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# Strength and Watertightness Properties of EVA Modified High Strength Concrete

## EVA 개질 고강도 콘크리트의 강도 및 수밀 특성

**Kim, Young Ik* · Sung, Chan Yong**,†**

김 영 익 · 성 찬 용

**Abstract**

This study was performed to evaluate strength and watertightness properties of EVA modified high strength concrete in order to improve durability of concrete used in agricultural water utilization facilities that are in constant contact with water. Materials used were cement, coarse and fine aggregates, silica fume, EVA and AE water reducing agent. Tests for the slump, compressive and flexural strengths, absorption ratio and permeability coefficient according to curing condition (water and water+dry curing) and content ratio of EVA were performed. The slump results of EVA modified high strength concrete similarly showed in the content ratio of EVA powder less than 4% and decreased in the content ratio of EVA powder more than 6% compared to that of concrete without EVA powder. The compressive strength of EVA modified high strength concrete decreased with increasing the content ratio of EVA powder. The flexural strength of EVA modified high strength concrete increased with increasing the content ratio of EVA powder in the content ratio of EVA powder ratio less than 4% and had similar or slightly decreased in the content ratio of EVA powder more than 6% compared to that of concrete without EVA powder. The absorption ratio and permeability coefficient of EVA modified high strength concrete decreased with increasing the content ratio of EVA powder in the content ratio of EVA powder less than 4% and slightly increased in the content ratio of EVA powder more than 6%.

*Keywords : EVA modified high strength concrete, EVA powder, Watertightness, Microstructure, Permeability coefficient*

# I. Introduction

According to the development of construction technology, modern structures have developed into ultra high story, large-scale, and specialized buildings. Thus, it is necessary to improve the performance of concrete due to these changes.

* Institute of Agricultural Science, Chungnam National University

** Professor, Division of Bio-Resources Engineering, College of Agriculture and Life Sciences, Chungnam National University

† Corresponding author. Tel.: +82-42-821-5798
Fax: +82-42-821-8877
E-mail address: cysung@cnu.ac.kr

In addition to the concept of high strength concrete, studies on high performance concrete requiring high workability, high durability, and high strength in construction have been actively conducted in Canada, America, and Japan.[10),11)]

In particular, studies on high performance concrete focusing on high strength and durability have been conducted in Canada and America.

The durability deterioration of concrete is caused by various factors. Furthermore, the durability of concrete can be significantly jeopardized due to alkali aggregate reaction, variations in volume due to thermal stress, permeability, freezing and thawing, neutralization, salt damage, and chemical corrosion.[3)]

In particular, agricultural water utilization facilities are distributed as small-scaled structures in large areas and are poorly constructed because they are considered short-term construction in the event of a lull in the agricultural season. In addition, such structures have several drawbacks regarding quality control. Compared to large-scaled structures, it is difficult for short-term construction structures to control quality because they are in constant contact with water and rapidly deteriorate due to freezing and thawing. Various types of concrete and admixture have been developed to improve the deterioration of durability in concrete. In particular, studies continue to be performed on modified concrete utilizing polymer, which significantly improves flexural bond and water-tightness characteristics based on polymer films.[4),7)]

In addition, polymer modified concrete demonstrated diverse properties due to the combination of polymer and cement. It also exhibited variations in properties, such as binder ratio, curing condition, and curing temperature due to the microstructure of concrete. Thus, it is necessary to perform various experiments and studies on this particular type of concrete.

Therefore, this study was performed to evaluate the slump, compressive and flexural strength, absorption ratio and permeability coefficient of EVA modified high strength concrete according to curing condition (water and water+dry curing) and content ratio of EVA in order to improve strength, freezing and thawing resistance and chemical corrosion of concrete used in agricultural water utilization facilities that is in constant contact with water.

## II. Materials and methods

### 1. Materials

The cement used in this study was Type I Portland cement by H Company in Korea, guaranteed by the KS F 5201. Natural sand was used as fine aggregate, and crushed stone was used as coarse aggregate. In addition, silica fume was used as an admixture material to guarantee superior initial strength, and ethylene vinyl acetate (EVA) powder was used in modified concrete in order to improve watertightness and durability. In addition, naphthalene sulfonic acid based AE water-reducing agent was used to improve workability. Tables 1, 2, 3, and 4 show the physical and chemical characteristics of these materials.

### 2. Mixture design and fabrication

The mixture ratio of cement and polymer used as a binder significantly affected the strength and

**Table 1 Chemical compositions of Type Ⅰ Portland cement**

(Unit: %)

| $SiO_2$ | $Al_2O_3$ | CaO | MgO | $SO_3$ | $K_2O$ | $Na_2O$ | $Fe_2O_3$ |
|---|---|---|---|---|---|---|---|
| 21.09 | 4.84 | 63.85 | 3.32 | 3.09 | 1.13 | 0.29 | 2.39 |

**Table 2 Physical properties of aggregate**

| Item | Size (mm) | Specific gravity (20℃) | Absorption (%) | Fineness modulus | Unit weight (kg/m³) |
|---|---|---|---|---|---|
| Fine aggregate | 〈4.75 | 2.62 | 2.35 | 2.35 | 1,471 |
| Coarse aggregate | 4.75~20 | 2.64 | 2.62 | 7.28 | 1,449 |

**Table 3 Chemical compositions and physical properties of silica fume**

| Chemical compositions (%) | | | | | | | Physical properties | |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | $Al_2O_3$ | CaO | MgO | $Fe_2O_3$ | $SO_3$ | Ig.loss | Specific gravity (20℃) | Specific surface area ($cm^2/g$) |
| 91.2 | 1.3 | 0.7 | 0.3 | 0.8 | - | 2.3 | 2.2 | 204,000 |

**Table 4 Physical properties of EVA powder [water-redispersible ethylene/vinyl acetate powder]**

| solid content | ash content (1000℃/30min) | Apparent density | appearance | stabilizing system | particle size |
|---|---|---|---|---|---|
| 99±1% | 11±2% | 540±50 g/l | white powder | polyvinyl alcohol | Max 4%, 400 ㎛이상 |

watertightness characteristics of concrete because EVA modified high strength concrete forms a structure due to the hydration of cement, forming polymer film, or combination of these elements. Thus, in order to analyze the strength and water-tightness characteristics of concrete according to the content ratio of EVA powder, the content ratio was established at 0~10% of the weight of the applied binder (533 $kgf/m^3$). Furthermore, the target strength and slump were configured to more than 45 MPa and 12 cm, respectively, in order to analyze the effects of EVA powder on the fabrication process of high strength concrete. The silica fume was 0% and 10% for the weight ratio of cement in order to analyze the water-tightness and strength characteristics between the EVA powder and the presence of admixtures. In addition, a high performance AE water-reducing agent was 1.3% of the weight of the binder in order to guarantee the fluidity of the water/binder.

The fabrication of EVA modified high strength concrete was performed based on the KS F 2405 compressive strength of concrete test method by applying a mixture process where fine and coarse aggregates, cement, silica fume, and EVA powder were applied and mixed for 30 seconds to perform dry mixing. Then, water was applied to this mixture and mixed for 1 minute. Finally, water and a high performance AE water-

**Table 5 Mixture design of EVA modified high strength concrete**

| Type | Aggregate size (mm) | W/B (%) | Binder ($kgf/m^3$) | | EVA powder ($kgf/m^3$) | Aggregate ($kgf/m^3$) | | AE water reducing agent ($kgf/m^3$) |
|---|---|---|---|---|---|---|---|---|
| | | | Cement | Silica fume | | Coarse | Fine | |
| EMHC | 5~20 | 30 | 533 | 0 | 0 | 960 | 680 | 6.9 |
| | | | 522 | | 11 | 950 | 674 | |
| | | | 512 | | 21 | 943 | 665 | |
| | | | 501 | | 32 | 530 | 660 | |
| | | | 480 | | 53 | 915 | 643 | |
| EMSHC | | | 480 | 53 | 0 | 950 | 670 | |
| | | | 469 | | 11 | 942 | 662 | |
| | | | 459 | | 21 | 938 | 650 | |
| | | | 448 | | 32 | 930 | 642 | |
| | | | 427 | | 53 | 920 | 620 | |

reducing agent were applied to this mixture and mixed for 30 seconds at 90 rpm of high revolution. Furthermore, after separating the specimens from the mold in which it had been placed for 24 hours, a curing process was applied in the following order: water curing (W, for 27 days) and dry curing (D, for 6 days)+water curing (W, for 21 days)

Table 5 demonstrates the mixture design of EVA modified high strength concrete.

## 3. Test methods

Slump tests were applied based on the KS F 2402 slump test method. Compressive strength tests were applied based on the KS F2405 compressive strength test method of concrete under a 1,275 N/s loading speed for a ø100×200 mm specimen. In addition, flexural strength tests were applied based on the KS F 2407 flexural strength test method of concrete under a 49 N/s loading speed for a 60×60×240 mm specimen. The microstructure of the concrete was measured at a magnification of 5,000 using an SEM (scanning electron microscope).

Fig. 1 illustrates the equipment applied in these tests. Absorption ratio tests were performed by measuring the weight of a specimen, which had been placed at room temperature both after drying it in a dry oven at 105±5 ℃ for 24 hours and after sinking it in water for 24 hours. Permeability coefficient was carried according to a method of internal pressure. Fig. 2 shows the equipment applied in the permeability test.

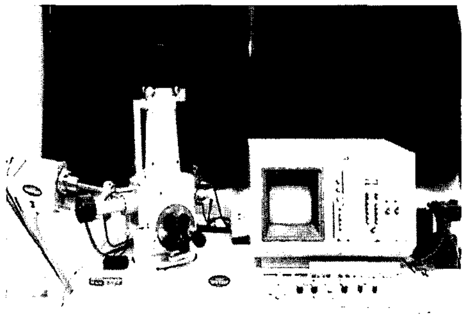


**Fig. 1 Testing apparatus of SEM**

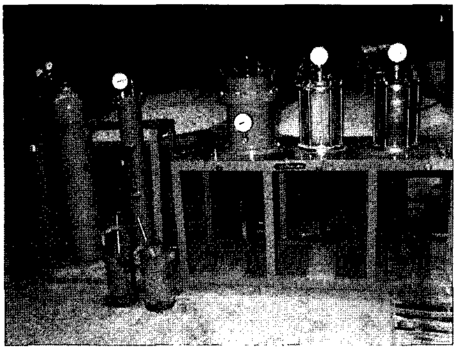


Fig. 2 Testing apparatus of Permeability

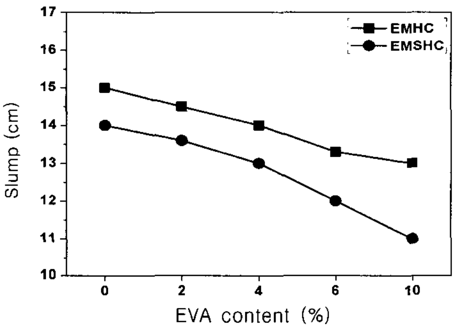



Fig. 3 Slump for EVA content

## Ⅲ. Results and discussions

### 1. Slump

Fig. 3 illustrates slumps according to the content ratio of EVA powder. The slump of EVA modified high strength concrete showed similar in an EVA powder content ratio of less than 4% and slightly decreased in the content ratio of EVA powder more than 6% compared to that of the concrete without EVA powder regardless of the silica fume. It was evident that the content of EVA powder less than 4% did not affect the workability of concrete as powder. But, the decrease of slump in the content ratio of EVA powder more than 6% is considered due to increasing viscosity because the content ratio of EVA powder was configured as the weight ratio of the amount of binder(cement+silica fume). Furthermore, the slump of EVA modified high strength concrete with a silica fume showed lower levels than that of EVA modified high strength concrete without silica fume.

### 2. Compressive strength

Fig. 4 illustrates compressive strength according to the content ratio of the EVA powder in water and dry-water curing.

In water and dry-water curing, the compressive strength of EVA modified high strength concrete slightly decreased in the content ratio of EVA powder less than 4%. But the compressive strength of EVA modified high strength concrete with the content ratio of EVA powder more than 6% significantly decreased, regardless of the silica fume. In addition, the compressive strength of EVA modified high strength concrete that was cured in dry-water showed higher than that of concrete fabricated by water curing, regardless of the content ratio of EVA powder.

Furthermore, the compressive strength of EVA

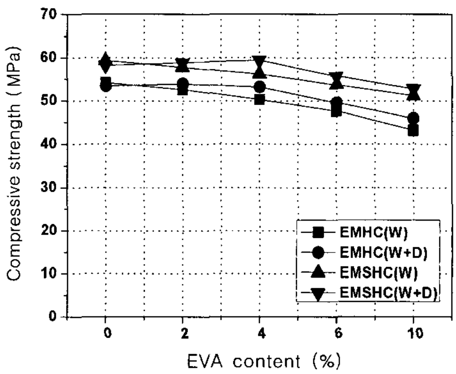



Fig. 4 Compressive stretgth for EVA content

modified high strength concrete with silica fume showed higher than that without silica fume.

In the hardening process of EVA modified high strength concrete, polymer film formed after the hydration process due to the evaporation of water in the EVA powder and moisture in the cement paste, transition zone, and capillary pore. Thus, it was evident that strength decreased because some of the non-hydrated cement was absorbed into the polymer film while being processed by the EVA powder which consequently interrupted the hydration process. In addition, cement required moisture to process hydration in the hardening process. However, the EVA powder required a retard moisture process at a specific time because the EVA powder formed polymer film by evaporating moisture after completing the redispersible process. Thus, it is necessary to continue studies on the effective interaction between organic and inorganic binder according to curing method and the content ratio of EVA powder.[2),4)]

## 3. Flexural strength

Fig. 5 illustrates flexural strength in water and dry-water curing according to the content ratio of EVA powder.

In water and dry-water curing, the flexural strength of EVA modified high strength concrete increased with increasing content ratio of EVA powder in the content ratio of EVA powder less than 4%. But the flexural strength of EVA modified high strength concrete with content ratio of EVA powder more than 6% showed similar or slightly decreased an compared to concrete without EVA powder, regardless of the

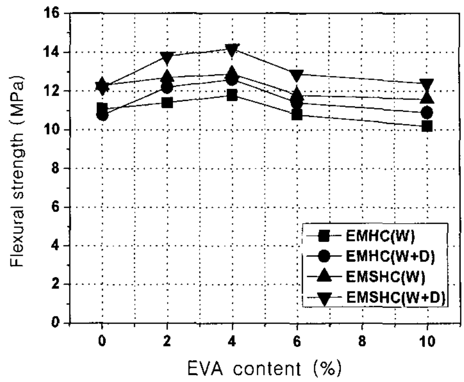


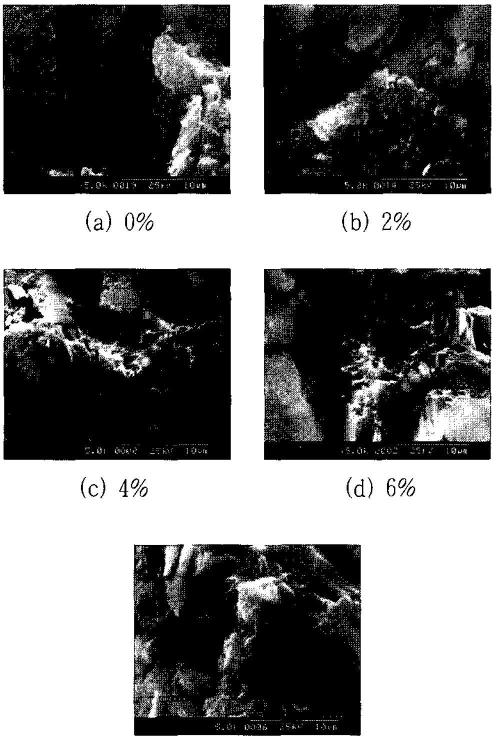

**Fig. 5 Flexural stretgth for EVA content**

silica fume. The flexural strength of the dry-water cured EVA modified high strength concrete was greater than the water cured EVA modified high strength concrete. Furthermore, similar to the results of compressive strength, the flexural strength of the EVA modified high strength concrete with a silica fume demonstrated higher levels than that without silica fume.

It was evident that polymer film formed in the transition zone by EVA powder content.[4),6)]

## 4. Microstructure

Fig. 6 shows the microstructure of the EVA powder modified concrete observed using an SEM according to the content ratio of EVA powder. As illustrated in Fig. 6(a), concrete without EVA powder produced calcium hydroxide crystals due to the hydration of cement. Furthermore, Fig. 6(b) - 6(e) illustrate the increase of adhesion between aggregates and paste due to the polymer film formed by the EVA powder in the transition zone according to the increasing the content ratio of EVA powder in which the polymer film played a role in cross-



(a) 0% (b) 2%

(c) 4% (d) 6%

(e) 10%

**Fig. 6 Microstructure of EVA modified concrete for EVA content**

linking. The pore existing in the transition zone decreased due to the formation of thin and fine polymer film with the content ratio of EVA powder less than 6%. In addition, it was evident that polymer film was largely distributed in the content ratio of EVA powder of approximately 10%.[5),9)]

## 5. Absorption ratio

Fig. 7 illustrates the absorption ratio in water and dry-water curing according to the content ratio of EVA powder.

In water and dry-water curing, the absorption ratio of EVA modified high strength concrete decreased with increasing content ratio of EVA

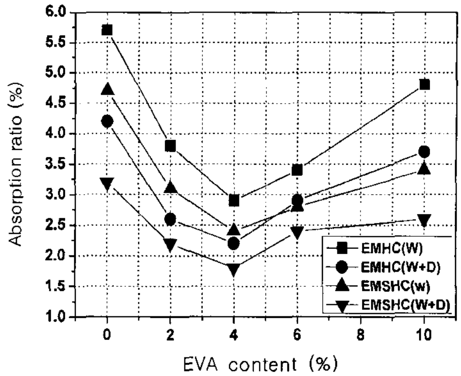



**Fig. 7 Absorption ratio for EVA content**

powder in the content ratio of EVA powder less than 4% and slightly increased in the content ratio of EVA powder more than 6%, regardless of the silica fume.

However, in all mixtures, the absorption ratio of EVA modified high strength concrete with EVA powder demonstrated lower than that of concrete without EVA powder. The EVA modified high strength concrete with a 4% EVA powder had the smallest absorption ratio. In addition, the absorption ratio of the dry-water cured EVA modified high strength concrete showed lower than the water cured EVA modified high strength concrete. Furthermore, the absorption ratio of the EVA modified high strength concrete with a silica fume demonstrated lower than concrete without silica fume because the density of the microstructure increased due to the promotion of hydration.

According to these results, cement, which was a type of inorganic binder, used in the EVA modified high strength concrete formed a dense internal structure due to hydration. However, the absorption ratio decreased due to the decrease in permeability because of polymer film formed at the transition zone and capillary pore. In addition, the absorption ratio of the EVA modified high strength concrete with a 10% content of EVA powder slightly increased compared to concrete with a 2~6% content of EVA powder despite the decrease in pores caused by the formation of polymer film.[1),8)]

## 6. Permeability coefficient

Fig. 8 shows the permeability coefficient in water and dry−water curing according to the content ratio of EVA powder.

Similar to the results obtained for absorption ratios, the permeability coefficient of EVA modified high strength concrete decreased with increasing content ratio of EVA powder in the content ratio of EVA powder less than 4% and slightly increased at the content ratio of more than 6%, regardless of the silica fume for water and dry−water curing. However, in all mixtures, the permeability coefficient of EVA modified high strength concrete with the admixture of EVA powder demonstrated lower than concrete without EVA powder. In addition, the EVA modified high strength concrete with a 4% content of EVA powder showed the lowest permeability coefficient. Furthermore, the permeability coefficient of the water and dry−water cured EVA modified high strength concrete showed lower levels the water cured EVA modified high strength concrete, regardless of the content ratio of EVA powder. According to these results, the EVA powder used in the EVA modified high strength concrete as a binder formed a dense microstructure due to the formation of polymer film at the transition zone and capillary pore.

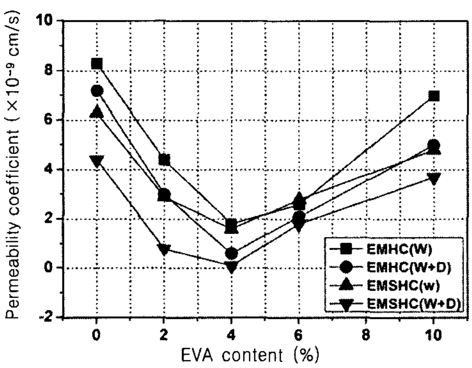



**Fig. 8 Permeability coefficient for EVA content**

Furthermore, it was evident that the permeability coefficient of the EVA modified high strength concrete with a 10% content of EVA powder slightly increased compared to concrete with a 2~6% content ratio of EVA powder despite the decrease of pores by the formation of polymer film.[1),8)]

## Ⅳ. Conclusions

This study was performed to evaluate the strength and watertightness of EVA modified high strength concrete according to curing condition (water and water+dry curing) and the content ratio of EVA in order to improve strength, freezing and thawing resistance and chemical corrosion of concrete used in agricultural water utilization facilities in constant contact with water.

The results of this study can be summarized as follows:

1. The slump of EVA modified high strength concrete similarly showed in an EVA powder content ratio of less than 4% and slightly decreased in the content ratio of EVA powder more than 4% compared to that of the concrete without

EVA powder regardless of the silica fume.

2. In water and dry-water curing, the compressive strength of EVA modified high strength concrete slightly decreased with increasing content ratio of EVA powder in the content ratio of EVA powder less than 4% but significantly decreased with the content ratio of EVA powder more than 6%, regardless of the silica fume. In addition, the compressive strength of EVA modified high strength concrete that was cured in dry-water showed higher than that of concrete by water curing, regardless of the content ratio of EVA powder.

3. In water and dry-water curing, the flexural strength of EVA modified high strength concrete increased with increasing the content ratio of EVA powder in EVA powder content ratio less than 4%. The flexural strength of EVA modified high strength concrete with the content ratio of EVA powder more than 6% showed similar or slightly decreased levels with an compared to concrete without EVA powder, regardless of the silica fume.

4. Regarding microstructure, concrete without EVA powder developed calcium hydroxide crystals due to cement hydration. However, the EVA modified high strength concrete with EVA powder formed polymer films in transition zones with increasing the content ratio of EVA powder.

5. The absorption ratio and permeability coefficient of EVA modified high strength concrete decreased with increasing the content ratio of EVA powder in the content ratio of EVA powder less than 4% and slightly increased in the content ratio of EVA powder more than 6%, regardless of the silica fume.

6. In the hardening process of EVA modified high strength concrete, after the hydration process, polymer film formed due to the evaporation of water in EVA powder and the moisture in the cement paste, transition zone, and capillary pore.

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