

## Physical properties of polymer-modified cement mortars by the functional additives and modification of polymerization

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Both polymerization modification and the use of functional additives for controlling air entrainment inside a polymer were examined for improving their performance in cement matrices. Functional additives were added to acrylic redispersible polymer powders at a glass-transition temperature of  $-11\text{ }^{\circ}\text{C}$ , and the polymerization method was modified. The physical properties of cement mortars produced with these polymers were evaluated. The performance improved and the average polymer-particle size decreased when using the modified emulsion polymerization method, while the air content in the polymer cement mortars decreased with the use of defoamer as a functional additive. Moreover, better compressive, flexural, and adhesion strengths were achieved, and the use of polymers with improved performance resulted in enhanced waterproofing. Scanning electron microscopy and energy-dispersive spectroscopy confirmed the formation of carbon-based polymer films around the pores and cracks inside the cement mortars.

**Key words:** Redispersible polymer powder, Polymerization modification, Functional additives.

### Introduction

Ordinary cement mortar and concrete have been widely used as maintenance and reinforcement materials for structures as they are easy to use and cost-competitive. However, they have several disadvantages such as weak tensile and flexural strengths, large drying shrinkage, weak adhesion strength, and weak resistance to many aggressive chemicals as well as freezing and thawing. To counteract these disadvantages, a polymer could be incorporated into ordinary cement mortar and concrete.

Cresson was the first to incorporate polymers into cement mortar and concrete. He used natural rubber latex as a coating material and cement as the filler. The current embodiment of polymer usage in cement mortar and concrete was first developed by Lefebure. Since then, polymers have been used in mortar and concrete for more than 70 years in various countries, and considerable research has been focused on expanding these applications [1].

Sugita et al. [2] studied the microstructure and complex mechanisms of latex paste and mortar and found that a large amount of polymer particles and cement hydrates were stacked between the aggregate and cement particles in layers by interface interactions. Geist et al [3], who first used polyvinyl acetate (PVAC) mortar, found that strength could be maximized when

the PVAC particle size was  $1\text{--}5\text{ }\mu\text{m}$ . In their study on the monomer ratios of ethylene-vinyl acetate (EVA), styrene-butadiene rubber (SBR), and polystyrene-butyl acryl ester, Ohama et al. [4] reported that the monomer ratio influences the strength of latex mortar within a certain polymer cement ratio; they [5] later reported a mechanism involving the interaction between the polymer and carboxylic groups.

In recent years, researchers have reported that the properties of polymer cement matrices vary according to the glass-transition temperatures of the polymers themselves. In particular, a polymer cement mortar using a polymer with a glass-transition temperature of  $-11\text{ }^{\circ}\text{C}$  has shown the best performance. There are several methods for improving the performance of polymers incorporated into cement for example, controlling the hardness via adjusting the glass-transition temperature  $T_g$ , providing functionality by the functional monomer, and using additives such as dispersing agents and/or thickeners. As such, the physical properties of the polymers could be modified in various ways to exhibit the most appropriate physical properties for the intended application.

This study attempted to improve the performances of the polymers in specifically selected ways by modifying their polymerizations and using a defoamer as a functional additive to control the air entrainment inside the polymers. In particular, the polymerization method was modified from emulsion monomer feed to monomer feed to reduce the polymer-particle size and to stabilize the synthesis. In addition, polyvinyl alcohol, used as a protective colloid, was substituted for denatured polyvinyl alcohol (PVOH) to improve

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the performance of the polymer.

The performance of polymers with a glass-transition temperature of  $-11\text{ }^{\circ}\text{C}$  was improved in two ways. The improvement in the pre- and post-performance physical properties of the polymers was compared to determine the effects of the improvement on the polymer cement mortars in which the improved polymers were used. Moreover, the properties of both ordinary cement mortar and polymer cement mortars using each polymer-before and after performance improvement-were compared and evaluated.

## Material and Methods

Redispersible polymer powders, which yielded the best results in the evaluation of the physical properties according to the glass-transition temperature, were selected. The redispersible polymer powders were synthesized by modifying the protective colloids, the polymerization, and the bonding of functional additives in order to improve the performance.

Polymer cement mortars were prepared using two types of improved redispersible polymer powders. Polymers with a glass-transition temperature of  $-11\text{ }^{\circ}\text{C}$  were selected based on the experimental results of polymer cement mortars according to the glass-transition temperatures, and redispersible polymer powders were prepared by binding them with a functional additive to improve the performance based on the determined monomer ratios. Furthermore, redispersible polymer powders were produced with improved performances by modifying the emulsion polymerization and protective colloids.

A defoamer was used as a functional additive for the performance improvement in this experiment by preventing performance degradation caused by excessive air entrainment in the redispersible polymer powders. In addition, PVOH was used as a protective colloid, and the emulsion polymerization method was modified from the emulsified monomer dripping method to the monomer dripping method.

In this study, five percent (5%) of the redispersible polymer powder relative to the total binder was used, and constant workability was obtained by maintaining  $4.5 \pm 1.5\%$  air content and  $155 \pm 10$  mm flow. The compressive strength, flexural strength, adhesion strength, and length change of the polymer cement mortars, as well as the condensation time, were measured at different aging times. The data were compared to the values for ordinary cement mortar.

Type 1 ordinary Portland cement was used according to ASTM C150 [8]; its chemical composition and physical properties are listed in Table 1. The aggregate was quartz sand No. 6 ( $\leq 0.67$  mm). The specific gravity of quartz sand was 2.61, and the water absorption of the quartz sand was 0.91%. The physical properties of silica fume (SF) are listed in Table 2. Melamine plasticizer

**Table 1.** Chemical composition and physical properties of ordinary Portland cement.

Chemical composition (%)		Physical properties	
SiO <sub>2</sub>	21.7	Density, g/cm <sup>3</sup>	3.15
Al <sub>2</sub> O <sub>3</sub>	5.7	Fineness, cm <sup>2</sup> /g	328
Fe <sub>2</sub> O <sub>3</sub>	3.2	Sat. Time (min)	Initial set. 221
CaO	63.1	Final set.	361
MgO	2.8	compressive strength, MPa	3 days 22.6
SO <sub>3</sub>	2.2	7 days	31.6

**Table 2.** Chemical composition and physical properties of silica fume.

Chemical composition (%)		Physical properties	
SiO <sub>2</sub>	91.2	Density, g/cm <sup>3</sup>	2.2
Al <sub>2</sub> O <sub>3</sub>	71.3		
Fe <sub>2</sub> O <sub>3</sub>	0.8	Fineness, cm <sup>2</sup> /g	20,470
CaO	0.7		
MgO	0.3		
K <sub>2</sub> O	0.8		

**Table 3.** Composition ratios of the polymers.

Properties	AC	DMAC	PMAC
T <sub>g</sub>	$-11\text{ }^{\circ}\text{C}$	$-11\text{ }^{\circ}\text{C}$	$-11\text{ }^{\circ}\text{C}$
MMA (%)	45	45	45
BA (%)	30	30	30
n-BMA (%)	–	–	–
EA (%)	5	5	5
2-EHA (%)	20	20	20

powder was used to manufacture both the ordinary cement mortar and polymer cement mortar.

The acrylic-ester copolymer emulsion (AC) composite was composed of hydrophilic ethylene unsaturated monomers and hydrophobic ethylene unsaturated monomers and was synthesized by adjusting the monomer ratio of 2-ethylhexyl acrylate (2-EHA), ethyl acrylate (EA), and methyl methacrylate (MMA). In addition, the glass-transition temperature (T<sub>g</sub>) of the synthesized emulsion was set at  $-11\text{ }^{\circ}\text{C}$ . The composition ratios of AC, as well as defoamer-modified acrylic (DMAC) latex and polymerization-modified acrylic (PMAC) latex are shown in Table 3.

Under laboratory conditions of  $20 \pm 2\text{ }^{\circ}\text{C}$  and relative humidity of at least 60%, the weighted cement, silica fume, sand, anti-foaming agent, and plasticizer were mixed. Water was added to the mixture to produce a polymer cement mortar. Table 4 shows the mix proportion ratio of the used polymer cement mortars.

In this study, the fundamental properties of redispersible polymer powders were evaluated by synthesizing one polymer with modified protective colloids via the polymerization method (PMAC) and another polymer with improved performance through the use of a defoamer

**Table 4.** Mix proportion of the improved polymer cement mortars.

Mortar type	Binder (Weight ratio)			S (Weight ratio)	SP** (B×%)	W/B* (%)	Defoamer/Polymer (%)
	Cement	SF	P***				
Control	1.0	–	–	2.45	0.5	54.0	–
AC	0.9	0.5	0.5	2.45	0.5	50.0	2.0
DMAC	0.9	0.5	0.5	2.45	0.5	50.0	2.0
PMAC	0.9	0.5	0.5	2.45	0.5	50.0	2.0

B\*: C+SF+P.

SP\*\*: SuperPlasticizers.

P\*\*\*: Polymer.

as a functional additive (DMAC). The following tests were performed for this evaluation: the glass-transition temperature was measured via differential scanning calorimetry (DSC), and the tensile strength was measured in accordance with the KS M3381 [8] “Test method for strength of Glass Fiber Reinforced plastic.” Furthermore, the average particle size was measured with a particle size analyzer, and the ash contents were measured in accordance with the KS M 0009 [9] “Test method for loss and residue of chemical products.”

Next, 2% of a redispersible polymer powder was left for 48 h in a measuring cylinder in order to evaluate its redispersibility by determining the sedimentation rate of the powder dispersed in a solution. The remaining monomers were analyzed by gas chromatography (GC) to evaluate the degree of polymerization of the modified polymers. Finally, the properties of the ordinary cement mortar and the polymer cement mortars were compared and evaluated.

To determine the setting time of the polymer cement mortars, the condensation time was measured according to ASTM C403 [10] and the compressive strength of the improved polymer cement mortars was tested according to ASTM C109 [11] at ages of 3, 7, 28, and 56 days. Moreover, the flexural strength of the modified polymer cement mortars was measured according to ASTM C348 [12] at a material age of 28 days, and the adhesion strength of the modified polymer cement mortars was tested according to KS F 4715 [13] and ASTM C1583 [14] using a connection to a jig that provided tensile force on the top of the sample on an area of 40 × 40 mm at material ages of 7, 14, and 28 days.

To determine the volume change of the modified polymer cement mortars, the length change was calculated by Eq. (1) and measured according to the ASTM C157 [15] dial-gauge method at a temperature of 20 ± 2 °C and relative humidity of 60 ± 10% for 56 days.

$$L_t = \left( \frac{L_0 - L_n}{L_0} \right) \times 100 \quad (1)$$

Here,  $L_t$  is the modulus of the length change (%),  $L_0$  is the initial mortar length, and  $L_n$  is the mortar length for

the given material age, in days.

Finally, water-absorption tests were performed in accordance with the KS F 2476 [16] at immersion times of 1, 3, 5, 9, 24, and 48 hrs. Based on these measurements, the water-absorption rates were calculated using Eq. (2):

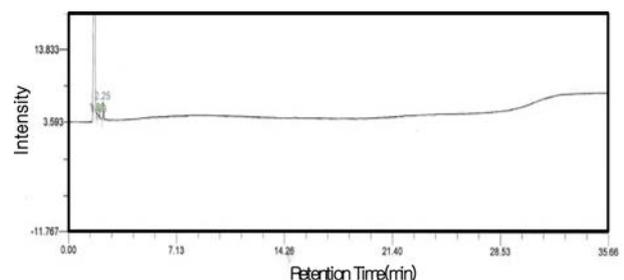
$$W_o = \left( \frac{W_1 - W_0}{W_0} \right) \quad (2)$$

where  $W_a$  is the water absorption rate (%),  $W_1$  is mass of the specimen for each time period of immersion (g), and  $W_0$  is the mass of the specimen before immersion (g).

## Results Discussion

The physical properties of the polymers are summarized in Table 5 and Figs. 2 and 3. As shown by the analysis, the glass-transition temperature remained constant because there was no variation in the monomer ratios when compared to that of AC. For the tensile strength, DMAC showed a slightly larger value. Regarding the elongation of the film, PMAC, which was modified via the polymerization method, had a 46% larger value than that of AC. The measurements of the ash content and remaining monomers were similar to those of the improved polymer (Fig. 1).

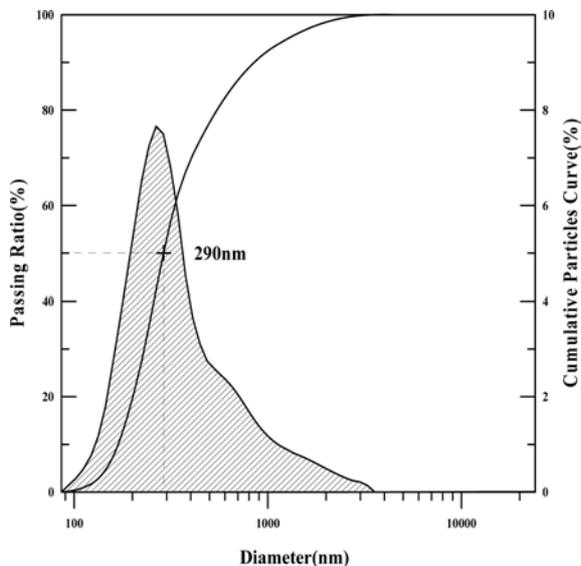
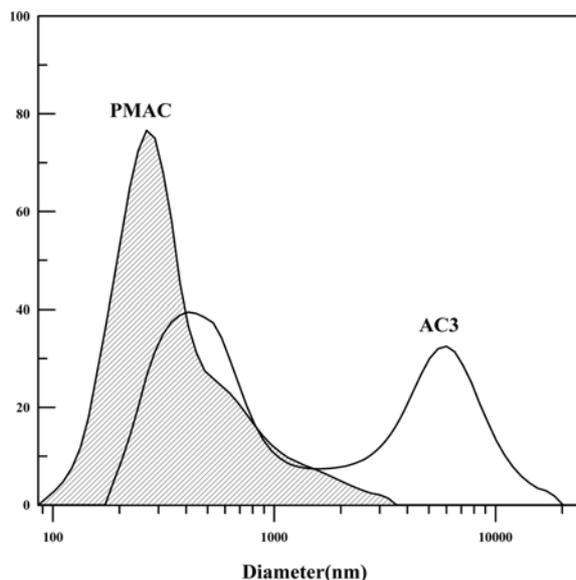
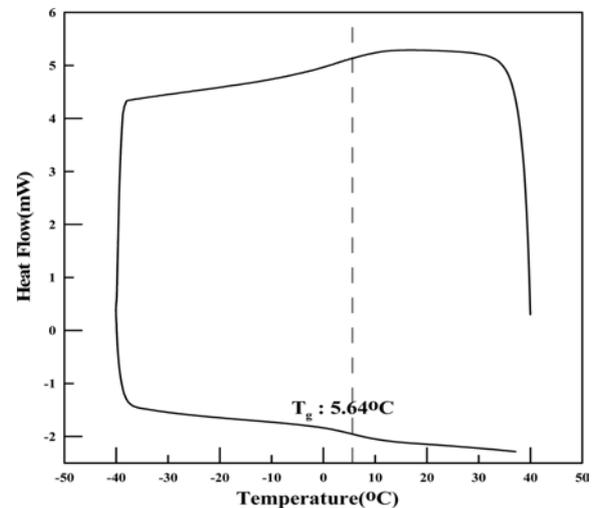
The measurement results of the average particle sizes confirmed that the particle size of PMAC was reduced to as much as 35% of that of AC, the unimproved polymer. In the case of DMAC, this decrease could be attributed to a slight decrease in the elongation together



**Fig. 1.** Remaining monomer analysis for PMAC.

**Table 5.** Properties of the resin powder pre- and post- performance improvement.

Properties	AC	DMAC	PMAC
Theoretical $T_g$	-11 °C	-11 °C	-11 °C
Experimental $T_g$	5.64 °C	5.64 °C	5.64 °C
Tensile strength of the film (20% dispersion)	10.5 N/mm <sup>2</sup>	11.0 N/mm <sup>2</sup>	10.5 N/mm <sup>2</sup>
20% Elongation of the film (20% dispersion)	150 %	145 %	196 %
Average particle size	831(32.7 × 10 <sup>-6</sup> ) nm	–	290(11.4 × 10 <sup>-6</sup> ) nm
emaining monomers	27.7 ppm	–	30.6 ppm
Ash content	14.39%	14.39%	14.21%
Redispersibility	1 hr	1.0 mm	1.0 mm
	2 hrs	1.0 mm	1.0 mm
	6 hrs	1.0 mm	1.0 mm
	24 hrs	3.0 mm	3.0 mm
	48 hrs	3.5 mm	3.5 mm

**Fig. 2.** Particle-size analysis for PMAC and AC.**Fig. 3.** DSC measurement results for DMAC.**Fig. 4.** DSC measurement results for PMAC.

with an increase in the tensile strength of the film that was created by inhibiting the formation of foam inside the polymer (Fig. 4). In the case of PMAC, which contained protective colloids and which was modified via the emulsion polymerization method, it was confirmed that the average polymer-particle size was significantly reduced due to the properties of the monomer feed (Fig. 5). Therefore, the performances of the polymer cement mortars using the improved polymers were expected to improve.

The air content and flow of the ordinary cement mortar and the polymer cement mortars prepared using AC, DMAC, and PMAC are summarized in Table 6 according to the type of polymer.

With the results shown in the above experiment in Table 6 on defoamer-added DMAC in which the air content decreased by about 10% compared to that of AC, air entrainment could be controlled with the addition of defoamer during polymerization.

In this study, defoamers were added to maintain the air content in a constant range. However, this addition

**Table 6.** Flow and air content of the polymer cement mortars.

Mortar type	Theoretical calculation $T_g$	Defoamer /Polymer	W/B	Flow	Air content
Control	–	–	54.0%	164 mm	5.6%
AC				160 mm	5.2%
DMAC	–11 °C	2.0 %	50.0%	154 mm	4.6%
PMAC				157 mm	5.9%

could not completely inhibit air entrainment, and thus, it was determined that adding defoamer during the polymerization process was more effective because the compressive strength could be enhanced by increasing the micropores and decreasing the total porosity inside the cement mortar via air entrainment control. In the case of PMAC, the flow slightly increased, and the air content slightly decreased, showing a similar tendency to that of AC.

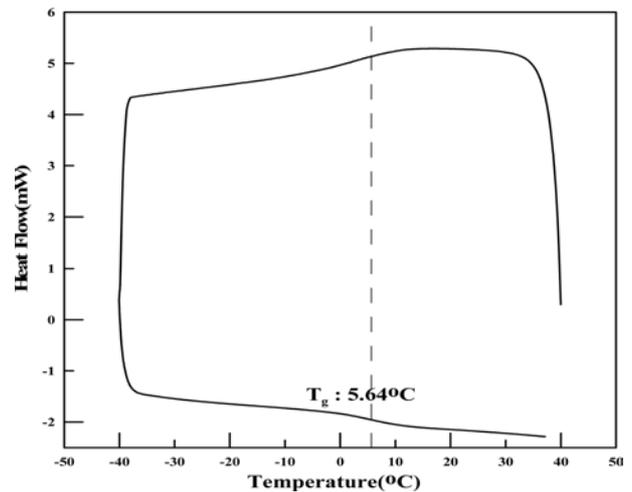
In general, the liquidity tends to increase as the air content increases. However, the fact that the liquidity did not increase in spite of an increase in the air content was due to the increased specific surface area of the polymer in contact with water inside the polymer cement mortar. Such an increase in the specific surface area resulted from a subtle change in the particle size of the improved PMAC compared to that of AC. In other words, an increase in the number of micro-particles increased the viscosity of the polymer cement mortar, leading to a decrease in the liquidity.

In order to compare the setting properties between the polymer cement mortars using DMAC, PMAC, and AC and those of the ordinary cement mortar, the setting times of the mortars were measured in accordance with the KS F 2436 [17] and the results are summarized in Fig. 6 according to the type of polymer. As shown in Fig. 6, the polymer cement mortars exhibited a tendency to delay setting when compared to the ordinary cement mortar.

The setting-time variations of the improved polymers PMAC and DMAC and the pre-performance improvement polymer AC did not demonstrate significant differences. These findings could be attributed to the use of a polymer with the same glass-transition temperature.

In particular, as shown in Fig. 6, the initial setting time of DMAC tended to be slightly earlier than that of AC. The reason for this trend was that the pores inside the polymer cement mortar decreased as the air entrainment of the polymer was controlled by defoamers added during the polymerization process. In other words, this penetration occurred when the penetration-resistance needle was impeded by a decrease in the internal pores, leading to an increase in the penetration resistance.

On the other hand, the initial setting time of PMAC was later than that of AC, but its final set occurred more quickly. These delayed initial set times were due to an increase in the number of polymer particles relative to the decrease in the sizes of the polymer

**Fig. 5.** Setting-time of Polymer mortar variation according to the performance in the polymers.

particles, which hindered the hydration rate of the cement particles. At the same time, the more rapid final set times were attributed to increases in the penetration resistance due to faster film formations inside the polymer cement mortars as the water redispersion of fine polymer particles was accelerated.

The compressive strengths of the ordinary cement mortar and the three polymer cement mortars were measured at ages of 3, 7, 28 and 56 days. The results are summarized in Table 7.

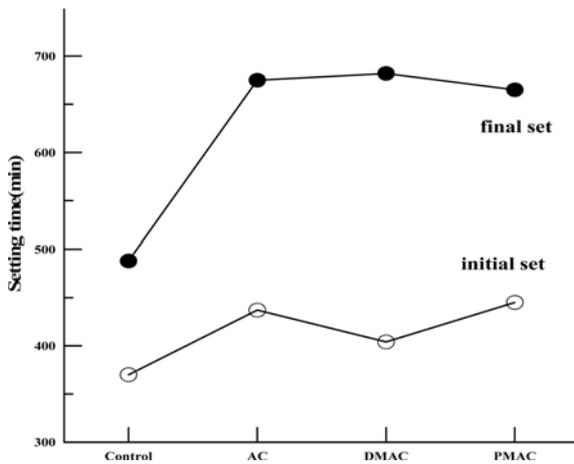
For the three different types of polymer powders, the compressive strength was expressed as a ratio of that of the specific polymer cement mortar to that of the ordinary cement mortar at each material age up to 56 days in Fig. 7. The compressive strengths increased by approximately 20-40% for both DMAC and PMAC compared to AC, and their compressive strengths increased by approximately 30-50% when compared to ordinary cement mortar, suggesting that the use of improved polymers in the polymer cement mortars improved the compressive strength.

When comparing PMAC and DMAC, which utilized different methods for their respective performance improvements, the observed trends differed slightly. In particular, DMAC showed the best compressive strength at ages up to 28 days, while PMAC showed the best long-term strength at 56 days. Such results suggested that performance improvement via control of the air

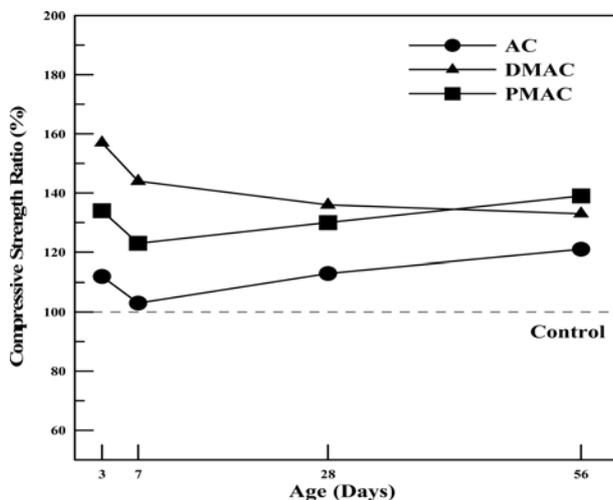
**Table 7.** Compressive strengths of the polymer mortars.

Mortar type	Compressive strength (Mpa)			
	3 days (%)	7 days (%)	28 days (%)	56 days (%)
Control	12.9(100)	23.0(100)	32.4(100)	35.8(100)
AC	14.4(112)	23.7(103)	36.7(113)	43.3(121)
DMAC	20.2(157)	33.2(144)	44.1(136)	47.6(133)
PMAC	17.3(134)	28.4(123)	40.6(125)	48.0(134)

※ ( ) is the Control (100% for ordinary cement mortars) for the compressive-strength ratios of the polymer mortars.

**Fig. 6.** Compressive-strength ratios of the polymer mortars.**Table 8.** Flexural strengths of the polymer mortars.

Mortar type	Flexural strength (Mpa)		Flexural strength ratio (%)	
	28 days	56 days	28 days	56 days
Control	6.5	7.0	100	100
AC	9.4	10.7	145	153
DMAC	11.3	11.9	174	170
PMAC	10.8	12.4	166	177

**Fig. 7.** Flexural-strength ratios of the polymer mortars.

entrainment was a highly effective method for improving the initial strength. When the performance was improved

by modifying the emulsion polymerization method, the formation of the polymer film inside the polymer cement mortar was accelerated by the reduced polymer particle size, resulting in a more elaborate form of film. This technique, in turn, inhibited the evaporation of water inside the mortar, causing hydration to occur over a long period. As a result, the strength tended to increase as the age increased.

Table 8 summarizes the flexural strengths of the ordinary cement mortar and the polymer cement mortars using AC, DMAC, and PMAC at the ages of 28 and 56 days along with the flexural strength ratios of the polymer cement mortars to the ordinary cement mortar.

Fig. 8 depicts the flexural-strength ratios of the prepared specimens at ages of 28 and 56 days in order to examine the manifestation of the flexural-strength properties in the polymer cement mortars before and after performance improvements. As shown in Fig. 8, the flexural strengths of DMAC and PMAC increased by approximately 15-20% at 28 days and by approximately 11-16% at 56 days when compared to that of AC. In particular, the flexural strength of PMAC increased by more than 10% over that of AC even after 28 days, indicating that there was an enhancement effect in the aged materials. The reason for this result was that, as shown in the compressive-strength results, the decreased total pores and the increased micropores with air-entrainment control, together with the reduced polymer particle size, made it possible to penetrate quickly between the aggregates and cement, increasing the binding abilities.

The adhesion strengths of the ordinary cement mortar and the polymer cement mortars using AC, DMAC, and PMAC at ages of 7, 14, and 28 days were measured as shown in Table 9 and Fig. 9. As shown in Fig. 9, each polymer cement mortar demonstrated 2-3 fold greater strength than that of the ordinary cement mortar, and the adhesion strength tended to increase with age. For DMAC and PMAC, the adhesion strength tended to increase compared to AC, and PMAC, in particular, showed an approximately 20-50% strength enhancement.

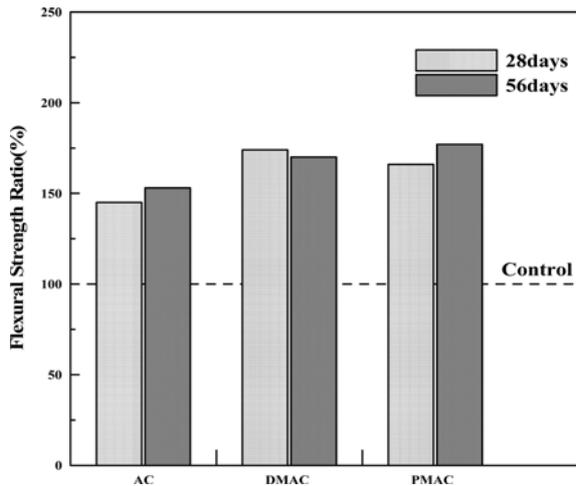
To examine the manifestation of the adhesion-strength properties in the improved polymer cement mortars, the adhesion strengths were measured at each material age up to 28 days. The adhesion-strength ratios of the polymer cement mortars to the ordinary cement mortars by material age are summarized in Fig. 10. As shown in Fig. 10, the adhesion strengths at material ages tended to decrease as early as 14 days.

The reason for this trend was that, in the case of the polymer cement mortars, the polymer films created at early ages adhered in such a way that they connected the interfaces of the mortars and parent concretes. In contrast, ordinary cement mortar showed better adhesion at later ages as hydration proceeded and

**Table 9.** Adhesion strengths of the polymer mortars.

Mortar type	Adhesion strengths/(Mpa)		
	7 days (%)	14 days (%)	28 days (%)
Control	0.9(131)	1.0(145)	1.6(232)
AC	1.8(261)	2.1(305)	2.9(421)
DMAC	2.3(334)	2.5(363)	3.2(464)
PMAC	2.8(406)	3.1(450)	3.4(493)

※ [ ] is the Control (100% for ordinary cement mortars) for the adhesion-strength ratios of polymer mortars.

**Fig. 8.** Adhesion strength of the polymer cement mortars.

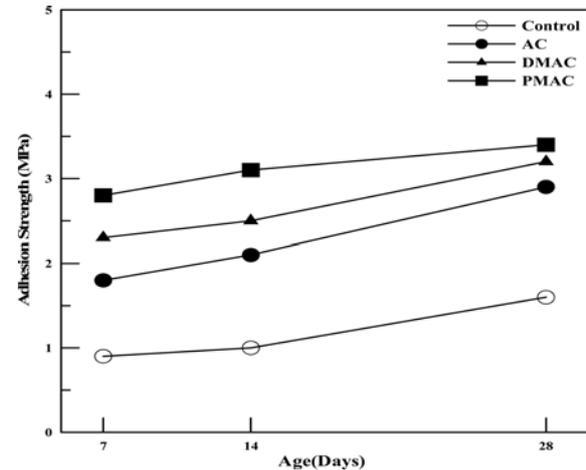
showed significantly less adhesion at early ages because the adhesion strength increased as the cement is hydrated and incorporated into the parent concrete, leading to a greater adhesion-strength ratio at early ages.

For DMAC, the adhesion strength increased as the internal pores decreased with air-entrainment control. On the other hand, PMAC showed an increase in the adhesion strength from early ages because the smaller polymer particles could penetrate into the interface between the polymer cement mortar and parent concrete more quickly, which eventually increased the binding ability.

In order to examine the volume changes of the polymer cement mortars in relation to the performance improvements of the polymers, polymer cement mortars were prepared by incorporating the three redispersible polymer powders: AC, DMAC, and PMAC. Table 10 and Fig. 10 show the results of the length changes used to compare the volume changes for each specimen up to 56 days in accordance with ASTM C157 [15]. As shown in Fig. 10, the rates of the length changes were low for all polymer cement mortars. In addition, the improved polymers PMAC and DMAC showed increased shrinkage changes when compared to the pre-performance improvement polymer AC, confirming the positive effect of performance improvement in the polymers.

**Table 10.** Length changes of the polymer mortars.

Days type	7 days ( $\times 10^{-3}$ , %)	28 days ( $\times 10^{-3}$ , %)	56 days ( $\times 10^{-3}$ , %)
Control	8.98	10.32	10.99
AC	1.25	3.59	4.48
DMAC	1.18	1.51	2.45
PMAC	1.01	1.18	1.34

**Fig. 9.** Adhesion strength of the polymer cement mortars.

In particular, PMAC showed the smallest shrinkage. By reducing the particle size, the formation of the impermeable polymer film inside the polymer cement mortar was accelerated and became more elaborate, suppressing evaporation inside the mortar to a greater extent.

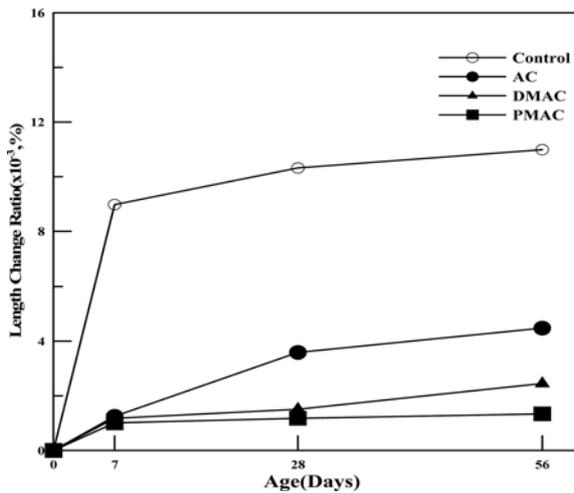
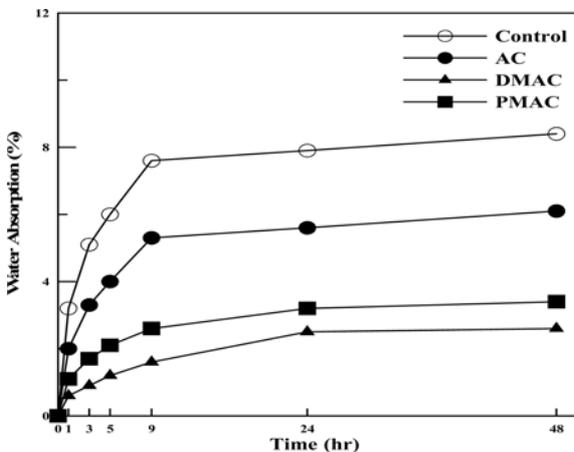
Water penetration into concrete structures, e.g., through osmosis, is a cause of performance degradation that can significantly affect durability. Moreover, water penetrating into the interior of a concrete will most likely contain aggressive ions; for example, chloride-containing water causes rebar corrosion and serious damage to concrete structures. Therefore, it is important to reduce water absorption in order to improve the durability of concrete structures.

Water absorption and penetration of ordinary polymer cement mortars and concretes tend to decrease with an increasing polymer-cement ratio rather than depending on the type of polymer incorporated into the mortar and concrete. In order to produce highly waterproof polymer cement mortars and concretes, it is important that they possess sealing effects via the creation of continuous polymer films or the filling of large pores with polymer particles.

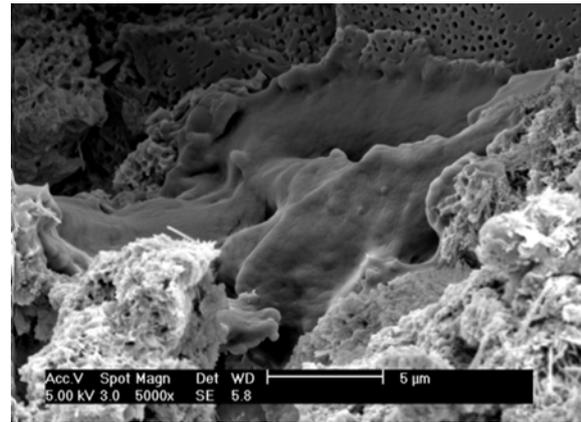
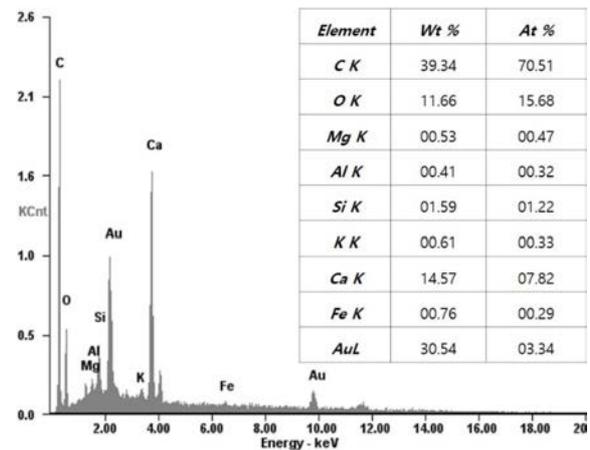
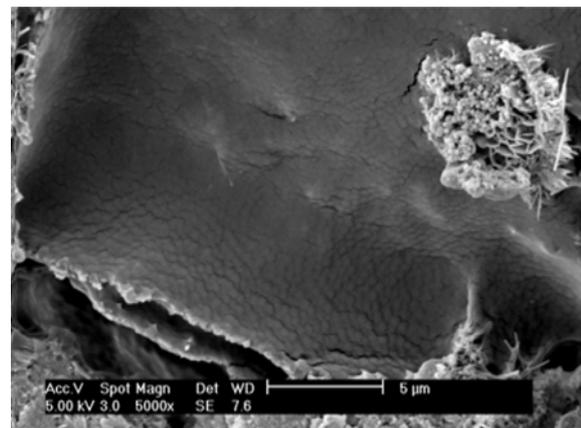
In this study, the absorption rates of the ordinary cement mortar and the polymer cement mortars using AC, DMAC, and PMAC were measured to evaluate the effects of the redispersible polymer powders in the mortars by way of their waterproofing performance. The experimental results are summarized in Table 11 and Fig. 11. As shown in Fig. 11, the absorption of

**Table 11.** Absorption rates of the polymer mortars.

Absorption hours	Control (%)	AC (%)	DMAC (%)	PMAC (%)
1	3.2	2.0	0.6	1.1
3	5.1	3.3	0.9	1.7
5	6.0	4.0	1.2	2.1
9	7.6	5.3	1.6	2.6
24	7.9	5.6	2.5	3.2
48	8.4	6.1	2.6	3.4

**Fig. 10.** Rate of the length change of the polymer mortars.**Fig. 11.** Water Absorption of the polymer mortars.

ordinary cement mortar was 8.4% at 48 hrs; in contrast, the absorption rates were improved by 72.6%, 30.9%, and 40.5% for the AC, DMAC, and PMAC polymer mortars, respectively. These results were consistent with the results of Song et al. [18]. The reason for this tendency was that water absorption was prevented by the formation of impermeable polymer films along with compact structures, caused by the lower water-binding-material ratios made possible with the use of the polymers. In particular, the improved DMAC and PMAC demonstrated significant improvements in their performance as a result of the enhanced compactness

**Fig. 12.** SEM image of the polymer film (DMAC).**Fig. 13.** EDS analysis of the polymer film (DMAC).**Fig. 14.** SEM image of the polymer film (PMAC).

of the films when compared to AC. This confirmed that performance improvements with the use of functional additives and with the modification of the emulsion polymerization method were effective in decreasing the absorption.

In order to observe the nature of the polymer films formed inside the improved polymer cement pastes, the microstructures were analyzed using scanning electron

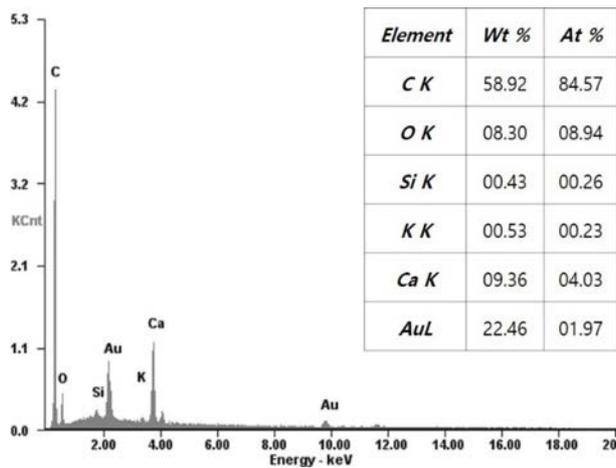


Fig. 15. EDS analysis of the polymer film (DMAC).

microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS). The EDS analysis results and SEM image of the DMAC polymer film are shown in Figs. 12 and 13, while the EDS analysis results and SEM image of the PMAC polymer film are depicted in Figs. 14 and 15. The improved polymers formed films by penetrating into the pores of the cement pastes. The EDS analysis results confirmed that the polymer films formed in the concrete pastes were mainly composed of carbon.

### Summary

After examining polymerization methods for the performance improvements of cement matrices, we drew the following conclusions. If performance was improved via the modification of emulsion polymerization, then the average polymer particle size decreased to about 30% of its original size. Moreover, the polymer cement mortars showed an approximate 10% reduction of the air content with the use of defoamer. An approximate 20-40% increase in the compressive strengths and more than 20% increase in the flexural strengths were observed when compared to the cases before performance improvement. In particular, the modification of emulsion polymerization resulted in an approximate 20-50% increase in the adhesion strength.

Furthermore, the use of an improved polymer increased the waterproofing performance; the results of SEM and EDS analysis confirmed that polymer films were mainly created around the cracks and pores inside the cement pastes. These results all indicated that the properties of acrylic redispersible polymer powders varied according to the glass-transition temperature and that the performance could be improved via the modification of protective colloids and emulsion polymerization as well as the use of a defoamer as a functional additive. The physical properties and durability of the polymer cement concretes could be enhanced by improving the performance of the polymers. In particular, the performance improvements

in the polymers significantly improved the performances of the polymer cement mortars and concretes, suggesting that the use of acrylic redispersible polymer powders should be an effective measure for improving the workability of concretes.

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