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Mechanical Properties and Durability of Asphalt Emulsion-Modified Cement Mortars

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Abstract

Asphalt emulsion is manufactured by the emulsification of asphalt, and is considered as an energy-saving, ecologically safe material because it does not need any heating processes with gas emission and fire hazard in its use. This study is concerned with evaluating the feasibility of the use of an asphalt emulsion as a polymeric admixture. Asphalt-modified mortars using an experimentally manufactured asphalt emulsion were prepared with various polymer-cement ratios, and tested for the mechanical properties such as strengths and adhesion and the properties related to durability such as water absorption, permeation, carbonation and chloride ion penetration. As a result, the waterproofness, carbonation resistance and chloride ion penetration resistance of the asphalt-modified mortars were markedly improved with an increase in the polymer-cement ratio, but their compressive strength and adhesion to mortar substrates were reduced with increasing polymer-cement ratio. Therefore, it is recommended to control their polymer-cement ratio to be 10% or lower in their practical applications. Further study to improve their compressive strength and adhesion is needed.

Keywords : asphalt emulsion, polymer, durability, admixture

1. Introduction

In general, asphalt is melted through any heating processes, and widely used as paving and waterproofing materials in the construction industry. Such heating processes accompany the emission of gases with disagreeable odors from the asphalt and the danger of fire, and the melted asphalt becomes a hazard to burn or scald for the human body.

The development of the application methods of the asphalt, which do not need any heating processes, is strongly requested in Korea. The active use of asphalt emulsion in the development is in progress. The asphalt emulsion is manufactured by the emulsification of the asphalt, and is an energy-saving, ecologically safe material because it does not need any heating processes with the gas emission and the danger of fire in its use.[1,2)]

Additionally, there exist a few efforts to use asphalt emulsion as cement modifier in Korea. Soh[3)] reported the modification effects of asphalt emulsion which was added to cement mortar. According to his results, asphalt modified cement mortar shows the strength reduction due to the high porosity with the increase in the addition ratio of asphalt emulsion. G. Li et al.[5)] conducted the experiments to evaluate the mechanical properties of a three-phase cement-asphalt emulsion composite(CAEC). Through experimental investigation, they reported that CAEC possessed most of the characteristics of both cement and asphalt, namely the longer fatigue life and lower temperature susceptibility of cement concrete, and higher toughness and flexibility of asphalt concrete.

The cost of the asphalt emulsion is much lower than that of ordinary polymeric admixtures such as SBR latex, EVA and PAE emulsions for polymer-modified mortars and concretes. If high-quality asphalt emulsion as a polymeric admixture is developed, its applications are found to expand considerably in the construction industry.[3)]

The purpose of this study is to investigate the basic properties of asphalt-modified mortars using an experimentally

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Table 1 Chemical compositions of ordinary Portland cement.

Chemical compositions (%)								
CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	insol.	ig. loss	Total
65.3	22.2	5.1	3.2	1.3	1.9	0.3	0.6	99.9

Table 2 Physical properties of ordinary Portland cement.

Density (g/cm^3)	Blaine fineness (cm^2g)	Setting time (h-min)		Compressive strength (MPa)		
		Initial set	Final set	3 d	7 d	28 d
3.14	3300	2-18	3-12	15.0	25.5	43.3

Table 3 Properties of asphalt emulsion.

Color	Density (g/cm^3, 20℃)	PH (20℃)	Viscosity (mPa · s, 20℃)	Total solids (%)
Blown	1.02	9.02	479	58.0

Table 4 Mix proportions of asphalt-modified mortars.

Type of mortar		Cement : sand (by mass)	Anti-foamer content(%)	Polymer-cement ratio (%)	Water-cement ratio (%)	Air content (%)	Flow (mm)
Unmodified mortar		1 : 3	0	0	63.3	6.3	168
Asphalt-modified mortar	AE-1			10	61.5	9.2	171
				20	61.5	10.6	169
				30	61.0	11.4	170
	AE-2		2	10	69.6	7.9	171
				20	73.6	8.8	169
				30	82.5	10.3	170

manufactured asphalt emulsion and evaluate the feasibility of the use of the asphalt emulsion as a polymeric admixture.

To these ends, asphalt-modified mortars using an experimentally manufactured asphalt emulsion, in this paper, were prepared with various polymer-cement ratios, and tested for strengths, adhesion, water absorption and permeation, carbonation and chloride ion penetration, which is generally considered as be a significant modification effect to cement mortar.[2,5,6]

2. Materials

Ordinary portland cement as specified in KS 5201(Specification for portland cements) was used for the preparation of asphalt-modified mortars. Tables 1 and 2 list the chemical compositions and physical properties of the cement. Standard sand, predominantly graded to pass a No.30(600 ㎛) and be retained on a No.50(300 ㎛)sieve, was used as a fine aggregate.

An asphalt emulsion experimentally manufactured in Korea was used in this study, whose properties are given in Table 3. A silicone emulsion-type antifoamer(AF) was added to the asphalt emulsion in a ratio of 2.0% of it to the total solids of the asphalt emulsion.

3. Testing procedures

3.1 Preparation of specimens

Fresh asphalt-modified mortars (AE) were mixed with mix proportions shown in Table 4 in accordance with the method conforming to KS F 2476 (Test method for polymer-modified mortars). Beam specimens 40×40×160mm for flexural and compressive strength, water absorption, accelerated carbonation and chloride ion penetration tests, and disk specimens Ø150×40mm for water permeation test were molded using the fresh asphalt-modified mortars, and subjected to a 2d-20℃-80% (RH)-moist plus 5d-20℃-water plus 21d-20℃-50% (RH)-dry curing. Special-shaped specimens for adhesion test were prepared by placing the fresh asphalt-modified mortars in size of 40×40×10mm on cement mortar substrates (cement: river sand = 1:3 (by mass); water-cement ratio = 65.0%; curing condition = 1d-20℃-80% (RH)-moist plus 27d-20℃-50%(RH)-dry curing) and by giving a 2d-20℃-80% (RH) -moist plus 5d-20℃-water plus 23d-or 173d-20℃-50%(RH)-dry curing.

3.2 Flexural and compressive strength tests

Beam specimens were tested for flexural and compressive

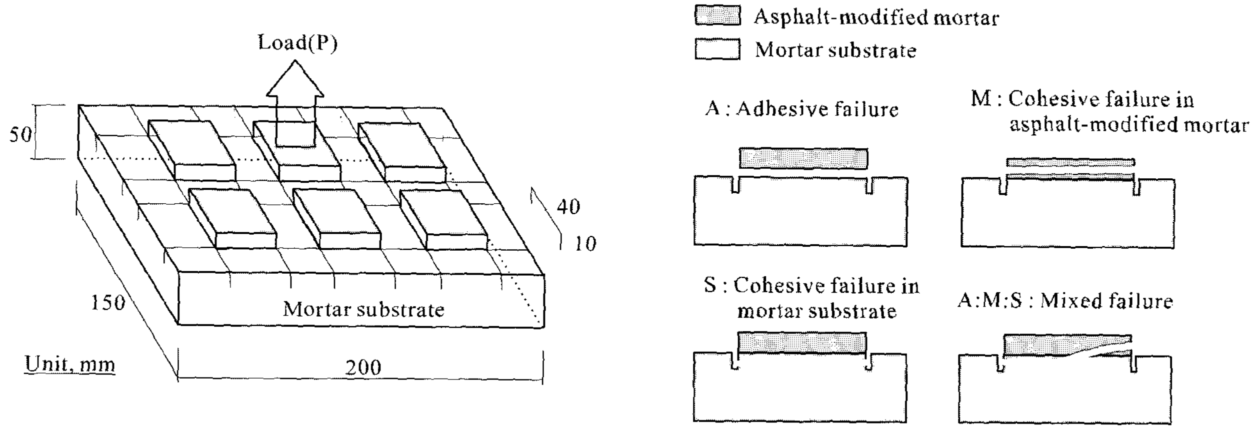


Fig. 1 Adhesion test in tension and types of failure modes of specimens.

strengths in accordance with KS F 2477 (Method of test for strength of polymer-modified mortar).

3.3 Adhesion test in tension

Special-shaped specimens [3,4] were tested for adhesion in tension by using a manually operated direct pull-gage machine as illustrated in Fig.1. After adhesion test, the specimens were observed for failure modes, which are classified into the following four types;

A : Adhesive failure
M : Cohesive failure in asphalt-modified mortar
S : Cohesive failure in mortar substrate
A:M:S : Mixed failure

As shown in Fig. 1, the type of failure mode is, in this study, classified into four types of 'A', 'M', 'S' and 'A:M:S'. In order to quantify the failure mode, the total area of the bonded surfaces was supposed to be 10, and the approximate ratios of 'A', 'M', 'S' and 'A:M:S' areas to the failed cross-sections were expressed as the quantification of 'A', 'M', 'S' and 'A:M:S' of each failure type.

3.4 Water absorption and permeation tests

According to JIS A 6203 (Polymer dispersions and redispersible polymer powders for cement modifiers) and KS F 2451 (Method of test for waterproof agent of cement for concrete in building construction), beam specimens were tested for water absorption and permeation, and their water absorption and permeation were determined.

3.5 Accelerated carbonation test

According to KS F 2476 (Test method for polymer-modified mortars), beam specimens were tested for accelerated carbonation in a carbonation test chamber, in which temperature, humidity and carbon dioxide (CO_2) gas concentration were controlled to be 20℃, 60% (RH) and 10%, and their carbonation depth was measured.

3.6 Chloride ion penetration test

According to KS F 2476 (Test method for polymer-modified mortars), beam specimens were tested for chloride ion penetration, and their chloride ion penetration depth was measured.

4. Test results and discussion

4.1 Flexural and compressive strengths

Fig. 2 illustrates the polymer-cement ratio vs. flexural and compressive strengths of asphalt-modified mortars. In case of not adding the antifoamer, the flexural strength of the asphalt-modified mortars was slightly higher at 10% of polymer-cement ratio than unmodified mortar, and showed the about 6MPa of the highest flexural strength a maximum at polymer-cement ratio of 10%, while those of the mortars with the antifoamer tended to gradually decrease with increasing polymer-cement ratio. The flexural strength of the mortars without the antifoamer was higher than that of the mortars with the antifoamer. The compressive strength of the asphalt-modified mortars decreased with an increase in the polymer-cement ratio in spite of the addition of the antifoamer. The compressive strength of the mortars without the antifoamer was somewhat larger than that of the mortars with the antifoamer.

The phenomenon of the reduction in the compressive and flexural strengths as shown in Fig. 2 is thought to be attributed to a marked increase in the water-cement ratio as listed in Table 4 with increasing polymer-cement ratio in spite of the addition of antifoamer. This result is entirely different from the existing investigations[7] using typical polymer dispersion or latex that have reported that the usage of anti-

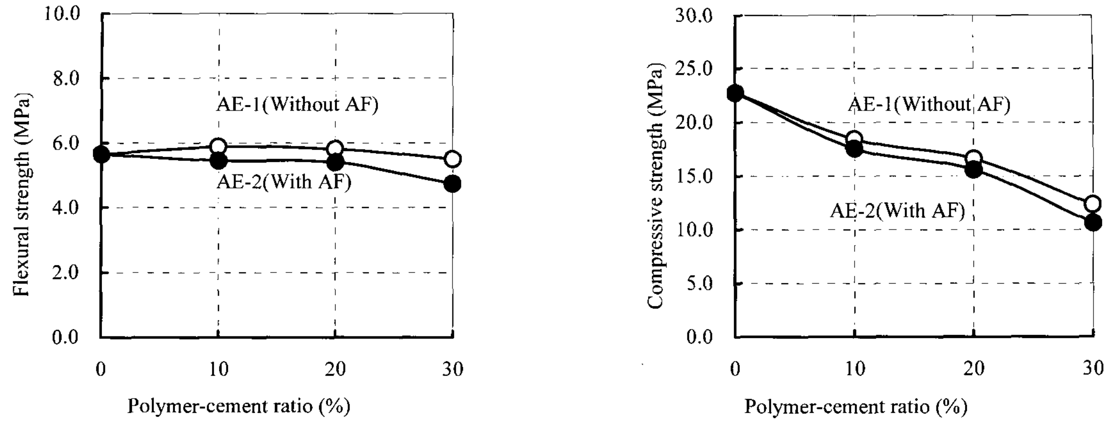


Fig. 2 Polymer-cement ratio vs. flexural and compressive strengths of asphalt-modified mortars.

foamer gave rise to the decrease in water-cement ratio to some extent and its compensation effect increased the flexural and compressive strength of the polymer-modified cement mortar or concrete.

Therefore, the asphalt-modified mortars with the antifoamer were not tested for other properties except the strengths. In other words, it was found that the antifoamer used was not suitable for the asphalt-modified mortars.

4.2 Adhesion in tension

Fig. 3 illustrates the adhesion in tension and failure mode distribution of asphalt-modified mortars (AE-1) to cement mortar substrates at curing periods of 1 and 6 months. The adhesion of the asphalt-modified mortars in tension tended to decrease with raising polymer-cement ratio in spite of the curing period.

The adhesion in tension at 6 months was higher than at 1 month. This is thought to be verified by the occurrence of the cohesive failure in the mortar substrate, denoted as 'S' described in 3.3 clause of this article, at 6 months of curing period. In case of the adhesion test at 1 month, the cohesive failure, 'S', in the asphalt-modified mortar tended to occur as polymer-cement ratio of asphalt-modified mortars increased from 10 to 30%. In case of the adhesion test at 6 months, the cohesive failures, 'S', in mortar substrate as well as the asphalt-modified mortar tended to occur as polymer-cement ratio increased from 10 to 30%.

Although the adhesion in tension decreased with increasing polymer-cement ratio, the adhesions in tension of all specimens at both 1 and 6 months were 1.2MPa or higher, and met the quality requirement for the adhesion in tension by the same test method as prescribed in JIS A 6203 (Polymer dispersions and redispersible polymer powders for cement modifiers).

4.3 Water absorption and water permeation

Fig. 4 exhibits the relationship of the polymer-cement ratio vs. water absorption and permeation of asphalt-modified

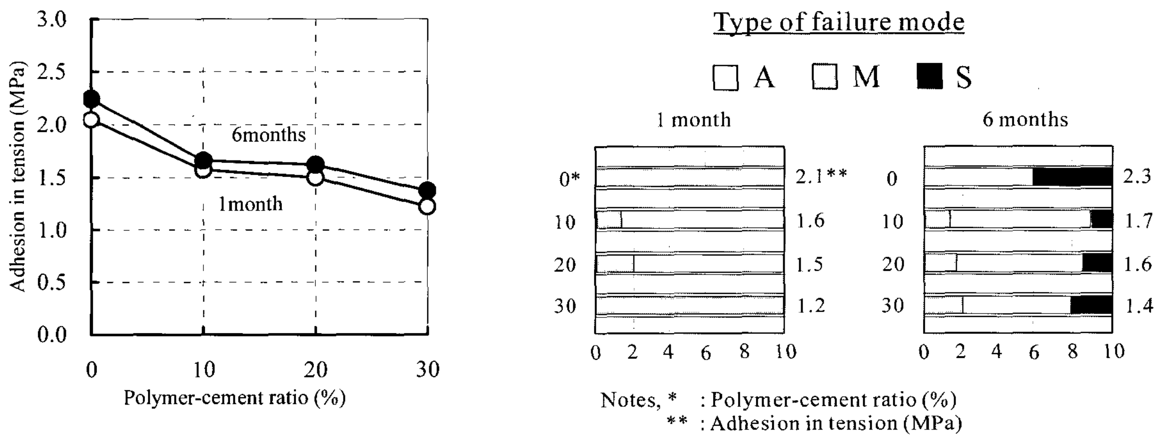


Fig. 3 Adhesion in tension to cement mortar substrates and failure mode distribution of asphalt-modified mortars (AE-1) at curing periods of 1 and 6 months.

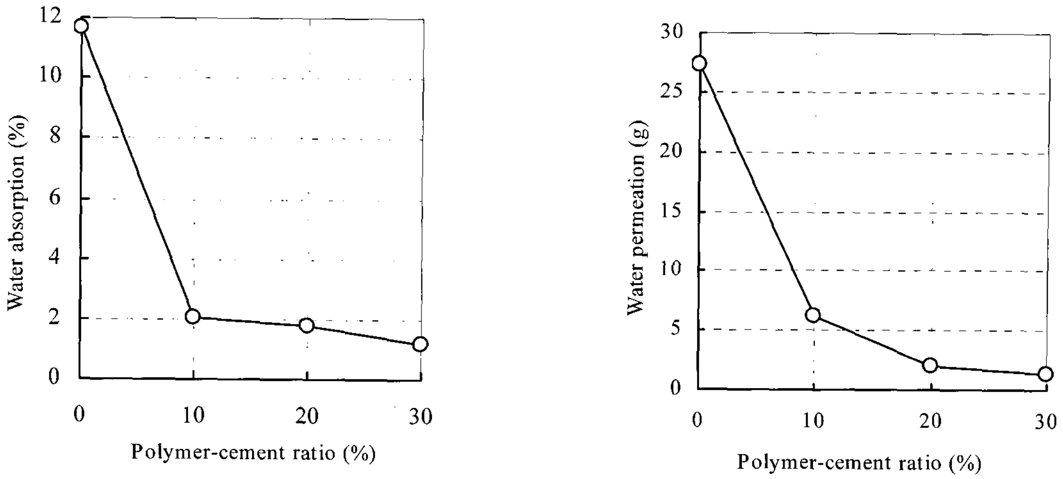


Fig. 4 Polymer-cement ratio vs. water absorption and permeation of asphalt-modified mortars (AE-1)

mortars (AE-1). The water absorption and permeation of the asphalt-modified mortars were sharply decreased with an increase in the polymer-cement ratio, which is very well coincided with that of polymer-modified cement mortar.[7] The water absorption and permeation at polymer-cement ratios of 20% or more were about 1/6 and 1/10 of those of unmodified mortar, respectively. Such excellent waterproofness of the asphalt-modified mortars is caused by the superior watertightness of asphalt itself, that is, the co-matrix phase, in which the impervious asphalt films as seen in Photo 1 interpenetrate throughout the cement hydrates in the mortars.

4.4 Carbonation and chloride penetration depth

Fig. 5 exhibits the relationship of the polymer-cement ratio vs. carbonation and chloride ion penetration depths of asphalt-modified mortars (AE-1). The carbonation and chloride ion penetration depths of the asphalt-modified mortars were reduced with raising polymer-cement ratio. This tendency also is evident from Photo 1, which represents the permeation depth of carbonation due to dioxide and chloride attack due to chloride ion as the increase in 0% to 30% of the polymer-cement ratio, respectively. The carbonation and chloride ion penetration depths at polymer-cement ratios of 20% or less were approximately 1/4 or less and 1/6 of those of unmodified mortar. Such superior carbonation resistance and chloride ion penetration resistance of the asphalt-modified mortars are due to the carbon dioxide gas and chloride ion barrier properties of the im proving asphalt films formed in the mortars as shown in Photo 1.

4.5 Microstructures

Photo 2 illustrates the asphalt films formed in an asphalt-modified mortar (AE-1) with a polymer-cement ratio of 20%, which was prepared with the procedure that after the asphalt-modified cement mortar at 28 days of curing age is immersed in nitric acid, the cement hydrates as well as the fine aggregates existing in this specimen is removed only except asphalt emulsion based on the property of asphalt emulsion enduring its attack. The white portion in Photo 2 indicates the polymer film formulated by asphalt emulsion and the other portion indicates the space filled with cement hydrates and fine aggregates.

From this SEM micrograph, it can be observed that the asphalt films form a network structure in the microstructure of the asphalt-modified mortar. Such asphalt films greatly contribute to the improved waterproofness, carbonation resistance and chloride ion penetration resistance of the asphalt-modified mortars compared to unmodified mortar, although their marked strength improvement is not made because of the low stiffness or elastic modulus of the asphalt itself. The interfacial pores between the cement hydrates and fine aggregate particles might be filled with by the asphalt emulsion with smaller particle sizes than cement particles and capillary pores with making the films or threads of the asphalt shown in Photo 2, which make the asphalt-modified cement mortar more impermeable compared to unmodified cement mortar.

5. Conclusions

The conclusions obtained from the above test results are summarized as follows:

1) Compared to unmodified mortar, the waterproofness, carbonation resistance and chloride ion penetration resistance of asphalt-modified mortars are markedly improved with increasing polymer cement ratio. By contrast, their flexural strength varies slightly with an increase in the polymer-cement ratio, and their compressive strength and adhesion in tension are decreased with increasing polymer-cement ratio.

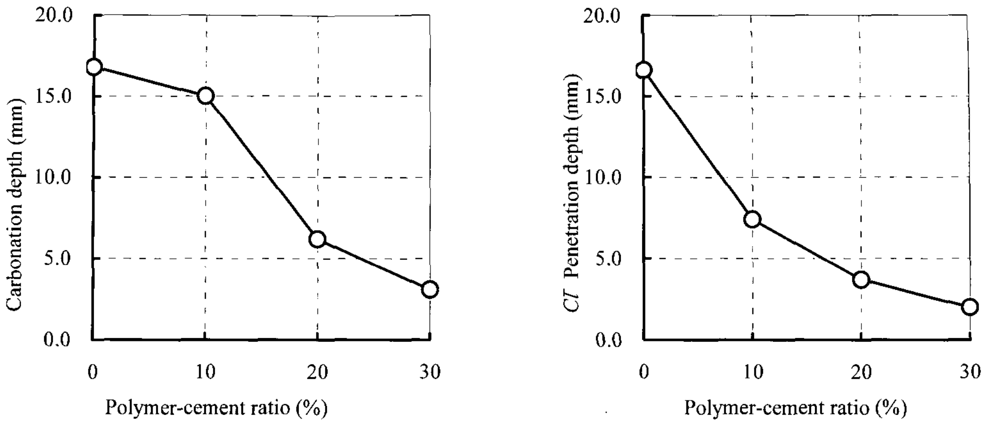


Fig. 5 Polymer-cement ratio vs. carbonation and chloride ion penetration depths of asphalt-modified mortars (AE-1)

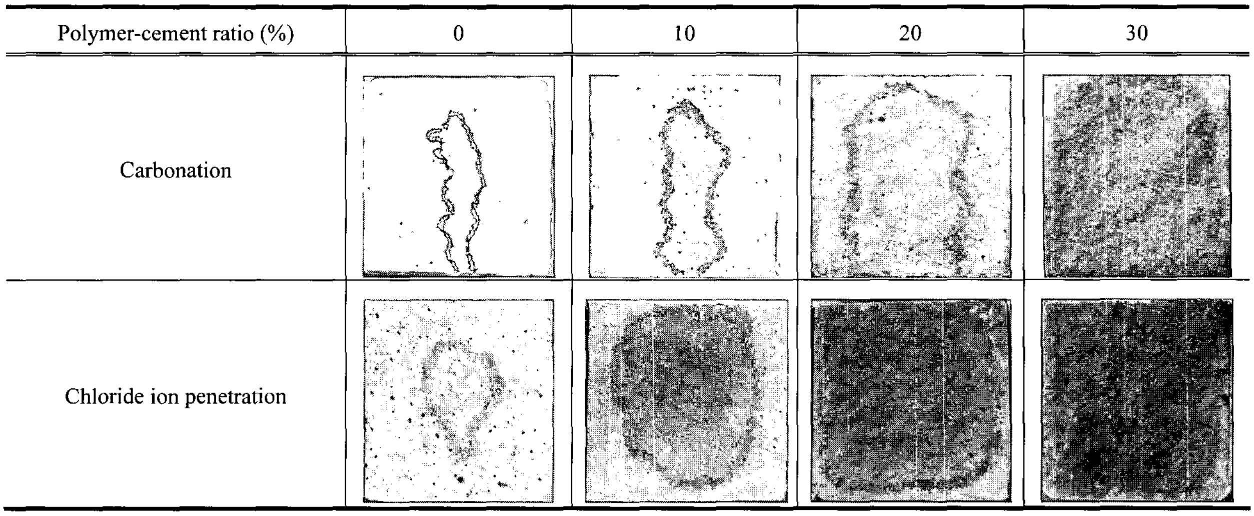
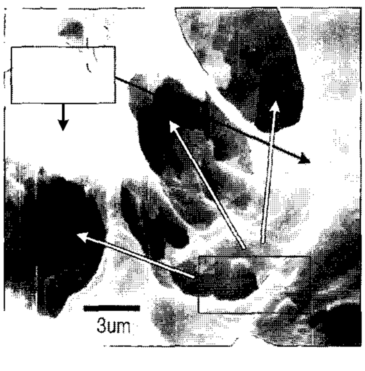


Photo 1 Polymer-cement ratio vs. carbonation and chloride ion penetration depths of asphalt-modified mortars (AE-1).
1 Photograph of sections of asphalt-modified mortars (AE-1) after carbonation and chloride ion penetration tests.



Asphalt-modified mortar (AE-1)

Photo 2 Asphalt films formed in asphalt-modified mortar (AE-1) with polymer-cement ratio of 20%.

2) From the view point of strength development, waterproofness and durability in the practical applications of asphalt-modified mortars, their polymer-cement ratio should be controlled at 20% or less. Further study to improve their compressive strength and adhesion is needed.

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