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Adhesive Strength in Tension of High Volume PAE-Modified Cement Mortar with High Flowability for Floor Finishing

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Abstract

Various researches on the application of polymer dispersions to the cement mortar and concrete have been carried out in many countries like America, Japan and Germany and so on due to their high performance and good modificaton effect. PAE of polymer dispersion widely used in situ was employed that the high flowability may be induced in the cement mortar. In order to investigate the modification of cement mortar with high flowability by PAE and fracture mode of adhesive strength properties in tension of that, experimental parameters were set as PAE solid-cement ratio(P/C) and cement:fine aggregate(C:F) and the experiments such as unit weight, flow, consistency change, crack resistance and segregation that inform on the general properties have been done. Adhesion in tension is measured with a view to comprehending the properties and fracture mode in tensile load. Consistency change of cement mortar modified by PAE did grow better as the ratio of PAE solid-cement increased and was much superior to that of resin based flooring such as polyurethane and epoxy which recorded the loss of consistency in 90 min. after mixing. Adhesive strength in tension increased with continuity during curing period and showed the maximum in case of C:F=1:1 and P/C=20%.

Keywords ***: PAE, cement mortar, self-leveling, consistency change, high volume, high flowability***

1. Introduction

1.1 Literature survey

Application of cementitious mortar is inevitable to assume the reduction of physical performance of segregation, bleeding and strength reduction although consistency and workability indicated as flow value tend to increase with increase in water-cement ratio. It has been performed a number of studies on the material and method of construction which can equally or more improve the performance of cement mortar as well as fall the economic damage with high flowability and good workability. Although there have been various approaches of material methodology to settle the problem of abrasion resistance, water resistance, and chemical resistance etc, organic polymeric materials that have the characteristics of hydrophilic colloid have been widely employed as a modification of cementitious mortar. It is already revealed that polymeric materials of polymer dispersion and redispersible powder have both the rheological properties and adhesive strength of cementitious mortar improved through surface active reaction and specific high viscosity of polymer solid itsef in comparison with non-modified mortar.

Ohama, et al.[1-3] practiced the experiment on the adhesion of polymer-modified mortars to ordinary cement mortar as a substrate, measured by four types of test methods such as adhesion in tension, flexure, direct shear and slant shear. It was concluded that the development of adhesion is attributed to the high adhesion of polymers and the adhesion is usually affected by polymer-cement ratio and the properties of substrates used and also stresses that the data on adhesion often show considerable scatter, and may vary depending on the testing methods, service conditions or porosity of substrates.

Alexanderson[4] studied a top layer of PCC for industrial floors with as slight as possible thickness and with such a

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fluid consistence that it can be pumped directly onto the concrete sub-base in order to minimize material and labor costs. Tamai et al.[5] studied the properties of high polymer cement mortar with flexibility provided the elasto-plastic substance of NM with additional elasticity by mixing a large amount of polymer emulsion in mixtures. Abeyruwan[6] investigated on the thermal influence on the bond of polymer-modified concrete overlays using Styrene Butadiene Rubber. Kim[7,8] developed the prepackaged redispersible polymer powder cement mortar by using a very variety of redispersible polymer powders ranging 5 to 20% by weight to cement.

In domestics, J.Y. Do and Y. S. Soh studied the development of polymer-modified cementitious self-leveling materials with thin coat. However hard it has been studied up to this point on various polymer modified mortars as well as adhesion of these in several conditions, as above investigation, it is currently poor in the investigation on adhesion in tension of high volume polymer modified cement mortar with high flowability applicable to the flooring material.

1.2 Research significance and purpose

The floor is a structural member that has much more frequent availability and contact with the resident or dweller than other members such as column, beam, girder, and wall. High chemical resistance, high impact resistance or high abrasion resistance, and so on must be retained in the floor member in order to enhance the health and comfort of resident. But the performance of cementitious mortar is very poor in abrasion resistance and chemical resistance because of those structural problem and the chemical properties of components. Low abrasion resistance result in the occurrence of dust in the interior of room and the easy carbonation of cementitious mortar due to the high permeabity, and those compositions cause the deformation and deficiency of those.

However the use of polymer in building material results in a substantial increase of the cost of materials. Therefore polymers have to be used only in such areas where the higher cost can be compensated for, e.g. by better properties, lower labor costs or otherwise, so that the total economy becomes reasonable.

For the purpose of improving or making up for the durability related to chemical resistance and permeability as well as above deficiency, mortar mainly composed of the resin such as epoxy and polyurethane (Resin Mortar;RM), not including the cementitious materials as binder, or modified mortar by adding the polymer emulsion such as the dispersion of SBR, PAE, EVA, and PVAC etc and redipersible powder such as SBR, EVA, and VA/VeoVa etc has been applied in situ. Adhesion in tension between mortar and the substrate of old concrete is the required performance essentially demanded for finishing material which is used to protect the old concrete and accomplish the environmental and healthy purpose. Various defects can occur in the interface between finishing material and substrate because the finishing material employed onto old concrete is heterogeneous with the substrate in nature in case of the application of resin mortar. Considering it is also possible that the similar phenomenon is generated as polymer modified mortar might be used, adhesion in tension between them is sure to be the important requirement in that most of defects appear as spalling/delamination and scaling originated from the decline of adhesion. Thus, general properties such as unit weight and consistency change of high flowability specimens made with PAE (Poly acrylic ester) whose application have been widely researched and modification to cement mortar owing to the less side effect to cement hydration, furthermore, adhesion in tension between specimens and concrete substrate was measured in order to investigate and comprehend both adhesion and fracture mode dependent on curing age, PAE solid-cement ratio, and cement:fine aggregate. The aim of this study is to present a direction that polymers including PAE emulsion can be actively used in construction by preparing the fundamental data of the presented above. Also, this study made an effort in investigating the adhesion in tension of interface between concrete substrate and cement mortar with high flowability modified by PAE emulsion

2. Experimental program

2.1 Material properties

2.1.1 Cement and fine aggregate

In this study, the ordinary Portland cement specified in KS 5201 was used for all the mortar mixes. Fine aggregate whose grade size is not more than 1.2mm as shown in Fig. 1 was used.

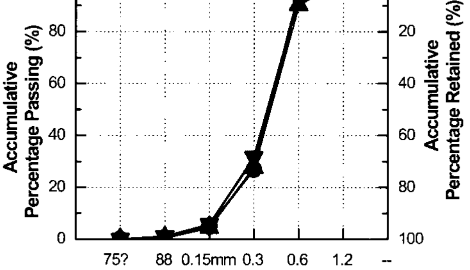


Fig. 1 Grading curve of silica sand used

2.1.2 Polymer dispersions for cement modifier

Commercial cement modifier used was poly acrylic ester (PAE) emulsion. The properties of the cement modifier used are given in Table 1 as shown blow.

2.1.3 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[3]. An excessive amount of entrained air causes a reduction in strength and is controlled by using 0.7 wt%[4,8] of proper silicone-emulsion type antifoamer to total solid weight of polymer dispersion.

2.1.4 Conventional floor-finishing materials

Polyurethane and epoxy having the characteristics of thermosetting liquid resin were used in order that it might be caught the mechanical performance of fresh and hardened materials and its properties were compared with those of polymer-modified cement mortar with high flowability by wide application of conventional floor-finishing materials in the same condition. Also, commercial self-leveling mortars (named as SL-1, SL-2, respectively) were used for the purpose of comparing the basic properties such as adhesion in tension and consistency change etc. with specimen of this study.

2.1.5 Chemical admixtures for adjusting the flowability

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

2.2 Preparation of specimen and experiments

2.2.1 Manufacture of substrate

The substrate for test was designed that the target compressive strength of concrete was decided with f_{28}=240 kgf/cm^2 and required slump value was not less than 15cm. Mix design proportion with any material content as represented in Table 2 was determined after trial mixing. The size of substrates for test was 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).

2.2.2 Mix design for specimen preparation

In accordance with JIS A 1171(Method of Making Test Sample of Polymer-Modified Mortar in the Laboratory),

Table 1 Properties of PAE emulsion

Density	pH	Viscosity (mPa·s)	Total solid
1.05	9.5	200	44.9

Table 2 Mix proportions of concrete substrate

W/C (%)	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

Table 3 Mix proportions of PAE-modified cement mortar with high flowability

Cement:fine aggregate	PAE-cement ratio (wt%)	Antifoamer (wt%)	Super-plasticizer (wt%)	Viscosity enhancing agent (wt%)	W/C (wt%)	Unit weight of each ingredient (kg/m^3)			
						Fine aggregate	Cement	PAE Solid	Water
1:1	10	0.7	2.0	N/A	37.0	851.5	858.1	83.4	317.5
	20		2.0	N/A	35.0	799.9	806.0	156.6	282.1
	30		2.0	N/A	36.2	736.1	741.7	216.2	268.7
	50		N/A	0.1	60.4	557.5	561.8	272.9	339.2
	75		N/A	0.12	90.6	427.7	431.0	314.0	390.3
1:3	10		2.0	N/A	84.0	1241.1	416.9	40.5	350.2
	20		2.0	N/A	78.0	1223.1	410.8	79.8	320.5
	30		2.0	N/A	74.0	1196.0	401.7	117.1	297.3
	50		2.0	N/A	71.4	1121.9	376.8	183.0	269.1
	75		N/A	N/A	90.6	965.5	324.3	236.3	293.7

polymer-modified cement mortars 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 3 and their flow was adjusted to be constant at 200±5mm.

2.2.3 Experimental items

Unit weight was measured as specified KS F 2475 (Method of Test for Unit Weight and Air Content of Fresh Polymer-Modified Mortar). Flow of specimens was measured 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 after mixing(F_1) and lapsing 90minutes after mixing(F_2) to measure consistency change is tested. Flows of specimens in all mixtures and conventional floorings were observed and consistency change was calculated as follows.

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

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. It was carried out conforming to the procedure as follows.

a. Procedure of adhesion test[9,10)]

The surface of each specimen placed horizontally was coated with an adequate adhesive. Then the upper jig for tensile loading was gently set and bonded on the epoxy-coated surface, and the adhesive forced out around the jig was carefully removed. After the storage of the specimen with the upper jig for tensile loading in the room for 24h, as shown in fig. 2, the load was vertically applied to the specimen by use of the lower jig for tensile loading and the maximum load indicated by the testing machine until the failure of the specimen was estimated.

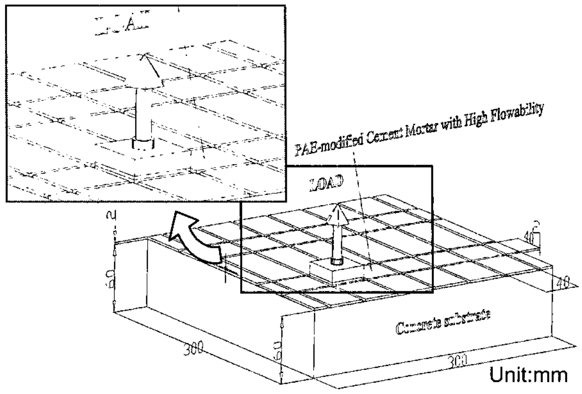


Fig. 2 Schematic of measurement of adhesion in tension

After the adhesion test, the fracture modes of the specimen were recorded. The adhesion of the specimen was calculated from the following equation, and rounded off to one decimal place.

$$\sigma_a = L/16$$

where; σ_a: adhesion (kgf/cm^2 or MPa), and
L : maximum load (kg or Newton)

3. Results and discussion

3.1 Unit weight

Fig. 3 represents the relation between PAE solid-cement ratio and the density of specimen designed as 1:1 and 1:3 of cement:fine aggregate in case of being coordinated as 200± 5mm of flow value. Unit weight of specimens decrease with increase in PAE-cement ratio not depending on the relative ratio between cement and fine aggregate and is measured to be approximately 2.0 to 1.5kg/*l* because specific gravity of fine aggregate used in this study is about 2.0 and that of PAE solid is about below 1.0. It causes, in accordance with the increase of PAE-cement ratio, that the volume occupied by PAE solid over unit volume is increased but the volume by fine aggregate become decreased.

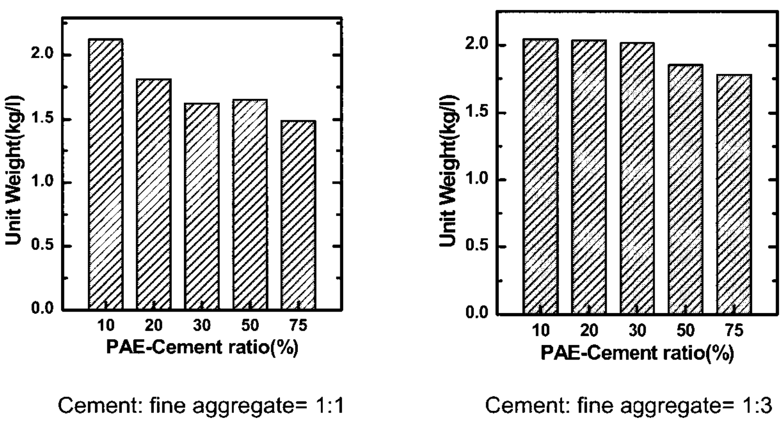


Fig. 3 Unit weight of PAE-modified cement mortar with high flowability according to C:F and P/C

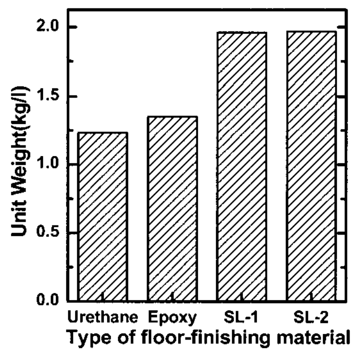


Fig. 4 Unit weight of commercial resin based flooring

Unit weight of specimens in which the ratio of fine aggregate to cement (by weight) is equal to 1:3 is wholly higher than that of specimens of C:F=1:1 in the range of 1.5%~2.5% in the difference of occupied volume of each materials with respectively different specific gravity. Fig. 4 shows the unit weights of commercial floor-finishing materials applied to finish office floor, garage structure, and industrial floor. The floor-finishing materials composed of Polyurethane and Epoxy resin, respectively, have unit weight of 1.5 below and SL-1 and SL-2 is almost similar or over to specimens made in this study.

3.2 Flow and consistency change

Figs. 5 and 6 illustrate the flow and the consistency change of PAE modified cement mortar with the change of polymer-cement ratio as well as cement-fine aggregate ratio and the commercially conventional floor-finishing material, respectively. It can be noted, through this study, that the consistency change decreases with increase in polymer-cement ratio, and consistency change of cement-sand ratio of 1:3 is higher than that of cement-sand ratio of 1:1 because the difference of the water absorption by fine aggregate is made and 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. When the ratio of fine aggregate to cement (by weight) is equal to 1:3, segregations occurred in both 10 and 20% of PAE-cement ratio because of insufficiency of PAE solid which is capable of preventing segregation of mixture by enhancing the viscosity regardless of inevitable high W/C caused by the flow coordination of the mixtures. Polyurethane and epoxy resins have been completely deprived of flow after lapsing 90 minutes because of initial fast chemical reaction as seen in Fig. 6. SL-1 and SL-2 that is commercial floor-finishing materials show a good consistent property in the change of 3% below with time.

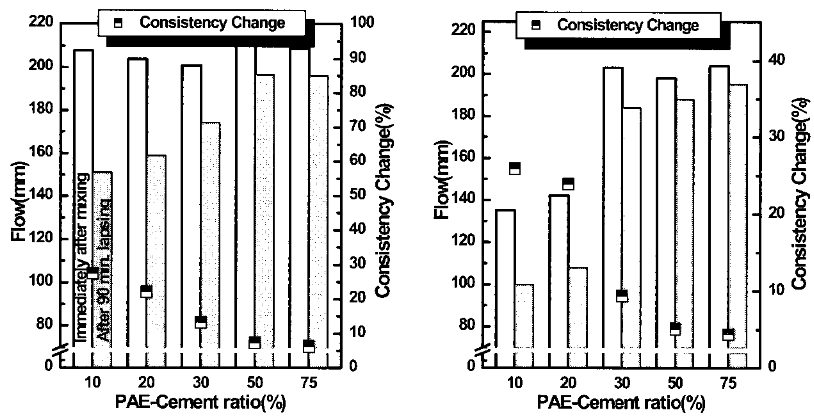
3.3 Crack resistance of confined specimen and segregation

In general, volume of cement paste is dependent on the moisture content of paste. Drying induces volume reduction (drying shrinkage) and it is inevitable that the initial drying (i.e. drying out phenomenon) of paste derives maximum dry shrinkage from paste.[11] Applying the above drying process to cement mortar results to the development of crack. This is due to the tensile stress according to the restraint provided during bonding to the substrate via both ends and beneath. Also crack can occur provided that the tensile strength of the specimen is lower than the tensile stress developed by both surface tension and restraint. Through consideration based on above, all the specimens prepared with PAE emulsion in this study are not cracked in standard condition of 20℃ and 65% relative humidity. But segregation and bleeding occurred in the specimens composed of the cement-fine aggregate ratio of 1:3 and PAE-cement ratio of 10% and 20% because of the reason why the binder of cement and PAE particle capable of promoting the cohesive between fine aggregate and matrix that allow the resistance to both bleeding and segregation to the polymer-modified cement mortar.[12]

3.4 Adhesion in tension

Fig. 7 represents relation between PAE-cement ratio and adhesion in tension of specimens with various curing ages for the relative long term of 50days.

In considering only adhesive strength of several required specimen properties, the specimen of which PAE-cement



Cement : fine aggregate= 1:1 Cement : fine aggregate= 1:3

Fig. 5 Flow and consistency change of PAE-modified cement mortar with high flowability according to C:F and P/C

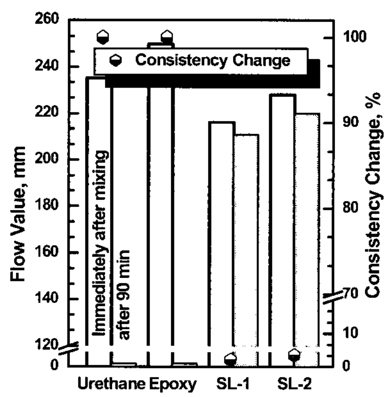
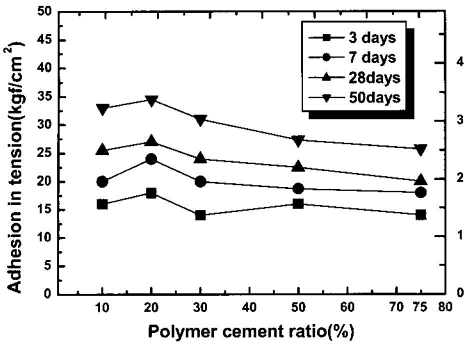
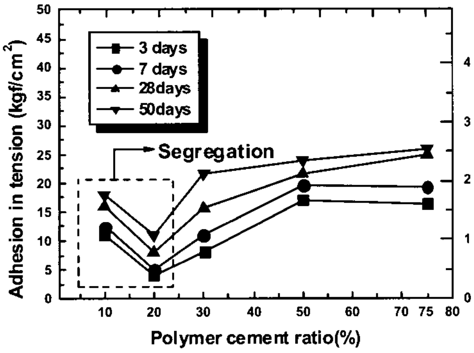


Fig. 6 Flow and consistency change of commercial floor-finishing

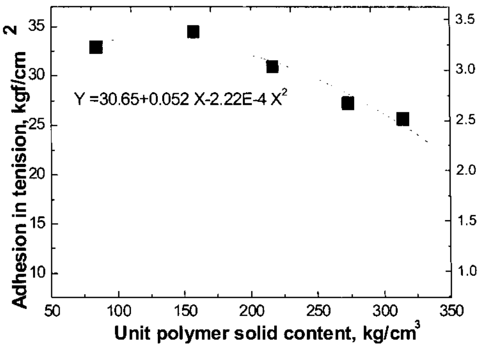


C:F=1:1

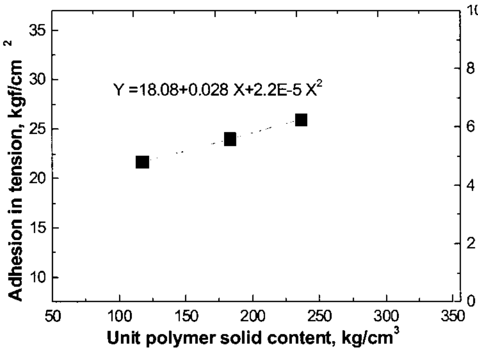


C:F=1:3

Fig. 7 Adhesion in tension of PAE-modified cement mortar with high flowability according to C:F and P/C



C:F=1:1



C:F=1:3

Fig. 9 Fitting curve of data about adhesion in tention based on the change of unit polymer solid content

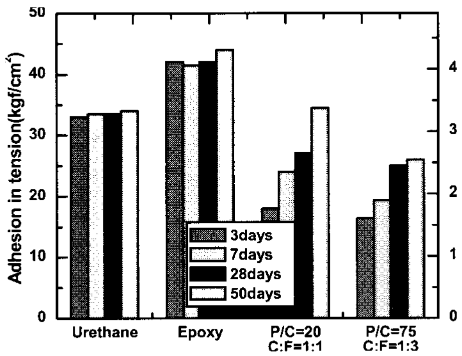


Fig. 8 Comparison of adhesion in tension between the PAE-modified and conventional floor

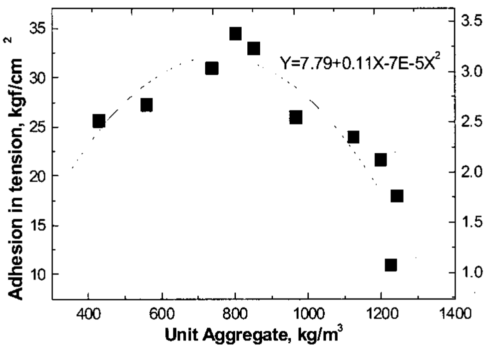


Fig. 10 Fitting curve of data about adhesion in tension based on the change of unit fine aggregate

ratio and cement:fine aggregate are 20% and 1:1, respectively, shows the highest level in this mix. The adhesion in tension of PAE modified cement mortar with high flowability decreases with increasing PAE-cement ratio in this mix after the maximum of adhesion in tension are exhibited at a peak because increasing PAE-cement ratio gives birth to the increase of unit water (water content per 1m cubic meter) in the mix by the reason why solid and water are fixed in PAE emulsion. When PAE-cement ratio is 75%, that is to say, water-cement ratio of the mixture that is the direct relation to strength and durability amounts so much as to 80%. Adhesion in tension also decreases with increase in cement-fine aggregate ratio because the quantity of binder (cement + PAE total solid) that can be made to promote adhesion relatively decreases with increasing of fine aggregate in all mixtures. Adhesive strength in tension is almost linearly increased with curing age in case of that cement:fine aggregate of specimen is 1:1 because of both the effect of strength development by cement hydration and water retention and sealing phenomenon by PAE emulsion. Fig. 8 shows the comparison of adhesion in tension between PAE-modified cement mortar with high flowability and resin based floor-finishing materials, e.g., polyurethane and epoxy resin. Specimen in this study appears to be somewhat inferior to that of flooring using epoxy resin although improved with increasing curing ages. However, the adhesion in tension of cement mortar with high flowability using PAE emulsion is about superior to that of conventional flooring using polyurethane resin. Most of the specimens are over 2.0MPa at curing age of 28 days and adhesion in tension over 3.0MPa is recorded only in case of that curing age is 50 days.

Figs. 9 and 10 represent fitting curve of data about adhesion in tension based on the change of unit polymer solid content and unit aggregate, respectively, together with related formula. It was found that the correlation between adhesion in tension and unit weight of each ingredient of specimens proved to be expressed as 2 degree function. So, the peak of adhesion in tension exists and after that, adhesion in tension tends to decrease together with the increase of both unit polymer content and unit fine aggregate.

From the above result, it was certified that adhesion in tension of PAE modified cement mortar with high flowability should be markedly affected by unit PAE solid content occupied in the mixtures of $1m^3$.

3.5 Fracture mode of specimens

Fig. 11 illustrates the schematic diagram and analysis of fracture mode of specimen in adhesive test and Table 4 represents the fracture mode of specimens caused by tensile load according to cement:fine aggregate and PAE-cement ratio of 10 to 75% with change in curing age. Adhesion in tension of interface between specimen and concrete substrate increases with curing age from the truth that adhesion in tension of specimen increases with curing age and fracture mode is fixed. It is observed that specimens of which PAE-cement ratio is below 20% is broken at the specimen of PAE-modified cement mortar and that of which PAE-cement ratio is over 30% is broken at the interface between specimen and concrete substrate when cement:fine aggregate is 1:1.

Table 4 Fracture mode of cement mortar with high flowability modified by PAE emulsion

C:F	P/C (%)	Fracture mode			
		3 days	7 days	28 days	50 days
1:1	10	S_{frac}	S_{frac}	S_{frac}	S_{frac}
	20	S_{frac}	S_{frac}	S_{frac}	S_{frac}
	30	S_{frac}	I_{frac}	I_{frac}	I_{frac}
	50	S_{frac}	I_{frac}	I_{frac}	I_{frac}
	75	I_{frac}	I_{frac}	I_{frac}	I_{frac}
1:3	10	S_{frac}	S_{frac}	S_{frac}	S_{frac}
	20	S_{frac}	S_{frac}	S_{frac}	S_{frac}
	30	S_{frac}	S_{frac}	S_{frac}	S_{frac}
	50	I_{frac}	I_{frac}	I_{frac}	I_{frac}
	75	I_{frac}	I_{frac}	C_{frac}	I_{frac}

a. C:F and P/C indicate cement:fine aggregate and polymer-cement ratio, respectively.
b. S_{frac}, I_{frac} and C_{frac} indicate the fracture in the specimen, interface between specimen and concrete substrate and concrete substrate, respectively.

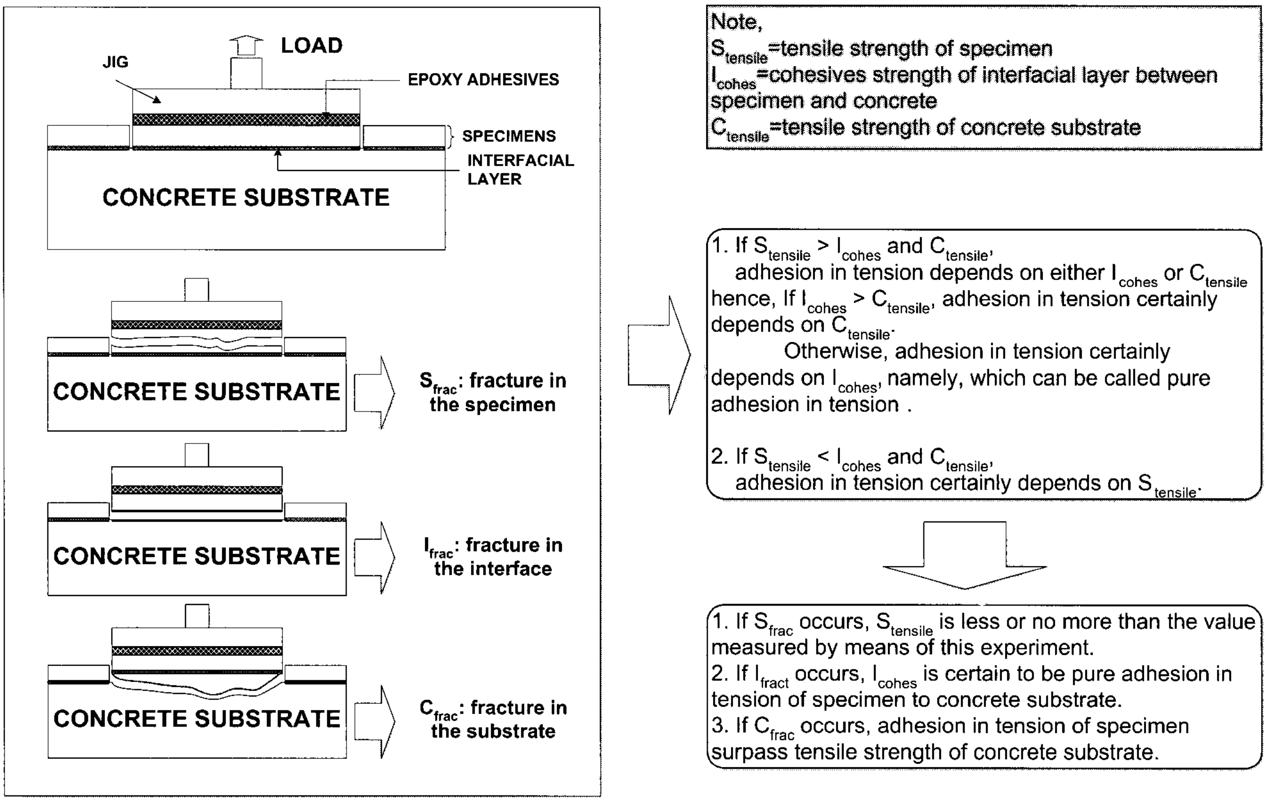


Fig. 11 Schematic diagram and analysis of fracture mode of specimen in adhesive test

Fracture of specimen occurred where PAE-cement ratio is not more that 30% when cement:fine aggregate is 1:3. Also, it finds that cement mortar with high flowability modified by PAE emulsion has the properties of assuming the fracture at the interface between specimen and concrete substrate in case of cement:fine aggregate of 1:1 having a more quantity of binder than that of 1:3 when PAE-cement ratio is over 30%. The tensile strength of specimen that is PAE-cement ratio of 20% and cement:fine aggregate of 1:1 can be estimated into below about 3.5Mpa, from the schematic diagram of Fig. 11, because adhesion in tension of specimen shows about 3.5Mpa.

4. Conclusions

This study has shown how adhesion in tension of cement mortar with high flowability modified by PAE emulsion was developed. Based on the test results, the following conclusions can be drawn.

1) Unit weight of specimens decrease with increase in PAE-cement ratio and amount approximately 1.5 to 2.0 kg/ℓ.
2) Consistency change decreased with increase in PAE-cement ratio, and consistency change of cement:fine aggregate ratio of 1:3 was higher than that of cement:fine aggregate ratio of 1:1. On the contrary, polyurethane and epoxy resin of conventional flooring had the considerable difficulty in consistency change.
3) Adhesion in tension of PAE-modified cement mortars was the highest in PAE-cement ratio of 20% and cement:fine aggregate of 1:1. The adhesion in tension of specimen of which PAE-cement ratio and cement:fine aggregate was 20% and 1:1, repectively, was higher at curing age of 50days than that of polyurethane resin, SL-1 and SL-2 although it was lower than that of epoxy resin.
4) Crack resistance of confined cement mortar with high flowability modifed by PAE emulsion was very good because all specimens was not cracked and segregation occurred at PAE-cement ratio of 10% and 20% in case of cement:fine aggregate of 1:3
5) It is observed that specimens of which PAE-cement ratio is below 20% is broken at the specimen of PAE-modified cement mortar and that of which PAE-cement ratio is over 30% is broken at the interface between specimen and concrete substrate when cement:fine aggregate is 1:1. Fracture of specimen occurred where PAE-cement ratio is below 30% when cement:fine aggregate is 1:3.
6) Consequently, adhesion properties in tension of specimen are comparable to those obtained with conventional resin-base floooring of polyurethane and epoxy.

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