

# STRENGTH AND SHRINKAGE PROPERTIES OF SELF-COMPACTING CONCRETES INCORPORATING WASTE PVC DUST

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## ABSTRACT

The aim of this study is to investigate the effects of using polyvinyl chloride dust on the compressive strength and shrinkage behavior of self-compacting concrete. Self-compacting concrete mixtures with polyvinyl chloride dust content were designed with a total binder content of 550 kg/m<sup>3</sup> and a water-to-binder (w/b) ratio of 0.35. Also fly ash content of the concrete batch was 110 kg/m<sup>3</sup>. Polyvinyl chloride dust was added in place of Portland cement at replacement levels of 0%, 5%, 10%, 15%, 20%, and 25% by weight in all mixtures. Six mixtures (one is selected as control mixture) were used in the study. According to test results, the compressive strength of the concrete samples significantly decrease with increasing polyvinyl chloride dust content. Dry shrinkage decreases when the percentage of polyvinyl chloride dust in the self-compacting concrete mixture increases. Similar to the drying shrinkage test results, self-compacting concrete incorporated with polyvinyl chloride dust exhibited lower weight loss in comparison with the control mixture. Also restrained shrinkage rate of self-compacting concrete specimen decreases when the percentages of polyvinyl chloride dust in specimen increase.

**Keywords:** Compressive strength, dry shrinkage, restrained shrinkage, PVC dust.

## 1. INTRODUCTION

Cement is one of the most energy consuming materials used in the construction industry and a major contributor to CO<sub>2</sub> emission in the atmosphere. According to the estimation, to manufacture 1 tonne of ordinary Portland 1 tonne of carbon dioxide is delivered to the atmosphere. Also exhaustion of limestone in some geographical regions is another problem for cement production [1].

The significant growth in the consumption of polyvinyl chloride (PVC) at many branches of industry, has caused to accumulation of hazardous waste products. It is also believed that a substantial amount of PVC waste will be derived from construction and demolition activities. Development of environmental conscious to diminish the negative environmental effects of the PVC waste is important for the future generations. Utilizing recycled PVC waste for concrete production can be one of the environmental friendly methods because there is a huge demand for concrete worldwide, especially in developing economies [2].

Self-compacting concrete or self-compacting concrete (SCC) that has high flowability property and high segregation resistance, was introduced in the late 1980s in Japan. When a reinforced concrete member is contentedly reinforced, it is hard to provide that formwork gets completely filled with concrete. In such cases SCC comes into appear by providing fully consolidation without voids or honeycombs. SCC also does not involve vibration for placing and compaction [3].

## 2. EXPERIMENTAL

### 2.1. Materials

#### 2.1.1. Cement

Portland Cement (PC) (CEM I 42.5R), specific gravity of  $3.15 \text{ g/cm}^3$  and a specific surface area  $326 \text{ m}^2/\text{kg}$  was used.

#### 2.1.2. Fly ash (FA)

In this experiment fly ash conforming to ASTM C 618 class was used. It has a specific gravity of  $2.25 \text{ g/cm}^3$  and a specific surface area of  $379 \text{ m}^2/\text{kg}$ .

#### 2.1.3. PVC dust

PVC dust with a specific gravity of  $1.35 \text{ g/cm}^3$  and a specific surface of  $16 \text{ m}^2/\text{kg}$  was used in this experiment.

**Table 1.** Chemical compositions of portland cement, fly ash and PVC dust.

Analysis report (%)	cement	fly Ash	PVC dust
CaO	62.58	4.24	-
SiO <sub>2</sub>	20.25	56.2	-
Al <sub>2</sub> O <sub>3</sub>	5.31	20.17	-
Fe <sub>2</sub> O <sub>3</sub>	4.04	6.69	-
MgO	2.82	1.92	-
SO <sub>3</sub>	2.73	0.49	-
K <sub>2</sub> O	0.92	1.89	-
Na <sub>2</sub> O	0.22	0.58	-
Ignition loss	3.02	1.78	≤1.00
Specific surface area (m <sup>2</sup> /kg)	326	379	16
Specific gravity	3.15	2.25	1.53

#### 2.1.4. Aggregates

Crushed stone, with a nominal size of 16 mm as a course aggregate and a natural river sand with a maximum size of 4 mm as a fine aggregate were used in this experiment. The sieve analysis and physical properties of the aggregates are given in Table 2.

**Table 2.** Sieve analysis of fine and course aggregates.

Sieve Size (mm)	Crushed stone 16-8 (mm)	Crushed stone 8-4 (mm)	Natural river sand
0.25	0	0	3.79
0.50	0	0	14.27
1.00	0	0	30.85
2.00	0	0	49.35
4.00	0	2.05	83.06
8.00	1.28	66.66	100
16.00	78.16	100	100
specific gravity	2.66	2.65	2.58

#### 2.1.5. Superplasticizer

Superplasticizers improve workability and strength of concrete with reduced water to cement ratio (w/c).

**Table 3.** Properties of superplasticizers.

Properties	Superplasticizer
Name	Glenium 51
Color tone	Dark brown
State	Liquid
Specific gravity (kg/l)	1.07
Chemical description	Polycarboxylic-ether
Recommended dosage	% 1-2 (binder content)

#### 2.2 Mix design of concrete

The self-compacting concrete mixtures were designed with a total binder mass of 550 kg/m<sup>3</sup> and at a constant w/b ratio of 0.35. Six SCC mixtures were produced in this study, and in each SCC mixture the PC was replaced with PVC dust at 0%, 5%, 10%, 15%, 20% and 25%

replacement ratios by weight. In addition, the FA was added into the mixtures with a constant ratio in order to increase or improve workability of the concrete. Totally six SCC mixtures, including a reference mixture, were produced according to above variables. The mix proportions of the study are shown in Table 4.

**Table 4.** Mix proportions for self-compacting concrete (kg/m<sup>3</sup>).

Mix ID	(w/b)	PC	FA	PVC	Water	SP	Coarse Agg.		Fine Agg.
							16-8 mm	8-4 mm	
PVC0S1	0.35	440	110	0	192.5	105	404.9	403.4	785.5
PVC0S2	0.35	418	110	22	192.5	95	400.0	398.5	776.0
PVC0S3	0.35	396	110	44	192.5	85	395.1	393.6	766.5
PVC0S4	0.35	374	110	66	192.5	80	390.2	388.7	757.0
PVC0S5	0.35	352	110	88	192.5	75	385.3	383.8	747.5
PVC0S6	0.35	330	110	110	192.5	70	380.4	378.9	738.0

### 2.3. Concrete casting

Concrete preparing and mixing procedures proposed by KH Khayat [4] were adopted to ensure uniformity and consistency in all mixtures of SCC. The mixing sequence and duration of the task of the production of self-compacting concrete were considered. The preparation procedure was firstly fine, and coarse aggregates mixed. Then cement, fly ash, PVC dust, and superplasticizer were added. All components were mixed in a revolving pan mixer. They were mixed evenly for 30 seconds. After that, half of the water was added in the blender, and mixing continued for 60 seconds. The aggregates were left to soak up water in a blender for 60 seconds. Then, mixing process began again for another 60 seconds.

Finally, the mixture was poured into a blender, along with superplasticizer and outstanding water. The concrete was mixed for 180 seconds and left to rest for another 120 seconds. The concrete was mixed for 2 minutes and additional tests were performed to determine the viability and conducted passing ability of the SCC, and the results were recorded. This process was followed by casting the concrete, which was protected by plastic sheet and was left in the casting room for 24 hours at  $20 \pm 2$  °C.

### 2.4. Test procedure:

#### 2.4.1 Compressive strength test

The compressive strength test was carried out on the cube specimens, that have dimensions of 150 x 150 x 150 mm, according to ASTM C39 [5] standard. Figure 1 shows testing procedure by using a 3000 kN capacity testing machine. The test was conducted on three specimens from each mixture, and they were checked at each testing stage. The compressive strength

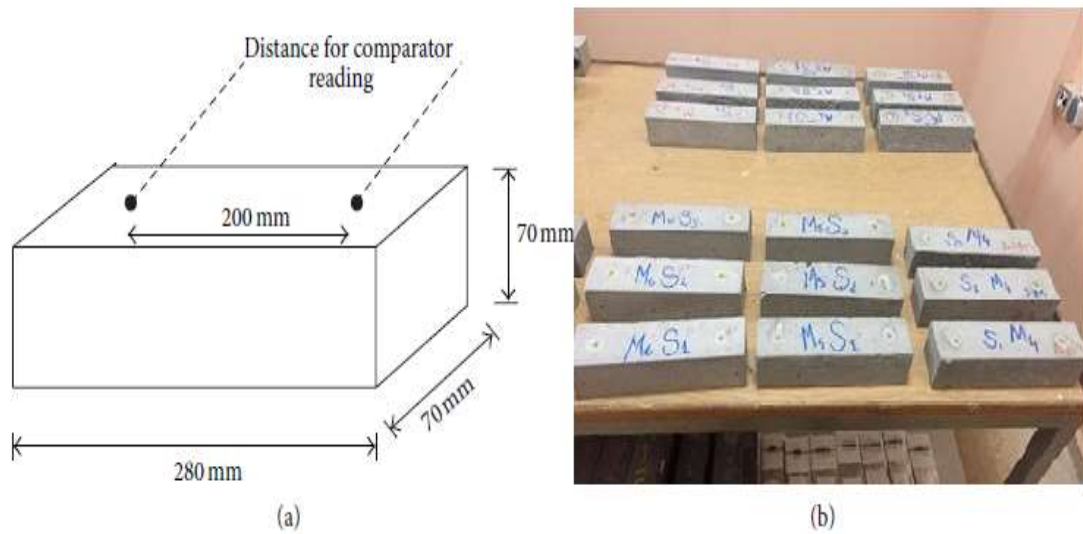
was measured by averaging the results from the three tested specimens at each stage of testing.



**Figure 1.** Compressive strength test.

#### **2.4.2. Drying shrinkage and weight loss**

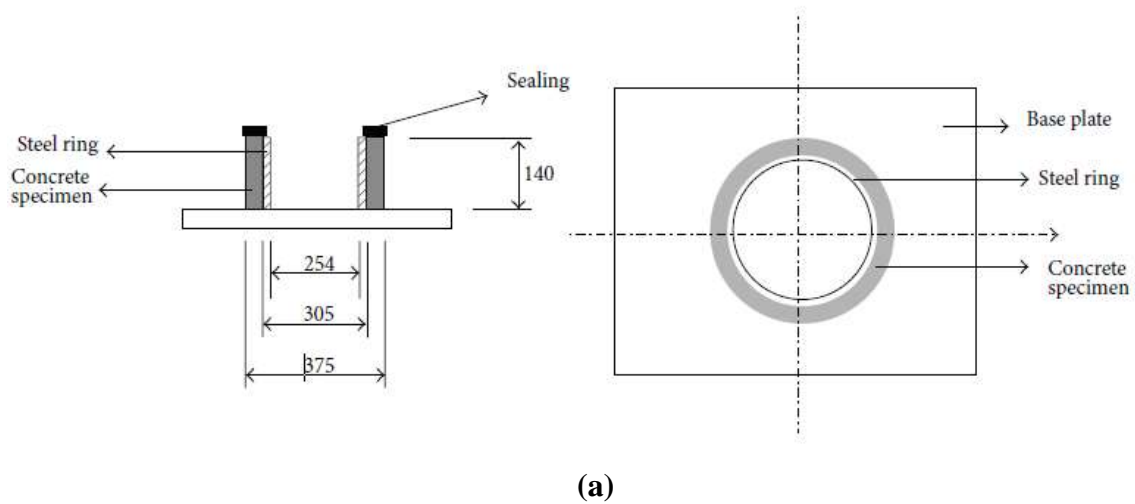
For measurement of dry shrinkage and weight loss of the SCC, the testing was conducted according to the ASTM C 157 standard with three rectangular prisms specimens having 70×70×280 mm dimensions [6]. The change in length was measured by using a dial gage extensometer with 200 mm gage length, and 0.002 strain for measuring. Measurements were implemented for the first 21 days once in every 24 hours, and then three times in a week. Meanwhile, measurements of weight loss were operated on the identical prism, too. After the gage length was fixed on each specimen via the glued pins on the face of prisms, the initial weight was recorded to monitor the weight loss during the drying period. Then, the prisms specimens were subject to drying, at  $23 \pm 2^\circ\text{C}$  and  $50 \pm 5\%$  relative humidity, for about 56 days.



**Figure 2.** Drying shrinkage test.

### 2.4.3. Restrained Shrinkage Cracking

Ring-type specimens were used in this study to observe the restrained shrinkage-induced cracking of concrete, the dimensions of the ring mould and photograph of a cracked specimen are shown in Figure. 3 (a,b). To measure the widths of the cracks on ring specimens, a special microscope setup was used [7, 8]. The crack widths reported here were the averages of three measurements: one at the ring's center, and the other two at the centers of the bottom and top halves of the ring. The surfaces of the specimens were examined for new cracks, and the measurement of the existing cracks' widths were taken every 24 hours during the first seven days after cracking, and then every 48 hours after that. Restrained crack widths given here are the average of two ring specimens.



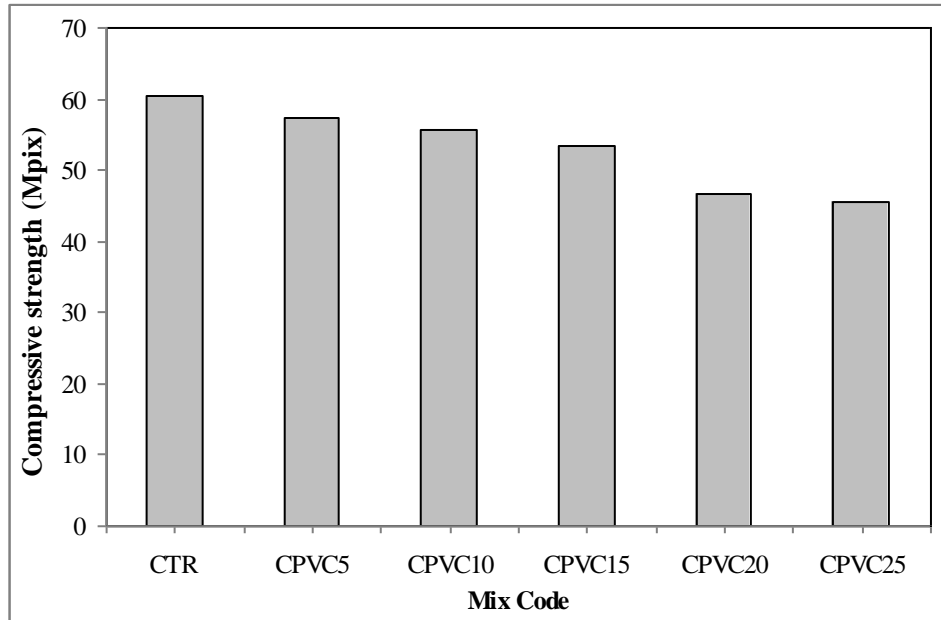
**Figure 3.** Rest ring shrinkage test.

### 3. TEST RESULTS AND DISCUSSION

#### 3.1. Compressive Strength

The compressive strengths of tested concrete specimens are given in Figure 4. The compressive strength of self-compacting concrete was obtained in the range of 45.54–60.40 MPa. According to test results, increment in the replacement level of PVC dust resulted decrease in compressive strength of SCC. Replacing Portland cement with 25% PVC dust

caused a reduction in the compressive strength of about 25%. Interestingly, the concrete specimen containing the highest replacement level of PVC dust, achieved the lowest compressive strength in all five the specimens. As indicated in Figure. 4, the addition of PVC dust with replacement levels 5%, 10%, 15%, 20% and 25%, caused a reduction in 56 day compressive strength values about 5%, 8%, 12%, 23%, and 25%, respectively.



**Figure 4.** Relationship between compressive strength and percentage of PVC dust.

### 3.2 Drying shrinkage and weight loss

Drying shrinkage is defined as reduction in concrete volume resulting from a loss of water from concrete [9]. Initially free water escapes to the concrete surface however, this usually causes minimal shrinkage. As the drying process continues the absorbed water, located in small capillaries, escapes. The loss of water produces tensile stresses, which causes the shrinkage of the concrete. The shrinkage due to loss of absorbed water significantly larger than the loss of free water [10, 11].

According to results of experiment, the difference between the amounts of the drying shrinkage of PVC dust-incorporated concrete was small, especially during the first week. But after 2 weeks, the difference became more significant. It can be concluded that the rate of drying shrinkage decreased with the increase in percentage of PVC dust. The results of weight loss with time due to the drying for SCC are shown in Figures 6, and it gives the maximum weight loss values of SCC. Similar to drying shrinkage test results, SCC incorporated with PVC dust have a lower weight loss compared to the control mixture. The difference of weight loss among SCC mixtures became more distinguishable after two weeks.



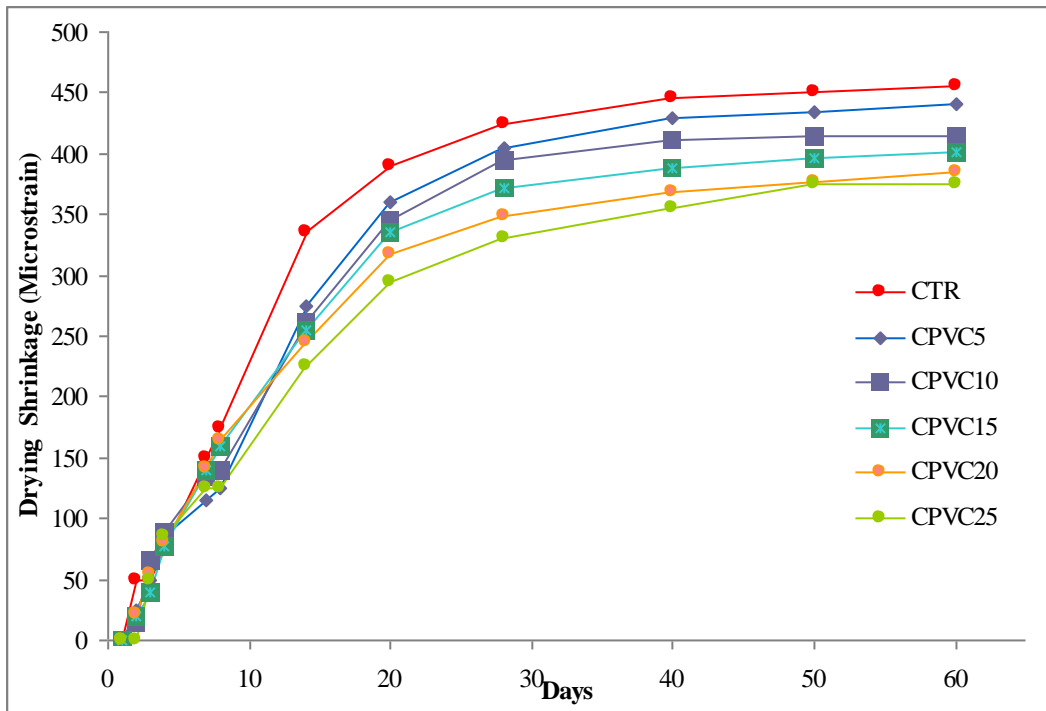


Figure 5. The relationship between dry shrinkage and percentages of PVC dust.

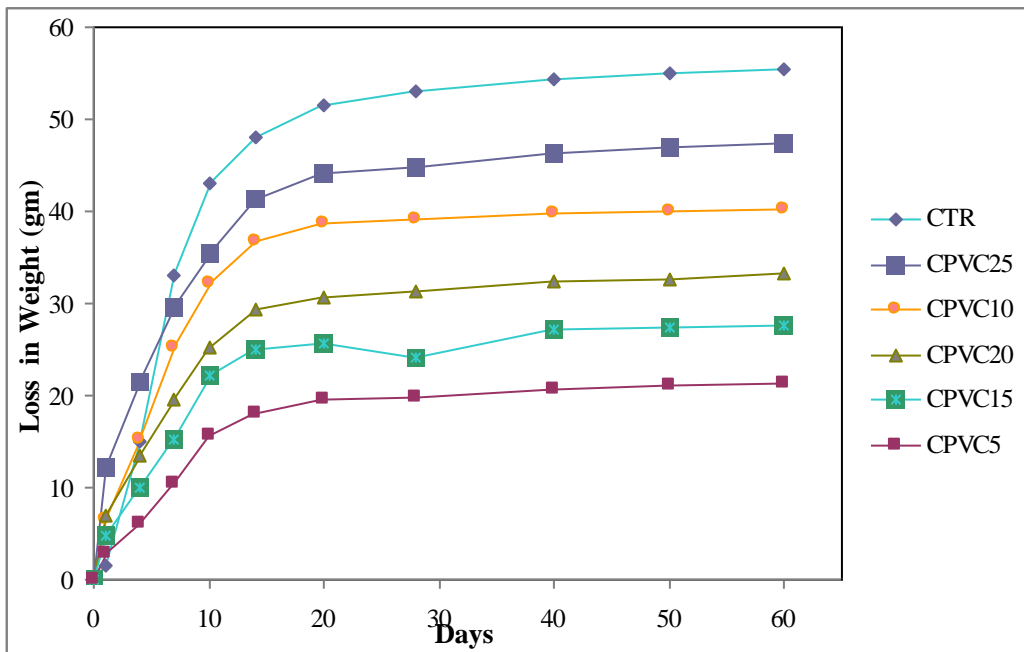


Figure 6. The relationship between weight loss and percentages of PVC dust.

### 3.3. Restrained shrinkage cracking

Figure 7 shows the concrete specimens crack development with time. From figure it can be observed that crack propagation was very fast during the first few days. Then, propagation speed increased with a decreasing rate, i.e. about half of the crack width occurred within the first ten days. The more the percentage of PVC dust were used, the lower the restrained shrinkage crack width were observed. PVC dust addition reduced the crack width relative to with the control specimen (no PVC addition). At the same time, increment in PVC dust ratio reduced the crack width and specimen containing 25% PVC dust have had the smallest crack width overall for the measuring intervals. The minimum crack width at the end of 56 days was found to be 0.625mm for mix 6 (PVC 25%).

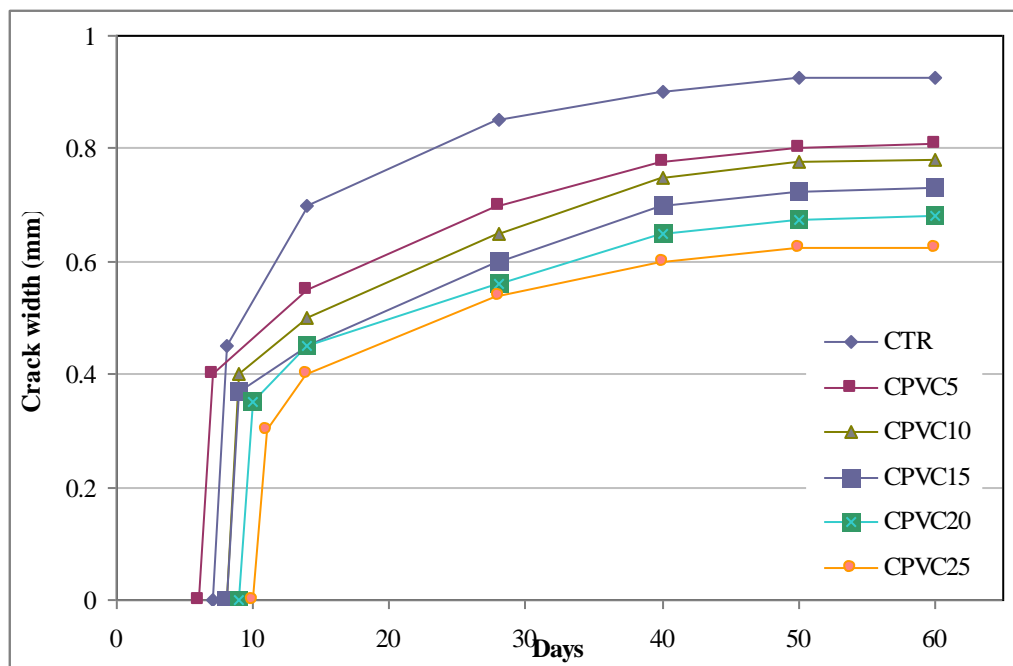


Figure 7. Restrained shrinkage.

## 4. CONCLUSIONS

From the results of experiments, the following conclusions can be obtained:

- The compressive strength significantly reduces with increasing replacement level of PVC dust content. Using PVC dust at different percentages (5, 10, 15, 20, and 25%) by weight decreased the compressive strength of all SCC specimens compared with the control specimen.
- The use of PVC dust in SCC decreases dry shrinkage at each additional percentage level of PVC dust. Similar to the drying shrinkage test results, SCC incorporated with PVC dust exhibited lower weight loss in comparison with the control mixture.
- The restrained shrinkage rate decreases with the increasing PVC dust proportion. Also increment in the percentage of PVC dust content decreases volume the pores and restrained shrinkage cracking width.

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