



Research article

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## The durability of white cement by using additives

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**Abstract.** White cement mortar suffers from the appearance of cracks when it is used in the facades of buildings, and these cracks affect its durability and shelf life. Therefore, three additives were suggested to be used with white cement mortar to reduce shrinkage, taking into consideration that they do not negatively affect other cement properties. A type of water-soluble polymer, Polyvinylpyrrolidone (PVP), as well as two types of steel fibers (hooked fibers and straight fibers) and they were all used in proportions 0 %, 1 %, 2 %, and 3 % of the weight of cement. A set of physical and mechanical tests were carried out in addition to dry shrinkage test such as setting time, compressive strength, flexural strength, and water absorption. It was found through these tests that all the additives reduced the dry shrinkage and the best results were obtained when using steel fibers with hooked ends by 3 % where the dry shrinkage was decreased by 75 %. The same type of fiber gave the highest flexural strength, with an increase of 16 % by using the same ratio. As for the use of 1 % straight steel fibers, it achieved the highest value in the compressive strength test, with an increase of 5 %. As for PVP, it reduced the water absorption by 6 % when it was used by 3 %.

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### 1. Introduction

Although its manufacturing cost is higher than ordinary Portland cement (OPC), however, white Portland cement (WPC) is widely used for aesthetic and decorative purposes, whether it is used as white cement alone or colored materials (pigments) are added. The energy saving factor is one of the most important factors encouraging the use of WPC in surface finishes because it is reflective of the sun's rays, as it provides light as well as reduces the heat entering the buildings. WPC has similar properties to ordinary cement, except for the color and the proportion of some compounds such as manganese and iron [1]. The uses of WPC in the construction of buildings are limited, and the main reason for that is because suffers from shrinkage at an early age and thus the causes formation of cracks [2]. Several studies have been published on WPC and the additives used for the purpose of improving some of its properties, including Carbone et al., who discussed the effect of a styrene-acrylic emulsion and ethylene-vinyl acetate on the properties of WPC mortar [3]. Cherop et al. added non-ionic cellulose ethers to WPC and studied their effect on it [4]. Shahi et al. assessed the impact of incorporating TiO<sub>2</sub> nanoparticles into white cement on the strength of their push-out bonds [5]. Dantas et al. investigated the impact of TiO<sub>2</sub> on the setting time of white cement [6]. Alshoabi et al. enhanced the self-cleaning capacity of white cement by incorporating nanopowders, including silver, zinc oxide, and titanium oxide [7]. Chen et al. enhanced the creep and viscosity properties of cement by incorporating polypropylene and polyvinyl alcohol into 3D-printed

structures [8]. Abdelzaher et al. recycled plastic waste and utilized it as an infill in white cement applications, thereby resolving the issue of plastic waste without impairing the properties of white cement [9].

As for the cement mortar without additives, it is prone to crack formation, and thus deformations occur due to shrinkage or other reasons related to the change in size where the addition of fibers can help reduce or control cracks [10, 11].

As mentioned earlier, the most prominent uses of WPC mortar are in surface finishes, especially considering that these finishes can have wide areas and dimensions and there are no breaks between them. Therefore, cracks are among the most important problems affecting the durability of WPC mortar.

Hence the aim of this study is to improve the durability of WPC mortar and controlling cracks by reducing shrinkage, which is the main cause of cracks when using white cement in large dimensions. through using three additives (Polyvinylpyrrolidone (PVP), hooked steel fibers, and straight steel fibers) and then studying the effect of the additives on the other properties of mortar in order to ensure that the additives have no negative effects and it is worth noting that the effect of any of the additives used in this research on the durability of white cement have been not studied previously.

## 2. Materials and Experimental work

### 2.1. Materials

#### 2.1.1. White Portland cement

The physical test and chemical analysis of the white cement used in this research were carried out, and it was found to be in conformity with the conditions of Iraqi Standard No. 5 of 2021 [12]. It is worth noting that the white cement used in this research was manufactured by the Iranian Urmia Company.

#### 2.1.2. Fine aggregate

When making cement mortar, standard sand must be used, standard sand was obtained after sieving and purification stages for sand found in Al-Akhaidar area – Karbala (Iraq), so standard sand compatible with ASTM-C778 [13] requirements was used. The gradation of standard aggregates is shown in Table 1.

**Table 1. Sieve analysis of standard aggregate**

Sieve size	Passing %
1.18 mm	100
0.600 mm	98.6
0.425 mm	74.1
0.300 mm	24.3
0.150 mm	0.12

#### 2.1.3. Polyvinylpyrrolidone

PVP is a water-soluble polymer derived from N-vinylpyrrolidone as the monomer and was provided by the CDH Company (India) in powder form, as shown in Fig. 1, and it is characterized by solubility in water. The PVP characteristics obtained from the manufacturer are shown in Table 2.



**Figure 1. PVP polymer.**

**Table 2. Properties of PVP.**

Properties	Value
Melting point	150 °C
Color	White
pH	4–7
Chemical formula	(C <sub>6</sub> H <sub>9</sub> NO) <sub>n</sub>

#### 2.1.4. Steel fibers

Two types of steel fibers were used in this research, and both types were supplied by the Turkish Atlas Company, one type was hooked ends and the other type was straight, and their properties are shown in Table 3 and their image is included in Fig. 2.

**Table 3. Characterizes of steel fibers.**

Properties	Straight steel fiber	Hooked steel fiber
Shape	Straight	Hooked End
Aspect ratio (l/d)	75	50
Tensile strength	2850 MPa	1100 MPa
Diameter	0.2 mm	0.7 mm
Length	15 mm	35 mm
Appearance	Gold	Grey
Density	7840 kg/m <sup>3</sup>	7800 kg/m <sup>3</sup>

**Figure 2. Types of steel fiber: (A) straight and (B) with hooked ends.**

#### 2.1.4. Water

For the purpose of completing the hydration reaction with cement, distilled water was used to give ideal reaction conditions away from the effects of impurities.

### 2.2. Mixture Coding

The code for each mixture is shown in Table 4.

**Table 4. Code of each mixture**

Mix.	Type of admixture	Weight ratio of cement
RM	–	–
PM1	PVP	1 %
PM2	PVP	2 %
PM3	PVP	3 %
HM1	Hooked steel fiber	1 %
HM2	Hooked steel fiber	2 %
HM3	Hooked steel fiber	3 %
SM1	Straight steel fiber	1 %
SM2	Straight steel fiber	2 %
SM3	Straight steel fiber	3 %

### 2.3. Curing

Curing conditions differ from one test to another. For example, the fresh state tests were done directly and did not need any curing. As for the hardened state tests, they were also variable. For example, the dry

shrinkage test required the sample to be placed in water for two days (after being placed in the mold for 24 hours) and then placed in an open air area at a temperature room for 25 days. As for the other tests, which are compressive strength, flexural strength, and water absorption, they have similar curing conditions, as they were immersed in water for a period of 27 days (after being placed in the mold for 24 hours).

## 2.4. Tests

### 2.4.1. Setting time

A standard Vicat apparatus (its image is in Fig. 3) was used to determine the amount of water needed to determine the consistency required to perform a setting time test, which was carried out in accordance with ASTM-C191 [14] when mixing cement with the additives used in this study. This test was performed by preparing the cement paste (without or with additives) and mixed with water determined by the consistency test then the dough was placed into the mold, the initial setting time was done by using the needle placed at the point where it contacts the surface of the test mass and allowing it to penetrate the test specimen due to its weight. This process was repeated to the point where the needle penetrates the cement paste to  $5 \pm 0.50$  mm from the bottom of the mold. The initial setting time is calculated from the moment that the water is added to the cement until the time the needle penetrates to a distance of  $5 \pm 0.50$  mm from the bottom. While the final setting time was determined using a needle that has a 5 mm diameter circle at its tip. If the needle reaches the surface of the die, it will leave a mark without penetration.

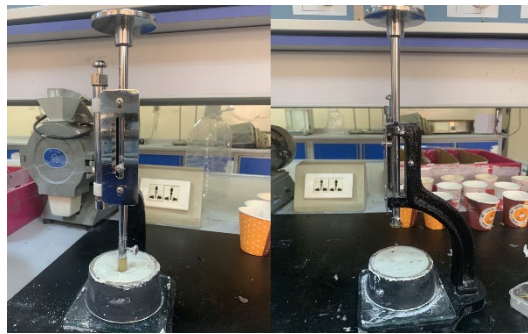


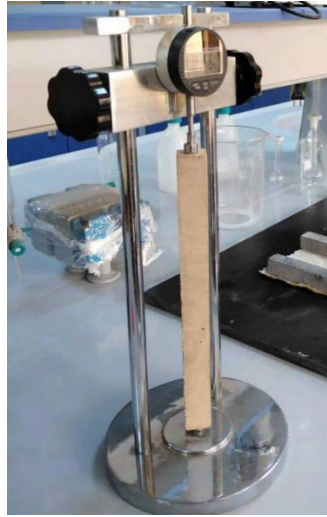
Figure 3. Vicat apparatus.

### 2.4.2. Dry shrinkage test

This test was performed in accordance with ASTM-C596 [15] where a cement to sand ratio 1 : 2 was used. Before placing the mortar into the molds for shrinkage test, a test shall be performed for each mortar to determine the amount of water that each sample needs in order to obtain a flow of 110 % (as shown in Fig. 4). The test molds had dimensions of 25 × 25 × 285 mm. The test was carried out by measuring the difference in the length of the prisms of the mortar before drying (after 3 days of pouring) and after drying (after 28 days of pouring). This test shows the possibility of cracking in the mortar because shrinkage is one of the main causes of cracks. The dry shrinkage test inspection machine is shown in Fig. 5.



Figure 4. Flow table test.



**Figure 5. Dry shrinkage test.**

#### **2.4.3. Compressive strength test**

The compressive strength test was determined according to ASTM-C150 [16] using cubes measuring  $50 \times 50 \times 50$  mm and averaging the compressive strength of three samples for each mix. The specimens were tested at loading rate of 1200 N/sec. The mixing ratio of cement : sand : water was 1 : 2.75 : 0.485, respectively, based on the requirements of the ASTM-C150 [11]. The cubes were tested 28 days after pouring the samples by a hydraulic machine with a capacity of 250 kN. Fig. 6 shows a sample during the test.



**Figure 6. Compressive strength test.**

#### **2.4.4. Flexural strength**

This test was performed with a  $40 \times 40 \times 160$  mm prism prepared in accordance with ASTM-C348 [17]. The mixing ratio of cement : sand : water was 1 : 2.75 : 0.485, respectively. Flexural strength was calculated by means of a three-point loading test for samples of all mortar mixtures with an age of 28 days, and the results were calculated for an average of 3 samples. A testing machine with a capacity of 250 kN was used to test the samples. Fig. 7 shows a sample during the test.



**Figure 7. Flexural strength test.**

#### **2.4.5. Water absorption**

Tests were carried out for samples with an age of 28 days using two cubic samples for each mix of mortar, and a water absorption test was performed depending on BS 1881-122 [18].

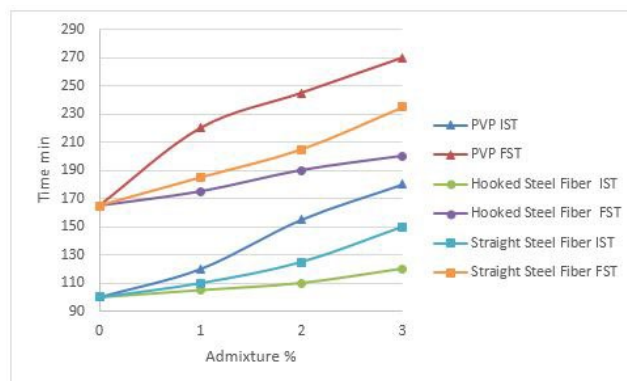
### 3. Results and Discussion

#### 3.1. Setting Time

The results of the setting time test were listed in Table 5 and Fig. 8. It can be understood from Table 5 that increasing the use of the percentage of PVP as a weight ratio from the weight of cement leads to an increase in the initial and final setting times where when adding 3 % of PVP, the initial setting time was increased by 80 % and the final setting time was increased by 64 %. This is due to the emergence of a polymeric film that is formed by PVP in the mortar and encapsulates the cement particles and hinders the cement particles from interacting with water, thus slowing the hydration of the cement [19]. It was also found that the steel fibers had no significant effect on the setting time, as it increased by a few minutes when the content of steel fibers increased in the cement because the surface of the steel fibers was smooth and free from roughness, so no agglomeration was observed during mixing [20].

**Table 5. Initial and final setting time**

Mixtures	Setting time	
	Initial (min.)	Final (min.)
RM	100	165
PM1	120	220
PM2	155	245
PM3	180	270
HM1	105	175
HM2	110	190
HM3	120	200
SM1	110	185
SM2	125	205
SM3	150	235



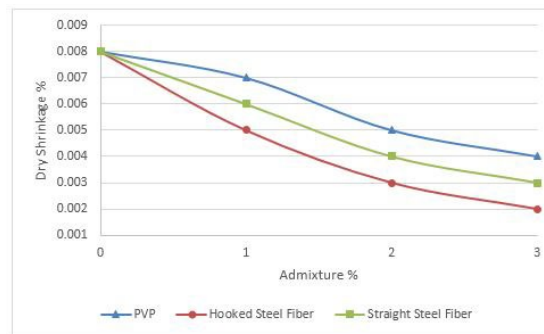
**Figure 8. Setting time results.**

#### 3.2. Dry Shrinkage

The results of the dry shrinkage test were listed in Table 6 and Fig. 9. In Table 6, it was observed that the shrinkage decreases with increasing the content of PVP in the cement, as the shrinkage values were decreased by 50 % when adding 3 % because PVP is considered effective in reducing dry shrinkage in mortar due to its high ability to reduce the surface tension of the medium [21]. It can also be observed that as the amount of fiber increases as a percentage of the weight of cement, the shrinkage values decrease due to the fact that steel fibers hinder crack growth, this is because steel fibers have high ductility with a strong crack control effect as the dry shrinkage leads to a reduction in starting the crack [22]. It can also be noted that the fibers with hooked ends have a higher capacity than the straight fibers because of their role in creating stronger interlocked particles, as the hooked fibers caused a shrinkage reduction of 75 %, while the straight fibers reduced shrinkage by 63 %. Since the fiber is a non-pozzolan material, when added, it reduces the heat given off by the cement because the cement content is reduced in the slurry, and the reaction is slowed slightly because it provides insulation between the particles.

**Table 6. Results of dry shrinkage test.**

Mixtures	Dry shrinkage (%)
RM	0.008
PM1	0.007
PM2	0.005
PM3	0.004
HM1	0.005
HM2	0.003
HM3	0.002
SM1	0.006
SM2	0.004
SM3	0.003

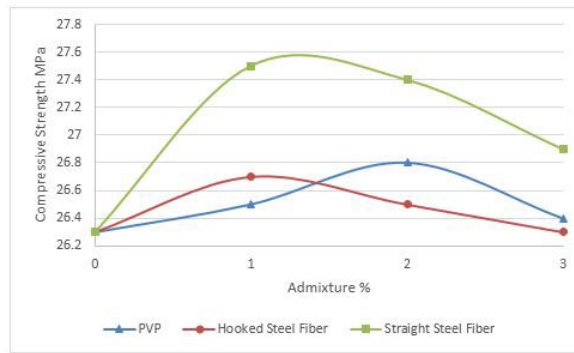
**Figure 9. Dry shrinkage results.**

### 3.3. Compressive Strength

The results of compressive strength test were listed in Table 7 and Fig. 10. From Table 7, it was noted that adding PVP in cement, it causes a slight increase in compressive strength and then decreases because the addition of PVP has a positive effect, in addition to being a water-soluble binder, it also reduces the gaps (pores) in the cement mortar [23]. As for the negative effects of compressive strength, if the PVP content is too high, the polymer film that surrounds the cement particles will prevent both the reaction and hydration processes between the cement particles and water, which leads to a decrease in the values of the compressive strength [14]. It was also observed that steel fibers increase the compressive strength, as the compressive strength was increased by 5 % when adding straight steel fibers by 1 %, and it is known that steel fibers work to withstand stresses and increase ductility [24], but increasing the percentage of steel fibers leads to a decrease in the amount of binder and thus reduce compressive strength. It was also noted that the straight fibers caused a higher increase than the hooked fibers due to having a higher aspect ratio.

**Table 7. Result of compressive strength test.**

Mixtures	Compressive strength (MPa)
RM	26.3
PM1	26.5
PM2	26.8
PM3	26.4
HM1	26.7
HM2	26.5
HM3	26.3
SM1	27.5
SM2	27.4
SM3	26.9



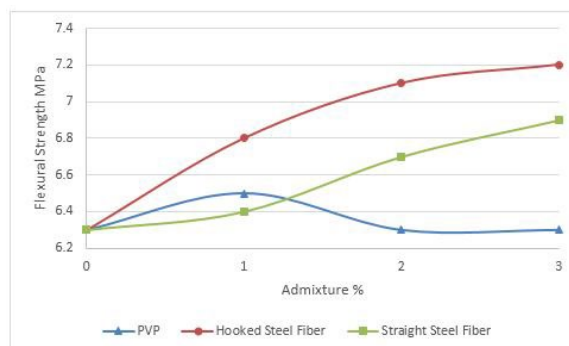
**Figure 10. Compressive strength results.**

### 3.4. Flexural Strength

The results of flexural strength test were listed in Table 8 and Fig. 11. It has been observed from Table 8 that by adding PVP as a percentage in cement, the flexural strength increases slightly, as it increases by 3 % when added by 1 %, then it decreases with increasing the addition. Where the decrease in flexural strength is attributed to the slowdown in the hydration rate of cement and this effect was mentioned previously, and the reason for the slight increase is due to the fact that PVP has a strong tensile strength compared to cement [14]. One of the important things in the following table is the increase obtained by using steel fibers with hooked ends where the flexural strength increased by 14 % when using 3 % of fibers. It is also known that steel fibers hinder crack growth and increase ductility and thus improve tensile properties. It is also noted that fibers with ends hooked fibers had better results than straight fibers, and this is because the fibers with hooked ends play a role similar to the anchor, which gives higher strength [25]. It was possible to obtain a higher increase in the value of flexural strength and it not caused by the decrease in the binder in the mortar.

**Table 8. Results of flexural strength.**

Mixtures	Flexural strength (MPa)
RM	6.3
PM1	6.5
PM2	6.3
PM3	6.3
HM1	6.8
HM2	7.1
HM3	7.2
SM1	6.4
SM2	6.7
SM3	6.9



**Figure 11. Flexural strength results.**

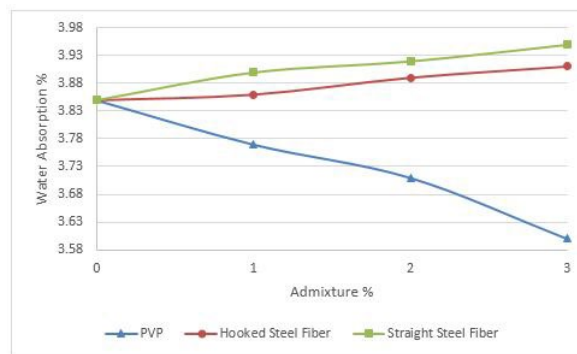
### 3.5. Water Absorption

The results of the water absorption test were listed in Table 9 and Fig. 12. It has been observed from Table 9 that the value of absorption decreases when adding the polymer PVP, as the absorption decreases by 6 % when adding 3 % of the polymer, due to the role that the polymer plays in filling the mortar voids

and thus reducing absorption [19]. It was also noted that the use of steel fibers caused a slight increase in absorption, and it reached the largest increase by 2.6 % when using straight fibers by 3 %, which is naturally not a significant increase, and we build our interpretation of this behavior as it was said by previous researchers “This is likely due to the emergence of an interfacial transition zone at the periphery of the fibers” [20].

**Table 9. Result of water absorption.**

Mixtures	Water absorption (%)
RM	3.85
PM1	3.77
PM2	3.71
PM3	3.60
HM1	3.86
HM2	3.89
HM3	3.91
SM1	3.90
SM2	3.92
SM3	3.95



**Figure 12. Water absorption results.**

#### 4. Conclusion

Based on all the tests that were conducted in this research, it was proved that all the used additives reduce shrinkage and increase the durability of the white mortar and do not have any negative effects on other properties if they are used in reasonable and acceptable proportions. Also, the following conclusion points can be drawn:

1. The initial setting time of the white cement was increased by 80 % and the final setting time was increased by 64 % for PVP fiber. In contrast, the steel fiber had no effect on the sitting time of the white cement according to the test results of this study, therefore, in cases where longer setting time is required, PVP should be used.
2. In terms of drying shrinkage reduction in white cement mixtures, the steel fibers with hooked ends showed approximately 75 % reduction, which was achieved by 3 % of hooked steel fiber content. Based on the results of this test, it is recommended to use hooked steel fibers in applications where white cement is used in large parts.
3. In general, the experimental results showed that the compressive strength of the white cement mixture was slightly improved by the addition of all types of fiber (PVP, straight steel, and hooked steel). The most important thing is that there is no negative effect when using any type of additives.
4. The flexural strength of the white cement containing 3 % of hooked steel fiber showed the highest increase by nearly 14 % compared to the flexural strength of the white cement mixture without any addition, this improvement gives it an advantage when using white cement in applications that are subject to tension.
5. Based on the test results of the water absorption for all the white cement mixtures, the using of 3 % of PVP fiber showed a 6 % water absorption reduction, which was the best results among other

addition of fiber in this study, even if the improvement is not major, it may help to keep the buildings' durability intact.

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