Capillarity of Concrete Incorporating Waste Ceramic Powder

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Received (Geliş): 24.02.2022 Revision (Düzeltme):18.03.2022 Accepted (Kabul): 22.03.2022

ABSTRACT

The durability of a concrete structure is directly related to its permeability. Capillary water absorption is a widely used test method to obtain information about the permeability properties of a concrete structure. This study focused on the relationship between the content of waste ceramic powder as a cement replacement material and the capillary water absorption capacity of concrete mixtures. Following this purpose, portland cement was substituted with waste ceramic powder in four different proportions of 0%, 10%, 20%, and 30%. The capillary water absorption amount of each concrete mixture was measured at the end of each 5, 10, 15, 30, 45 and 60 minutes period. From the test results, it was seen that the capillary water absorption decreased when the cement was replaced up to 10% with waste ceramic powder, while it increased at other replacement ratios of 20% and 30% compared to the control concrete. This is attributed to the fact that waste ceramic powder can exhibit better filling properties when replaced with cement up to 10% level to reduce the capillary pores of the concrete, increase the density and impermeability of the concrete microstructure, and restrict the free movement of water through the concrete.

Keywords: Capillary water absorption, Cement, Concrete, Permeability, Waste ceramic powder

Atık Seramik Tozu İçeren Betonun Kapilaritesi

ÖZ

Beton yapıların durabilitesi, permeabilitesiyle (geçirgenlik) doğrudan ilişkilidir. Kapiler su emme deneyi, betonların permeabilitesi hakkında yorum yapmak için yaygın olarak kullanılan bir test yöntemidir. Bu çalışmada, çimento ikame malzemesi olarak kullanılan atık seramik tozu içeriği ile beton karışımlarına ait kapiler su emme kapasitesi arasındaki ilişki ele alınmıştır. Bu amaçla Portland çimentosu %0, %10, %20 ve %30 olmak üzere dört farklı oranda seramik atığı tozu ile ikame edilmiştir. Her bir beton karışımının kapiler su emmesi 5, 10, 15, 30, 45 ve 60 dakikalık zaman periyotlarının sonunda hesaplanmıştır. Test sonuçlarından, kapiler su absorpsiyonunun kontrol beton sonucuna göre %10'a kadar yer değiştirme ile azaldığı, %20 ve %30 olan diğer ikame oranlarında ise arttığı görülmüştür. Bu, atık seramik tozunun, betonun kılcal gözeneklerini azaltmak, beton mikro yapısının yoğunluğunu ve geçirimsizliğini arttırmak ve suyun beton içinde serbest hareketini kısıtlamak için çimento ile %10 seviyesine kadar değiştirildiğinde daha iyi bir dolgu özelliği gösterebileceğine bağlanmaktadır.

Anahtar Kelimeler: Beton, Çimento, Kapiler su emme, Permeabilite, Seramik atık tozu

INTRODUCTION

Its versatility, availability and easily handled properties make concrete the most used construction material after water all around the world [1,2]. Concrete structures undergo severe durability issues during their service life [3-5]. One of the most important aspects of concrete's durability is permeability of it [6]. The permeability property of concrete is a measure of the quantity of water that can be transferred through its structure [7,8]. It is very important for structures including dams, water storage, highways to withstand harsh environmental conditions and water pressure [9]. It is expected from durable concrete to be relatively impervious, and generally concrete with lower permeability means higher durable concrete [10]. Permeability of concretes is generated by several factors such as the amount of cementitious material, water content, aggregate grading and consolidation [11]. Some waste materials also may act as a good filler in concrete and this leads to enhancing its imperviousness. The permeability of concrete is directly related to its capillary water absorption capacity. It is an important criterion to obtain information about the durability of concrete. Capillary water absorption is the movement of liquid or water through the concrete structure by the effect of capillary suction [12]. The water transfer through tiny voids in concrete when partially dry concrete's surface is exposed to water pressure. The pore structure in paste has a great effect on capillary water absorption of concrete and is the only phase that governs the immersion and transfer of water through concrete structure [13]. Some studies have been met to evaluate the sorptivity of concrete mixtures when the literature was reviewed. Khatib et al. performed a study to investigate the capillarity water absorption of concrete incorporating waste foundry sand and presented in their study the results of capillary water absorption of concretes whose fine aggregate's content was replaced with waste foundry sand in various levels. The results showed a systematic increase in capillary water absorption with increasing content of waste foundry sand [14]. Jamshidi et al. investigated the effect of sewage sludge ash on the capillary water absorption capacity of concrete. In their study, sewage sludge ash was incorporated into the concrete as a filler material in ratios of 5%, 10% and 20% percentage of cement. They concluded from their experimental results that the concrete with 5% and 10% sewage sludge ash content had the same capillary water absorption as control concrete, but capillary water absorption increased with 20% content of sewage sludge ash [15]. Al-Goody et al. indicated from their studies that capillary water absorption decreased systematically with nano-silica content but decreased till a certain level with fly ash content [6]. Bozkurt and Yazıcıoğlu reported from their investigations that concrete with silica fume showed better capillary water absorption resistance when compared with control concrete and fly ash introduced concrete [16]. Qiu et al. examined the capillary water absorption properties of coal gangue concretes that were reinforced with 0.5%, 1% and 1.5 steel fiber volume. Results from their studies demonstrated that capillary water absorption decreased with 1% steel fiber content but increased with the other content of 0% and 1.5% [17].

This study presented herein investigated the effect of waste ceramic powder (WCP) as a cement replacement material on the capillary absorption of concrete mixtures. The ceramic wastes are generated from factories and construction sites during production and labor activities. Disposal of these wastes into the environment poses a serious threat to living health and also creates extra costs to storage in landfills. It is an urgent sustainability concern to find effective solutions for recycling these wastes to prevent their harmful effect. An effective way seems to use these types of waste in the concrete industry. Some waste materials such as eggshell powder, corn cob ash, rice husk ash, slate stone waste powder and waste ceramic powder have been used in concrete production as a cement substitute material for years [18-22]. The use of these types of materials as a cement replacement material is also a beneficial way to reduce the harmful effect of cement production, which is responsible for a huge amount of carbon dioxide release, by minimizing the need for cement amount in concrete. At this point in this study, the cement was substituted with WCP in proportions of 0%, 10%, 20% and 30% and it was investigated that the relationship between WCP content and capillary water absorption of the concrete mixture. The all-concrete mixtures were prepared with constant water to binder (cement, WCP) ratio of 0.30 and cured in 20 ˚C water for 28 days. After the curing process, the capillary water absorption test was performed on concrete specimens for periods of 5, 10, 15, 30, 45 and 60 min. Also, the regression analysis between water absorption during 28-days of water curing by mass and capillary water absorption of specimens for each period was made to reveal their linear relationship level. It is noticed from the test results that the 10% content of WCP decreased the capillarity water absorption while 20% and 30% content of it increased it when compared with control concrete results. As for regression analysis, there was seen a strong linear relationship between water absorption by mass and capillary water absorption ($r>0,75$). The highest correlation and determination coefficient was obtained as 0,91 and 0,83 respectively for 10 min. exposure to capillary action.

EXPERIMENTAL STUDY

Materials

In this study, portland cement (CEM I 42.5 R) and WCP were used as binding materials to produce concrete mixtures. Ceramic wastes were collected from factories and construction sites and ground into cement particle size approximately 90 µ. by grinder machine as shown in Figure 1.

a) b)

Figure 1. Ceramic waste (a), Waste Ceramic Powder (b)

Cement and WCP had the specific gravity of 2,95 and 2,74 and specific surface area 4600 and 4936 cm^2/g respectively. The physical and chemical properties of portland cement and WCP are presented in Table 1. The main oxides in WCP are SiO_2 and AI_2O_3 in the percentage of 65,89% and 17,01% as seen from chemical compositions respectively. The aggregate used in this study is quartz with a specific gravity of 2,67 g/cm^3. The superplasticizer is Polycarboxylic Ether-based and named Master Glenium 128 supplied from BASF Chemistry Industry with a density of 1,061–1,101 kg/lt to obtain fluidity and decrease the cement content in the concrete mixture [23].

Mixture Design

In this study, a total of four different concrete mixtures were designed. Portland cement was substituted with WCP in ratios of 0%, 10%, 20% and 30% by mass. The concrete mixtures were designed in constant binder amount with a 0.30 water to binder ratio. The binder amount was taken as the total of cement and WCP in mixtures. The specimens with 50 mm cubic size were employed in the capillary absorption test. Table 2 summarizes the concrete mixture compositions studied in this research. The abbreviations used for concrete mixtures containing WCP in ratios of 0%, 10%, 20% and 30% are CC, C10, C20 and C30

Table 1. Physical properties and chemical compositions of Portland cement and WCP

Analysis Report	Cement	WCP
SiO_2 (%)	24,18	65,89
Al_2O_3 (%)	6,57	17,01
Fe_2O_3 (%)	4,15	2,67
CaO (%)	56,05	6,45
MgO (%)	1,33	1,25
SO_3 (%)	2,80	0,14
K_2O (%)	1,22	2,34
Na_2O (%)	0,34	3,10
Cl (%)	0,0071	0,0007
Ignition Loss (%)	4,50	1,15
Specific gravity (g/cm^3)	2,95	2,82
Specific surface (cm^2/g)	4600	4936

Table 2. Mixture composition of concrete types (kg/m^3)

Materials	CC	C10	C20	C30
Cement	380	342	304	266
WCP	-	38	76	114
Water	114	114	114	114
Superplasticizer	4	4	4	4
0-4 mm Aggregate	926	926	926	926
4-8 mm Aggregate	463	463	463	463
8-16 mm Aggregate	581	581	581	581

Test Procedure

Capillary Water Absorption

Capillary water absorption (sorptivity) is the absorption of water through tiny pores in concrete composites with surface interaction and provides information on the microstructure and durability of cement-based composites. A capillary water absorption test was performed to determine the sorptivity coefficient of concrete specimens based on the standard of TS EN 13057 and ASTM C1585-04 [24,25]. The test was performed on a total of 12 cubes (three specimens for each concrete mixture) with 50 mm sides after 28 days of water curing. Test specimens were dried in an electric oven at 110 ± 5 ˚C until they reached the constant mass after completing the curing process. The sides of the cubes were covered with paraffin to prevent water ingression from the cube sides. Then, specimens were removed from the test mechanism at the end of the time of 5, 10, 15, 30, 45 and 60 minutes and weighed at the accuracy of 0,01g to measure the absorbed amount of water. The sorptivity index or coefficient of each concrete specimen was calculated following Eq. (1) and the test results were evaluated for each replacement level.

$$S=(Q/A)/\sqrt{t} \quad (1)$$

where;

S is the sorptivity (capillary water absorption) (kg/h$^{1/2}$)

Q is the volume of the water absorbed (m^3)

A is the surface area in contact with water (m^2)

t is the time (h).

Then, the square root of the elapsed time versus Q/A was plotted and the sorptivity index (capillary water absorption) was determined from the slope of the linear relationship of best fit. Figure 2 shows how to interact the surface of concrete specimens with water during the capillary water absorption test.

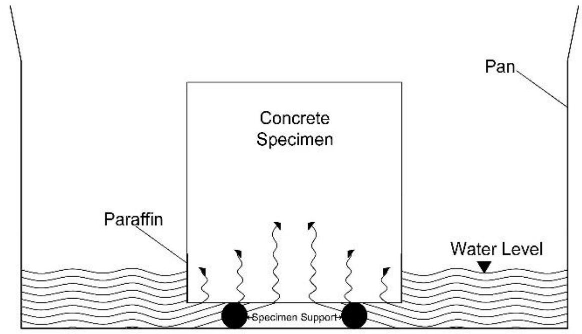

Figure 2. Detail of capillary water absorption test

RESULTS and DISCUSSION

The sorptivity index was calculated at a given time for each concrete mixture at the end of the capillary water absorption test. Figure 3 shows the test results of concrete mixtures exposed to water interactions for 5 min. The sorptivity index value changes between 2.05 and 2.33 kg/(m^2.h$^{0.5}$) calculated at the end of 5 min. for C10 and C30 mixtures respectively. The results indicated that the sorptivity index value decreased with incorporating of 10% WCP but increased with the content of 20% and 30% compared with control concrete. Replacing cement with WCP at a level of 10% decreased the sorptivity index for the time of 5 minutes by 6.82% compared with control concrete. However, in substitution ratios of 20% and 30%, it increased 2.28% and 5.91% compared with control concrete respectively as seen in Figure 3.

After 10 min. exposure to water through surface interaction, the sorptivity index decreased from 2.07 to 1.89 with a 10% substitution ratio. However, a systematic increase was observed at the other substitution ratios of 20% and 30%. The CC's sorptivity index increased from 2.07 to 2.13 and 2.24 kg/(m^2.h$^{0.5}$) for mixtures C20 and C30 respectively.

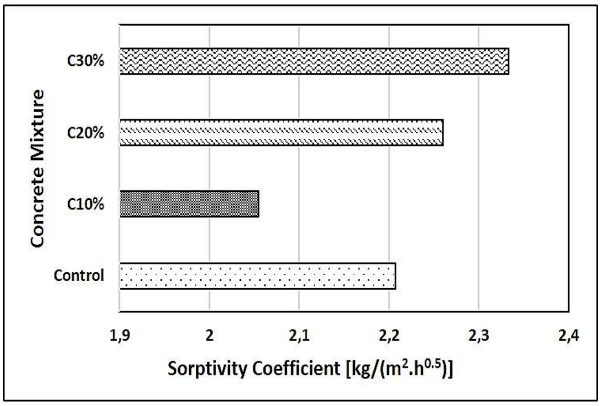

Figure 3. Sorptivity index of concretes at 5 minutes

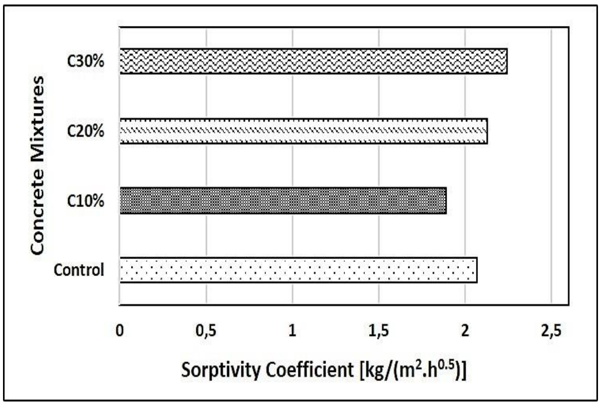

Figure 4. Sorptivity index of concretes at 10 minutes

At the end of the time of 15 min. the high and low sorptivity index value was measured as 1,72 and 2,13 kg/($m^2.h^{0.5}$) for mixtures of again C10 and C30 respectively. The sorptivity index value for C20 was increased by 2.54% when it was compared with C30 as given in Figure 5.

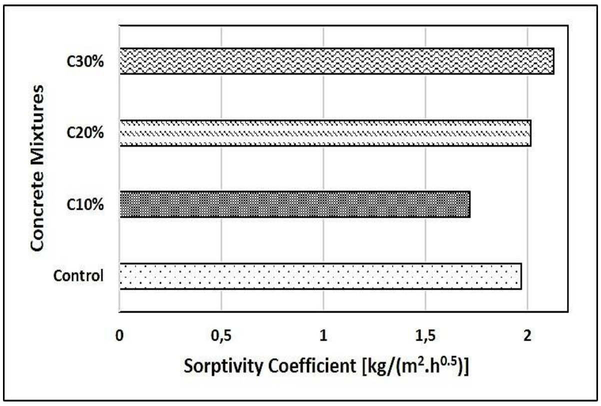

Figure 5. Sorptivity index of concretes at 15 minutes

The sorptivity index was calculated as 1.71, 1.46, 1.89, and 1.92 kg/($m^2.h^{0.5}$) at the end of 30 min. for mixtures CC, C10, C20 and C30 respectively. As shown in Figure 6, it decreased by 14.62% but increased by 10.52% and 12.28% for the mixture of C10, C20 and C30 respectively.

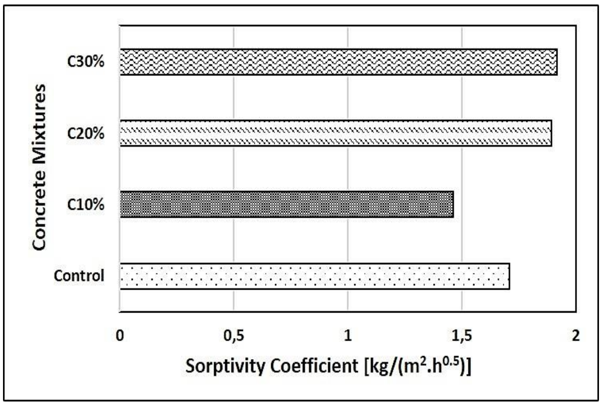

Figure 6. Sorptivity index of concretes at 30 minutes

After exposure to water effect by capillarity suction for 45 min. the sorptivity index shaped as 1,59, 1,30, 1.70, and 1.80 kg/($m^2.h^{0.5}$) for CC, C10, C20 and C30 mixtures respectively. For the 10% content of WCP, the sorptivity decreased by 18,88%. Then, it enhanced with the other replacement ratios by 6.92% for C20 and 13,21% for C30 mixtures when compared with the control concrete mixture presented as in Figure 7.

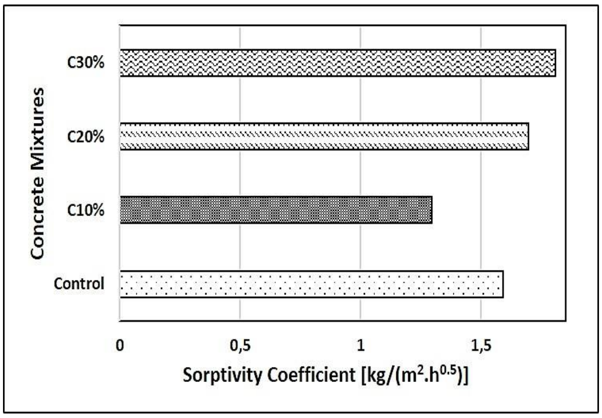

Figure 7. Sorptivity index of concretes at 45 minutes

When the sorptivity index results of 60 minutes of water exposure were examined, it was seen that there were parallel measurements for the WCP content with the other test periods. The sorptivity index decreased again with 10% substitution rate and increased with 20% and 30% other substitution rates. It decreased by 18.49% with 10% incorporation of WCP. However, for C20 and C30 mixtures, an increase of 3.42% and 12.33% was obtained, respectively. The test results were submitted in Figure 8.

When all sorptivity index results were analyzed, it was concluded that up to 10% WCP replacement with cement increased the density and compactness of concrete, resulting in improvements in resistance to water penetration and ingression into the concrete microstructure. However, after a substitution ratio of 10%, it was seen that the sorptivity index enhanced, meaning the weak and porous microstructure compared with control concrete. All sorptivity index results for each concrete mixture are given together in Figure 9 for all time intervals. It is seen that capillary water absorption decreases with 10% WCP incorporation but after that replacement level, it systematically increases for all time exposure.

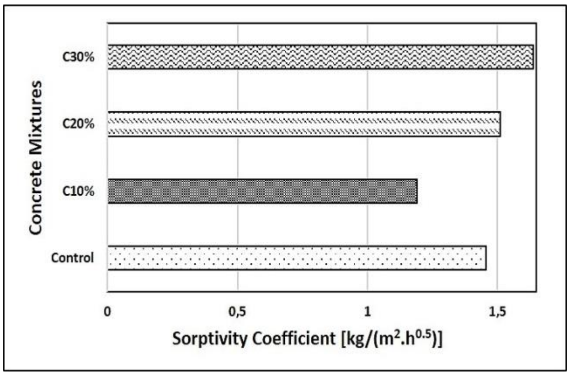

Figure 8. Sorptivity index of concretes at 60 minutes

The linear relationship between 28 days of water absorption by mass and sorptivity index of concrete specimens for all time conducted in the study was given in Figure 10. When all regression analyzes were scrutinized for each time interval, it was concluded that there was a strong linear relationship between the mixture's water absorption and sorptivity index (r>0,75). The highest regression and determination coefficient was measured as 0,91 and 0,83 for 10 min. sorptivity test, and its linear equation was given in Eq. (2):

$$y=0,0879x+1,3076 \tag{2}$$

Where;

y= is the sorptivity (capillary water absorption) ($kg/h^{1/2}$)

x= Water absorption by mass (%) as immersed into water for 28 days.

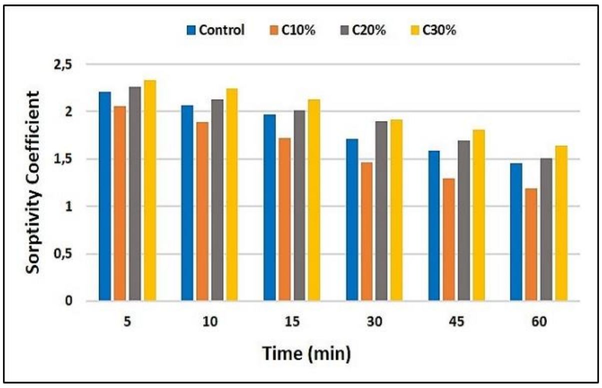

Figure 9. Summarization of sorptivity coefficients of concretes for all periods

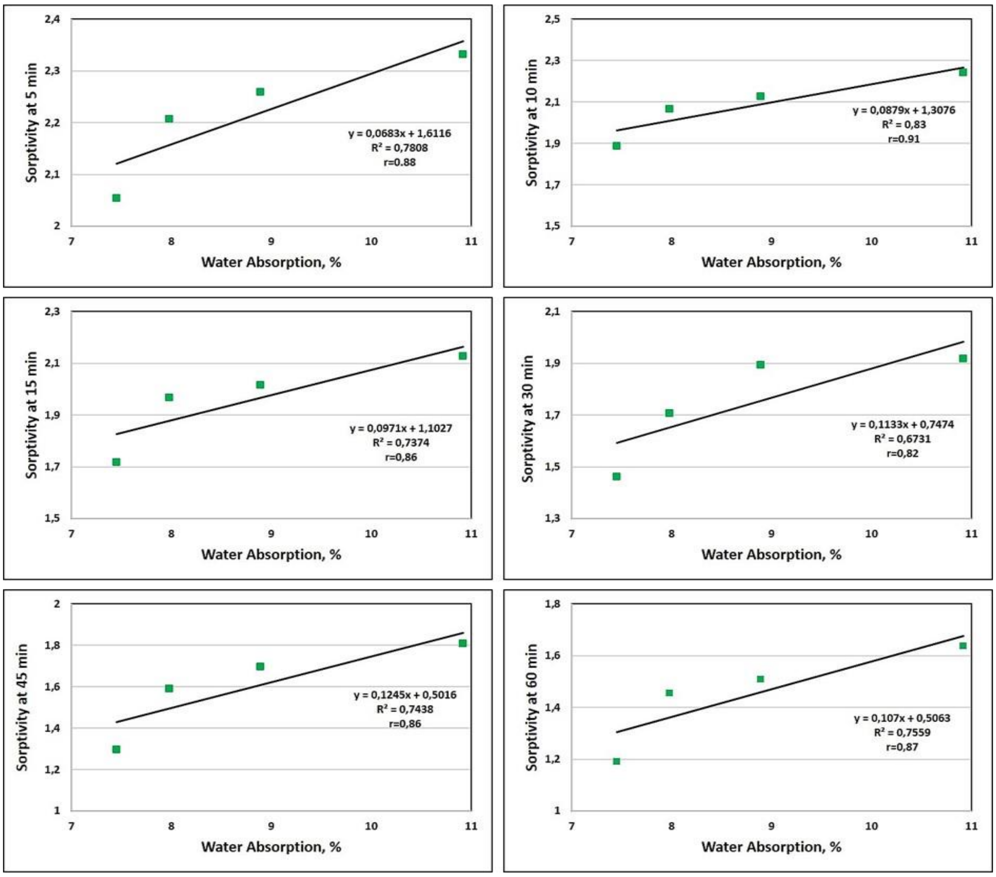

Figure 10. The relationship between water absorption by mass and sorptivity for all period

CONCLUSIONS

The capillary water absorption (sorptivity) of concrete mixtures was affected by the waste ceramic powder (WCP) content. The increase in WCP content up to a level of 10% in concrete mixture resulted in a decrease in the sorptivity index of concrete which was attributed to the improvement in denseness and compactness of the microstructure of concrete and reduction in porous structure or volume of voids. Out of 10% substitution ratios with 20% and 30% examined in this paper, it was deduced that the increase in sorptivity index namely increase in capillary water absorption were observed. This is likely due to resulting in weak microstructure after the 10% replacement ratio occurred, resulting in more water absorption and transition and immersion of water into the concrete structure. From the overall test results, it was concluded that a 10% WCP replacement with cement could act as a better filler to increase the denseness, compactness, and impermeability of the concrete structure, lessen the capillary void and inhibit water transition and immersion into the concrete microstructure. Utilization from WCP to improve the durability of concrete by limiting water absorption through surface interactions is also a beneficial way to minimize the harmful impact of such wastes on the environment and also to minimize cement production, which is responsible for the big portion of carbon dioxide gas emissions. In future studies, it should be considered that other waste materials such as eggshell powder, corncob ash, waste slate dust, in addition to ceramic powder, should be included in the process and evaluated scientifically.

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