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Effect of curing methods on compressive strength of pervious concrete containing silica fume and calcium carbonate

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Abstract

Concrete curing plays a critical role in the development of compressive strength, particularly in pervious concrete, which is highly susceptible to moisture loss due to its porous structure. This study investigates the effects of different curing methods on the compressive strength of pervious concrete and examines how the incorporation of silica fume (SF) and calcium carbonate powder (CC) influences the curing sensitivity index (CSI). Experimental results indicate that water curing consistently yields the highest compressive strength across all pervious concrete mixes at 7 and 28 days, followed by plastic and air curing. The presence of silica fume increases CSI, making pervious concrete more dependent on curing conditions, particularly under air curing. In contrast, calcium carbonate powder reduces CSI, enhancing curing efficiency and mitigating sensitivity to curing variations. Notably, a ternary blend of silica fume and calcium carbonate significantly lowers CSI at early ages, indicating improved curing resilience. However, at 28 days, the effect of CC in mitigating curing sensitivity diminishes slightly, while SF continues to increase curing dependency. These findings suggest that optimal curing strategies should be tailored to the binder composition, with calcium carbonate powder proving effective in stabilizing curing sensitivity. The results contribute to developing more durable and sustainable pervious concrete mixes with enhanced performance under variable curing conditions.

Keywords: Pervious concrete, Curing method, Compressive strength, Curing sensitivity index

1. Introduction

Concrete curing is a crucial process, designed to preserve moisture in freshly poured concrete, ensuring an adequate water supply for the cement's hydration reaction. This process significantly enhances the compressive strength and durability of concrete over time. Previous research has examined and compared the effectiveness of various curing methods. Al-Gahtani [1] found that the compressive strength of concrete cured with wet burlap exceeded that of specimens cured with a curing solution. Similarly, Wongsanga et al. [2] demonstrated that for conventional concrete comprising solely cement as a binding material, the most effective curing methods for achieving optimal compressive strength are water curing, followed by wet burlap curing, wet sand curing, curing with a solution, and air curing, respectively. The curing sensitivity index (CSI) of concrete has been introduced to quantify the sensitivity of a specific mixture of concrete to change in curing methods [3-5]. It was defined as the ratio between the difference in compressive strength of concrete cured under water and that cured in air, calculated in percentage relative to the compressive strength of concrete cured with water.

Pervious concrete is a type of concrete that is designed to have high porosity. It contains a network of internal cavities that are interconnected, creating what is known as the effective void. This porosity is achieved by adjusting the basic ingredients of the concrete. Typically, pervious concrete is made using only Portland cement, water, and coarse aggregate, and it may contain little or no fine aggregate. In general, the effective void content of pervious concrete ranges from 15-35%, the permeability coefficient ranges from 1.4-12.2 mm/s, and the compressive strength ranges from 2.8-28 MPa for pavement applications [6]. This permeability feature enables rapid water infiltration through pervious concrete, making it a favored choice for pavement applications where waterlogging is undesirable, such as roads, parking lots, and walkways [7-9].

The curing process for pervious concrete is more crucial than other concrete types. Typically, on-site curing of pervious concrete involves covering it with plastic to prevent moisture loss. However, pervious concrete is highly susceptible to moisture loss due to its structure of interconnecting cavities and its use as a paving material with substantial surface area exposed to air [10]. Improper curing methods or accidental damage, such as a torn plastic covering, can greatly affect the development of compressive strength in pervious concrete.

Research on the impact of curing methods on pervious concrete properties is comparatively limited. Yusak et al. [11] found that pervious concrete cured with plastic exhibited the highest compressive strength at 28 days. Conversely, pervious concrete cured in water throughout the testing period showed the relatively lowest 28 days compressive strength, compared to other curing methods.

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According to Rangelov et al. [12], the maximum compressive strength values were obtained when pervious concrete was cured in the air for two weeks and then moisture-cured for an additional two weeks. On the other hand, the lowest compressive strength was obtained after continuous air curing. Furthermore, their research indicated that curing in moist ambient conditions for 3 weeks did not contribute to strength enhancement. Yeih and Chang [13] studied the effect of curing methods on the compressive strength of pervious concrete using blast furnace slag as aggregate. It was found that, overall, curing with saturated lime water provides higher compressive strength than curing in air. However, Ibrahim et al. [14] noted that the curing method had minimal impact on the compressive strength of pervious concrete when using oil palm shell ash as an aggregate. They found that curing in water yielded the highest compressive strength. Furthermore, they observed that curing in air or in water for only the initial 3 days resulted in a compressive strength value that was only 5 percent lower than that achieved by continuous water curing.

From the above information, it is evident that most studies have focused on pervious concrete using Portland cement as the sole cementing material. Also, there were conflicting results between the findings of Yusak et al. [11], Rangelov et al. [12], Yeih and Chang [13], and Ibrahim et al. [14]. In addition, silica fume and calcium carbonate powder have been increasingly used as substitute materials for Portland cement in producing pervious concrete [15-23]. These materials aim to enhance the properties of cement paste and reduce the amount of cement used. The incorporation of these materials in pervious concrete may lead to changes in its curing sensitivity index. Therefore, this study aims to achieve two main objectives: 1) to investigate the effect of different curing methods on the compressive strength of pervious concrete, and 2) to examine the impact of incorporating silica fume and calcium carbonate powder into pervious concrete mixtures on their curing sensitivity index.

2. Materials and methods

2.1 Materials

This research used two sizes of crushed limestone coarse aggregate, 3/4" and 3/8" sizes, mixed at a ratio of 50:50 by weight. Properties of the coarse aggregate are shown in Table 1. Portland cement type 1 according to TIS 15-2012 standard [24], which has a specific gravity of 3.15, was used as the main cementing material. Densified silica fume from Elkem (Thailand) Co., Ltd., and calcium carbonate powder (Calcrete F3) from Surin Omya Chemical (Thailand) Co., Ltd., were used to partially replace Portland cement. The chemical and physical properties of cement, silica fume, and calcium carbonate powder are shown in Table 2.

Table 1 Properties of coarse aggregates

Properties	Gravel size	
	Retained on sieve No. 3/4"	Retained on sieve No. 3/8"
Specific gravity	2.71	2.76
Water absorption [%]	0.70	0.81
Rodded unit weight [kg/m^3]	1,510	1,567

Table 2 Chemical and physical properties of Portland cement, silica fume, and calcium carbonate powder

Chemical properties	Portland Cement	Silica Fume	Calcium Carbonate
CaO	70.4	-	-
SiO_2	15.9	85.0	-
Al_2O_3	3.79	-	-
Fe_2O_3	3.71	-	0.02
MgO	0.75	-	-
SO_3	4.22	-	-
K_2O	0.43	-	-
Na_2O	0.18	-	-
$CaCO_3$	-	-	98.5
$MgCO_3$	-	-	0.8
HCl	-	-	1.0
LOI	2.00	-	-
Specific gravity	3.15	2.30	2.70
%Retained on sieve No.325	Not tested	10.0	1.50

2.2 Concrete mix proportions

Six pervious concrete mixtures were tested in this study, as shown in Table 3. The first mix was a controlled pervious concrete that used cement as the sole binder (Control). The second and third mixtures were pervious concrete in which Portland cement was replaced with silica fume at 10 and 20 percent by weight (SF10 and SF20), respectively. The fourth and fifth mixtures were pervious concrete that replaced Portland cement with 10 and 20 percent calcium carbonate powder by weight (CC10 and CC20). The last mixture was a pervious concrete that replaced 20 percent of Portland cement with 10 percent silica fume and 10 percent calcium carbonate powder (SF10CC10). It can be seen that all concrete mixtures used only 264.3 kg/m^3 of cementitious material and used two sizes of crushed limestone aggregate, 3/4" and 3/8", in a ratio of 1:1, with a total stone weight of 1,940.2 kg/m^3. A constant water-to-binder ratio of 0.48 (by weight) was used for every concrete mixture. For pervious concrete containing silica fume and calcium carbonate, a slightly different amount of superplasticizer (SP) (0.3 - 0.5 percent of the weight of the cementitious materials) was required to adjust the liquidity of the cement paste, The use of superplasticizer contributes to improved dispersion of cement particles and enhances the coating of the aggregates.

Table 3 Mix proportions of pervious concrete

Ingredients	Concrete Mixtures (kg/m³)					
	Control	SF10	SF20	CC10	CC20	SF10CC10
OPC	264.3	237.9	211.4	237.9	211.4	211.4
CC	0	0	0	26.4	52.9	26.4
SF	0	26.4	52.9	0	0	26.4
Gravel 3/4"	970.6	970.6	970.6	970.6	970.6	970.6
Gravel 3/8”	970.6	970.6	970.6	970.6	970.6	970.6
Water	127.3	127.3	127.3	127.3	127.3	127.3
SP	0	0.4%	0.5%	0.3%	0.4%	0.4%

OPC = Portland cement, CC = Limestone Powder, SF = Silica Fume, SP = Superplasticizer (% by weight of the total cementitious materials)

2.3 Concrete mixing and sample preparations

The concrete mixing process for each mixture was started by mixing all coarse aggregates and 20% of the mixing water in a mixer for 1 minute. Then, all the cement and cement replacement materials (silica fume and/or calcium carbonate powder) were added. The remaining 80% of the water, which had been mixed with the superplasticizer, was gradually added, and the mixing was continued for 4 minutes, or until it was observed that the cement paste had uniformly coated the surface of all the coarse aggregates. Next, the fresh concrete was poured into cylindrical molds with a diameter of 10 centimeters and a height of 20 centimeters, divided into 3 layers. Each layer was compacted by applying 25 blows of standard compaction hammer, to ensure that the aggregate particles were densely packed in the molds. The molds were then covered with plastic film to prevent water evaporation. After demolding at 24 hours, the concrete samples were cured using three different methods: water curing, plastic curing (wrapping with three layers of plastic film), and air curing. All curing methods were subjected to the same control temperature at 29±2 °C, to ensure that temperature differences do not affect the strength development of the concrete.

2.4 Test methods

Testing of effective void content in this research was conducted following ASTM C1754 [25]. Effective void content refers to the volume of interconnected voids that allow water to permeate through, expressed as a percentage of the concrete specimen's volume. It can be calculated using equation (1)

$$\phi\,(\%) = \left[1 - \frac{(w_2 - w_1)}{\rho_w V}\right] 100 \tag{1}$$

where ϕ is the effective void content (%), V is the volume of the pervious concrete specimen (cm³), w_1 is the weight of the pervious concrete specimen weighed in water (g), w_2 is the weight of the pervious concrete specimen in a saturated surface-dry condition (g), and ρ_w is the density of water (g/cm³)

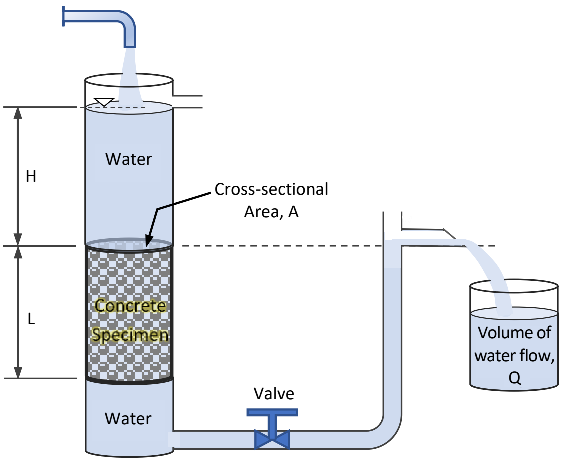

Figure 1 Test setup for constant head permeability of pervious concrete

The permeability test in this study was carried out using the constant head permeability test setup, as shown in Figure 1, which is suitable for determining the permeability of highly porous materials [7]. The permeability of the material is assessed based on the permeability coefficient, which can be calculated using equation (2), where k is the water permeability coefficient (mm/s), Q is the volume of water passing through the specimen (cm³), L is the height of the specimen (mm), A is the cross-sectional area of the specimen (cm²), H is the height of the water level causing the flow (cm), and t is the time taken for the test (s).

$$k = \frac{QL}{AHt} \tag{2}$$

The compressive strength test of the pervious concrete was conducted following ASTM C39 [26], using cylindrical test specimens with a diameter of 10 centimeters and a height of 20 centimeters. The tests were performed at 7 days and 28 days, with 5 specimens tested at each age to determine the average compressive strength reported in this article.

3. Results and discussions

3.1 Effective void content of pervious concrete

Figure 2 compares the effective void content of different pervious concrete specimens, based on the average values from 3 concrete samples. Overall, the effective void content varies within a narrow range of 13.20% to 18.94%. The pervious concrete made entirely from cement (Control) has an effective void content of 15.91%, which is close to the minimum threshold of void content (15%) for pervious pavement, as recommended by ACI [6]. The pervious concrete mixed with 10% silica fume (SF10) has the lowest effective void content of 13.20%. In contrast, the concrete mixed with 10% calcium carbonate (CC10) has the highest of 18.94%. The variations in effective void content among pervious concrete mixes can be attributed to the effects of specific gravity, particle size, and reactivity of the cement replacement materials. The lower effective void content of the SF10 sample may be dominated by the effect of material-specific gravity. Since silica fume has a lower specific gravity (2.3) than cement (3.15), its replacement increases the overall paste volume [27], leading to reduced effective void contents. In contrast, calcium carbonate has a higher specific gravity (2.7) than silica fume, contributing less to paste volume increase. In addition, the extremely fine particle sizes of calcium carbonate powder, with 1.5% retained on sieve No.325, are believed to be the key mechanism in refining the microstructure of the paste [28], leading to a reduced paste volume and increased effective void contents of the CC10 sample. The sample containing both silica fume and calcium carbonate (SF10CC10) has an intermediate void content of 17.11%, as the beneficial effect of silica fume in reducing voids is partially compensated by the presence of calcium carbonate. Nevertheless, all of the above-mentioned mechanisms may work concurrently, making a complex physicochemical effect on the volumetric change of cement paste. Further systematic experimental research is needed to elucidate this phenomenon.

Overall, it is evident from the above data that replacing cement with 10% to 20% silica fume and/or calcium carbonate powder has a minimal effect on the effective void content. This can be attributed to the increased viscosity of pastes containing silica fume and/or calcium carbonate powder, which necessitates a higher dosage of superplasticizer to achieve the desired fluidity. When the viscosity of the modified paste closely matches that of the control, only minor changes in the effective void content are observed.

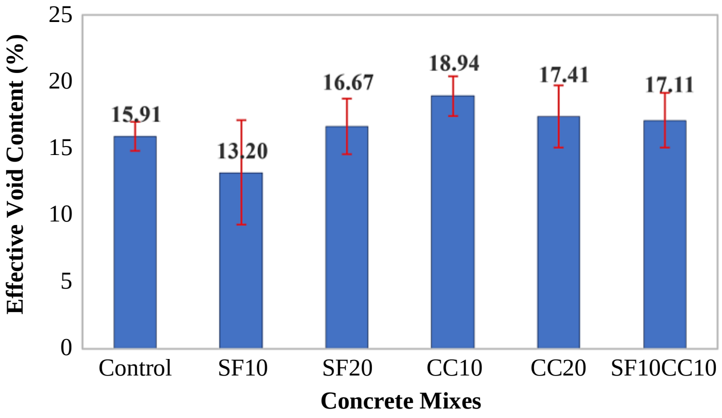

Figure 2 Effective void content of pervious concrete

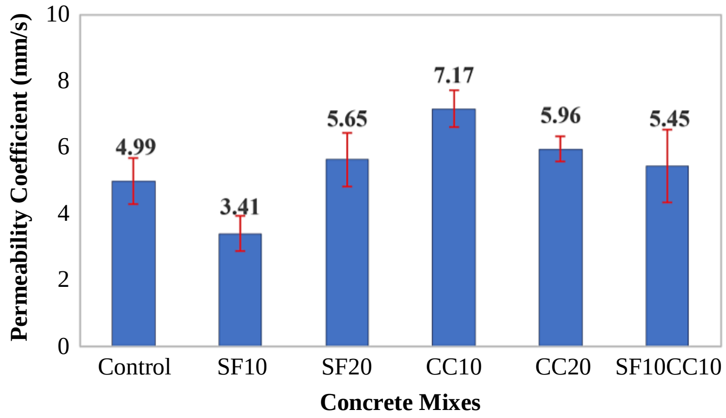

Figure 3 Water permeability of pervious concrete

3.2 Water permeability of pervious concrete

Figure 3 compares the water permeability coefficient of various pervious concrete specimens, based on the average values from 3 concrete samples. The figure shows that the trend of variation in the permeability coefficient is similar to that of the effective void content. The concrete mixed with 10% silica fume (SF10) has the lowest permeability coefficient of 3.41 mm/s, while the concrete mixed with 10% calcium carbonate (CC10) has the highest of 7.17 mm/s. This indicates that the permeability of pervious concrete tends to correlate with the effective void content.

3.3 Relationship between water permeability and effective void content

Figure 4 shows the relationship between the permeability coefficient and the effective void content of the pervious concrete specimens. It can be observed that these two properties exhibit a linear relationship: as the effective void content increases, the water permeability coefficient of the concrete also increases proportionally. The linear regression equation y = 0.636x−5.084 indicates that for every 1% increase in effective void content, the permeability coefficient increases by approximately 0.636 mm/s. The R^2 = 0.975 suggests a strong correlation between these variables. This finding is consistent with previous research that studied the properties of pervious concrete made with coarse aggregates of three sizes and found a linear relationship between permeability coefficient and effective void content [7]. Although the effective void content of the concrete studied in this research ranges from 13.20% to 18.94%, whereas in the previous study [7], it ranged from 21.2% to 25.9%, indicating that the pervious concrete with two-size coarse aggregates in this study exhibits a pore structure similar to that of pervious concrete made with coarse aggregates of three sizes. Therefore, the linear relationship between permeability and effective void content remains similar.

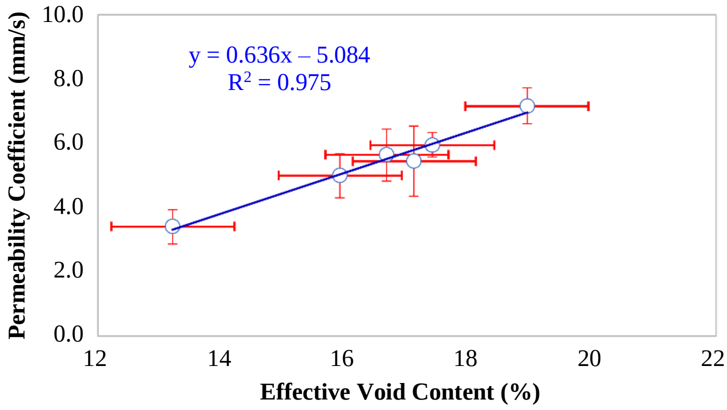

Figure 4 Relationship between water permeability coefficient and effective void content of pervious concrete

3.4 Effect of curing methods on compressive strength

Figures 5(a) and (b) provide a comparison of the compressive strength of different pervious concrete mixes subjected to various curing methods for 7 and 28 days, respectively.

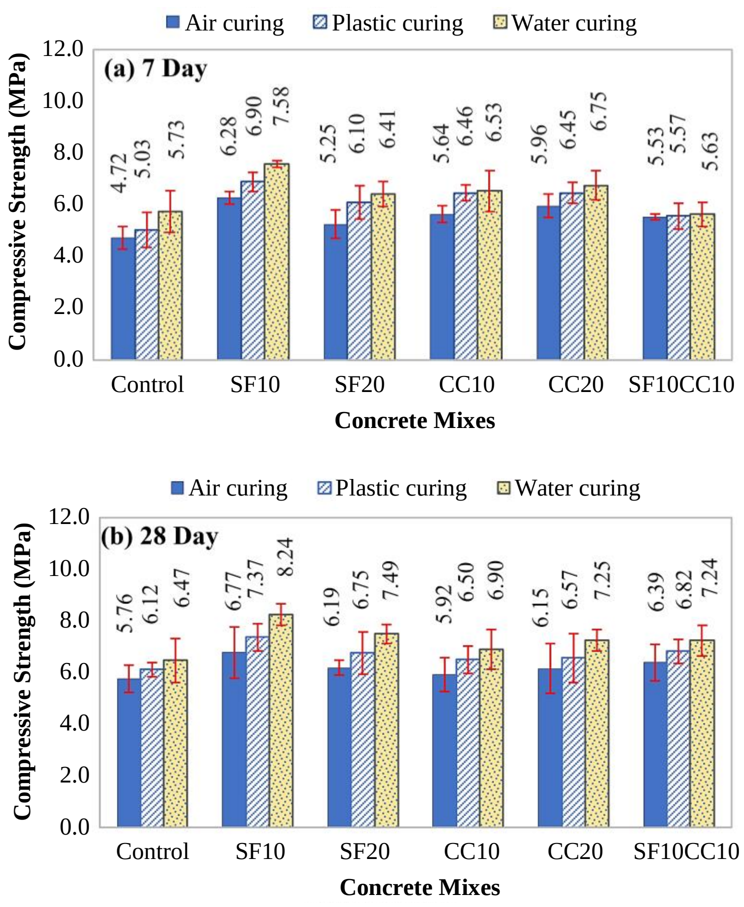

Figure 5 Compressive strength of pervious concrete: (a) at 7 days, (b) at 28 days

For 7 days of curing, it can be seen from Figure 5(a) that water curing consistently produces the highest compressive strength across all concrete mixes, followed by plastic curing and, lastly, air curing. For the Control group, which relies solely on cement as the binder, the compressive strengths achieved are 5.73 MPa, 5.03 MPa, and 4.72 MPa for water curing, plastic curing, and air curing, respectively. Similarly, the SF10 pervious concrete, where 10% of the cement is replaced with silica fume, attains compressive strengths of 7.58 MPa, 6.90 MPa, and 6.28 MPa for the respective curing methods. Following a similar trend, the CC10 pervious concrete, with 10% of the cement replaced by calcium carbonate, achieves compressive strengths of 6.53 MPa, 6.46 MPa, and 5.64 MPa for water curing, plastic curing, and air curing, respectively. However, for the mix with trinary blended binders (SF10CC10), the 7-day compressive strengths obtained from the three curing methods are not different, ranging between 5.5 – 5.6 MPa.

For 28 days of curing (Figure 5(b)), the influence of the curing method on compressive strength remains pronounced, mirroring the trends observed at 7 days. Specifically, water curing continues to yield the highest compressive strength, followed by plastic curing and then air curing. However, the influence of curing methods becomes more evident in the mix SF10CC10, in which water curing, plastic curing, and air curing yield 28-day compressive strength of 7.24 MPa, 6.82 MPa, and 6.39 MPa, respectively. These findings align with the research conducted on pervious concrete with blast furnace slag aggregate by Yeih and Chang [13]. Furthermore, Wongsanga et al. [2] also reported a similar effect of curing on compressive strength of normal concrete, in which water curing exhibited 14.0%–18.2% higher compressive strength at 28 days, as compared to air curing.

Figure 5 also illustrates the effect of increasing the silica fume replacement on compressive strength, showing a noticeable reduction in strength. For example, after 7 days of water curing (Figure 5(a)), the SF20 mix achieves a compressive strength of 6.41 MPa, which is 15.4% lower than the 7.58 MPa recorded for the SF10 mix. Similarly, at 28 days of underwater curing (Figure 5(b)), the compressive strength of the SF20 mix is 9.1% lower than that of the SF10 mix. These findings are consistent with those of Pradhan and Behera [19], who reported that an 8% replacement of cement with silica fume yields the highest compressive strength, while higher replacement levels result in strength reductions. Seeni et al. [20] also noted that a 15% replacement of cement with silica fume is optimal for balancing the physical, hydrological, and mechanical properties of pervious concrete. Kumar and Srikanth [22] explained that higher silica fume replacement levels reduce compressive strength because the paste lacks sufficient calcium hydroxide to react with the silica fume.

Conversely, compressive strength is slightly improved by increasing the calcium carbonate replacement percentage from 10% to 20%. For example, at 7 days of water curing (Figure 5(a)), the compressive strength of the CC20 mix is 6.75 MPa, which is 3.4% higher than the 6.53 MPa recorded for CC10. At 28 days of water curing (Figure 5(b)), CC20 exhibits a 5.1% strength enhancement in comparison to CC10. This can be attributed to the extremely fine particles of the calcium carbonate powder. Fine particle sizes could have a better pore-filling effect and refine the packing density, making a dense microstructure of the paste [29-31]. Furthermore, its high surface provides precipitation sites for cement hydration products, accelerating the hydration process of the cement [32].

The results highlight the significant impact of curing methods on the compressive strength of pervious concrete mixes. Water curing always provides the maximum compressive strength across all mixes, particularly in concrete with silica fume replacements (SF10 and SF20), where the strength is notably enhanced compared to other curing methods. This demonstrates the critical role of moisture in achieving optimal hydration and strength development, especially for mixes containing supplementary cementitious materials like silica fume. In contrast, air curing yields the lowest compressive strengths for all concrete types, indicating insufficient moisture retention and incomplete hydration, which leads to weaker concrete. Plastic curing falls between air and water curing, but its performance is closer to that of water curing, suggesting that it can be a practical alternative when water curing is not possible.

The combination of silica fume and calcium carbonate (SF10CC10) also benefits significantly from water curing, showing that these materials work synergistically when moisture is adequately maintained. Overall, the findings emphasize the importance of proper curing, particularly water curing, to maximize the strength of the pervious concrete, especially when using supplementary materials.

3.5 Effect of silica fume and calcium carbonate powder on curing sensitivity

The curing sensitivity of various pervious concrete can be evaluated through the curing sensitivity index (CSI), as shown in Equation (3), where ${f_c}'_{wc}$ is the compressive strength of water-cured concrete, ${f_c}'_{non-wc}$ is the compressive strength of concrete cured in the air or with plastic. A higher CSI value indicates a greater sensitivity of the concrete to the curing method employed.

$$CSI = \left(\frac{{f_c}'_{wc} - {f_c}'_{non-wc}}{{f_c}'_{wc}}\right)100 \tag{3}$$

Figure 6(a)-(b) compares the CSI values of different pervious concrete mixes cured under various curing methods at 7 and 28 days, respectively. At 7 days of age, it can be seen from Figure 6(a) that the effect of silica fume (SF) on the curing sensitivity index (CSI) varies depending on the curing method.

Under air curing, the CSI of concrete increases with an increasing silica fume replacement level. The CSI of SF10 concrete (17.21%) is slightly lower than that of the control concrete (17.64%), but SF20 concrete exhibits a higher CSI of 18.13%. This trend suggests that incorporating silica fume enhances the curing sensitivity of the pervious concrete, making it more dependent on proper curing conditions. In contrast, under plastic curing, the CSI values are significantly lower, with SF10 and SF20 showing CSI values of 9.06% and 4.86%, respectively, compared to 12.23% for the control mix. This indicates that silica fume improves the concrete's performance under plastic curing by reducing its sensitivity to curing variations. It can be hypothesized that the negative impact of silica fume on curing sensitivity of the pervious concrete is due to the greatly decreased pozzolanic reaction rate of silica fume when the internal moisture content of the concrete sample was lower, especially when the curing method was changed from water curing to air curing. This hypothesis is supported by the work of Atiş et al. [33], who discovered that the compressive strength of concrete mixed with silica fume cured at 65% RH was approximately 13% lower than that of concrete mixed with silica fume cured at 100% RH, and this difference increased with the silica fume replacement ratio.

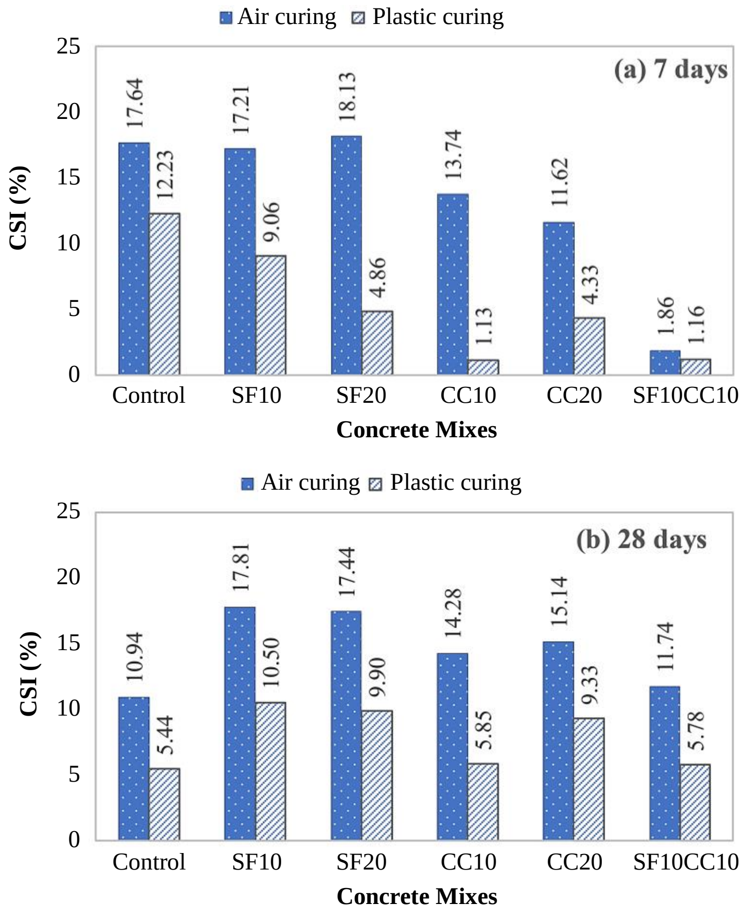

Figure 6 Curing sensitivity index (CSI) of pervious concrete: (a) at 7 days and (b) at 28 days

The incorporation of calcium carbonate powder (CC) in concrete mixtures affects the CSI differently from silica fume. For air curing, the replacement of 10% and 20% of Portland cement with calcium carbonate powder reduces the CSI values to 13.74% (CC10) and 11.62% (CC20), respectively, compared to the control mix (17.64%). This suggests that calcium carbonate powder reduces the curing sensitivity of concrete, making it less dependent on curing conditions. Similarly, under plastic curing, the CSI values of CC10 and CC20 are lower than the control mix, with values of 1.13% and 4.33%, respectively. This indicates that calcium carbonate powder can improve the curing efficiency of concrete by reducing its reliance on proper curing methods, particularly at higher replacement levels. This is consistent with the research findings of Srijan et al. [3], Hussain et al. [4], and Hussain et al. [5], which state that the use of limestone powder lowers the CSI of regular concrete. It can be anticipated that calcium carbonate powder, which has a similar chemical composition to limestone powder, could accelerate the hydration of cement, especially at an early age [34]. Consequently, a considerable amount of the cement reacts at an early age, improving the pore structure of the paste, and lowering the CSI of the pervious concrete.

The combined effect of silica fume (SF) and calcium carbonate powder (CC) on the curing sensitivity index (CSI) in the SF10CC10 mix shows a significant reduction in CSI compared to mixes containing only silica fume. Under air curing, the CSI of SF10CC10 is only 1.86%, which is much lower than that of SF10 (17.21%) and SF20 (18.13%). Similarly, under plastic curing, the CSI of SF10CC10 is 1.16%, which is also significantly lower than the corresponding values for SF10 (9.06%) and SF20 (4.86%). This indicates that the combination of silica fume and calcium carbonate powder significantly reduces the curing sensitivity of concrete, making it less dependent on the curing method. The reduction in CSI suggests that calcium carbonate powder helps counteract the increased curing sensitivity caused by silica fume, leading to a more stable and less curing-dependent concrete mixture.

At 28 days of curing (Figure 6(b)), the curing sensitivity index (CSI) values at 28 days exhibit some key differences compared to the 7-day results. Generally, the CSI values of the control pervious concrete decrease over time, indicating that the influence of curing conditions becomes less significant as hydration reactions continue.

For the pervious concrete with silica fume, the CSI values for SF10 and SF20 under air curing remain high at 17.81% and 17.44%, respectively, which are still greater than the control mix (10.94%). This confirmed that silica fume increases the curing sensitivity of concrete over both short- and long-term curing durations. However, compared to the 7-day results (17.21% for SF10 and 18.13% for SF20), the CSI values at 28 days show only slight reductions. This suggests that silica fume continues to increase the curing dependency of the pervious concrete, even at later ages. Under plastic curing, the CSI values for SF10 and SF20 at 28 days are 10.50% and 9.90%, respectively, which are slightly higher than their 7-day values (9.06% and 4.86%). This indicates that while silica fume improves long-term strength, it remains sensitive to curing conditions, particularly in air-curing environments.

For the pervious concrete with calcium carbonate, it can be seen that, under air curing, CC10 and CC20 exhibit CSI values of 14.28% and 15.14%, respectively, which are marginally higher than their 7-day values (13.74% and 11.62%). This suggests that while calcium carbonate powder initially helps reduce curing sensitivity, its effect may diminish slightly over time. Under plastic curing, the CSI values for CC10 and CC20 at 28 days (5.85% and 9.33%) are still lower than those of silica fume mixes, although they increase when compared to their 7-day values (1.13% and 4.33%).

For the ternary mixed binders, the CSI value of the SF10CC10 mix is 11.74% under air curing, which is much lower than SF10 and SF20 but somewhat higher than the control mix. This is still a significant increase over the 7-day CSI of 1.86%, demonstrating that while the combination of silica fume and calcium carbonate powder efficiently lowers early-age curing sensitivity, its long-term effects are substantially lessened. Under plastic curing, the CSI value of SF10CC10 at 28 days (5.78%) is somewhat higher than at 7 days (1.16%), indicating that the mix benefits from better curing efficiency but does not strongly mitigate curing sensitivity with time.

4. Conclusions

From the above experimental results, it can be concluded that

1) The curing method plays a crucial role in determining the compressive strength of pervious concrete. Among the methods examined, water curing consistently results in the highest compressive strength across all mix designs, followed by plastic curing, while air curing produces the lowest strength. This trend remains consistent at both 7 and 28 days, highlighting the significance of proper curing in optimizing concrete performance.
2) The incorporation of silica fume increases the curing sensitivity of pervious concrete, as evidenced by higher CSI values under air curing compared to the control mix. This suggests that silica fume requires effective curing to achieve optimal strength due to its high pozzolanic reactivity.
3) Calcium carbonate powder reduces the curing sensitivity, particularly at early ages, as seen in the lower CSI values for CC10 and CC20 mixes. This indicates that calcium carbonate powder enhances early hydration, making the concrete less dependent on curing conditions.
4) The combination of silica fume and calcium carbonate powder (SF10CC10) significantly reduces CSI at 7 days, demonstrating improved curing efficiency. However, at 28 days, the CSI of SF10CC10 slightly increases, suggesting that while the combined effect is beneficial in early curing stages, long-term strength development still depends on proper curing practices.

5. Acknowledgements

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