used as replacement material in mortars and concretes [29–31]. However, little research has been attempted on pond ash as a concrete binder constituent. The mechanical and durability of pond ash concrete, including its cube compressive, split tensile, flexural, acid attack, and chloride resistance tests were earlier studied [32]. However, in this study, the strength, mineralogical, and durability, of concrete were analyzed, when 10% pond ash was replaced with cement.

## 2. MATERIALS

### 2.1. Cement

Ordinary Portland Cement (OPC) of 53 grade is a binding material and its parameters are in accordance with IS 12269-1987. The chemical constituents of OPC were

\* Corresponding author. Tel.: +91-6369716179.  
E-mail: [yuvarajk@ksrct.ac.in](mailto:yuvarajk@ksrct.ac.in) (Y.Kandasamy)

identified using JSX-1000S XRF spectrometers with X-Ray Fluorescence (XRF). The chemical constituents of the OPC was presented in Fig. 1. Calcium oxide (CaO), Silicon dioxide (SiO<sub>2</sub>) and Aluminum oxide (Al<sub>2</sub>O<sub>3</sub>) were predominant elements in OPC. SEM image of OPC is shown in Fig. 2, where the particles have an angular structure with sharp edges. The XRD pattern for OPC is shown in Fig. 3, where the composition showed Alite (C<sub>3</sub>S) and Belite (C<sub>2</sub>S) as the principal elements.

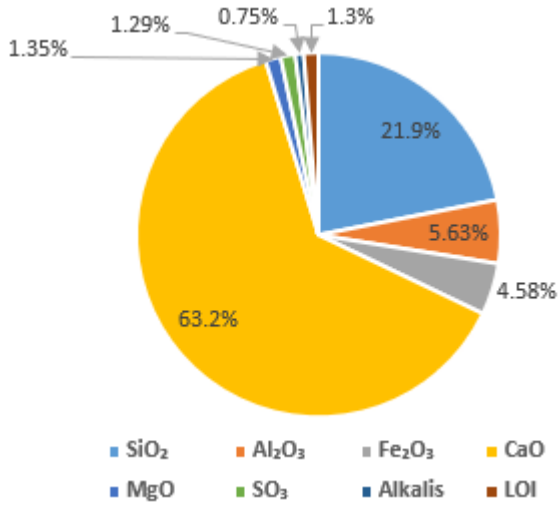


Fig. 1. Chemical constituents of ordinary Portland cement identified by x-ray fluorescence

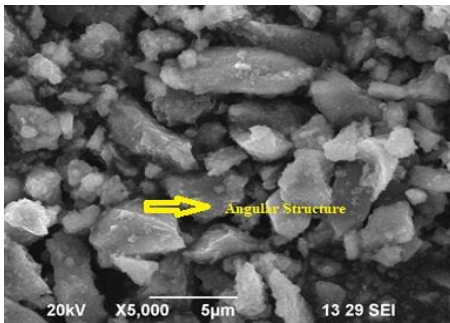


Fig. 2. Scanning electron microscopy (SEM) image of ordinary Portland cement

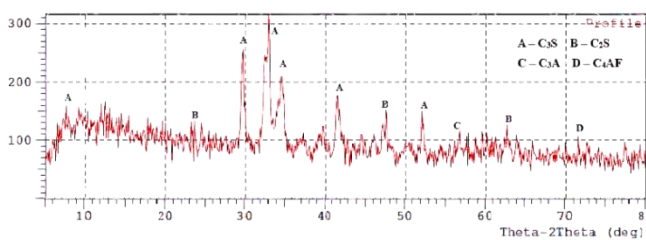


Fig. 3. X-ray diffraction pattern of ordinary Portland cement

## 2.2. Pond ash

Pond ash is a by-product of the combustion of pulverized coal. A total of 400 kg of wet pond ash was obtained from the Thermal Power Station, Mettur, Tamil Nadu, India. The pond ash was dried for 48 hours at ambient temperature and sieved at 300 microns to remove all coarse particles. To reduce the particle size to 45 microns, the pond ash was ground using a pulverizer machine (rotation speed

of 960 rpm). The specific area and specific gravity of Pulverized Pond Ash (PPA) were found to be 398 m<sup>2</sup>/kg and 2.17 respectively. The chemical constituents of the PPA are shown in Fig. 4, in which silicon dioxide (SiO<sub>2</sub>) and Aluminum oxide (Al<sub>2</sub>O<sub>3</sub>) were the predominant elements. PPA showed the broken hollow cenosphere of the pond transformed into angular fragments (Fig. 5). The most prominent crystalline phase is quartz, followed by mullite and magnetite (Fig. 6).

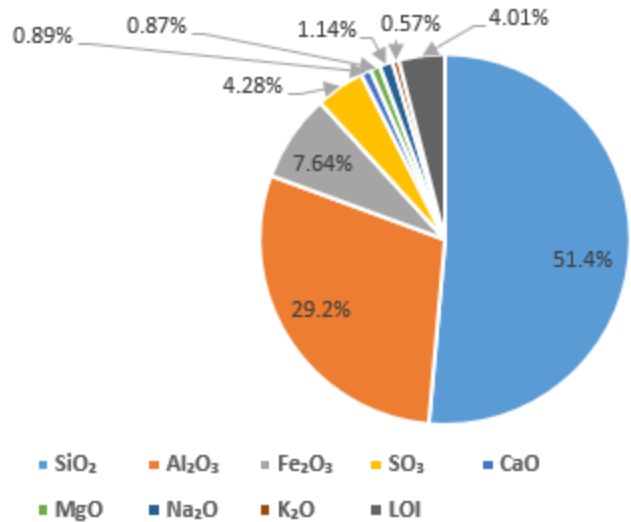


Fig. 4. Chemical constituents of pulverized pond ash

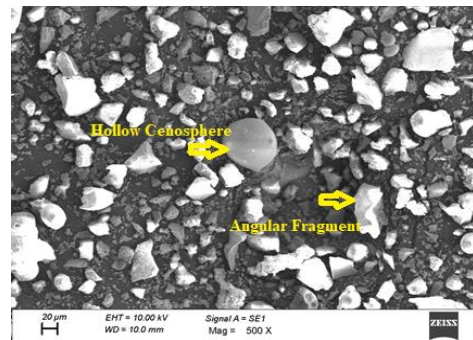


Fig. 5. SEM image of pulverized pond ash

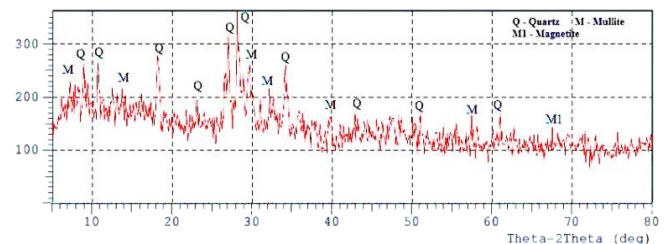


Fig. 6. XRD Image of pulverized pond ash

## 2.3. Fine and coarse aggregate

The locally available sand (M-sand) with a specific gravity of 2.71 was used as the fine aggregate. The fineness modulus of M-sand was measured at 2.46, with a bulk density of 1850 kg/m<sup>3</sup>. The coarse aggregate with a specific gravity of 2.69 and a bulk density of 1695 kg/m<sup>3</sup> was used in this study. Testing was conducted on fine and coarse aggregates according to the prescribed IS 2386-1963 procedure.

## 2.4. Water

The concrete was produced with potable water containing no chemicals or organic matter, according to IS 456-2000.

## 2.5. Experimental methods

### 2.5.1. Hardened concrete

Hardened concrete was studied using a Lawrence and Mayo test machine with 1500 kN capacity as depicted in Fig. 7. In accordance with ASTM C39 [33], cylindrical specimens of 300 mm height and 150 mm diameter were tested for cylinder compressive strength. Three cylinders of each composition were used to measure the cylinder compressive strength at 28, 56, and 90 days.



Fig. 7. Test setup for cylinder specimen

### 2.5.2. Mineralogical studies

Pulverized pond ash concrete mix was analyzed using XRD (Shimadzu XRD 6000, 40 kV, 35 mA) at 28, 56, and 90 days. The diffraction pattern was recorded between a range of  $5.00^\circ - 80.00^\circ 2\theta$ , by step size of  $0.01^\circ 2\theta$ , divergence slit of  $1.00^\circ$  and step time of 0.60 s.

### 2.5.3. Sulphate resistance test

ASTM C 1012 [34] is used to determine sulphate resistance. CC and PPAC were assessed for sulphate resistance using a  $150 \times 150 \times 150$  mm cube. Specimens were immersed in a solution of 5 % magnesium sulphate ( $MgSO_4$ ) for 28, 56, and 90 days as shown in Fig. 8. The initial weight of the specimens was measured before acid immersion. The specimens were removed and their weights were measured using a 1500 kN compressive test machine. Three cubes of each composition were used to measure the specimen's weight at 28, 56, and 90 days.



Fig. 8. Cube immersed in  $MgSO_4$  Solution

### 2.5.4. Water absorption test

According to ASTM C642 [35], the water absorption test was performed on  $150 \times 150 \times 150$  mm cube specimens at 28, 56, and 90 days of curing. Initially, the specimens were weighed to record their mass before undergoing the heating process. The specimens were then placed in a hot air oven set at  $105^\circ C$  ( $221^\circ F$ ) and heated for a continuous duration of 24 hours. This heating duration was carefully maintained to ensure that the specimens were thoroughly dried.

After the heating period, the specimens were removed from the oven and allowed to cool to ambient temperature. Following cooling, they were immersed in water to achieve saturation. Finally, to determine the water absorption accurately, the specimens were periodically removed from the water, approximately every 24 hours, and surface dried before being weighed again. This procedure was repeated until the weight of the specimens stabilized, indicating that they had reached a constant weight. The average weight was determined from measurements taken from three cubes of each composition.

### 2.5.5. Sorptivity test

A Sorptivity test was performed at the age of 28, 56, and 90 days according to ASTM C 1585 standards [36]. Cylinder discs (90 mm diameter and 50 mm thickness) were cast to determine the sorptivity of CC and PPAC, as shown in Fig. 9. Initially, the specimen was weighed before immersing in water. The concrete specimens were then wax sealed and immersed in water (in a 5 mm tray). The concrete samples were taken out and weighed at the prescribed intervals. The sorptivity performance of CC and PPAC was assessed using eighteen concrete specimens.



Fig. 9. Specimen for sorptivity test

## 3. RESULTS AND DISCUSSION

### 3.1. Cylinder compressive strength

The cylinder compressive strength of CC and PPAC was measured at 28, 56 and 90 days, and the results were displayed (Fig. 10). The PPAC mix demonstrated consistently higher compressive strength than the CC mix across all time intervals. At 28 days, PPAC had a strength of 27.62 MPa, surpassing CC 24.94 MPa. By 56 days, PPAC reached 31.79 MPa, while CC lagged at 28.11 MPa. At 90 days, the PPAC mix continued to outperform with a strength of 33.43 MPa, compared to CC 29.41 MPa. This result suggests that the PPAC mix is more effective in developing and maintaining higher strength over time. The

formation of additional C-S-H gel was caused by the interaction between silica and portlandite, which occurred later in the curing process and enhanced the strength of the concrete [37, 38]. The production of secondary C-S-H gel, a substance that gives concrete its increased strength [39, 40]. Similarly, the high surface area and C-S-H gel are the main factors in improving the concrete hardened characteristics [41]. The cylinder compressive strength of the PPAC mix was 10.74 %, 13.09 %, and 13.66 % higher than the conventional mix at ages 28, 56, and 90 days, respectively.

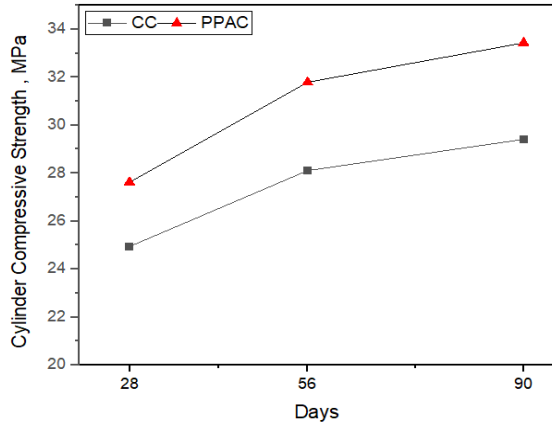


Fig. 10. Cylinder compressive strength for CC and PPAC

### 3.2. XRD analysis

Fig. 11 a–c displays the XRD pattern of PPAC at 28, 56, and 90 days.

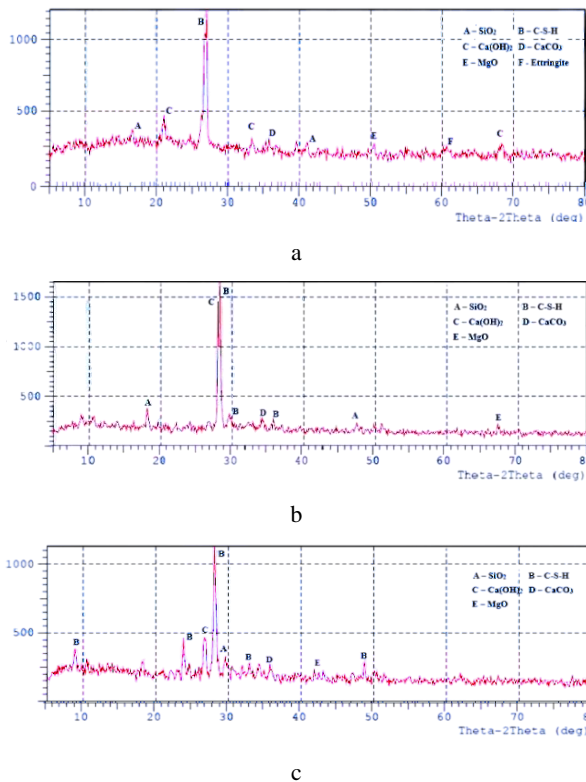


Fig. 11. XRD patterns of PPAC mix: a—at 28 days; b—at 56 days; c—90 days

In Fig. 11 a, large peaks in the range of  $16^\circ$  to  $36^\circ$  on the  $2\theta$  demonstrate the presence of both major crystalline

and minor amorphous phases in PPAC. The important components of the broad peaks were  $\text{SiO}_2$ , C-S-H,  $\text{Ca(OH)}_2$ ,  $\text{CaCO}_3$ , and Ettringite. The main crystalline peaks represent the C-S-H. The production of secondary C-S-H gels is caused by adding  $\text{SiO}_2$  to concrete. Moreover, Ettringite had a minor impact on the formation of C-S-H gels in the PPAC mix. The large peaks in the range of  $28^\circ$  to  $35^\circ$  on the  $2\theta$  in Fig. 11 b showed that PPAC contains both major crystalline and minor amorphous phases. The broad peaks contain significant amounts of  $\text{SiO}_2$ , C-S-H,  $\text{Ca(OH)}_2$ ,  $\text{CaCO}_3$ , and MgO. The major peaks exhibited greater source component dissolution as a result of secondary hydration [35, 36]. Fig. 11 c indicates a major crystalline phase and a minor amorphous phase in PPAC, indicated by the broad peaks between  $24^\circ$  and  $36^\circ$  on the  $2\theta$  scale. According to XRD data, the consumption of  $\text{Ca(OH)}_2$  is significantly lower at 56 and 90 days than it is at 28 days, which is caused by the loss of cement content and the pozzolanic activity of source material. This observation is related to [42], in which the ratio of calcium hydroxide (CH), (created during hydration), decreased with concrete age. Peak intensity and quantity have improved considerably at 56 and 90 days compared to 28 days. The peak intensity and quantity improved with the number of days and indicated the saturation point of the concrete [43].

### 3.3. Sulphate resistance test

#### 3.3.1. Weight gain

Fig. 12 displays the weight change after exposure to the  $\text{MgSO}_4$  solution for CC and PPAC. The weight gained significantly with immersion durations of 28, 56, and 90 days for both CC and PPAC mixtures. However, PPAC weight gain is slightly different from CC in terms of percentage.

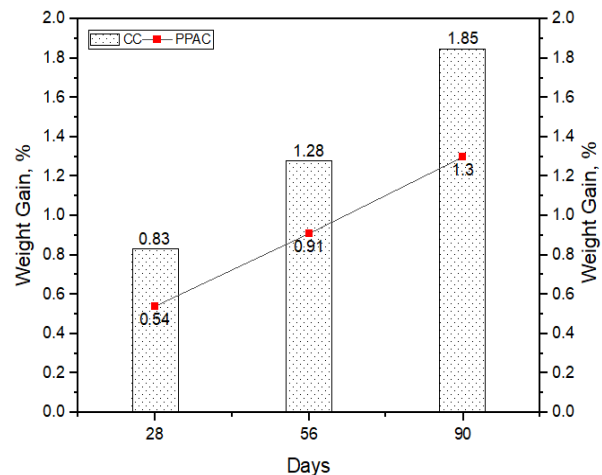


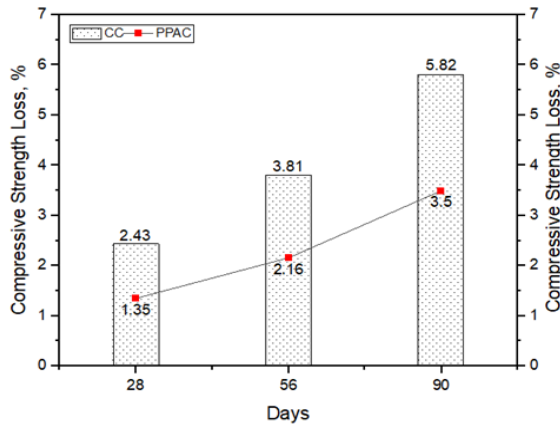
Fig. 12. Weight gain for CC and PPAC against  $\text{MgSO}_4$  solution

PPAC attained significantly less weight gain than CC. The PPAC mix has shown an increased weight percentage between 0.54 % to 1.30 %. CC has shown an increased weight percentage between 0.83 % and 1.85 %, substantially higher than the PPAC. Concrete is generally more porous and permeable, so sulfate ions in it take up pore space. As a result of  $\text{MgSO}_4$  precipitation in the porous voids in concrete, the concrete structures gained weight. A similar result was found by [44]. In comparison with the CC

mix, the PPAC showed lower weight gain due to lesser sorptivity and permeability.

### 3.3.2. Compressive strength loss

Fig. 13. illustrates the compressive reduction in strength of CC and PPAC. Both the concrete showed slightly decreased compressive strength against the  $MgSO_4$  solution throughout 28, 56, and 90 days. There was a lower percentage of compressive strength loss in PPAC than in CC.

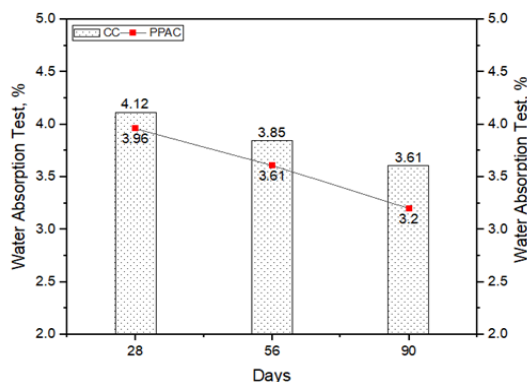


**Fig. 13.** Compressive strength loss for CC and PPAC against  $MgSO_4$  solution

Compressive strength loss of the PPAC mix (1.35 % and 3.50 %) and CC mix (2.43 % and 5.82 %) showed higher loss of CC than the PPAC. The initial stages of conventional concrete exposure to sulphate solutions, result in the creation of Ettringite and gypsum. This leads to an adverse influence on durability and causes a higher loss of compressive strength. The mechanism behind this is the reaction of sulphate with an excess amount of calcium hydroxide (CH). The inclusion of  $SiO_2$  in the pulverized pond ash reacts with the excess CH. As a result, the percentage of CH decreased. At this juncture, PPAC has displayed better performance than CC.

### 3.4. Water absorption test

The water absorption test for CC and PPAC is shown in Fig. 14.



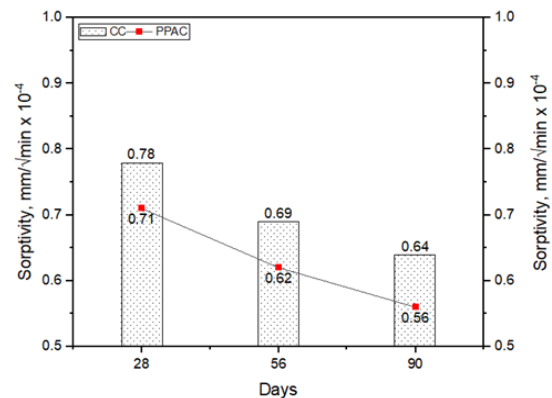
**Fig. 14.** Water absorption test for CC and PPAC

After 28, 56, and 90 days, the water absorption of PPAC is less than that of CC. The decreased water absorption was due to the pulverized pond ash particles fineness, which reduced the amount of microspores left behind by other

concrete constituents. This finding is consistent with observations reported by [45], where it was noted that the fineness of supplementary materials significantly reduces water absorption in concrete. Similarly, [46] proved that adding MHA to concrete caused a reduction in water absorption after 28 days.

### 3.5. Sorptivity test

The test finding was displayed in Fig. 15 for the sorptivity of CC and PPAC mixtures at ages 28, 56, and 90 days. As the curing age is increased, the CC and PPAC showed decreased sorptivity.



**Fig. 15.** Sorptivity test for CC and PPAC

Besides, PPAC had less sorptivity than CC mix with all the ages. Concrete with supplementary cementitious reduced its sorptivity as a result of various factors, including the addition of C-S-H, the smaller particle size, and a higher specific surface area. This observation was correlated with [47, 48], where the replacement of Portland cement by fly ash decreased the porosity. Similarly, [49] explained the 10% substitution of FA and the sorptivity of FA concrete exhibited lower values than CC.

## 4. CONCLUSIONS

According to the experimental findings, the following prominent conclusions were as follows:

1. At ages 28, 56, and 90 days, the PPAC mix exhibited significant improvement over the CC mix in terms of cylinder compressive strength by 10.74 %, 13.09 %, and 13.66 %. The interaction between silica and portlandite, formed more C-S-H gel, and increased the concrete strength.
2. From the XRD data,  $Ca(OH)_2$  consumption decreased significantly at 56 and 90 days than 28 days. The Peak intensity and quantity have significantly increased between 56 and 90 days than 28 days. The Peak intensity and quantity have been substantially increased during 56 and 90 days than 28 days. It is due to the loss of cement content and the pozzolanic activity of source material.
3. The CC and PPAC mix displayed increased weight at all ages with a 5 % magnesium sulfate ( $MgSO_4$ ) solution. The PPAC demonstrated higher residual compressive strength than CC at ages 28, 56, and 90 days with percentages of 1.08 %, 1.65 %, and 2.32 %.
4. PPAC water absorption is lower than that of CC, due to the finer particle size and the existence of vitreous Si

components in the PA. In addition, the PPAC showed a lower sorptivity value at all ages than the CC. The sorptivity of PPAC was 8.93 %, 10.14 %, and 12.5 % lower than CC at ages 28, 56, and 90 days. Hence, the influence of pulverized pond ash concrete makes it the ideal material to meet the contemporary needs of the construction industry.

- Therefore, the utilization of pulverized pond ash concrete demonstrates its suitability as an ideal material to fulfill the current requirements of the construction industry.

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