LAUTECH Journal of Civil and Environmental Studies
Volume 6, Issue 2
DOI: 10.36108/laujoces/1202.60.0201

# Water Absorption, Sorptivity and Permeability Properties of Concrete Containing Chemical and Mineral Admixtures

[1] Akinkurolere, O.O., [2] Awolusi, T.F., [3*] Oguntayo, D.O., [4] Babalola, O.E., [3] Aladegboye, O. and [5] Oyejobi, D.O.

[1]Department of Civil Engineering, Ekiti State University, Ado-Ekiti, Nigeria.
[2]Department of Civil Engineering. Afe Babalola University, Ado-Ekiti, Nigeria.
[3]Department of Civil Engineering. Landmark University, Omu-aran, Nigeria.
[4]Faculty of Civil Engineering. Ton Duc Thang University, Ho Chi Minh, Vietnam.
[5]Department of Civil Engineering. University of Ilorin, Ilorin, Nigeria.

[*]Corresponding E-mail: femdan122@gmail.com

*Submitted on: 20/01/2021* *Accepted on: 21/04/2021*

## Abstract

*Concrete durability, especially in water-logged environments might not be possible with conventional constituents of concrete. A combination of mineral and chemical admixtures in different proportions is used to study water absorption, sorptivity, and permeability behavior of concrete. The water absorption, sorptivity, and permeability test were carried out using nine (9) trial mixes of different proportions of Calcined Clay (CC), Sawdust Ash (SDA), Crystalline Based Admixture (CBA), and Superplasticizer (SP). The results showed that treating concrete with 5% CC + 5% SDA+1% CBA combination gives optimum performance in terms of sorptivity with reduced water absorption value of 4.60%. While the permeability coefficient of concrete is reduced when CC and SDA are added to concrete mix separately, the reactivity between their combination (CC and SDA) significantly increased permeability coefficient of the concrete. The study demonstrates that production of concrete with the right proportions of admixture and pozzolanas improve the durability of concrete structures.*

**Keywords:** Concrete, durability, admixture, water absorption, sorptivity, permeability

## Introduction

Concrete remains the most widely used construction material. As a composite material, its major constituents include fine aggregates, coarse aggregates, water and cement. These constituents are properly mixed to produce concrete (Akyildiz, 2018). The cement is usually Ordinary Portland Cement which serves as binder for aggregates. However, the environmental pollution and energy consumption related to the use and production of cement (Hatungimana et al., 2019; Hossain et al., 2020) has necessitated the construction industry and researchers in seeking alternative ways and materials with cementitious property to produce concrete with similar strength and durability. According to Akyildiz (2018), one of such alternative is to use supplementary cementitious materials as a partial replacement of cement in concrete. The combination of cement with other supplementary cementitious materials reduces cost, improves performance, and enhances environmental compatibility of concrete (Olufemi, 2012; Palanisamy et al., 2020).

The durability of concrete structures subjected to harsh situations depends largely on the penetrability of the pore arrangement (Achal et al., 2010; Choudhary et al., 2020; Henkensiefken et al., 2009). The use of simple parameters such as permeability, water absorption and rate of water absorption (sorptivity) is being increasingly used as a measure to determine resistance of concrete when exposed to aggressive environments (Kubissa & Jaskulski, 2013; Thokchom et al., 2009). Sorptivity and water absorption are reliable ways for measuring the ability of a material to absorb and transmit water by capillarity (Yang et al., 2019), and can be determined through a simple test by allowing one face of concrete samples to be in contact with water and the mass (non-destructive) or height (destructive) of water absorbed by capillary suction measured at predefined intervals (Bozkurt & Yazicioglu, 2010); the lower the value of water absorption and sorptivity, the better is the potential durability of the concrete (Maroliya, 2012).

Permeability of concrete is also a key parameter that affects the serviceability and durability of concrete in aggressive environments since water acts as either the major agent responsible for the deterioration of concrete or the transport medium for aggressive species like chloride or sulfate ions (Liu et al., 2018). Permeability measures the rate at which fluid, gas, or liquid permeates through the material under a given pressure head. (Kubissa & Jaskulski, 2013). Hence, the more quickly a fluid moves through the material, the higher permeability and lower anticipated durability (Elawady et al., 2014).

In order to improve the pore structure of concrete and enhanced its durability, water-proofing admixtures and pozzolana materials have been proven applicable ( Dembovska et al., 2017; Drochytka et al., 2019). Therefore, this study is aimed at examining the influence of different proportions of pozzolanas (sawdust ash and calcined clay) and chemical admixtures (crystalline based admixture with superplasticizer) on the durability property of concrete.

## Materials and Methods

### Experimental Materials

### Binder Material

Portland Limestone Cement (PLC) of Grade 42.5R with properties conforming to BS EN 197-1:2000. Saw-dust was collected from a saw-mill in Ikere-Ekiti, Ekiti State. This material was burnt to ashes in a controlled environment, grounded and sieved through BS sieve 425 mm. The saw-dust ash is shown in Figure 1. The chemical composition of saw dust as contained in Raheem et al. (2012) include SiO2, Al2O3, Fe2O3, CaO, MgO, SO3, Na2O, K2O, CaCO3, LOI, LSF, SR, and AR (in 65.75%, 5.23%, 2.03%, 9.62%, 4.09%, 1.09%, 0.06%, 2.43%, 7.92%, 4.30%, 1.71%, 10.67% and 12.32% percentage respectively).

**Figure 1.** Saw dust ash

The clay used in the study was sourced from a clay production company located in Ire Ekiti, Ekiti State. The clay samples were molded into balls of about 150 mm diameter, before drying for two weeks. In order to achieve calcination the dried samples were subjected to firing using a muffle furnace at 900oC for 2 hours. After cooling the calcined clay was pulverized. The calcined clay is shown in Figure 2. (The chemical composition of Clay as contained in Osuji & Akinwamide (2018) include $SiO_2$, $Al_2O_3$, $Fe_2O_3$, $Ti_2O$, $K_2O$, MgO, CaO, NiO and LOI in 42.9, 21, 10.99, 2.08, 0.15, 0.31, 0.08, 0.02 and 8.28 percentage respectively).

**Figure 2.** Clay after calcination

### Aggregate

The fine aggregate used was stone dust sourced from quarry site in Ado – Ekiti. The coarse aggregate was crushed granite aggregates sourced from the same site. The particle size ranged from 10 to 20 mm and conformed to BS 812-101:1984 . Two categories of coarse aggregate were considered. The first category passed through 20 mm sieve size and retained on sieve size 10 mm while the second category passed through sieve size 10 mm. According to Ayub *et al*. (2013) the crushed rock aggregate sizes of 10 to 20 mm are usually preferable in concrete mix since they are not too angular or elongated.

### Admixtures

The Crystalline-Based Admixtures (CBA) used in this study was manufactured and supplied by Advanced Concrete Technology Limited Ikeja, Lagos State. The CBA is in dry powdered form, hydrophilic in nature, and reacts with the constituents of the cement matrix to form CSH crystals. These crystals produce pore shrinking deposits that are found to improve the concrete's ability to resist water penetration under pressure. ThePolycarboxylic ether polymers superplasticizer (COSTAMIX300) used was also manufactured by the same company.

### Mix Proportion

The mix proportioning of constituent materials includes the variations in the quantity of mineral and chemical admixtures as shown in Table1.The Taguchi experimental design (L9) was used to vary the quantity of Calcined clay, Sawdust ash, Crystalline based admixture and superplasticizer. The Taguchi method was employed in order to avoid testing all possible combinations of the aforementioned factors. This was done in order to reduce the number of possible combinations methods was used. In order to achieve a target slump of 30±5 mm the water cement ratio varied between 0.6 and 0.7.

## Testing of the Specimens

### Sorptivity test

Sorptivity test was carried out for the nine different concrete mixes according to ASTM C1585:2007. Concrete samples of 100x100x100 mm cubes were coated with epoxy resin on the four adjacent sides for unidirectional absorption through the exposed face. Before coating, the test cubes were dried at 105 °C in a ventilated oven for 6-hours. The samples were then exposed to 10 ± 1 mm of water as shown in Figure 3. The time intervals considered during immersion are 5, 10, 20, 30, 60, 180, 360, and 1440 minutes. The samples were weighed and recorded at each time interval and compared with their initial mass before exposure to water. This was done to determine the weight gained. The sorptivity, S [$m.s^{-1/2}$], was obtained using equation 1 and 2 (Pandi & Ganesan, 2015; Yang et al., 2019):

**Table 1.** Proportions of materials in the mix

| Run No | Cement (kg) | FA (kg) | CA (10 mm) | CA (20 mm) | Calcined Clay (%) (kg) | SDA (%) (kg) | CBA (%) (kg) | SP(%) (kg) |
|---|---|---|---|---|---|---|---|---|
| 1 | 364 | 764 | 562 | 562 | (5%) 18.2 | (5%) 18.2 | (1%) 18.2 | (0%) 0 |
| 2 | 364 | 764 | 562 | 562 | (5%) 18.2 | (2.5%) 9.1 | (0%) 0 | (2%) 7.28 |
| 3 | 364 | 764 | 562 | 562 | (5%) 18.2 | (0%) 0 | (2%) 7.28 | (1%) 3.64 |
| 4 | 364 | 764 | 562 | 562 | ( 0%) 0 | (2.5%) 9.1 | (1%) 3.64 | (1%) 3.64 |
| 5 | 364 | 764 | 562 | 562 | (2.5%) 9.1 | (0%) 0 | (1%) 3.64 | (2%) 7.28 |
| 6 | 364 | 764 | 562 | 562 | (2.5%) 9.1 | (5%) 18.2 | (0%) 0 | (1%) 3.64 |
| 7 | 364 | 764 | 562 | 562 | (2.5%) 9.1 | (2.5%) 9.1 | (2%) 7.28 | (0%) 0 |
| 8 | 364 | 764 | 562 | 562 | ( 0%) 0 | (5%) 18.2 | (2%) 7.28 | (2%) 7.28 |
| 9 | 364 | 764 | 562 | 562 | ( 0%) 0 | ( 0%) 0 | ( 0%) 0 | ( 0%) 0 |

FA- Fine Aggregate, CA – Coarse Aggregate, SP- Superplasticizer, CC - Calcined Clay, SDA- Sawdust ash, CBA - Crystalline Based Admixture

$$I = S.t^{\frac{1}{2}} \quad (1)$$

$$I = \frac{\Delta w}{Ad} \quad (2)$$

Where, S = sorptivity in ($m/s^{1/2}$)

t= expose time (seconds)

$\Delta w$ = weight gained (grams)

A = surface area of the specimen through which water penetrated ($m^2$).

d = density of water ($gm^{-3}$)

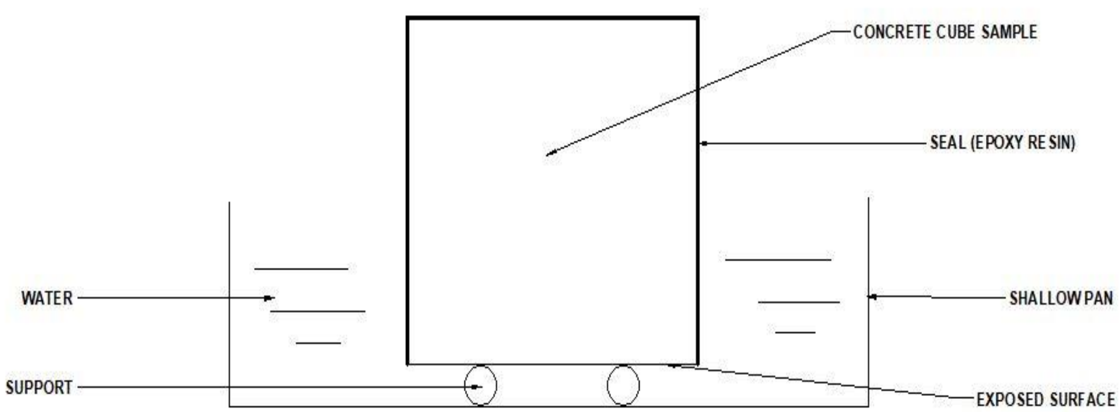


**Figure 3.** Sorptivity testing set-up

## Water absorption test

In order to find out the quantity of water absorbed under specified conditions, water absorption test was conducted in accordance with ASTM C1585:2007 using concrete specimen size 100 × 100 mm cube. The concrete samples after 28 days were oven-dried at temperature of 105 $^oC$ for 6 hours, subsequently wholly immersed in water for 24 hours, and weighed thereafter. The test was carried out for the nine experimental runs with different combinations of concrete. The water absorption was computed using Equation 3 (Balakrishma et al., 2018; Pandi & Ganesan, 2015)

$$\text{Percentage of Water Absorption} = \frac{W_2 - W_1}{W_1} \quad (3)$$

Where; W1 = Oven dry weight of samples (gm)

W2 = Wet weight of samples (gm)

## Permeability test

The permeability of concrete samples of size Ø60 × 40 mm cylinder was measured in accordance with ASTM D4491-99a using automatic concrete water permeability device as shown in **Figure 4**. The sides of the specimen are sealed with epoxy, and water is applied to the top surface only under pressure. The apparatus applies a hydrostatic water pressure of 30 bars for a period of 6hours. The water permeated through specimens is directly collected and measured in a graduated cylinder. Based on the applied hydrostatic pressure, duration, specimen dimensions, and the permeated amount of water, the permeability coefficient in cm/sec was determined by applying Darcy's law given in equation 4:

$$K = \frac{Q*H}{A*T*P} \quad (4)$$

Where;

K = Permeability coefficient, cm/sec
Q = Permeated water, $cm^3$
H = Height of the specimen, cm
A = Surface area of the specimen, $cm^2$
P = Water head, cm
T = Test time, sec

**Figure 4.** Permeability test set up for determining the water permeability of concrete

## Results and Discussion

### Water absorption and sorptivity

The influence of applying different proportions of mineral and chemical admixtures on the water absorption of concrete is shown in Figure 5. For the different concrete mix investigated, concrete sample ( Run number 1) containing 5% calcined clay, 5% sawdust ash, 1% crystalline-based admixture, and 0% Superplaticizer give the lowest water absorption value of 4.60%, which amount to about 7.2% reduction in water absorption when compared to control sample (Run number 9) with water absorption of 4.92%. This could be ascribed to the fact that the addition of pozzolanic materials and admixture were able to fill up the pores and voids created in the concrete. Also, a low water absorption values of 4.65% and 4.62% were obtained for Run numbers 8 (0% CC, 5% SDA, 2% CBA, and 2% SP) and 4 (0% CC, 2.5% SDA, 1% CBA, and 1% SP) respectively. In addition, run numbers 4 and 8 had water absorption value lower than that of the control mix samples (Run number 9), however the water absorption values of both runs 4 and 8 were higher than Run number 1(5% CC, 5% SDA, 1% CBA, and 0% SP). This may be attributed to the fact that SDA content in the mix gives enhanced reactivity with the presence of CBA resulting in retaining some air voids in concrete and forming greater void spaces than those formed in concrete treated with lower admixtures dosages as the case in run number 1.

The presence of superplasticizer improved workability as observed during mixing however this admixture contributed to the slight increase in the values of water absorption. The presence of sawdust ash in concrete mix enhanced the resistance to water absorption compared to calcined clay and crystalline-based admixture respectively. This is observed when percentage replacement of SDA was reduced in Runs 2 and 4, and absent in Runs 3 and 5 which all resulted in corresponding higher water absorption values. Likewise, with 5% SDA and 0% calcined clay in Run 8, water absorption is very close to that of Run 1 when calcined clay was present.


**Figure 5.** Water Absorption against Run Number

The sorptivity test results of concrete mixes for the different time intervals are presented in Table 2. The average sorptivity values for each run are presented in Figure 6. It can be seen that from Run 1 to run 6, the sorptivity decreases for all the specimens of concrete. However, Run 2 with mix proportion of 5%CC+2.5%SDA+0%CBA+2%SP has the lowest sorptivity. Hence, the incorporation of 5% calcined clay with 2.5% sawdust ash tends to beneficially reduce the sorptivity coefficient.

Furthermore, calcined clay significantly contributed to reduction in transmission of water through capillarity in concrete as seen in the lowest sorptivity value of Run 2 with 5% calcined clay content and highest sorptivity value in Run 8 with 0% calcined clay content. On the other hand, CBA has little or no contribution in resisting the uprising of water as seen when it was absent in Run 2 and present at 2% in Runs 7 and 8. Comparing with control, Run 2 with 5% calcined clay, 2.5% SDA, 0% CBA, and 2% Superplaticizer has higher resistance to water penetration, with reduction up to 54 % compared to control samples.

**Table 2.** Sorptivity Value for Different Mix Proportion Considered

| **Time (min)** | **Sorptivity (ms-$^{1/2}$)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Run 1 | Run 2 | Run 3 | Run 4 | Run 5 | Run 6 | Run 7 | Run 8 | Run 9 |
| 5 | 0.0289 | 0.0231 | 0.0231 | 0.0664 | 0.0260 | 0.0318 | 0.0548 | 0.1155 | 0.1097 |
| 10 | 0.0286 | 0.0265 | 0.0327 | 0.0531 | 0.0286 | 0.0347 | 0.0837 | 0.0816 | 0.0796 |
| 20 | 0.0332 | 0.0303 | 0.0303 | 0.0563 | 0.0462 | 0.0361 | 0.0736 | 0.0722 | 0.0606 |
| 30 | 0.0342 | 0.0283 | 0.0283 | 0.0530 | 0.0460 | 0.0448 | 0.0766 | 0.0589 | 0.0566 |
| 60 | 0.0375 | 0.0283 | 0.0267 | 0.0450 | 0.0375 | 0.0392 | 0.0658 | 0.0592 | 0.0550 |
| 180 | 0.0342 | 0.0269 | 0.0322 | 0.0452 | 0.0284 | 0.0313 | 0.0467 | 0.0409 | 0.0375 |
| 360 | 0.0354 | 0.0279 | 0.0276 | 0.0401 | 0.0225 | 0.0344 | 0.0480 | 0.0381 | 0.0350 |
| 1440 | 0.0359 | 0.0209 | 0.0265 | 0.0303 | 0.0163 | 0.0289 | 0.0265 | 0.0226 | 0.0226 |
| **AVERAGE** | 0.0335 | 0.0265 | 0.0284 | 0.0487 | 0.0314 | 0.0351 | 0.0595 | 0.0611 | 0.0571 |

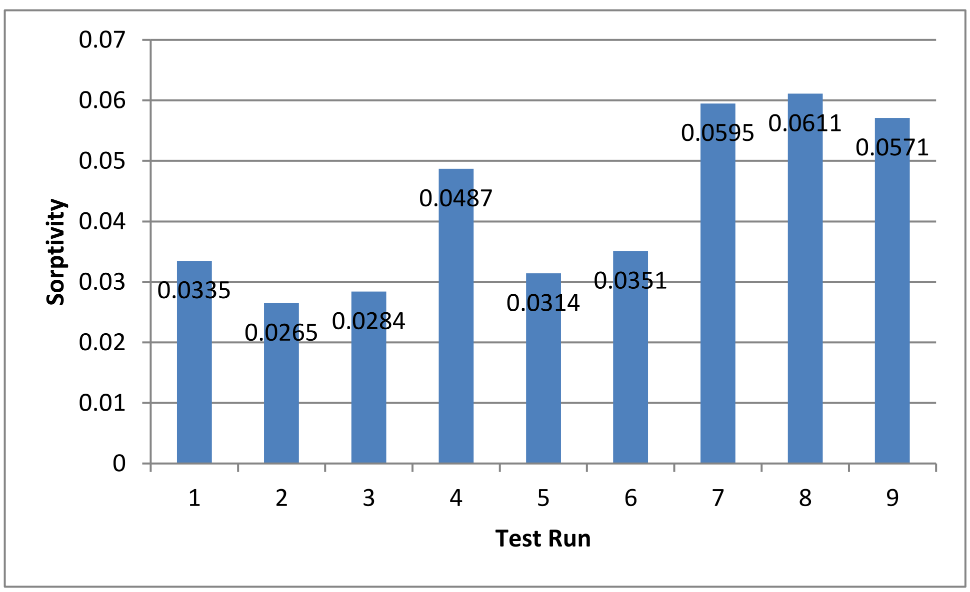


**Figure 6.** Sorptivity of samples

*Permeability:* Figure 7 shows the permeability coefficients of specimens with different mix proportions. Mix proportions of Runs 3, 4, 5, and 8 have reduced coefficient of permeability compared to that of control mix. It is observed that the addition of calcined clay and SDA separately in concrete mix as in the case of Runs 3, 4, 5, and 8 leads to a significant reduction in permeability coefficient of concrete, while their combination tends to increase concrete permeability with increase permeability coefficient as seen in runs 1, 2, 6, and 7. However, under the forced pressure, the influence of calcined clay, SDA, CBA based on their level of replacement percentage content in concrete mix on permeability coefficient did not follow a regular trend. This could be attributed to the fact that the permeability is measured under forced applied pressure and not through a natural process.

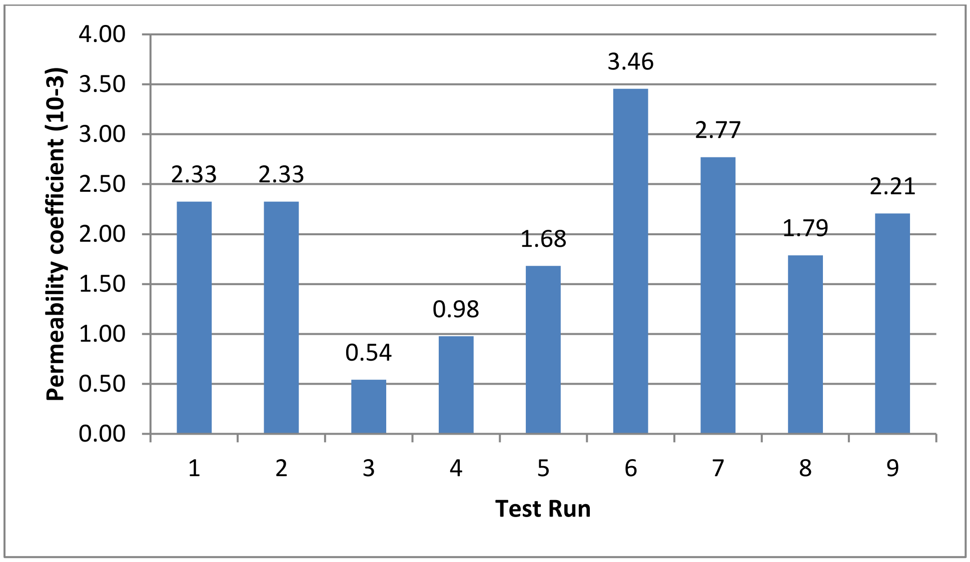


**Figure 7.** Permeability Coefficients for different mix proportions

## Conclusion

This study described the water absorption, sorptivity and permeability behaviour of concrete Containing mineral and chemical admixture. All tests carried out on the test specimens are different in principle and procedure. While water absorption was full immersion for 24 hours, sorptivity test specimen was carried out to achieve unidirectionly movement of water and water permeability test was set-up under pressure through only the top surface for 6 hours. The difference in the modus operandi and governing equations of each test justified the reason for different trends observed in the results.

The main conclusions derived from this study can be summarized as follows:

i. Water absorption, sorptivity, and permeability of concrete mix with combination of mineral and chemical admixtures varied between 4.60 - 7.20 %, 0.0265 - 0.0611 (ms-1/2), and 0.54 - 3.46 respectively.

ii. The optimum durability performance in terms of sortivity and water absorption is achieved with treating concrete with 5% Calcined Clay + 5% SDA+1% CBA combination while run 3 with 5% CC + 0% SDA + 2% CBA + 1 SP perform best in terms of permeability test under pressure

iii. In overall, with the inclusion of varying proportions of calcined clay, SDA, CBA, and Superplaticizer, deterioration of concrete can be minimized which will lead to avoidance of serviceability defects, and possible eradication of corrosion of reinforcing bars with the ingress of water in the presence of oxygen can be substantially reduced.

## Acknowledgements

The authors are grateful to Advanced Concrete Technology Limited, Ikeja, Lagos State for providing the crystalline based admixture and superplasticizer used in the study. The authors are also grateful to the management of Ire Clay Production Limited Company in Ire town, Ekiti State.

## References

Achal, V., Mukherjee, A., & Reddy, M. S. (2011). Microbial concrete: way to enhance the durability of building structures. *Journal of materials in civil engineering*, *23*(6), 730-734.

Akyildiz, A. (2018). Water Absorption and Sorptivity Properties of Concrete Containing Granulated Blast Furnace Slag. *IOSR Journal of Mechanical and Civil Engineering*, 15(6), 66–69. https://doi.org/10.9790/1684-1506016669.

Astm, C. (2004). 1585-04. Standard test method for measurement of rate of absorption of water by hydraulic-cement concretes. *ASTM International*.

ASTM C1602/C1602M-18. *Standard Specification for Mixing Water for Concrete American Society of Testing and Materials, West Conshohocken, PA.*

ASTM D 4491. (2014). Standard Test Methods for Water Permeability of Geotextiles by Permittivity.

Ayub, T., Shafiq, N., & Nuruddin, M. F. (2014). Mechanical properties of high-performance concrete reinforced with basalt fibers. *Procedia Engineering*, *77*, 131-139.

Balakrishma, M. N., Mohamad, F., Evans, R., & Rahman, M. M. (2018). Assessment of sorptivity coefficient in concrete cubes. *Discovery*, *54*(274), 377–386.

Bozkurt, N., &Yazicioglu, S. (2010). Strength and capillary water absorption of lightweight concrete under different curing conditions. *Indian Journal of Engineering and Materials Sciences*, *17*(2), 145–151.

*BS 812-101 : Guide to sampling and testing* of aggregates. British Standard Institution, London; UK.

Cappellesso, V. G., dos Santos Petry, N., Dal Molin, D. C. C., &Masuero, A. B. (2016). Use of crystalline waterproofing to reduce capillary porosity in concrete. *Journal of Building Pathology and Rehabilitation*, *1*(1), 9.

Choudhary, R., Gupta, R., Nagar, R., & Jain, A. (2020). Sorptivity characteristics of high strength self-consolidating concrete produced by marble waste powder, fly ash, and micro silica. *Materials Today: Proceedings*.

Dembovska, L., Bajare, D., Pundiene, I., & Vitola, L. (2017). Effect of pozzolanic additives on the strength development of high performance concrete. *Procedia Engineering*, *172*, 202-210.

Drochytka, R., Ledl, M., Bydzovsky, J., Zizkova, N., & Bester, J. (2019). Use of Secondary Crystallization and Fly Ash in Waterproofing Materials to Increase Concrete Resistance to Aggressive Gases and Liquids. *Advances in Civil Engineering*, *2019*.

Drochytka, R., Ledl, M., Bydzovsky, J., Zizkova, N., & Bester, J. (2019). Use of Secondary Crystallization and Fly Ash in Waterproofing Materials to Increase Concrete Resistance to Aggressive Gases and Liquids. *Advances in Civil Engineering*, *2019*.

EN, B. S. (2000). 197-1, Cement-Part 1: Composition, specifications and conformity criteria for common cements. *British Standards Institution*.

Elawady, E., & Amr, A. (2014). El Hefnawy, Rania AF Ibrahim,'Comparative Study on Strength, Permeability and Sorptivity of Concrete and their relation with Concrete Durability'. *International Journal of Engineering and Innovative Technology*, *4*(4), 132-139.

Hatungimana, D., Taşköprü, C., İçhedef, M., Saç, M. M., &Yazıcı, Ş. (2019). Compressive strength, water absorption, water sorptivity and surface radon exhalation rate of silica fume and fly ash based mortar. *Journal of Building Engineering*, *23*, 369-376.

Henkensiefken, R., Castro, J., Bentz, D., Nantung, T., & Weiss, J. (2009). Water absorption in internally cured mortar made with water-filled lightweight aggregate. *Cement and Concrete Research*, *39*(10), 883-892.

Hossain, M. M., Karim, M. R., Elahi, M. M. A., & Zain, M. F. M. (2020). Water absorption and sorptivity of alkali-activated ternary blended composite binder. *Journal of Building Engineering*, 101370.

Kubissa, W., & Jaskulski, R. (2013). Measuring and time variability of the sorptivity of concrete. *Procedia Engineering*, *57*, 634-641.

Liu, H., Liu, R., Yang, H., Ma, C., & Zhou, H. (2018, February). Experimental study on the performance of pervious concrete. In *IOP Conference Series: Earth and Environmental Science* (Vol. 113, No. 1, p. 012126). IOP Publishing.

Maroliya, M. K. (2012). Estimation of Water Sorptivity as Durability Index for Ultra High Strength Reactive Powder Concrete. *International Journal of Engineering Research and Development*, *4*(3), 53-56.

Folagbade, S. O. (2012). Sorptivity of cement combination concretes containing portland cement, fly ash and metakaolin. *International Journal of Engineering Research and Applications (IJERA) ISSN*, 2248-9622.

Osuji, O. S., &Akinwamide, J. T. (2018). Physico-Chemical Properties of Lateritic Soils in Ado-Ekiti, South Western Nigeria. *Universal Journal of Environmental Research & Technology*, *7*(1).

Palanisamy, M., Kolandasamy, P., Awoyera, P., Gobinath, R., Muthusamy, S., Krishnasamy, T. R., & Viloria, A. (2020). Permeability properties of lightweight self-consolidating concrete made with coconut shell aggregate. *Journal of Materials Research and Technology*.

Shah, R. A., & Pitroda, J. (2013). Effect of Water Absorption and Sorptivity on durability of pozzocrete mortar. *International Journal of Emerging Science and Engineering (IJESE) ISSN: 2319, 6378*.

Raheem, A. A., Olasunkanmi, B. S., & Folorunso, C. S. (2012). Saw dust ash as partial replacement for cement in concrete. *Organization, technology & management in construction: an international journal*, *4*(2), 474-480.

Thokchom, S., Ghosh, P., & Ghosh, S. (2009). Effect of water absorption, porosity and sorptivity on durability of geopolymer mortars. *ARPN Journal of engineering and Applied Sciences*, *4*(7), 28-32.

Yang, L., Gao, D., Zhang, Y., Tang, J., & Li, Y. (2019). Relationship between sorptivity and capillary coefficient for water absorption of cement-based materials: theory analysis and experiment. *Royal Society open science*, *6*(6), 190112.