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Air Permeability of Hardener-Free Epoxy-Modified Mortars Using NDT

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Abstract

The purpose of this study is to investigate the air permeability of hardener-free epoxy-modified mortars by applying a non-destructive testing method developed by RILEM Technical Committee 189-NEC. Considering intelligent patch materials for the repair work of deteriorated reinforced concrete structures, hardener-free epoxy-modified mortars using a bisphenol A-type epoxy resin without any hardener are prepared with various polymer-cement ratios, and tested for moisture content, air permeability and strength. As a result, although there is no significant strength improvement, the coefficient of air permeability of the hardener-free epoxy-modified mortars is markedly decreased with an increase in the polymer-cement ratio.

Keywords: epoxy-modified mortar; air permeability; hardener-free epoxy resin; polymer-cement ratio; strength

1. Introduction

Recently, the rapid deterioration of reinforced concrete structures due to chloride-induced corrosion, alkali-aggregate reaction and early carbonation has become a serious problem. The polymer-modified mortar which is produced by mixing polymeric admixtures with cement mortar is currently used in large quantities as a popular repair material for the deteriorated reinforced concrete structures because of its high flexural and tensile strengths, adhesion to cement concrete, waterproofness, airtightness and durability. In particular, it was noted that polymer-modified mortar using a hardener-free epoxy resin has a self-healing or self-repairing function for micro cracks. Such a function is developed by the self-capsuled epoxy resin formed in the mortar [1]. Because the hardener-free epoxy resin can harden in the presence of alkali or hydroxide ions in the mortar and cause its self-capsulation [1-3]. The air permeability of patch materials or cover concrete plays an important role in the durability of repair work for deteriorated reinforced concrete structures because it controls the rate of penetration of air with moisture.

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Hardener-free epoxy-modified mortar system is an option as an intelligent patch material for deteriorated reinforced concrete structures. The purpose of this study is to investigate the air permeability of the hardener-free epoxy-modified mortars by applying a non-destructive in-situ testing method specified in the State-of-the-Art Report of RILEM Technical Committee on Non-Destructive Evaluation of the Penetrability and Thickness of Concrete Cover. Hardener-free epoxy-modified mortars using a bisphenol A-type epoxy resin without any hardener are prepared with polymer-cement ratios (epoxy-cement ratios) of 0, 5, 10, 15, and 20 %, and tested for air permeability after a 28-d dry curing. The hardener-free epoxy-modified mortars with the same polymer-cement ratios are also prepared, and tested for moisture content and strength.

2. Materials

2.1. *Cement*

Ordinary Portland cement as specified in JIS (Japanese Industrial Standard) R 5210 (Portland cement) was used as a cement. The properties of the cement are given in Table 1.

TALBE 1: PHYSICAL PROPERTIES AND CHEMICAL COMPOSITIONS OF CEMENT

Density (g/cm^3)	Blaine specific surface (cm^2/g)	Setting time (h-min)		Compressive strength (MPa)		
		Initial set	Final set	3d	7d	28d
3.16	3370	2-10	3-30	28.8	43.6	61.2

Chemical compositions (%)		
MgO	SO_3	ig. loss
1.48	2.12	1.90

2.2. *Fine aggregate*

Toyoura standard sand as specified in ex-JIS R 5201 (Physical Testing Methods for Cement) was used as a fine aggregate. The properties of the fine aggregate are listed in Table 2.

TABLE 2: PROPERTIES OF TOYOURA STANDARD SAND

Size (mm)	Fineness modulus	Bulk density (kg/l)	Density (g/cm^3)	Water absorption (%)
0.106-0.30	1.36	1.52	2.63	0.11

2.3. *Polymeric admixture*

A diglycidyl ether of bisphenoal A was used as a polymeric admixture. The properties of the epoxy resin are shown in Table 3.

TABLE 3: PROPERTIES OF EPOXY RESIN

Epoxy equivalent	Molecular weight	Density (g/cm^3, 20℃)	Viscosity (MPa・s, 20℃)	Flash point (℃)
184	380	1.16	38000	264

3. Testing Procedures

3.1. *Preparation of specimens*

According to JIS A 1171 (Test Methods for Polymer-Modified Mortar), hardener-free epoxy-modified mortars were mixed with a mass ratio of cement to fine aggregate 1:3, polymer-cement ratios (P/C) of 0, 5, 10, 15 and 20%, and a water-cement ratio of 50.0%. Their flows were in the range of 170 ± 5. Cylindrical specimens $\phi\, 150 \times 300$ mm for air permeability test and beam specimens $40 \times 40 \times 160$ mm for strength test were molded, and subjected to a 20℃-60%(RH)-dry curing for 28 d.

3.2. *Moisture content determination*

The moisture content of cylindrical specimens was determined by using the Concrete and Mortar Moisture Tester (HI-520, manufacturer: Kett Electric Laboratory) as shown in Figure 1 before air permeability test.

3.3. *Air permeability test*

The air permeability test of cylindrical specimens was carried out by using the "Torrent Permeability Tester", developed at "Holderbank" Management & Consulting Ltd. (currently Holcim Support Ltd.) in Switzerland. The distinctive characteristic features of this method are a two-chamber vacuum cell and a regulator that balances the pressure in the inner (measuring) chamber and in the outer (guard-ring) chamber as shown in Figure 1.

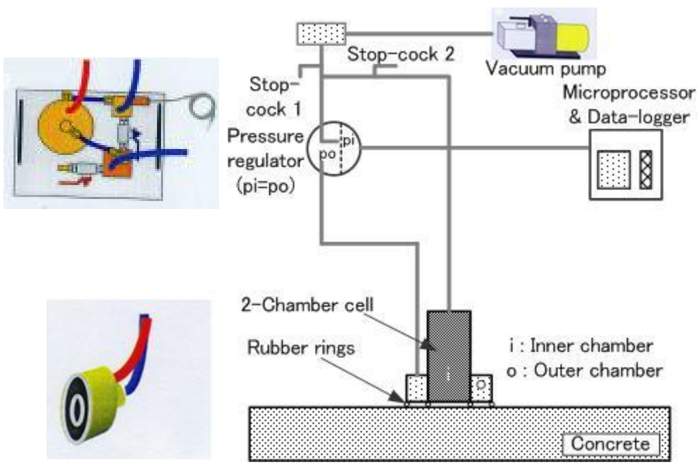

Figure 1: Torrent Permeability Tester.

The operation is as follows: the cell is placed on the concrete surface, and a vacuum is created in both chambers with the pump. Due to the external atmospheric pressure and the rubber rings, the cell is pressed against the surface, and both chambers are sealed, making the cell self-supported. After 1 min, stop-cock 2 (as shown in Figure 2) is closed, which insulates the inner chamber system. From this moment, the pressure in the inner chamber starts to increase, as air is drawn from the underlying concrete. The rate of rise in pressure, which is directly proportional to the permeability of the concrete, is recorded. Meanwhile, the vacuum pump continues to operate on the outer chamber, through the pressure regulator, the latter ensures that the pressure in the outer chamber is always kept equal to the pressure in the inner chamber. Thus, the outer chamber acts as a "guard-ring", helping to create a controlled air flow into the inner chamber, expected to follow the pattern sketched in Figure 3. The method allows an estimate of the depth of concrete L (mm) affected by the test, as a function of kT, of the open porosity of the concrete and of the duration of the test *t* (s).

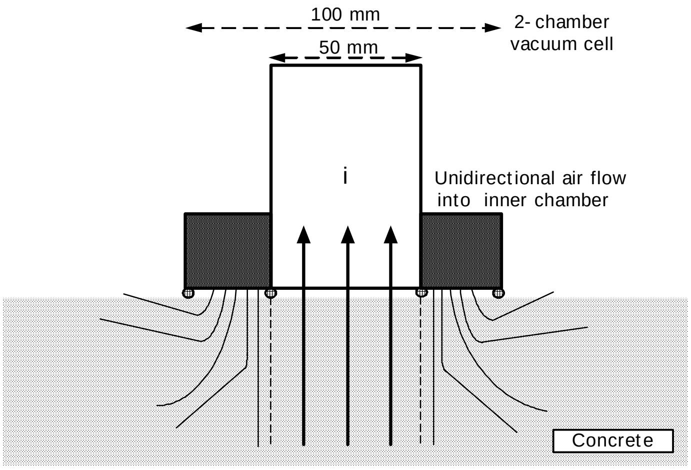

Figure 2: Theoretical air flow into double -chamber cell in Torrent Permeability Tester.

3.4. Strength test

Beams specimens 40× 40 × 160 mm for flexural strength and broken half specimens 40 × 40 × 80 mm for compressive strength were tested in accordance with JIS A 1171.

4. Test results and discussion

Figure 3 represents the moisture content of hardener-free epoxy-modified mortars with different polymer-cement ratios before air permeability test. The moisture content of the epoxy-modified mortars is recorded higher with increasing polymer-cement ratio. The moisture content of unmodified mortar is lower than that of the epoxy-modified mortars with higher polymer-cement ratios. This can be explained that the epoxy resin in the matrixes of the epoxy-modified mortars may improve their water retentivity, and then the retained water in the mortars may take an important role in the hardening reaction of the hardener-free epoxy resin with cement hydrates.

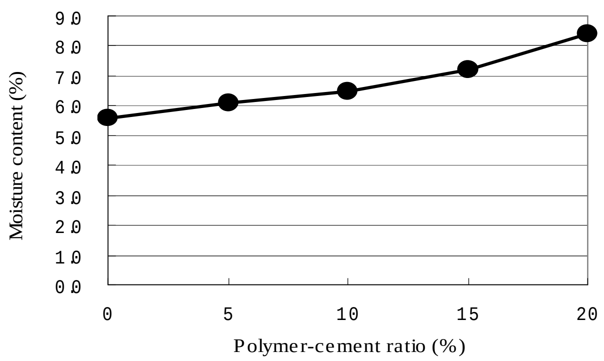

Figure 3: Polymer-cement ratio vs. moisture content of hardener-free epoxy-modified mortars.

Figure 4 illustrates the coefficient of air permeability (kT) of hardener-free epoxy modified mortars with different polymer-cement ratios. The air permeability of unmodified mortar is quite higher than that of epoxy-modified mortars. The air permeability of the epoxy-modified mortars is decreased with increasing polymer-cement ratio.

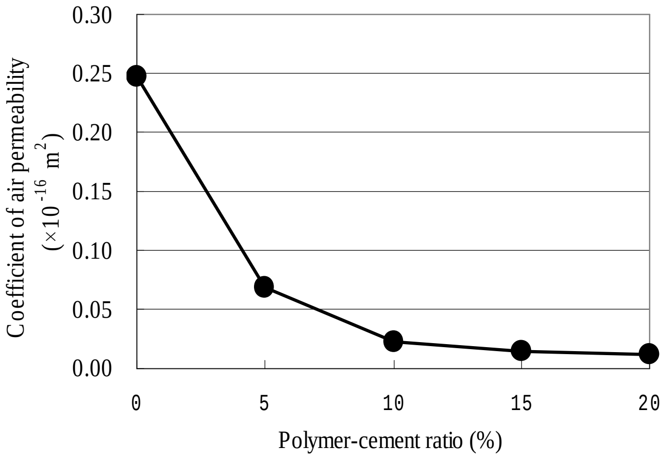

Figure 4: Polymer-cement ratio vs. coefficient of air permeability (kT) of hardener-free epoxy-modified mortars.

Table 4 shows a classification of the quality of the "covercrete" by Torrent Permeability Tester, based on the values of coefficient of air permeability (kT) of relatively young at ages up to 2 months [4,5].

TABLE 4: CLASSIFICATION OF QUALITY OF COVERCRETE, BASED ON COEFFICIENT OF AIR PERMEABILITY, KT

Covercrete grade	A	B	C	D	E
Quality	Excellent	Very good	Fair	Poor	Very poor
Coefficient of air permeability, kT (10^{-16} m^2)	<0.01	0.01-0.1	0.1-1	1-10	>10

The coefficient of air permeability (kT) of epoxy-modified mortars with polymer cement ratios of 5, 10, 15 and 20% is in a range of Covercrete Grade B (Very good: 0.01–0.1) as given in Table 4. This means that the epoxy-modified mortars with polymer-cement ratios of 5 to 20% may offer excellent performance as repair materials.

Figure 5 represents the coefficient of air permeability (kT) vs. moisture content (M) of hardener-free epoxy modified mortars. It can be seen that there is reasonably good correlation between the coefficient of air permeability and moisture content of the hardener-free epoxy-modified mortars [6].

Figure 6 exhibits the compressive and flexural strengths of hardener-free epoxy-modified mortars with different polymer-cement ratios. No significant strength improvement is observed in the epoxy-modified mortars with polymer-cement ratios of 5, 10, 15 and 20 % after a 28-d dry curing. The reason for this can be explained that the hardening rate of the epoxy resin in the hardener-free epoxy-modified mortars is low, and their strength development at an age of 28d is inferior at high polymer-cement ratio.

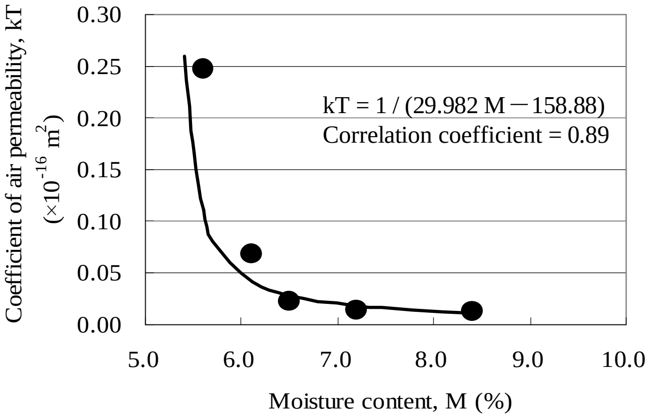

Figure 5: Relationship between coefficient of air permeability (kT) and moisture content (M) of hardener-free epoxy-modified mortars.

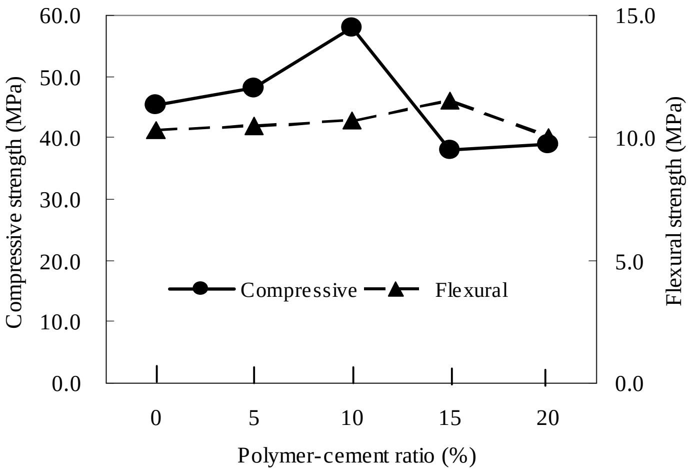

Figure 6: Polymer-cement ratio vs. compressive and flexural strengths of hardener-free epoxy-modified mortars.

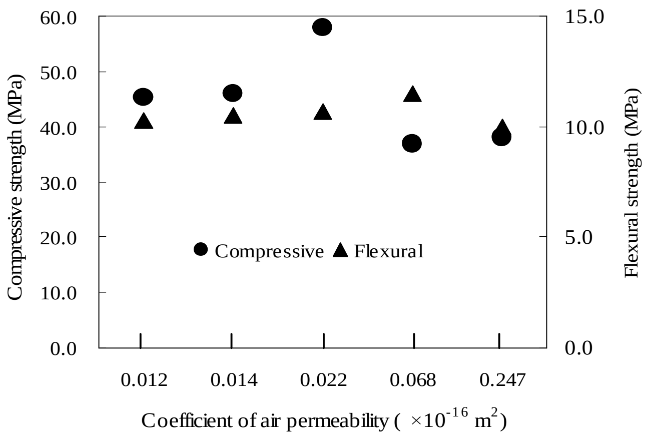

Figure 7: Relationship between coefficient of air permeability (kT) and compressive and flexural strengths of hardener-free epoxy-modified mortars.

Figure 7 shows the relationship between the coefficient of air permeability (kT) and compressive and flexural strengths of hardener-free epoxy-modified mortars. There is no significant relationship between the compressive and flexural strengths and coefficient of air permeability (kT) after a 28-d curing at 20℃ and 60%(RH). As discussed above, the hardener-free epoxy-modified mortars are immature because of a short curing period. The air permeability which is one of the important factors for the durability of repair materials is evaluated independently.

5. Conclusions

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

(1) The coefficient of air permeability (kT) of hardener-free epoxy-modified mortars is reduced with increasing polymer-cement ratio. The epoxy-modified mortars with polymer-cement ratios of 5 to 20% are classified as Covercrete Grade B (Very good) (see Table 4).
(2) The moisture content of hardener-free epoxy-modified mortars becomes higher with an increase in the polymer-cement ratio. There is the reasonably good correlation between the coefficient of air permeability (kT) and moisture content of the epoxy-modified mortars.
(3) No significant strength development is observed in hardener-free epoxy-modified mortars with polymer-cement ratios exceeding 10% at a short curing period after a 28-d curing at 20℃ and 60%(RH).
(4) There is no good correlation between the strength and coefficient of air permeability (kT) of hardener-free epoxy modified mortars at a short curing period after a 28-d curing at 20℃ and 60%(RH).

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