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Araştırma / Research

BASIC DURABILITY PROPERTIES OF STANDARD MORTARS PRODUCED WITH RECYCLED GLASS POWDER

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ABSTRACT

This research presents the basic durability properties of standard mortars (SMs) produced with recycled glass powder (RGP). In this study, six SM mixtures as well as control mixture were designed with constant water/binder (w/b) ratio of 0.48. In the mixtures, cement was replaced by RGP partially ranging from 0% to 30% by steps of 5% increment. Firstly, the slump flow diameters of SMs are determined and then the basic durability properties of SMs were observed in terms of water sorptivity, rapid chloride permeability and gas permeability. Finally, the relations between basic durability properties were determined for 7 and 28 days. According to test results, it is found that the RGP increased the workability of SMs. In addition, the highest durability performance was determined for SM incorporating 5% RGP. However, basic durability performances of SMs incorporating 10% RGP were also identified as higher than that of the control mixture. When the correlation coefficients are considered, strong relationships between durability properties are determined.

Keywords: Standard mortar; durability properties; recycled glass powder; correlation coefficient

GERİ DÖNÜŞTÜRÜLMÜŞ CAM TOZUYLA ÜRETİLEN STANDART HARÇLARIN TEMEL DURABİLİTE ÖZELLİKLERİ

ÖZ

Bu araştırmada geri dönüştürülmüş cam tozuyla (GDCT) üretilen standart harçların (SH) temel durabilite özellikleri değerlendirilmektedir. Bu çalışmada, kontrol karışımının yanı sıra altı SH karışımı 0,48 sabit su/bağlayıcı oranıyla tasarlanmıştır. Karışımlarda, çimento %0'dan %30'a kadar %5 artışlarla kısmen GDCT ile yer değiştirilmiştir. İlk aşamada, SH'lerin yayılma çapları belirlenmiş, sonrasında SH'lerin temel durabilite özelliklerinden kılcal su geçirimliliği, hızlı klor geçirimliliği ve gaz geçirimliliği sonuçları üzerine etkileri gözlemlenmiştir. Son olarak, temel durabilite özellikleri arasındaki ilişkiler 7 ve 28 gün için belirlenmiştir. Deney sonuçlarına göre, GDCT'nin SH'lerin işlenebilirliğini artırdığı tespit edilmiştir. Ayrıca, en yüksek durabilite performansı %5 GDCT içeren SH için belirlenmiştir. Bununla birlikte, %10 GDCT içeren SH'lerin temel durabilite performanslarının kontrol karışımından daha yüksek olduğu tespit edilmiştir. Korelasyon katsayıları değerlendirildiğinde, durabilite özellikleri arasında güçlü ilişkiler olduğu tespit edilmiştir.

Anahtar Kelimeler: Standart harç; durabilite özellikleri; geri dönüştürülmüş cam tozu; korelasyon katsayısı

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1. INTRODUCTION

In the recent years, the increased attention of waste material reuse, new eco-compatible products manufacturing and environmental problems led to set objectives the European Commission. Supporting municipal waste recycling up to 65% level and decreasing landfill to a maximum of 10% level by 2030 are some of these objectives [1,2]. Therefore, supplementary cementitious materials (SCMs) such as silica fume which is a by-product of silicon and/or ferrosilicon alloy production, fly ash which is a waste-product formed by the burning of coal or blast furnace slag which is a by-product of pig iron production have been utilized extensively to partially replace Portland cement in concrete or mortar. For example, the cement manufacturers in the Europe have substituted 25% of cement clinkers with SCMs, in the past 20 years [3]. The SCMs used instead of cement such as silica fume, fly ash and blast furnace slag presents environmental advantages by providing decrease in solid waste disposal and landfills. In addition, the utilization of natural resources, carbon dioxide emission and energy consumption could be reduced during the cement production process by using SCMs [4].

One of the SCMs used in concrete or mortar is recycled glass powder (RGP). The utilization of RGP in new material production in the glass industry is not recommended because of the final products will have poor quality. Moreover, impurity removal and colour sorting processes of glass are expensive [2,5]. Glass waste incineration forms problems because of the solid residue could contain hazardous materials [2,6]. Therefore, the use of RGP as a viable SCM in addition to silica fume, fly ash and blast furnace slag has received increased awareness due to the rising cost of local virgin materials and the environmental impact of replacing cement in construction industry [7-11]. In addition, the finely ground (38–45 μm) RGP with high silica content (SiO_2 > 70%), amorphous nature and high surface area propose that RGP could be used as an alternative SCM to partially replace cement in concrete or mortar [12-15]. It is known that, SCMs are widely used in concrete or mortar to extend their service life and develop their durability characteristics [16]. Previous studies have demonstrated that micro-scale size RGPs develop the durability performances of concrete or mortar [8-10, 17,18]. Additionally, the pozzolanic property of RGP with a micro-scale size distribution contributes improvement in the mechanical and durability performances of concrete or mortar [7,9,10,19,20]. However, there can be some negative effects of RGP usage in concrete or mortar. The high alkali content of RGP can be important problem for its utilization in mortar or concrete [21]. Depending on their types, glasses include Na_2O in the ranges of 9-21% [22]. However, when the particle size of glass is reduced to 300 μm or finer, glass particles do not cause alkali–silica reaction [23].

When the abovementioned literature information have been taken into account, it was thought that the effect of RGP on the durability properties of SMs should be investigated which is not studied in detail in the previous researches. Therefore, the slump flow diameter and durability properties of SM incorporating RGP in the ratios of 0%, 5%, 10%, 15%, 20%, 25% and 30% were evaluated in this study. SMs were tested for their water sorptivity, rapid chloride permeability and gas permeability at the ages of 7 and 28 days. In addition, the relationships between rapid chloride permeability/water sorptivity coefficient, apparent gas permeability coefficient/water sorptivity coefficient and rapid chloride permeability/water sorptivity coefficient were determined for 7 and 28 days.

2. EXPERIMENTAL PROGRAM

2.1. Materials

In this experimental study CEM I 42.5 R Portland cement (PC) was used for producing of SMs. RGP was utilized as a secondary binder material. Chemical and physical properties of PC and RGP are listed in Table 1. In addition, standard sand (CEN reference sand) was used as fine aggregate in the SMs. CEN reference sand is round grained and contains SiO_2 of approximately 98% in its chemical composition.

2.2. Mortar mixture proportioning and casting

Seven SM mixtures were produced with constant water/binder ratio of 0.48 and total binder (PC+RGP) content of 500 kg/m^3. The mixture proportions were given in Table 2. Mixtures were named depending on RGP usage percentage. For example, SM30 is standard mortar containing 30% RGP replacement with PC. In addition, all SM mixtures were produced according to ASTM C305-12 standard [24].

Table 1. Chemical and physical properties PC and RGP

Chemical Composition (%)	PC	RGP
CaO	62.58	9.89
SiO_2	20.25	71.79
Al_2O_3	5.31	1.04
Fe_2O_3	4.04	0.11
MgO	2.82	4.1
SO_3	2.73	0.23
K_2O	0.92	0.2
Na_2O	0.22	12.41
Physical Properties		
Loss of Ignition	2.96	-
Specific Gravity	3.15	2.60
Blaine Fineness (m^2/kg)	326	-

Table 2. Mixture proportions of SMs (kg/m^3)

Mix. Code	w/b	Water	PC	RGP	Standard Sand
SM0	0.48	242	500	0	1375
SM5	0.48	242	475	25	1375
SM10	0.48	242	450	50	1375
SM15	0.48	242	425	75	1375
SM20	0.48	242	400	100	1375
SM25	0.48	242	375	125	1375
SM30	0.48	242	350	150	1375

2.3. Test Procedures

2.3.1. Slump Flow Test

Slump flow diameters of SM mixtures were determined with the aid of ASTM C1437-15 [25]. During testing firstly, a layer of mortar about 25 mm in thickness was placed in the mold and then tamped 20 times with the tamper. After the mold was filled with mortar for the second time, it was tamped with the tamper as specified for the first layer. The surface of the mold was smoothed with a trowel. The mold was lifted away from the mortar. The table was dropped 25 times in 15 s. Finally, the slump flow diameters of spreading mortars were determined in two perpendicular directions. In addition, the photographic view of measurement of slump flow diameter for SM5 mixture is indicated in Figure 1.

Figure 1. Slump flow diameter of SM5

2.3.2. Water Sorptivity Test

The test was performed on the three disc specimens of 50 mm height and 100 mm diameter. Firstly, the test samples have to be fully dried. Therefore, test samples were dried in an oven at 100±5 °C until they reached constant mass. The time required for this was approximately 24 hours. Afterwards, the sides of the samples were covered with the aid of a waterproof material. The water sorptivity test was performed by setting the samples on glass rods in a small tray such that their bottom surfaces were in contact with a thin water layer of about 5 mm high. This test procedure permits free water movement through the bottom surfaces of the test samples. Mass variation data were gathered during the tests at various time intervals from 0 to 64 min. In order to measure the water sorptivity coefficient, the volume of water soaked up was plotted graphically according to the square root of time. The slope of the line showed water sorptivity coefficient. The water sorptivity coefficients of SM mixtures by using the test device given in Figure 2 were determined at 7 and 28-day. The relation used for calculation of sorptivity is given in Equation 1.

$$I = S'\sqrt{t} \tag{1}$$

Where, S' is sorptivity (mm/min$^{1/2}$) and I is cumulative infiltration (mm) at time t (min).

Figure 2. Water sorptivity test set-up

2.3.3. Rapid Chloride Permeability Test

An experimental setup was followed to measure the resistance of SM mixtures against chloride ion penetration as shown in Figure 3. Rapid chloride permeability test was performed as suitable to ASTM C1202 [26] on three mortar discs with 50 mm height and 100 mm diameter. The resistance of vacuumed mortar (Figure 3a) against the penetration of the chloride ions was determined in terms of charge passed through the mortar according to ASTM C1202 [26]. The permeability level of SM mixtures could be estimated by comparing the total charge, after 6h, with the permeability scale presented in Table 3. The test results were presented by taking the averages of three mortar specimens. The test was applied on all samples at 7 and 28-day.

Table 3. Permeability scale for chlorides, ASTM C1202 [26]

Charge Passed, Coulombs	Permeability Chloride
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very Low
<100	Negligible

(a) (b)

Figure 3. (a) Vacuum device and (b) RCPT test set up

2.3.4. Gas Permeability Test

Gas permeability values of the mortar were determined on 50 mm high and 100 mm diameter disk samples cut from mortar cylinders according to the CEMBUREAU method a proposed by RILEM TC 116-PCD [27]. Firstly, mortar samples were dried at 50±5 °C and then left to cool to environment temperature in a closed container. Oxygen gas was used as the permeating medium. Three different inlet gas pressures as 150, 200 and 300 kPa were applied to the all samples. Gas permeability coefficients were calculated for each level by using Hagen–Poiseuille relationship for laminar flow of a compressible fluid through a porous media with small capillaries under steady-state condition. Apparent gas permeability coefficient was the average of these coefficients as recommended by RILEM TC 116-PCD [27]. The photographic views of the gas permeability test apparatus are shown in Figure 4. The apparent gas permeability coefficient (K_a) can be computed utilizing the modified Darcy's equation (Equation 2) as follows:

$$K_a = \frac{2P_2QL\eta}{A(P_1^2 - P_2^2)} \qquad (2)$$

Where K_a is the gas permeability coefficient (m^2), Q is rate of flow of air bubble (m^3/sn), L is the height of sample (m), η is the viscosity of oxygen ($2.02x10^{-5}$ Nsn/m^2), A is the cross-sectional area of the sample (m^2), P_1 is the inlet gas pressure (N/m^2) and P_2 is the outlet gas pressure (N/m^2). Three samples for each mortar mixture were tested at 7 and 28-day and the average of them were identified as the test result.

Figure 4. Gas permeability test set-up

3. RESULTS AND DISCUSSION

3.1. Slump Flow Diameter

The slump flow diameter variations of SMs are presented in Figure 5. The slump flow diameters for SM mixtures produced in this study ranged between 16.67 and 17.08 cm. Within this range, the lowest slump flow diameter was measured for the control mixture while the SM mixture with 30% RGP had the highest slump flow. Therefore, as seen in Figure 5, the workability of SM improved with increased RGP content. For example, the workability of SM30 mixture increased by as much as 2.46% compared to SM0 mixture. In parallel to this result, Afshinnia and Rangaraju [28] reported that glass powder used instead of cement increased considerably the workability of concrete.

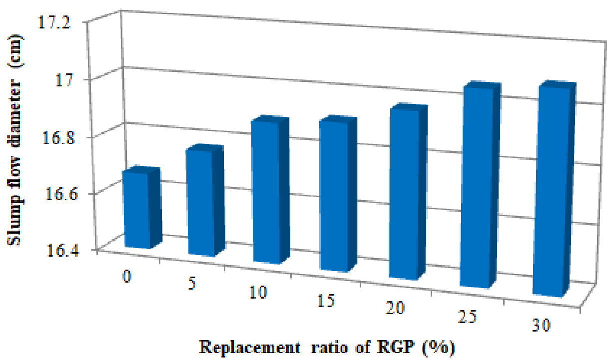

Figure 5. Slump flow diameter variations of SMs

3.2. Water Sorptivity, Rapid Chloride Permeability and Gas Permeability

The variations of the water sorptivity coefficient for 7 and 28 days according to the replacement level of RGP are shown in Figure 6. The water sorptivity coefficients of SMs changed in the range of 0.0950-0.2118 mm/min$^{0.5}$ for 7 days and in the range of 0.0893-0.1389 mm/min$^{0.5}$ for 28 days. According to test results, SM incorporating 5% RGP exhibited a decrease in water sorptivity coefficient at both test ages. After this level (5% RGP content), the water sorptivity coefficient increased with increasing replacement level of RGP at both ages. However, the water sorptivity coefficient of SM incorporating 10% RGP was lower than that of control mixture for 7 and 28 days. Therefore, SMs incorporating RGP in the ratios of 5% and 10% improved water sorptivity coefficient.

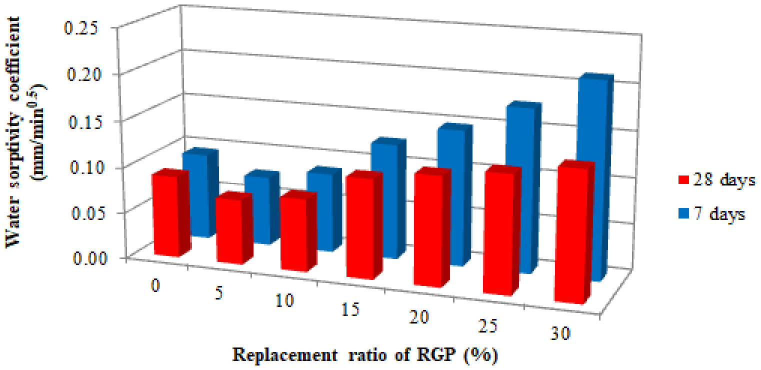

Figure 6. Variation of water sorptivity coefficients of SMs

The variation of the chloride ion permeability with respect to the RGP content is presented as Coulombs (C) in Figure 7. The best results in terms of chloride ion permeability were obtained from mixture containing 5% RGP. The chloride ion permeability for SM5 mixture was determined as 7146 C and 5756 C for 7 and 28 days, respectively. As illustrated in Figure 7, after 5% RGP content, increasing the replacement level of RGP caused an increase in chloride ion permeability at 7 and 28 days. However, rapid chloride permeability values of SM5 and SM10 mixtures were lower than that of SM0 mixture at both ages. Therefore, it can be said that RPG is useful up to 10% level for 7 and 28 days. According to permeability scale for chlorides in the ASTM C1202 [26], all of the SM mixtures have been shown ‘‘High Permeability Chloride’’ for 7 and 28 days. This ‘‘High Permeability Chloride’’ can be explained with high water/binder ratio of SM mixtures. In addition, the chloride ion permeability of SMs can decrease with increased test time.

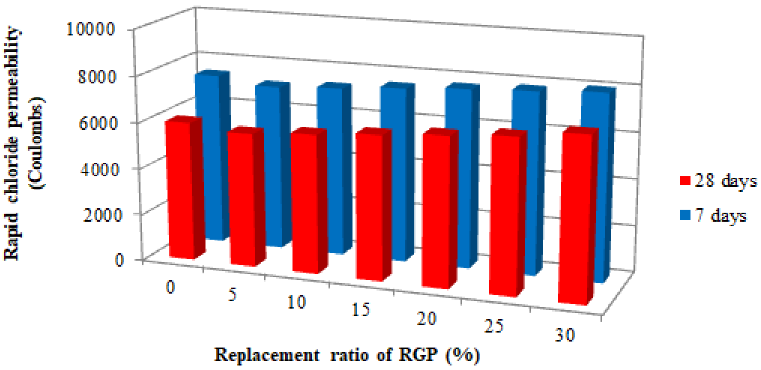

Figure 7. Rapid chloride permeability test results of SMs

The apparent gas permeability coefficients of SMs measured at 7 and 28 days are plotted graphically in Figure 8. Taking into account the apparent gas permeability coefficient for SM0 mixture was measured as 7.34×10^{-16} m^2 and 5.22×10^{-16} m^2 at 7 and 28 days, respectively. The lowest apparent gas permeability coefficient was obtained from SM5 mixture as 6.04×10^{-16} m^2 and 4.14×10^{-16} m^2 for 7 and 28 days, respectively. After 5% RGP content, the apparent gas permeability coefficient increased with increasing replacement level of RGP at 7 and 28 days. Therefore, the highest apparent gas permeability coefficient was measured for SM30 mixture as 8.78×10^{-16} m^2 and 6.03×10^{-16} m^2 for 7 and 28 days, respectively. However, the apparent gas permeability coefficient of SM10 was lower than that of SM0. Therefore, SM5 and SM10 mixtures are beneficial in terms of the apparent gas permeability coefficient, when compared to control mixture.

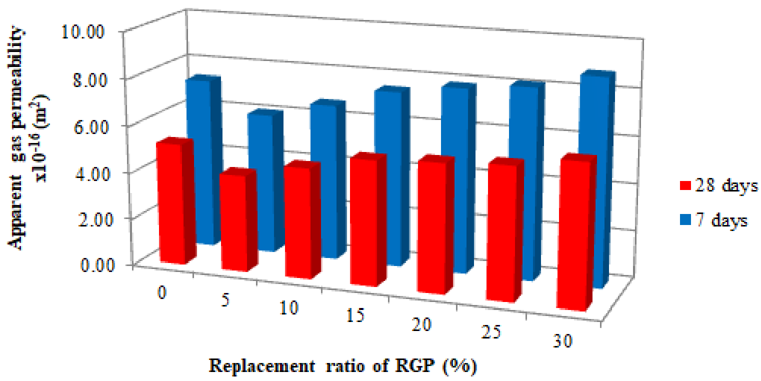

Figure 8. Variation of apparent gas permeability coefficients of SMs

According to 7 and 28 days test results, the basic durability tests clearly showed that RGP can be used in SM up to 10% content. The RGP mineral provided an additional advantage by exhibiting pozzolanic reaction. It is known that, the amorphous silica (SiO_2) in the RGP reacts with the calcium hydroxide (portlandite–$Ca(OH)_2$) constituted during cement hydration and generates gels of calcium–silicate–hydrate (C–S–H) [10,29]. In addition, at the laboratory scale, the RGP has been utilized successfully to design various concrete or mortar mixtures. For example, Tagnit-Hamou [30-32], Tagnit-Hamou and Bengougam [33] and Schwarz et al. [26] utilized the RGP in normal concrete mixtures as a partial cement replacement in percentages up to 30%. These studies indicated that useful effects, including increased workability and reduced chloride permeability, when using RGP. However, in this study, the RGP did not yield beneficial results up to 30% content due to early age performance (7 and 28 days) of SM was examined. It is known that, pozzolanic materials can improve strength and durability performances of concrete or mortar depending on the test age [35]. Therefore, it should be known that RGP's pozzolanic reaction, which is slower than the hydration of Portland cement at early age, will advance with time [10].

The relationships between rapid chloride permeability/water sorptivity coefficient, apparent gas permeability coefficient/water sorptivity coefficient and rapid chloride permeability/water sorptivity coefficient were presented graphically for 7 and 28 days in Figure 9, in Figure 10 and in Figure 11, respectively. Chloride ion permeability values and water sorptivity coefficients of samples have strong relationship with correlation coefficients of 0.9659 and 0.9478 for 7 and 28 days, respectively. In addition, correlation coefficients for apparent gas permeability coefficients and water sorptivity coefficients were determined as 0.8939 and 0.8956 at 7 and 28 days, respectively. According to these correlation coefficients determined for 7 and 28 days, it is seen that there is an important correlation between apparent gas permeability coefficients and water sorptivity coefficients. Finally, when the correlation coefficients of chloride ion permeability values and water sorptivity coefficients were assessed, it is found that correlation coefficients were 0.9701 and 0.844 for 7 and 28 days, respectively. According to these results, there are a strong correlation for especially 7 days between chloride ion permeability values and water sorptivity coefficients.

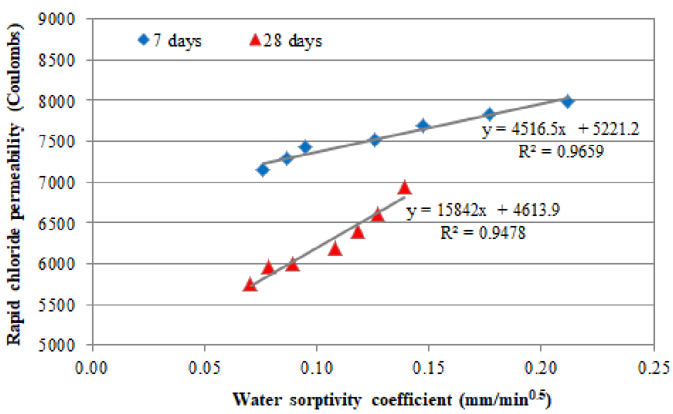

Figure 9. The relationship between rapid chloride permeability and water sorptivity coefficient

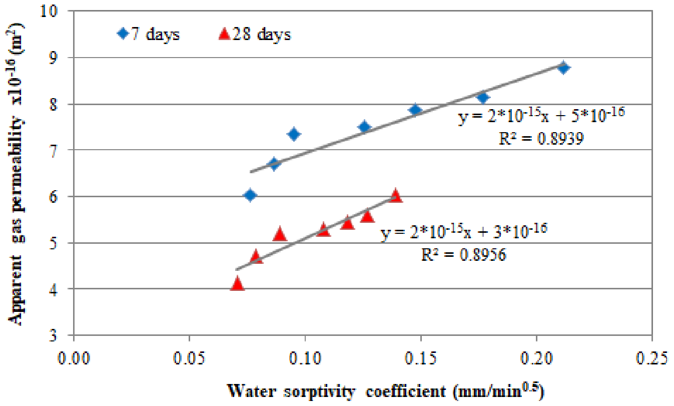

Figure 10. The relationship between apparent gas permeability coefficient and water sorptivity coefficient

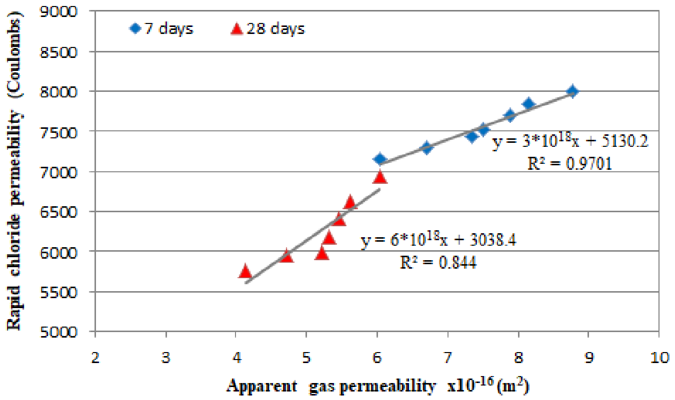

Figure 11. The relationship between rapid chloride permeability and apparent gas permeability coefficient

4. CONCLUSIONS

The results obtained from this study which investigated of the effect of RGP mineral on fresh and especially the basic durability properties of SM are presented below;

1) Slump flow diameters of SMs increased with increasing replacement level of RGP.
2) Water sorptivity coefficient, rapid chloride permeability and gas permeability test results indicated that RGP can be successfully used in SM up to 10% content with respect to early age performance (7 and 28 days) of SMs. This situation can be explained with additional C-S-H provided mortar thanks to high silica content (SiO_2 > 70%), high surface area and amorphous nature of RGP mineral. In addition, the effect on durability performance of the RGP and usage rate of the RGP may be better at later ages because of increased pozzolanic reaction with increasing test age of the RGP.
3) The correlation coefficients between rapid chloride permeability values/water sorptivity coefficients, apparent gas permeability coefficients/water sorptivity coefficients and rapid chloride permeability values/water sorptivity coefficients of SMs were extremely high for both test ages.

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