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Performance of polymer-modified self-leveling mortars with high polymer–cement ratio for floor finishing

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Abstract

Recently, polymer-modified mortar has been studied for proposed use on industrial floors as top coat with thin thickness, typically 5–15 mm. The purpose of this study is to evaluate basic properties of self-leveling materials using polymer dispersions as kinds of SBR latex, PAE and St/BA emulsions for thin coatings (under 3 mm in thickness). Superplasticizer and thickener have been included in the mixes to reduce bleeding and drying shrinkage as well as to facilitate the workability required. The self-leveling materials using four types of polymer dispersion are prepared with polymer–cement ratios of 50% and 75%, and were tested for basic characteristics such as density, flow, consistency change and adhesion in tension. The test results showed that the self-leveling mortars using PAE emulsion at a curing age of 28 days were almost equal to those of conventional floor using urethane and epoxy resins. The adhesion in tension of self-leveling mortars using SBR latex and PAE emulsion at a curing age of 3 days is over 1.67 MPa. It was noted that the consistency change is strongly dependent on the type of polymer dispersion. It is concluded that the self-leveling mortars with polymer dispersions can be used in the same manner as conventional floor-finishing materials using thermosetting resin in practical applications.

Keywords: Polymer-modified mortar; SEM; Bond strength; Polymers; Consistency change

1. Introduction

1.1. Literature survey

The floor of a building is a complex system with the function of sealing a building for a long time against a series of factors like light, water, temperature, corrosion, abrasion, etc. The features of seamless floorings (self-leveling floorings) are well established. The floor finishes (coatings) in concrete structures are used in order to improve the several durabilities, such as scuff resistance, slip resistance, chemical resistance and abrasion resistance. These floorings are able to be classified into two types of the immpregrants like MMA and styrene and surface finishes using liquid resins. The immpregrants that are permeable at concrete substrate have the serious difficulty to conceive the performance of them in visual because of no external appearance and also a great deal of cost. Surface finishes using liquid resins, such as urethane, epoxy, polymethyl methacrylate and unsaturated polyester resins, have the defects of surface slip, low abrasion resistance induced by traffic volume and degradation by the sun (ultraviolet rays) and reaction with H_2O in pouring and curing [1–4]. These floors must be easily installed, durable, lightweight, flexible, slip- and dent-resistant, scratch- and scuff-resistant, stain- and dirt-resistant, fungus-resistant, heel mark-resistant and have superior chemical resistance compared to many flooring materials.

1.2. Research significance and purposes

As already stated, conventional floors composed of only resin like immpregrant and surface adhesive essentially have the problem that conventional resin floors are different with concrete substrates in terms of the heterogeneous nature in organic and inorganic compounds. Polymer latexes or emulsions as cement modifiers, which are very chemically stable toward the extremely active

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Table 1
Chemical compositions of ordinary Portland cement

CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	Insoluble	Ig. loss	Total (%)
65.3	22.2	5.1	3.2	1.3	1.9	0.3	0.6	99.9

cations such as Ca^{2+} and Al^{3+} liberated during cement hydration, have no bad influence on cement hydration and make the formations of continuous polymer films are used in this study [5,6].

Consequently, the purposes of this study are to obtain the basic properties of polymer-modified self-leveling mortars and to compare conventional floorings to those by considering the physical properties of the polymer-modified self-leveling mortars regarded as the homogeneous system of concrete.

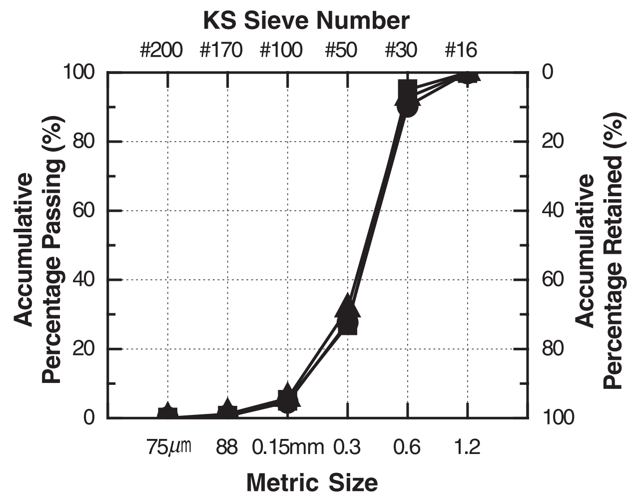

Fig. 1. Grading curve for silica sand.

2. Experimental

2.1. Materials

2.1.1. Cement and fine aggregate

In this study, the ordinary Portland cement specified in KS L 5201(Portland Cement) was used for all the mortar mixes. The chemical compositions and physical properties of the cement are listed in Tables 1 and 2, respectively, and fine aggregate whose size is not more than 1.2 mm as shown in Fig. 1 was used.

2.1.2. Polymer dispersions for cement modifiers

Commercial cement modifier used were a styrene–butadiene rubber (SBR) latex, a polyacrylic ester (PAE) emulsion and two poly(styrene-butyl acrylate) (St/BA) emulsions. The properties of the cement modifier used are given in Table 3.

2.1.3. Antifoamer

Surfactants in polymer dispersions are generally classified into the following three types by the kind of electrical charges on the polymer particles, which are determined by the type of the surfactants used in the production of the dispersions: cationic (or positively charged), anionic (or negatively charged) and nonionic (not charged). In most polymer-modified mortars, a large quantity of air is entrained in ordinary cement mortar because of an action of the surfactants contained as emulsifiers and stabilizers in polymer dispersions [5,6]. Because an excessive amount of entrained air induced by those causes a reduction in strength, it should be controlled by using 0.7% of a proper silicone-emulsion type antifoamer to total solids of polymer dispersions [7,8].

2.1.4. Conventional floor-finishing materials

Urethane and epoxy resin floor-finishing materials having the qualities of thermosetting liquid resins were employed in order that we might catch the mechanical performance of the fresh and hardened materials and compare its properties with that of polymer-modified self-leveling mortars by wide application of conventional floor-finishing materials in the same condition. Also, commercial cementitious self-leveling mortars (SL-1 and SL-2) were used.

2.1.5. Admixtures for adjusting the fluidity

In this study, a thickener of water-soluble cellulose ether-type (hydroxy ethyl cellulose, HEC) was used in case excessive water exists in that the demanded flow in this study is satisfied. A naphthalene sulfonate-formalde-

Table 2
Physical properties of ordinary Portland cement

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

Table 3
Properties of polymer dispersions for cement modifiers

Type of cement modifier	Appearance	Density (g/cm^3)	pH (20 °C)	Viscosity (mPa s)	Total solids (%)
SBR	Milky white	1.01	7.8	82	48.5
PAE	Milky white	1.05	9.5	200	44.9
St/BA-1	Milky white	1.04	7.5	2470	56.0
St/BA-2	Milky white	1.04	6.8	146	56.0

Table 4
Mix proportions of concrete substrates

Water–cement ratio, W/C (%)	Sand–aggregate ratio, S/A (%)	Quantity of material per unit volume of concrete (kg/m^3)			
		Water	Cement	Fine aggregate	Coarse aggregate
53	44	213	396	780	981

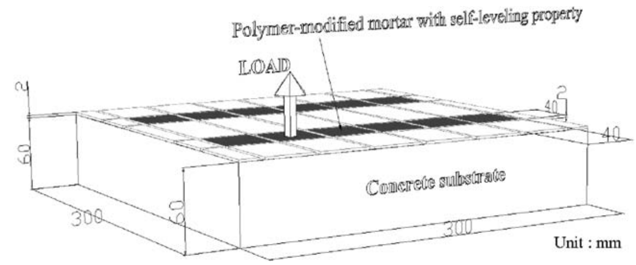

Fig. 2. Specimens for adhesion test in tension.

hyde condensate-type superplasticizer was employed in case less water.

2.2. Test procedures

2.2.1. Preparation of concrete substrates

Concrete substrates for test were designed that the target compressive strength of concrete was 23.5 MPa at an age of 28 days, and the slump value was not less than 15.0 cm. Mix design proportions of the concrete as shown in Table 4 were determined after trial mixing. The size of concrete substrates for test was 300 × 300 × 60 mm, and their surfaces were rubbed for the purpose of removing dust by using No. 150 of the abrasive papers as specified in the KS L 6003 (Abrasive Papers).

2.2.2. Preparation of polymer-modified self-leveling mortars and conventional floor-finishing materials

In accordance with JIS A 1171(Test Methods for Polymer-Modified Mortar), polymer-modified self-leveling mortars were prepared with cement–sand ratios of 1:1 and 1:3 (by mass) and polymer–cement ratios (calculated on the basis of the total solids of each polymer dispersion) of 50% and 75%. The mortars were mixed with the mix proportions given in Table 5, and their flow was adjusted to be constant at 200 ± 5 mm. Conventional floor-finishing materials were also prepared with the mix proportions specified by their manufacturers.

2.2.3. Density and air content test

Fresh self-leveling mortars and floor-finishing materials were measured for densitiy and air content as specified in KS F 2475 (Method of Test for Unit Weight and Air Content of Fresh Polymer-Modified Mortar).

2.2.4. Flow and consistency change

Fresh self-leveling mortars and floor-finishing materials were tested for flow according to J-16B-103 and for consistency change in accordance with KS F 4716 (Cement Filling Compound for Surface Preparation), and the consistency change was calculated as follows:

$$\text{Consistency change (\%)} = \frac{F_1 - F_2}{F_1} \times 100$$

where F_1: flow immediately after mixing and F_2: flow at 90 min after mixing.

Table 5
Mix proportions of polymer-modified self-leveling mortars

Type of mortar	Cement–sand ratio, C:S	Polymer–cement ratio, P/C (%)	Antifoamer content (%)	Superplasticizer content (%)	Thickener content (%)	Water–cement ratio, W/C (%)
SBR-modified	1:1	50	0.7	N/A	0.08	53.3
		75		N/A	0.10	80.2
	1:3	50		2.0	N/A	56.5
		75		N/A	N/A	80.3
PAE-modified	1:1	50		N/A	0.10	60.4
		75		N/A	0.12	90.5
	1:3	50		2.0	N/A	71.4
		75		N/A	N/A	90.6
St/BA-1-modified	1:1	50		2.0	N/A	45.0
		75		2.0	N/A	60.5
	1:3	50		2.0	N/A	58.0
		75		2.0	N/A	65.0
St/BA-2-modified	1:1	50		2.0	N/A	46.0
		75		2.0	N/A	60.0
	1:3	50		2.0	N/A	63.5
		75		2.0	N/A	66.6

2.2.5. Adhesion in tension

According to KS F 4716, specimens were made by bonding fresh self-leveling mortars and floor-finishing materials in the dimensions of $40 \times 40 \times 2$ mm on concrete substrates as illustrated in Fig. 2, and then subjected to a 20 °C-65% (RH)-dry cure for 3, 7 and 28 days. As shown in Fig. 2, the cured bonded specimens were tested for adhesion in tension.

2.2.6. Crack resistance

Self-leveling mortars and floor-finishing materials were tested for crack resistance according to KS F 4716.

2.2.7. Observation of microstructures of adhesive interface

Microstructure photos of the adhesive interfaces between the cured self-leveling mortars and concrete substrates at an age of 28 days were recorded by using a scanning electron microscope (SEM).

3. Results and discussion

3.1. Density

Because the density and usage quantity of polymer dispersions are much lower than other composition materials of floor finishings, the density of polymer-modified mortars having self-leveling property changes with difference of the quantity of cement and aggregate used in the mix [2,5,17].

Figs. 3 and 4 illustrate the density of polymer-modified self-leveling mortar and floor-finishing materials with different polymer–cement ratios and cement–sand ratios. It is confirmed that the density and air content at P/C = 75% become smaller than that of P/C = 50% because of an increase in water–cement ratio. In the conventional floor-finishing materials, the density of urethane and epoxy resin floor-finishing materials is lower than that of the polymer-modified self-leveling mortars. By contrast, the density of the cementitious self-leveling floor-finishing materials such as SL-1 and SL-2 is fairly higher than that of the polymer-modified self-leveling mortars.

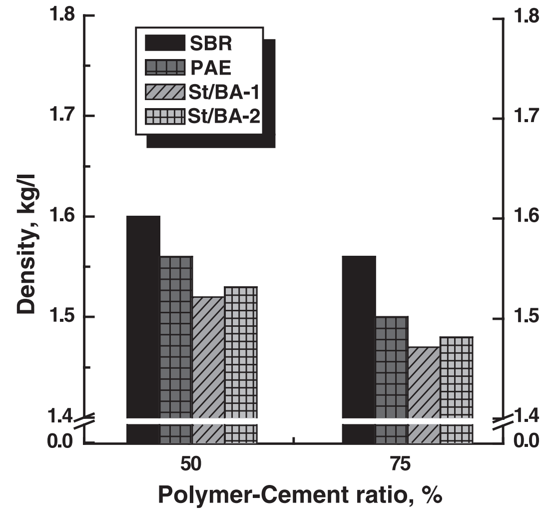

Fig. 4. Relation between polymer–cement ratio and density of polymer-modified self-leveling mortars with C:S of 1:3.

3.2. Flow and consistency change

Fig. 5 shows the flow and consistency change of the conventional floor-finishing materials. Fig. 6 illustrates the flow and consistency change of polymer-modified self-leveling mortars with different polymer–cement and cement–sand ratios. In general, it is noted that the consistency change

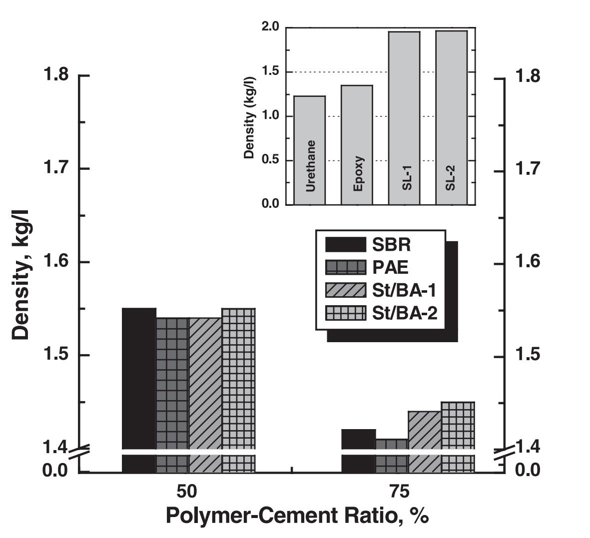

Fig. 3. Relation between polymer–cement ratio and density of polymer-modified self-leveling mortars with C:S of 1:1 and density of conventional floor-finishing materials.

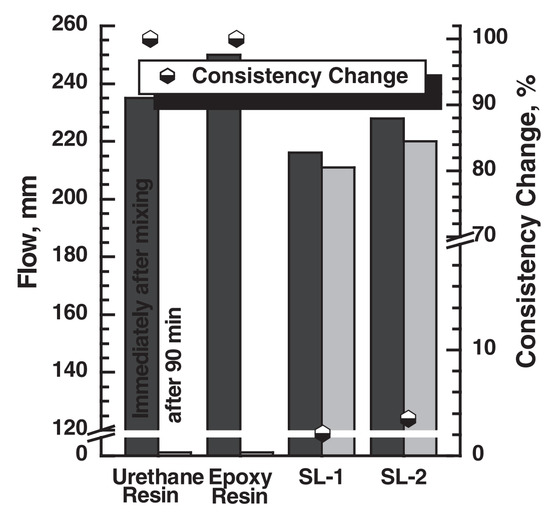

Fig. 5. Flow and consistency change of conventional floor-finishing materials.

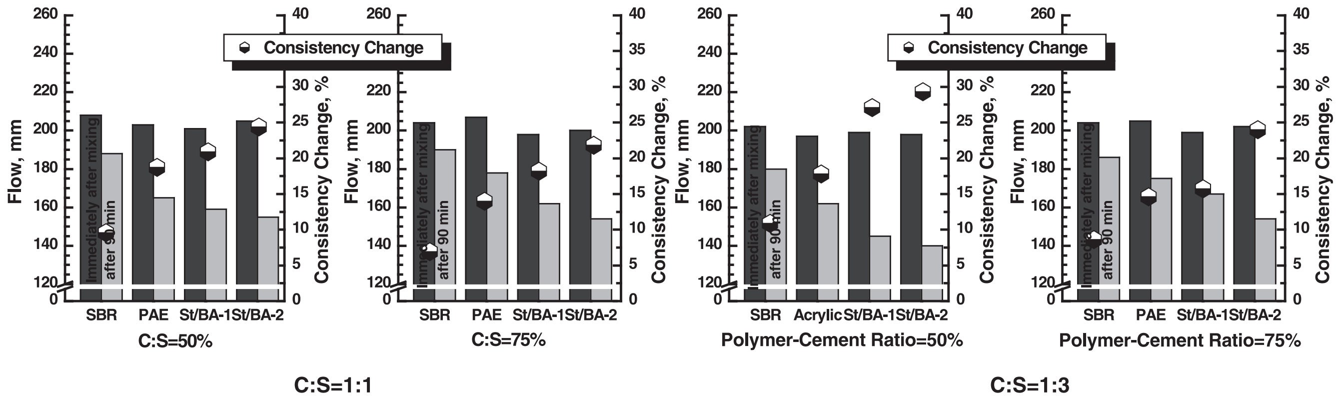

Fig. 6. Relation between polymer–cement ratio and flow and consistency of polymer-modified self-leveling mortars.

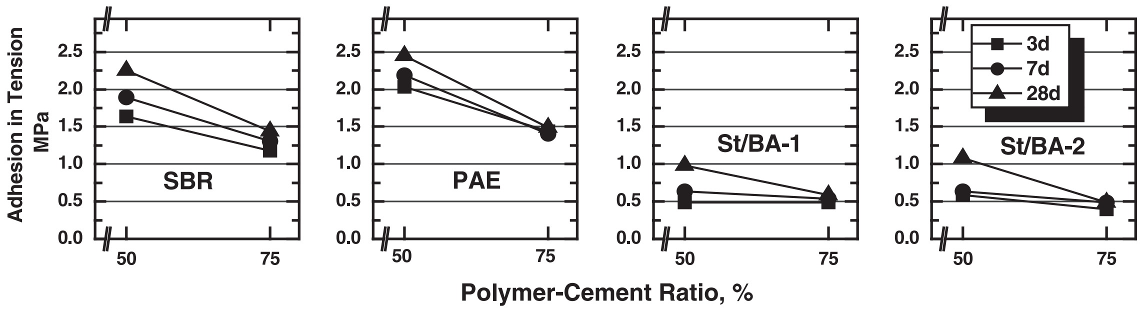

Fig. 7. Relation between polymer–cement ratio and adhesion in tension of polymer-modified self-leveling mortars with C:S = 1:1.

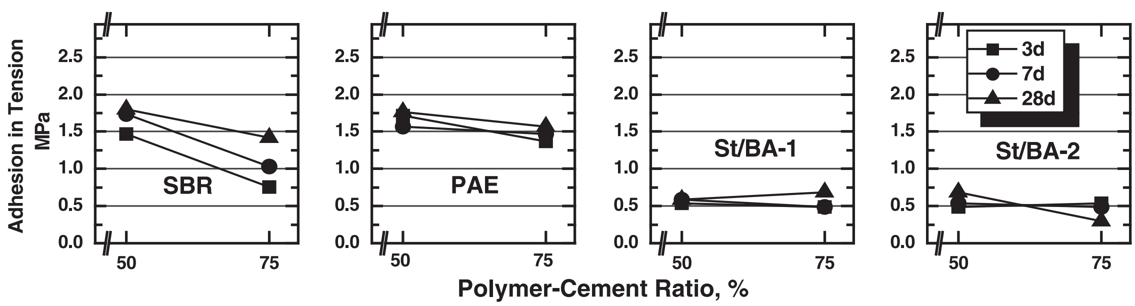

Fig. 8. Relation between polymer–cement ratio and adhesion in tension of polymer-modified self-leveling mortars with C:S = 1:3.

of the polymer-modified self-leveling mortars decreases with increasing polymer–cement ratio, and the consistency change at a cement–sand ratio of 1:3 is higher than that at a cement–sand ratio of 1:1. This is judged from the reason why the grain shape of silica sand seems to be angular and the quantity of the water adsorbed in the surfaces of fine aggregate increases with increasing amount of fine aggregate. [16] Consequently, SBR-modified self-leveling mortars have the best consistency change, while the St/BA-1 and the St/BA-2-modified mortars (even though having self-leveling) do not have so much good consistency change in comparison with other mortars because of different physical properties of cement modifier. The urethane and epoxy resin floor-finishing materials have been completely deprived of fluidity after lapsing 90 min because of initial fast chemical reaction as seen in Fig. 5.

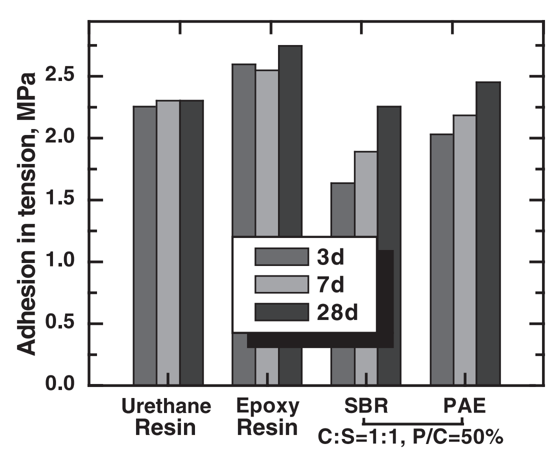

Fig. 9. Comparison of adhesion in tension between SBR and PAE-modified self-leveling mortars and conventional floor-finishing materials.

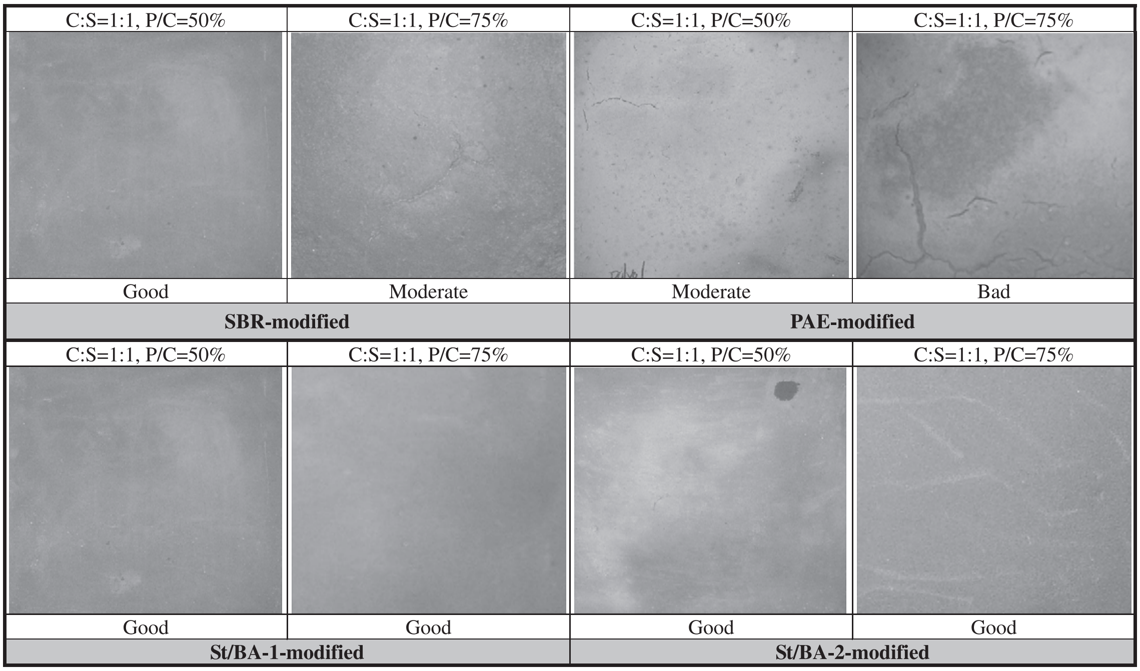

Fig. 10. Crack resistance of polymer-modified self-leveling mortars with C:S = 1:1.

3.3. Adhesion in tension

The modification of mortars with film-forming thermoplastic materials like emulsions considerably increases the adhesion to different substrates. This is the main reason for the widespread use of these products all over the world [9,14].

Figs. 7 and 8 represent the relation between polymer–cement ratio and adhesion in tension of polymer-modified self-leveling mortars with various curing ages. The adhesion in tension of the polymer-modified self-leveling mortars decreases with increasing polymer–cement ratio because increasing polymer–cement ratio causes an increase in mixing water content in the mix by the reason why the rations of the

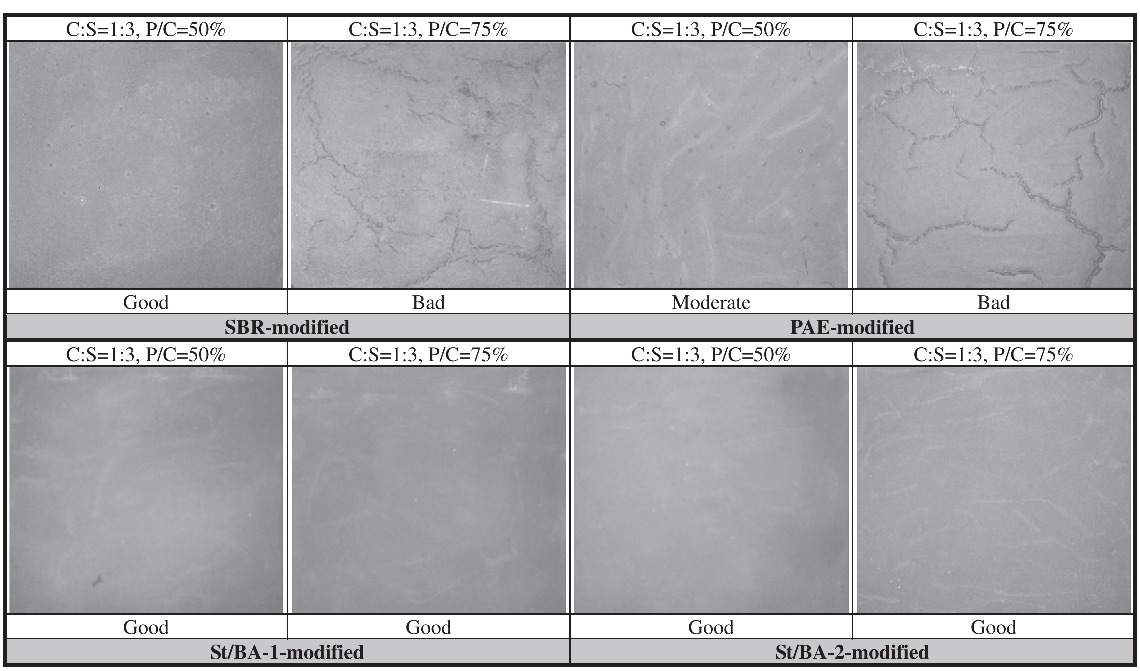

Fig. 11. Crack resistance of polymer-modified self-leveling mortars with C:S = 1:3.

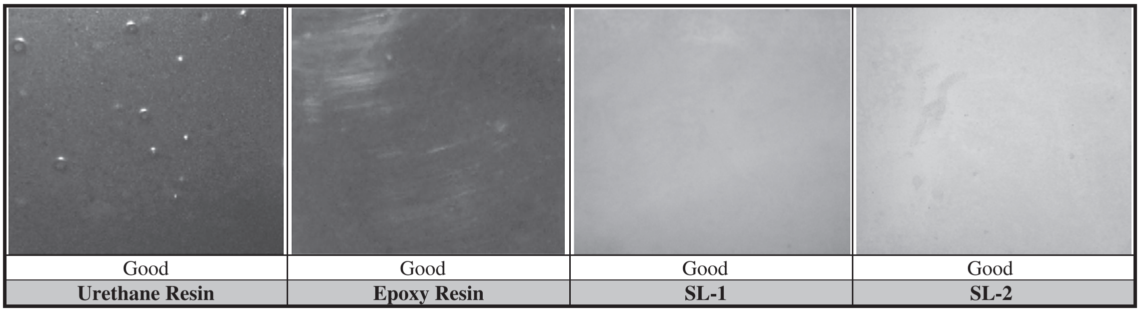

Fig. 12. Crack resistance of conventional floor-finishing materials.

solids and water are fixed in the polymer dispersions. In other words, the total water–cement ratio was 80% in the SBR-modified self-leveling mortar having a flow range of 200 mm and a polymer–cement ratio of 75%. The adhesion in tension also decreases with an increase in cement–sand ratio because the quantity of binder (cement + total solids of polymer dispersions) that can be made to promote the adhesion relatively decreases with increasing fine aggregate content throughout all polymer-modified self-leveling mortars.

Fig. 9 shows the comparison of adhesion in tension between SBR- and PAE-modified self-leveling mortars and conventional floor-finishing materials. Adhesion in tension of conventional cementitious self-leveling materials using redispersible polymer powder is improved with increasing curing age, and somewhat inferior to that of epoxy resin floor-finishing material. However, the adhesion in tension of PAE-modified self-leveling mortars is over about 2.1 MPa at an age of 3 days. It is almost equal to that of urethane resin floor-finishing materials. The highest adhesion in tension is achieved for the conventional epoxy resin floor-finishing materials.

3.4. Crack resistance

Figs. 10 and 11 represent the crack resistance of polymer-modified self-leveling mortars. Fig. 12 shows the crack

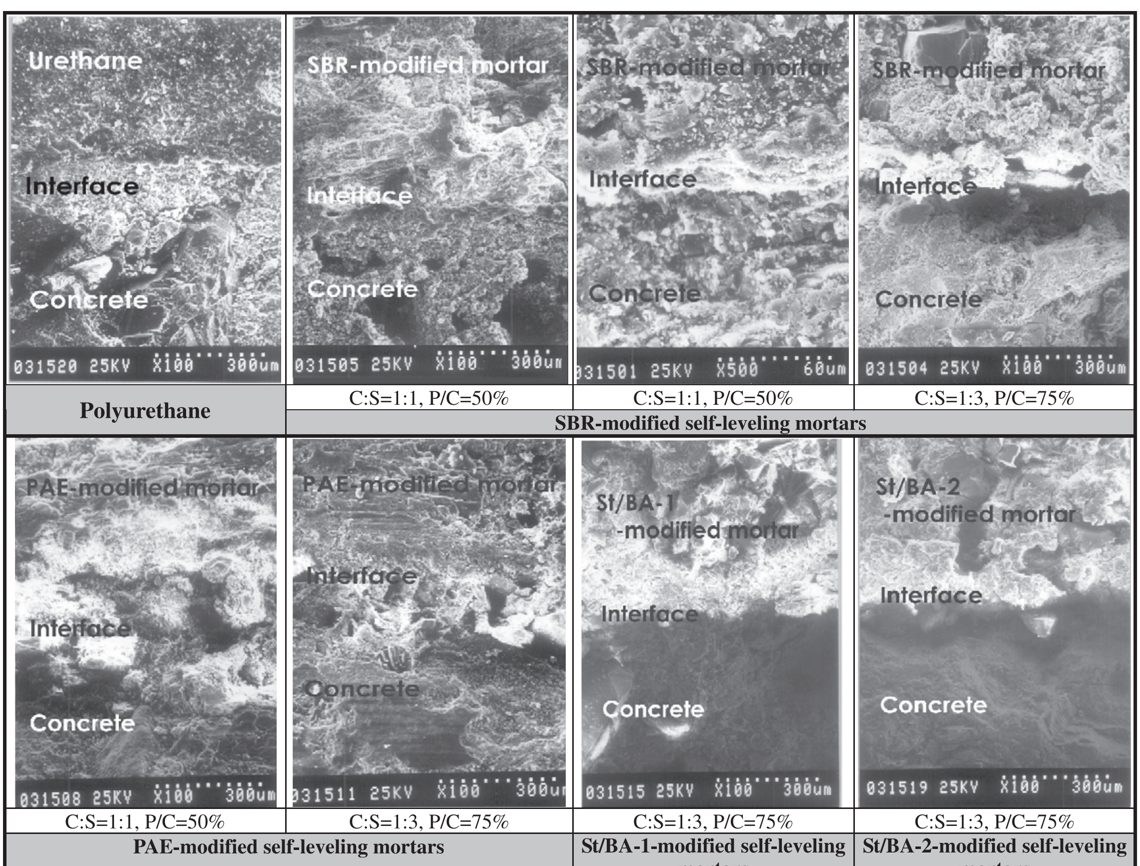

Fig. 13. SEM observation of interfaces between polymer-modified self-leveling mortars and concrete substrates.

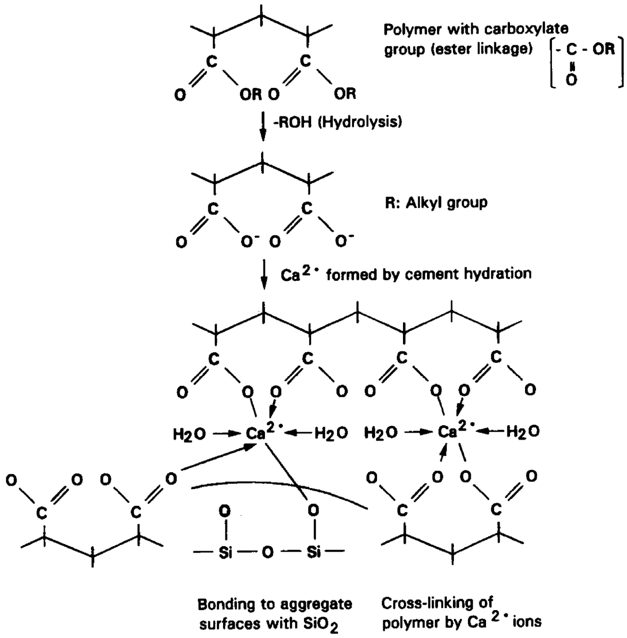

Fig. 14. Illustration of reaction between polymer with carboxylate group, cement and aggregate (from Ohama) [6].

resistance of conventional floor-finishing materials. In general, volume of cement paste is dependent on the moisture content of the cement paste. Drying induces volume reduction (dry shrinkage) and it happens that the initial drying (i.e., dry-out phenomenon) of the cement paste attributes to the maximum drying shrinkage from the paste. When a drying phenomenon like the above is allowed to occur in the cement mortar, the restraint provided by bond to the substrate induces a tensile stress and as a result of this, a crack is likely to be developed before the specimen attains a phase of endurance for the stress. The dry shrinkage is markedly affected by water–cement ratio [10,11].

SBR- and PAE-modified self-leveling mortars have severe cracks at a cement–sand ratio of 1:1, and a single crack at a that of 1:3 with a polymer–cement ratio of 50%. This is judged that the evaporation or evaporation velocity of a surplus water decreases with increasing the quantity of the water adsorbed on the surface of fine aggregate. Because the total solids of St/BA emulsion is about 57%, the water–cement ratio of St/BA-modified self-leveling mortar ranges from 45.0% to 65.0% and is relatively low. Due to that, no shrinkage crack will result from the initial drying (dry-out phenomenon). It is evidently considered that the properties such as adhesion, crack resistance, etc. of the polymer-modified mortars are dependent on the fact that each polymer particle shows the different physical qualities [5,6].

3.5. Microstructures of interfaces

Fig. 13 illustrates the interfaces between polymer-modified self-leveling mortars using various polymer dispersions at different polymer–cement ratio and concrete substrates by SEM. In general, with water withdrawal during cement hydration, the polymer particles flocculate to form a continuous close-packed layer of polymer particles on the surfaces of the cement–gel–unhydrated-cement particle mixtures and simultaneously adhere to the mixtures and the silicate layer over the aggregate surfaces as shown in Fig. 14 [12,15].

Some chemical reactions may take place between the particle surfaces of reactive polymers such as PAE and calcium ions (Ca^{2+}), calcium hydroxide [$Ca(OH)_2$] crystal surfaces or silicate surfaces over the aggregates [6]. Fig. 15 shows the adhesion mechanism of polymer-modified self-leveling mortars to concrete substrates. Parts of the polymer dispersions penetrate into the surface layers of the concrete substrates and reinforce their bonded surfaces. The formed polymer films at the bonded interfaces result in the formation of the chemical bonds and micromechanical interlocking mechanisms between the self-leveling mortars and concrete substrates [13]. Each part of the polymer films plays a specific role in the adhesion of the polymer-modified self-leveling mortars to the concrete substrates.

4. Conclusions

The following conclusions can be obtained from the test results.

(1) Irrespective of the type of polymer dispersion and cement–sand ratio, the density of polymer-modified self-

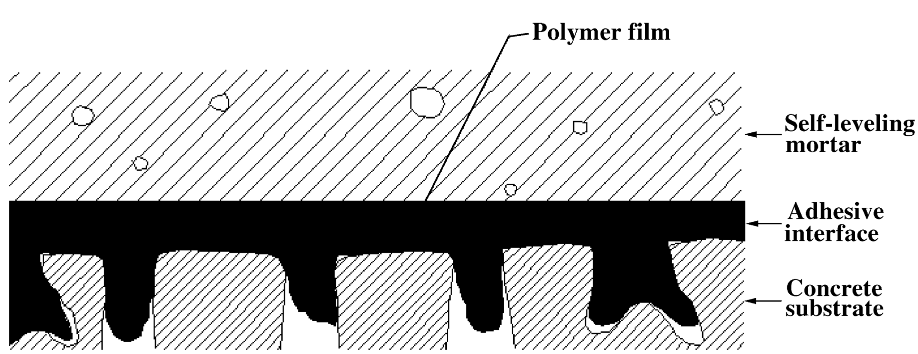

Fig. 15. Illustration of adhesion between polymer-modified self-leveling mortar and concrete substrate.

leveling mortars at a polymer–cement ratio of 50% is higher than that at a polymer–cement ratio of 75%.

(2) The consistency change of polymer-modified self-leveling mortars is much dependent on the type of polymer dispersions, and only SBR-modified and PAE-modified self-leveling mortars with four types of cement modifiers satisfy KS requirements (– 15 to 15) for the consistency change. On the contrary, conventional urethane and epoxy resin floor-finishing materials have a considerable difficulty in the consistency change.

(3) Irrespective of the type of polymer dispersion and cement–sand ratio, the adhesion in tension of polymer-modified self-leveling mortars is high at a polymer–cement ratio of 50%. The adhesion in tension of SBR- and PAE-modified self-leveling mortars is by far higher than that of St/BA-modified self-leveling mortars. Above all, the adhesion of PAE-modified self-leveling mortars is the highest at a cement–sand ratio of 1:1 and has almost equal to that of conventional thermosetting resin floor-finishing materials.

(4) Crack resistance of St/BA-1- and St/BA-2-modified self-leveling mortars is better than that of other polymer-modified self-leveling mortars.

(5) In conclusion, polymer-modified self-leveling mortars can be used in the same manner as conventional thermosetting resin floor-finishing materials in practical applications.

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