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Development of Polymer-Modified Cementitious Self-Leveling Materials for Thin Coat

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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 ~ 15mm. The purpose of this study is to evaluate basic properties of self-leveling materials using polymer dispersions as kinds of SBR, PAE, St/BA with thin coat (under 3mm). 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 ratio which respectively range from 50% and 75%, and tested for basic characteristics such as unit weight, air content, flow, consistency change and adhesion in tension. From the test results, the self-leveling materials using PAE emulsion at curing age of 28days are almost equal to those of conventional floor using urethane and epoxy resin. The adhesion in tension of self-leveling mortars using SBR latex and PAE emulsion at curing age of 3days is over 17 kgf/cm^2 (1.67MPa). Consistency change is strongly dependent on the type of polymer dispersion. It is concluded that the self-leveling materials using polymer dispersions can be used in the same manner as conventional floor using thermosetting resin in practical applications, in the selection of polymer dispersions.

Keywords: cement modifier, self-leveling materials, adhesion in tension, consistency change, polymer-cement ratio

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 flooring (self-leveling floor) are well established. The surface finishes (coating) of concrete structures are used in order that they may improve the several durabilities such as scuff resistant, slip resistant, chemical resistance, and abrasion. Most of all, these flooring classified into two types of what is permeable at concrete substrate have the serious difficulty to conceive the performance of them in visual because of no external appearance and a great deal of cost. Surface adhesive such as urethane, epoxy, polymethyl methacrylate and unsaturated polyester etc have the defect 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] So, 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 floor materials.

1.2 Research Significance and Purpose

As already stated, conventional floor essentially has the problem that conventional resin floor is different with concrete substrate in terms of the heterogeneous nature in organics and inorganic compound. So, polymer latex or emulsion of cement modifier which is very chemically stable toward the extremely active cations such as $Ca^{2+}$and Al^{3+} liberated during cement hydration and has no bad influence on cement hydration and makes the formations of continuous polymer film or is used in this study.[5, 6]

Consequently, the objective of this study is to obtain the foundations for basic properties data of polymer-modified cementitious self-leveling floor and to compare conventional

Table 1 Chemical composition of ordinary portland cement

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

Specific gravity	Fineness (cm2/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 dispersion for cement modifier

Type of cement modifier	Appearance	Specific gravity (20℃)	pH (20℃)	Viscosity (mPa・s)	Total solid content (wt%)
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

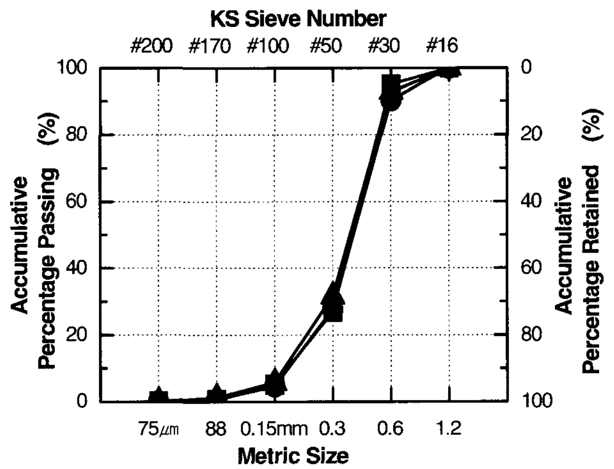

Fig. 1 Grading curve of silica sand used

floorings to those by considering physical properties of polymer-modified cementitious self-leveling taken into account the homogeneous system of concrete.

2. Experimental Program

2.1 Material Properties

(1) Cement and Fine Aggregate

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

(2) Polymer Dispersions for Cement Modifier

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

(3) Antifoaming Agent

Surfactant in polymer latexes are generally classified into the following three types by the kind of electrical charges on the polymer particles, which is determined by the type of surfactants used in the production of the latexes: cationic (or positively charged), anionic (or negatively charged) and nonionic(not charged). So, in most polymer-modified mortars, a large quantity of air is entrained compared to that in ordinary cement mortar because of an action of surfactants contained as emulsifiers and stabilizers in polymer dispersion as shown above.[5, 6] An excessive amount of entrained air causes a reduction in strength and is controlled by using 0.7wt%[7] of proper silicone-emulsion type antifoamer to total solid weight of polymer dispersion.

(4) Conventional Floor-Finishing Materials

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

(5) Admixtures for Adjusting the Flowability

In this study, thickener of water-soluble cellulose ether type (hydroxy ethyl cellulose, HEC) was used on condition that excessive water exists. Naphthalene type was employed in case of the opposite.

Table 4 Mix proportion of concrete substrate

Water-cement ratio (%)	Sand-aggregate ratio (%)	Unit weight (kg/m^3)			
		Water	Cement	Fine aggregate	Coarse aggregate
53	44	213	396	780	981

Table 5 Mix proportions of polymer-modified cementitious self-leveling mortar

Type of mortar	Cement-sand ratio	Polymer-cement ratio (wt%)	Antifoamer (wt%)	Superplasticizer (wt%)	Thickener (wt%)	W/C(%)
SBR-modified	1:1	50	0.7	N/a	0.08	53.3
		75		N/a	0.1	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	0.1	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 Test Procedure

(1) Manufacture of Substrate

The substrate for test was designed that the target compressive strength of concrete was decided with σ_{28}=240 kgf/㎠ and required slump value was not less than 15cm. Mix design proportion with any material content as represented in table 4 was determined after trial mixing. The size of substrates for test amount to 300mm×300mm×60mm and the surfaces of those were rubbed and made clean for the purpose of removing dust damages such as laitance etc, by using No.150 of the abrasive papers as specified in the KS L 6003(Abrasive Papers).

(2) Mix Design for Specimen Preparation

In accordance with JIS A 1171(Method of Making Test Sample of Polymer-Modified Mortar in the Laboratory), polymer-modified cementitious self-leveling floor were prepared with cement-sand ratios of 1:1 and 1:3(by weight) respectively and polymer-cement ratios (calculated on the basis of the total solids of each emulsion) 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± 5mm.

(3) Unit Weight and Air Content Test

The fresh mortars were measured for unit weight and air-content as specified KS F 2475(Method of Test for Unit Weight and Air Content of Fresh Polymer-Modified Mortar).

(4) Flow and Consistency Change

Flow of specimens by using cylindrical mold of the size ϕ5×5mm, as specified JASS-16B-103, and consistency change, as specified KS F 4716(Cement Filling Compound for Surface Preparation), in immediately mixing(F_1) and lapsing 90minutes after mixing(F_2) to measure consistency change is tested as time goes by. Flows of specimens in all mixtures and conventional floorings were observed and consistency change was calculated as follows.

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

(5) Adhesion in Tension

According to KS F 4716(Cement Filling Compound for Surface Preparation), 40×40×2mm specimens were molded and then subjected to a 20℃-65 % R.H.-dry cure. As shown in Fig. 2, the cured bonded specimens were tested for adhesion in tension.

(6) Crack Resistance

Crack resistance, as specified KS F 4716(Cement Filling Compound for Surface Preparation), was determined in all mixtures and conventional floorings.

(7) Observation of Microstructures of Interface

Microstructures of adhesive interfaces between cured self-leveling mortars and concrete substrates were observed by using a scanning electron microscope (SEM).

3. Results and Discussion

3.1 Unit Weight and Air Content

Generally, because the specific gravity of polymer dispersion is ranged from 1.01 to 1.06, unit weight of polymer-modified mortar having self-leveling changes according to the quantity of cement and aggregate using in the mix. In most polymer-modified mortars, a large quantity of air is entrained compared to that of ordinary cement mortar because of an action of surfactants contained as emulsifiers and stabilizers in polymer dispersion as shown above.[5] The more did the amount of fine aggregate range from 0.3 to 0.6mm, the more is air content increase, because entrapped air which fine aggregates under 0.6mm in the grade size induce into the mixtures have bound to the void of fine aggregate.[8]

Fig. 3 and 4 illustrate the unit weight and air content of polymer-modified self-leveling materials with the change of polymer cement ratio and cement-sand ratio. It is confirmed that the unit weight and the air content of P/C=75% become smaller than that of P/C=50% because of the increase of water-cement ratio. The air content of each types considerably increase with increasing cement-sand ratio, and this is estimated by the reason why the increase of fine aggregate generally results in the increase of entrapped air in fresh mortar as explained above. Consequently, the air content of these mixes is in the range of 4 to 18 % in case of cement-sand ratio of 1:3 and that of SBR-modified mortar is the lowest among 4 types of polymer-modified self-leveling mortars. In the St/BA-1 and the St/BA-2-modified mortars having self-leveling, although the St/BA-1 and the St/BA-2-modified mortars having self-leveling are composed of the same monomer such as Styrene and Butyl Acrylate, the air content of the St/BA-1-modified mortar is higher in comparison with that of the St/BA-2-modified mortar because of the difference of viscosity.[9] In the conventional flooring, the unit weight of flooring using polyurethane and epoxy resin is lower than that of self-leveling materials using polymer dispersions. By contrast, the cementitious self-leveling materials such as SL-1 and SL-2 are fairly higher than that of self-leveling materials using polymer dispersions.

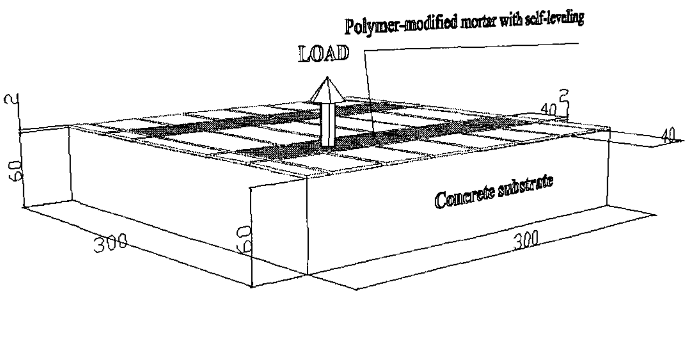

Fig. 2 Specimen for adhesion test in tension (unit:mm)

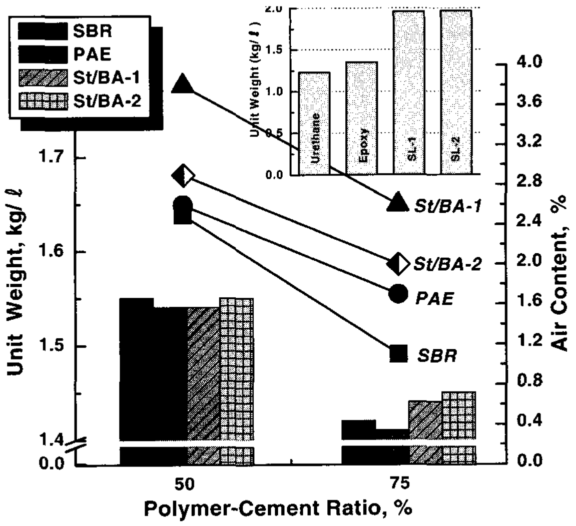

Fig. 3 Relation between polymer-cement ratio and unit weight and air content of polymer-modified self-leveling floor in case of cement-sand ratio of 1:1 and unit weight of conventional flooring

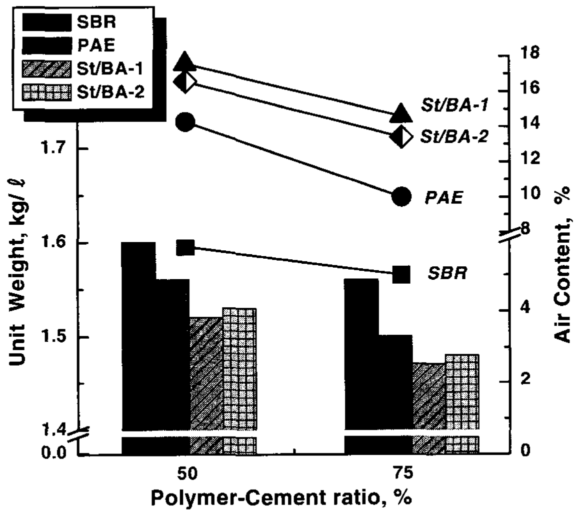

Fig. 4 Relation between polymer-cement ratio and unit weight and air content of polymer-modified self-leveling floor in case of cement-sand ratio of 1:3 and unit weight of conventional flooring

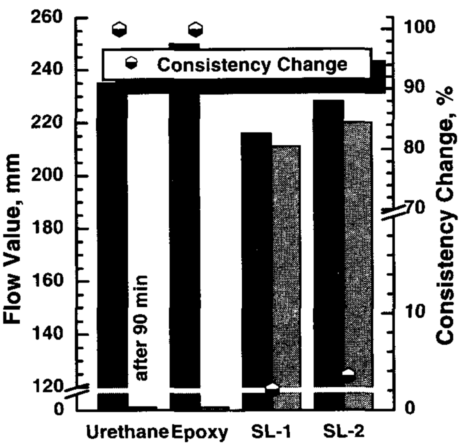

Fig. 5 Flow and consistency change of conventional flooring

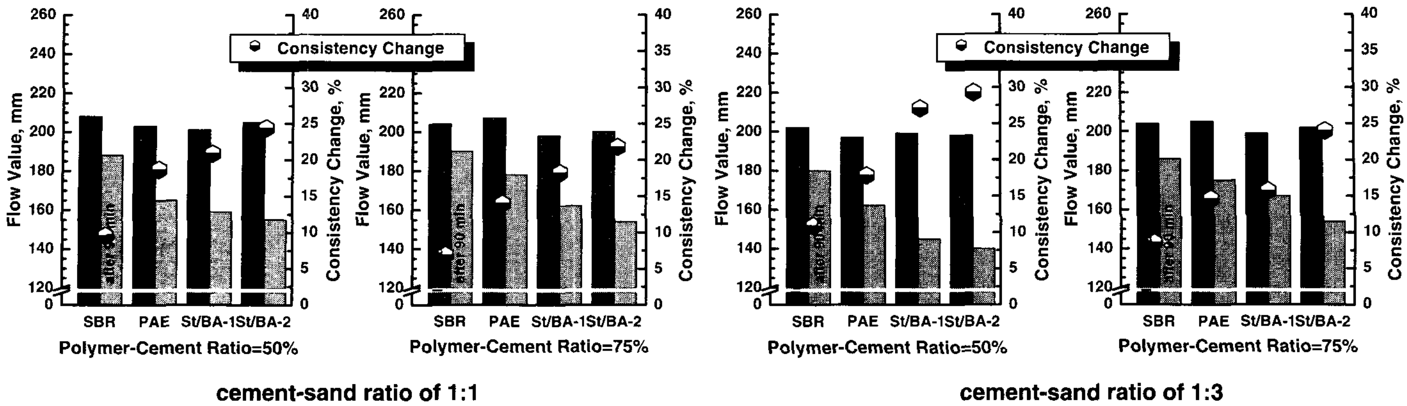

Fig. 6 Relation between polymer-cement ratio and flow and consistency of polymer-modified self-leveling

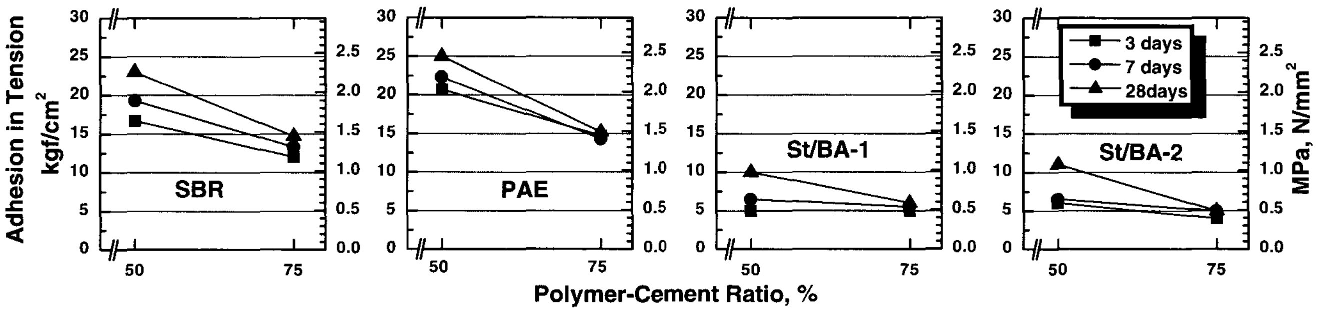

Fig. 7 Relation between polymer-cement ratio and adhesion in tension of polymer-modified self-leveling mortar(C:S=1:1)

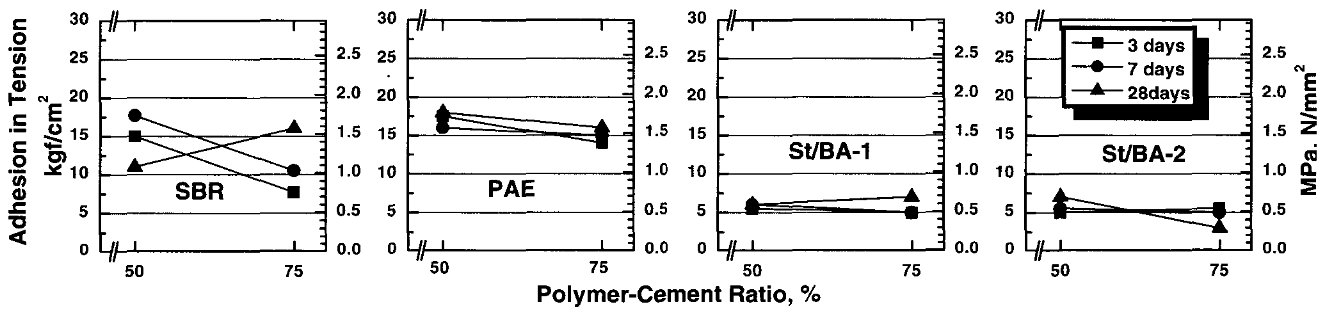

Fig. 8 Relation between polymer-cement ratio and adhesion in tension of polymer-modified self-leveling mortar(C:S=1:3)

3.2 Flow and Consistency Change

Fig. 5 shows the flow and consistency change of the conventional flooring and Fig. 6 illustrates the flow and the consistency change of self-leveling materials with the change of polymer-cement ratio and cement-sand ratio. In general, it is revealed that the consistency change decreases with increasing polymer-cement ratio, and consistency change of cement-sand ratio of 1:3 is higher than that of cement-sand ratio of 1:1. This is judged the reason why the grain shape of silica sand seems to be angular and the quantity of water adsorbed in surface of fine aggregate increase with increasing amount of fine aggregate. Consequently, SBR-modified mortar has the best property of consistency change and that of the St/BA-1 and the St/BA-2-modified mortar having self-leveling is not much good in comparison with other specimens because of different physical property of cement modifier.

Polyurethane and epoxy resins have been completely deprived of flow after lapsing 90 minutes because of initial fast chemical reaction as seen in Fig. 5.

3.3 Adhesion in Tension

Fig. 7 and Fig. 8 represent relation between polymer-cement ratios and adhesion in tension of self-leveling materials using polymer dispersions with various curing ages. The adhesion in tension of polymer-modified self-leveling materials decreases with increasing polymer-cement ratio in this mix because increasing polymer-cement ratio is to increase mix water content in the mix by the reason why solid and water are fixed in the polymer latex. That is to say, when

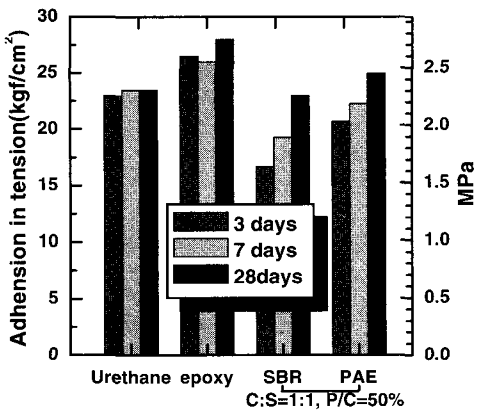

Fig. 9 Comparison of adhesion in tension between the SBR and PAE-modified and conventional floor

polymer-cement ratio is 75 %, water-cement ratios of the mixtures are about 80 % in case of SBR-modified mortar with self-flowablility.

Adhesion in tension also decreases with the increase of cement-sand ratio because the quantity of binder (cement + polymer total solid) that can be made to promote adhesion relatively decreases with increasing of fine aggregate only in all bulks.

Fig. 9 shows comparison of adhesion in tension between the SBR and PAE-modified self-leveling floor and convension of self-leveling materials using polymer dispersions is improved with increasing curing ages, and somewhat inferior to that of floor using epoxy resin. However, the adhesion in tension of self-leveling materials using PAE emulsion is almost equal to that of conventional floor using urethane resin. It is over 20kgf/cm^2 at curing age of 3 days. The highest adhesion in tension is achieved in the conventional floor using epoxy resin.

3.4 Crack Resistance

Fig. 10 and 11 represents the result of crack resistance of specimens. And Fig. 12 shows the crack resistance of conventional resin floor. In general, volume of cement paste is dependent on the moisture content of paste. Dry induces volume reduction (dry shrinkage) and it happens that the initial dry (i.e. dry out phenomenon) of paste derive maximum dry shrinkage from paste. When dry mechanism as above is applied to cement mortar, crack is developed by tensile stress according to restraint provided by bond to the substrate through the end and beneath portions. So, dry shrinkage is markedly affected by water-cement ratio.[10, 11]

The specimens made by SBR latex and PAE emulsion are very cracked in the cement-sand ratio of 1:1 and not cracked in that of 1:3 with polymer-cement ratio of 50%. This is judged that evaporation and evaporation velocity etc of a surplus water decreases with increasing the quantity of water adsorbed in surface of fine aggregate. Because total solid

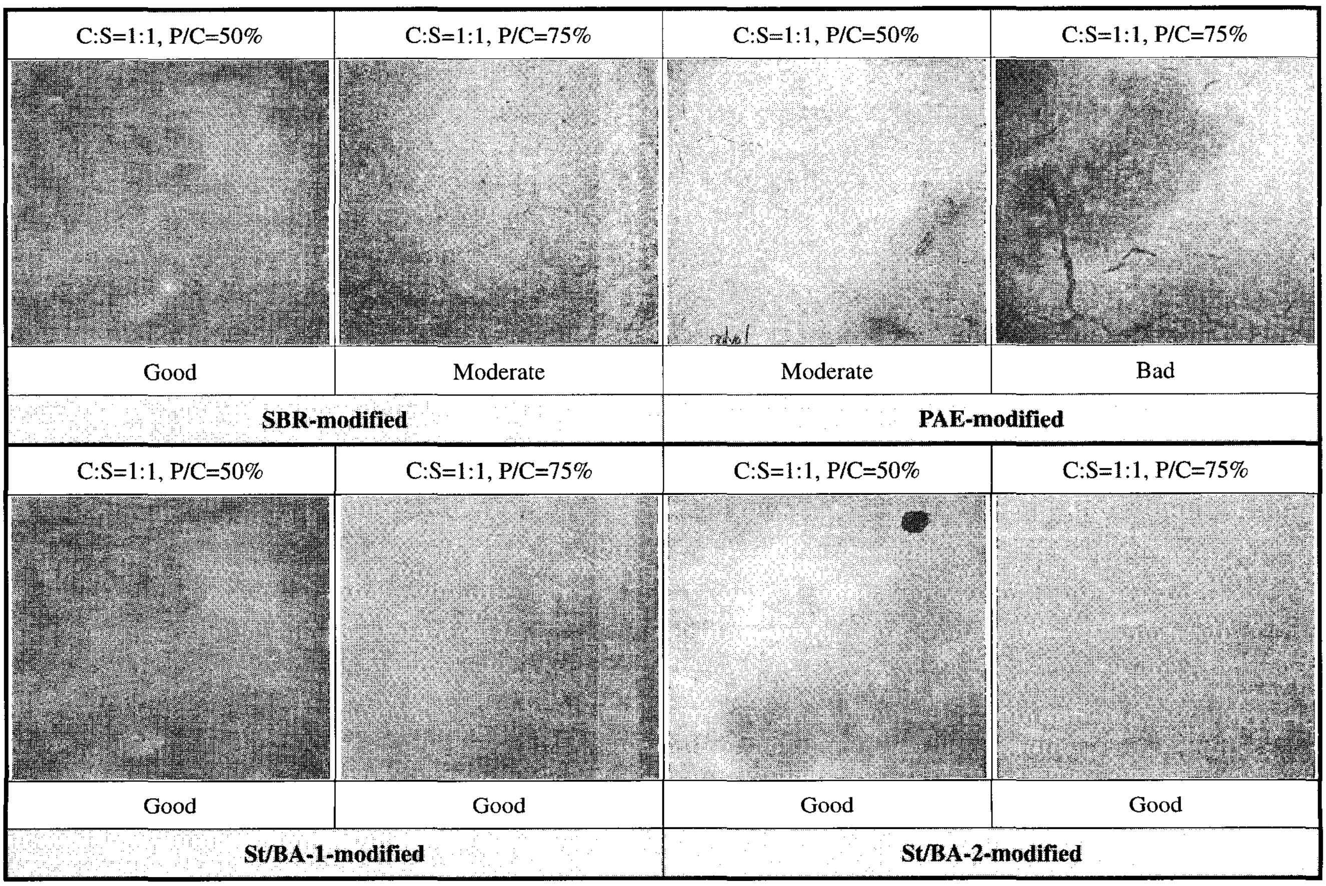

Fig. 10 Crack resistance of polymer-modified cementitious self-leveling floor in case of C:S=1:1

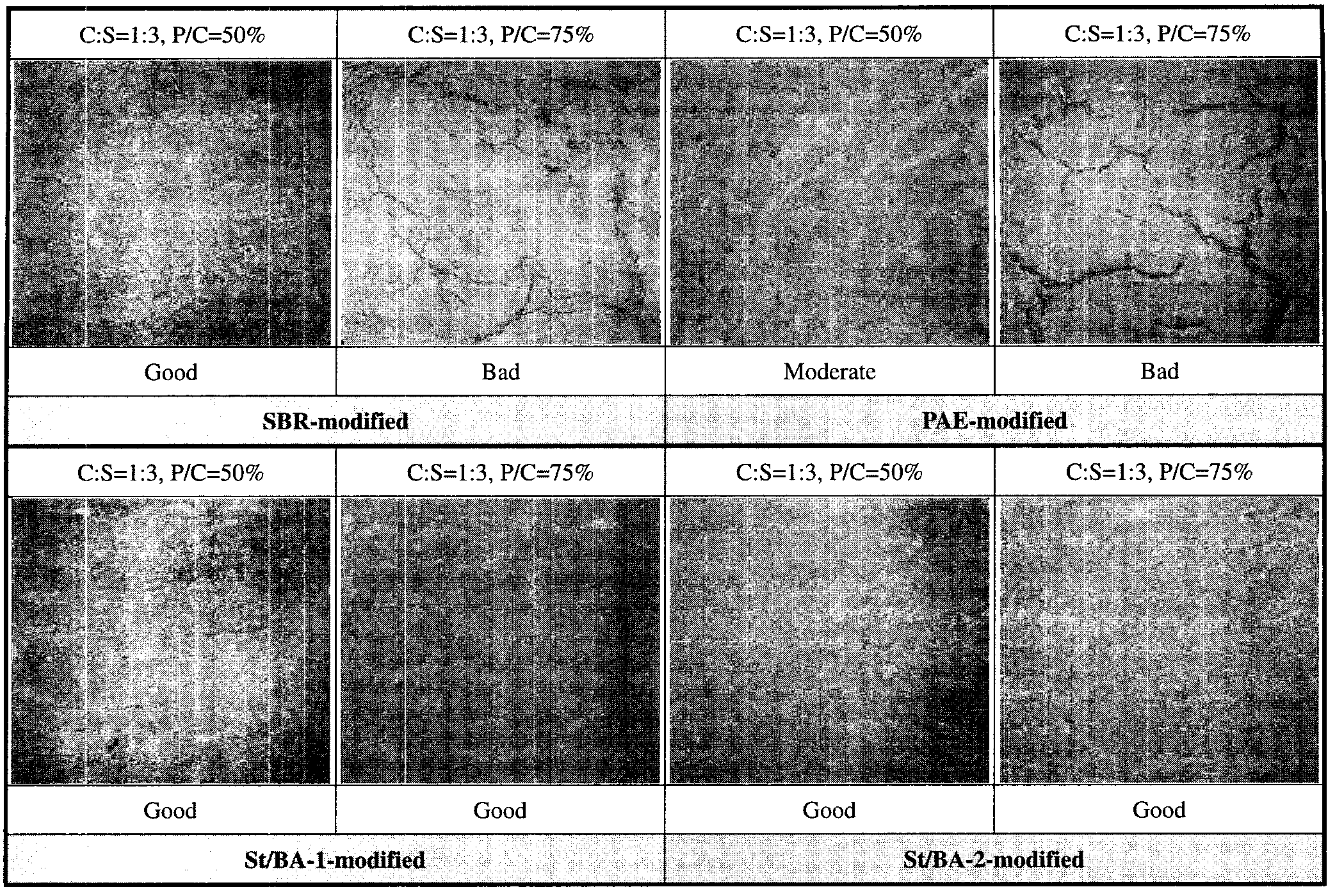

Fig. 11 Crack resistance of polymer-modified cementitious self-leveling floor in case of C:S=1:3

content of St/BA emulsion is about 57 %, the water-cement ratio of St/BA-modified mortar ranges from 45-65% and get relatively low. And so, no shrinkage crack result from the initial dry(dry out phenomenon). It is considered that each property of the polymer-modified mortars as adhesion, crack resistance etc, are dependent on the fact that each polymer particle shows the different physical qualities.

3.5 Microstructures of Interface

Fig. 14 illustrates the observation of interface between specimens and substrates with SEM as the change of polymer-cement ratio and the types of polymer dispersion. In general, with water withdrawal by 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. 13.[12]

Some chemical reactions may take place between the particle surfaces of reactive polymers such as poly acrylic esters(PAE) and calcium ions (Ca^{2+}), calcium hydroxide[$Ca(OH)_2$] crystal surfaces , or silicate surfaces over the aggregates. Fig. 15 shows adhesion mechanism of poly mer-modified self-leveling mortars to concrete substrates. Part of the polymer dispersions penetrate into the surface layers of

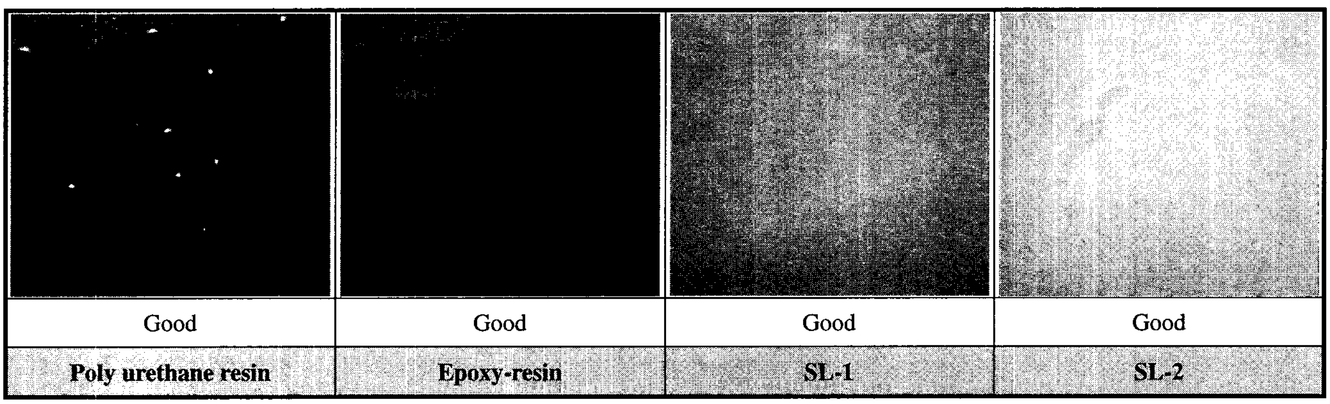

Fig. 12 Crack resistance of conventional floor

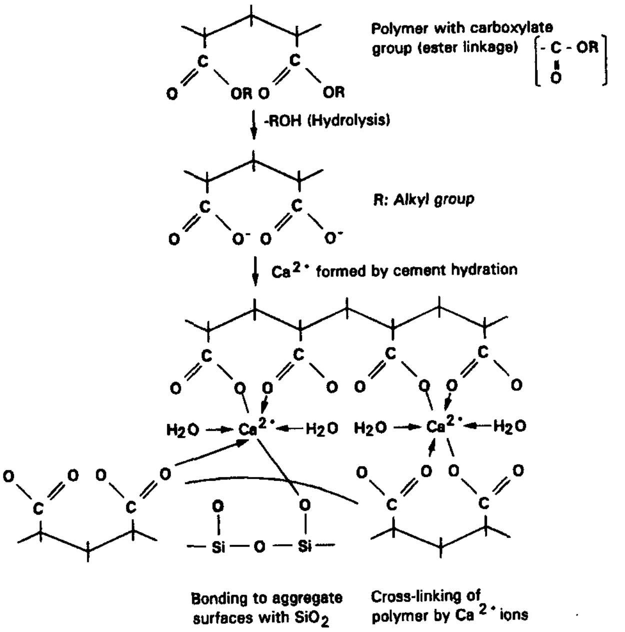

Fig. 13 Illustration of reaction between polymer with carbonxylate group, cement and aggregate

the concrete substrates, and reinforce their adhesive surfaces. The formed polymer films at the adhesive interfaces result in the formation of the chemical bonds and micro mechanical interlocking mechanisms between the self-leveling mortar and concrete substrate.(13) Each part of the polymer films plays a specific role in the adhesion of the polymer-modified self-leveling mortar to the concrete substrates.

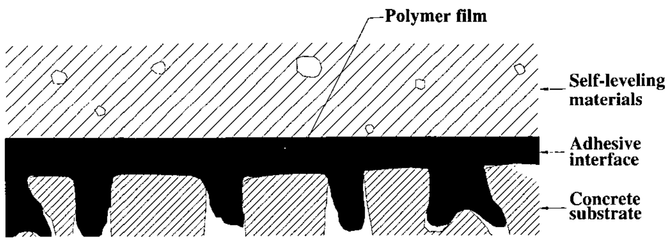

Fig. 15 Illustration of adhesion between polymer-modified self-leveling mortar and concrete substrate

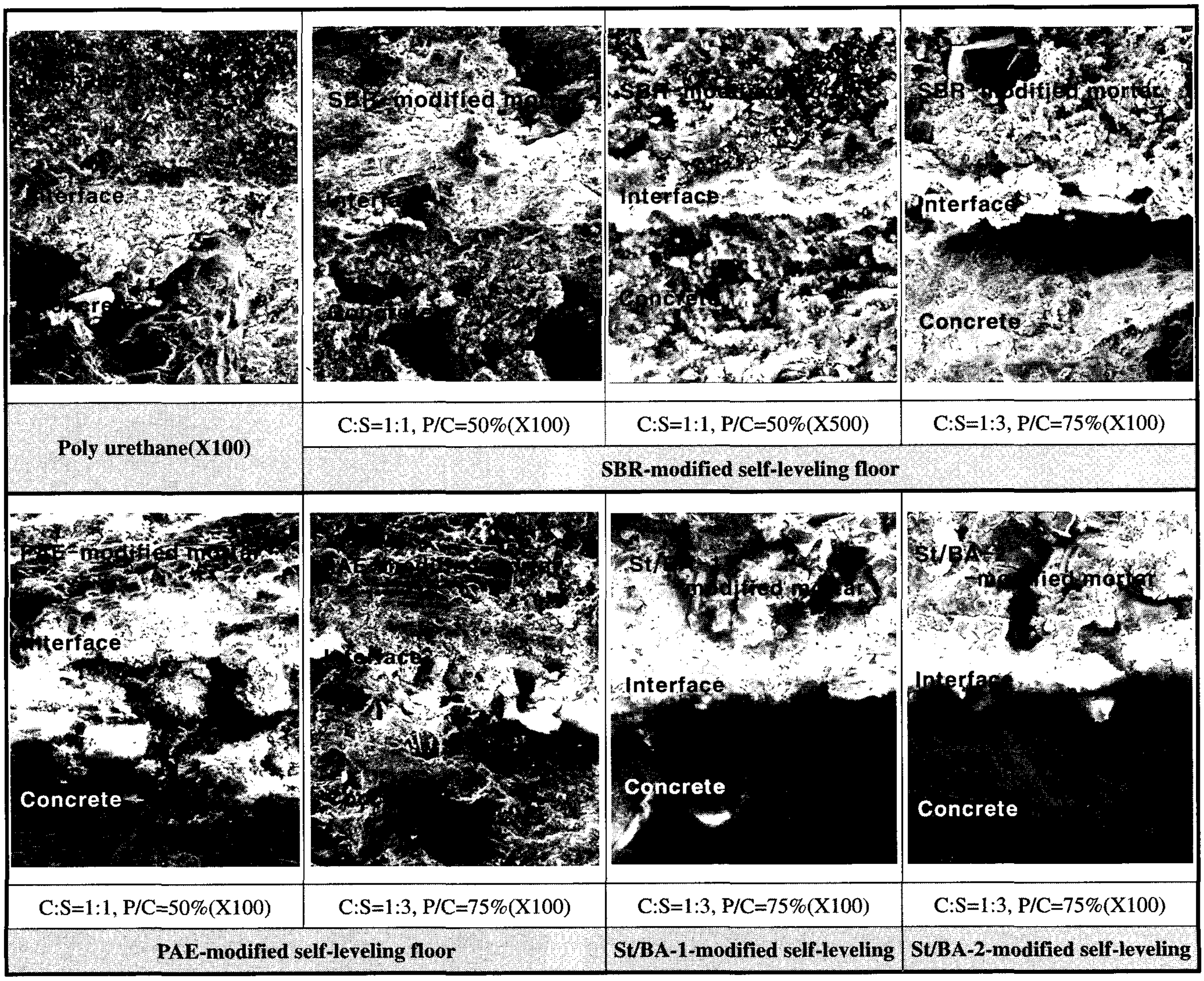

Fig. 14 Observation of interface between specimens and substrates with SEM

4. Conclusions

The following conclusions can be obtained from the above test results :

1) Irrespective of the type of polymer dispersion and cement-sand ratio, the unit weights and the air contents of self-leveling mortar at a polymer-cement ratio of 50 % are somewhat or much higher than those of polymer-cement ratio of 75 %.
2) The consistency change of polymer-modified cementitious self-leveling is very dependent on the types of polymer dispersions and only SBR-modified and PAE-modified self-leveling of four types of cement modifier accept KS specification (-15～15) for the consistency change. On the contrary, polyurethane and epoxy resin of conventional flooring have the considerable difficulty in consistency change.
3) Irrespective of the type of polymer dispersion and cement-sand ratio, the adhesion in tension of polymer-modified cementitious self-leveling mortars is high in 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 mortars. Above all, adhesion of PAE-modified self-leveling mortars is highest in case of cement-sand ratio of 1:1 and has almost equal property in comparison of that of conventional thermosetting resin floor.
4) Crack resistance of the self-leveling materials using St/BA-1 and St/BA-2 is better than other polymer-modified self-leveling mortars.
5) In conclusion, the self-leveling materials using polymer dispersions can be used in the same manner as conventional floor using thermosetting resin in practical applications, in the selection of polymer dispersions.

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