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Fire-protecting performance of polymer-modified mortars using redispersible polymer powders

1. Introduction

In recent years, polymer-modified mortars using various polymer dispersions and redispersible polymer powders have widely been used in building construction as finish materials such as repair materials for damaged reinforced concrete structures, waterproofing materials, tile adhesives and floorings. The research and development of the polymer-modified mortars have actively been carried out for many years, and their superior properties have been well known. However, it is generally considered that their thermal resistance and fire-protecting performance are limited since they contain polymers which are thermally unstable and combustible. Investigations on such properties of the polymer-modified mortars have hardly been reported till now (1-2). In Japan, the Building Standards Law was revised in June 2005. It was officially recognized by this revision that the polymer-modified mortars can be used as repair materials for deteriorated reinforced concrete structures in building construction. The noncombustibility behaviour of the polymer-modified mortars became an important topic in the Japanese construction industry. On the other hand, in the manufacture of polymer-modified mortar products, the change of two-prepackaged systems to one-prepackeged systems using redispersible polymer powders is promoted in Japan at present.

In this paper, the polymer-modified mortars using three types of commercial redispersible polymer powders for polymeric admixtures are prepared with various polymer-cement ratios, and tested for reaction to fire in accordance with ISO 5660-1:2002 [Reaction to fire tests -Heat release, smoke production and mass loss rate- Part 1: Heat release rate (cone calorimeter method)]. Based on the test results, the acceptability of the polymer-modified mortars as noncombustible materials is judged.

Table 1

PHYSICAL PROPERTIES AND CHEMICAL COMPOSITIONS OF CEMENT

Density, g/cm^3	Blaine specific surface, cm^2/g	Setting time h-min		Compressive strength of mortar, MPa		
		Initial set	Final set	3d	7d	28d
3.16	3220	2-12	3-19	29.7	46.8	64.0
Chemical compositions, %						
MgO		SO_3		ig. loss		
0.94		2.06		1.36		

2. Materials

2.1. Cement and fine aggregate

Ordinary Portland cement as specified in JIS (Japanese Industrial Standard) R 5210 (Portland cement) was used as a cement. Table 1 lists the physical properties and chemical compositions of the ordinary Portland cement. ISO standard sand as specified in JIS R 5201(Physical testing methods for cement) was employed as a fine aggregate. Table 2 gives the properties of the ISO standard sand.

Table 2

PROPERTIES OF ISO STANDARD SAND

Size mm	Fineness modulus	Bulk density kg/l	Density g/cm^3	Moisture content %
0.08-2.00	2.93-3.14	1.74	2.63	0.20

2.2. Polymeric admixtures

Commercial redispersible polymer powders used as polymeric admixtures were polyacrylic ester (PAE), poly (ethylene-vinyl acetate) (EVA) and poly (vinyl acetate- vinyl versatate-acrylic ester) (VAVeoVaAE) powders. Before mixing, a silicone-coated-silica-type antifoamer was added to the redispersibe polymer powders at a ratio of 1.0% (mass fraction) of the powders. Table 3 shows the properties of the redispersible polymer powders.

Table 3

PROPERTIES OF REDISPERSIBLE POLYMER POWDERS

Type of redispersible polymer powder	Volatile matter %	Ignition residue %	Apparent density g/cm^3
PAE	1.2	9.1	0.51
EVA	1.1	7.8	0.49
VAVeoVaAE	0.3	12.8	0.54

Table 4

MIX PROPORTIONS OF THE POLYMER-MODIFIED MORTARS

Type of mortar	Cement : sand by mass	Polymer-cement ratio, P/C, %	Water-cement ratio %	Air content %	Flow
Unmodified	1 : 3	0	50.0	3.8	169
PAE-modified		5	45.6	4.3	167
		10	44.4	3.5	165
		15	45.6	2.7	166
		20	45.6	3.6	175
EVA-modified		5	46.7	3.5	174
		10	45.6	3.2	166
		15	44.4	3.3	173
		20	43.3	3.6	168
VAVeoVaAE-modified		5	47.8	5.6	165
		10	47.8	3.0	165
		15	47.8	3.8	171
		20	47.8	3.9	167

3. Testing procedures

3.1. Preparation of Specimens

According to JIS A 1171 (Test methods for polymer-modified mortar), polymer-modified mortars using redispersible polymer powders were mixed with a mass ratio of cement to fine aggregate 1:3 and polymer-cement ratios (P/C) of 0, 5, 10, 15 and 20%, and their flow was adjusted to be constant at 170±5 in the water-cement ratio range of 43.3 to 50.0%. Table 4 gives the mix proportions of the polymer-modified mortars. Plate specimens 100×100×10 mm were moulded, and subjected to a 2d-20ºC-90%(RH)-moist plus 5d-20ºC-water plus 21d-20ºC-60% (RH)-dry curing. The plate specimens were dried at 60ºC for 24h.

2.3. Heat Release Test by Cone Calorimeter Method

According to the heat release test by ISO 5660-1:2002 for the fire-protecting performance evaluation as prescribed in Paragraph 9 of Article 2 of the Building Standards Law in Japan, plate specimens were heated for 20 min by using a cone calorimeter. Figure 1 represents the cone calorimeter. The total heat release and heat release rate of the specimens during heating were recorded. The specimens were judged for the acceptability as three gradings by noncombustibility for fire-preventive materials. Table 5 shows the criteria for judgment for grading by noncombustibility for fire-preventive materials according to the Building Standards Law in Japan.

3. Test results and discussion

Figure 2a represents the heating time vs. total heat release of polymer-modified mortars using redispersible polymer powders. The total heat release of all the polymer-modified mortars with polymer-cement ratios of 0, 5 and 10% does not reach 8MJ/m^2 (quality requirement) for 20 min from the start of heating. The total heat release of PAE-modified mortar with a polymer-cement ratio of 15% exceeds 8MJ/m^2 at heating times of 5 to 10 min. The total heat release of EVA-modified mortar with a polymer-cement ratio of 20% exceeds 8MJ/m^2 at heating times of 5 to 10 min. PAE- and VAVeoVaAE-modified mortars with a polymer-cement ratio of 20% were broken down by explosive fracture at heating times of 5 min or shorter. The cracks and holes penetrating through the back of all polymer-modified mortars except PAE- and VAVeoVaAE-modified mortars with of a polymer-cement ratio of 20%, are absent for 20 min from the start of heating.

Figure 2b illustrates the heating time vs. heat release rate of polymer-modified mortars using redispersible polymer powders. The maximum heat release rate of all the polymer-modified mortars for 20 min from the start of heating does not reach 200 kW/m^2 (quality requirement) for longer than 10s regardless of the polymer type and polymer-cement ratio. The heat release rate of PAE-, EVA- and VAVeoVaAE-modified mortars with polymer-cement ratios of 5, 10 and 15% reaches a maximum at heating times of 5 to 10 min irrespective of the polymer-cement ratio. In particular, a rise in the heat release rate of the PAE-modified mortars is marked compared to that of the EVA- and VAVeoVaAE-modified mortars. However, at

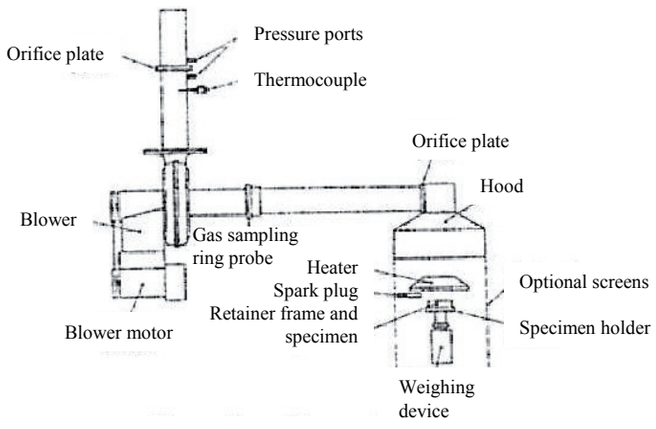

Fig. 1. Cone calorimeter

Table 5

CRITERIA FOR JUDGMENT FOR GRADING BY NONCOMBUSTIBILITY FOR FIRE-PREVENTIVE MATERIALS

Grading for fire-preventive material	Criteria for judgment
Noncombustible material	Total heat release shall be 8MJ/m² or less for 20 min from the start of heating. Cracks and holes penetrating through the back are absent for 20 min from the start of heating. Maximum heat release rate for 20 min from the start of heating shall be not exceed 200kW/m² for longer than 10s.
Quasi- noncombustible material	Total heat release shall be 8MJ/m² or less for 10 min from the start of heating. Cracks and holes penetrating through the back are absent for 10 min from the start of heating. Maximum heat release rate for 10 min from the start of heating shall be not exceed 200kW/m² for longer than 10s.
Flame-retardant material	Total heat release shall be 8MJ/m² or less for 5min from the start of heating. Cracks and holes penetrating through the back are absent for 5 min from the start of heating. Maximum heat release rate for 5 min from the start of heating shall be not exceed 200kW/m² for longer than 10s.

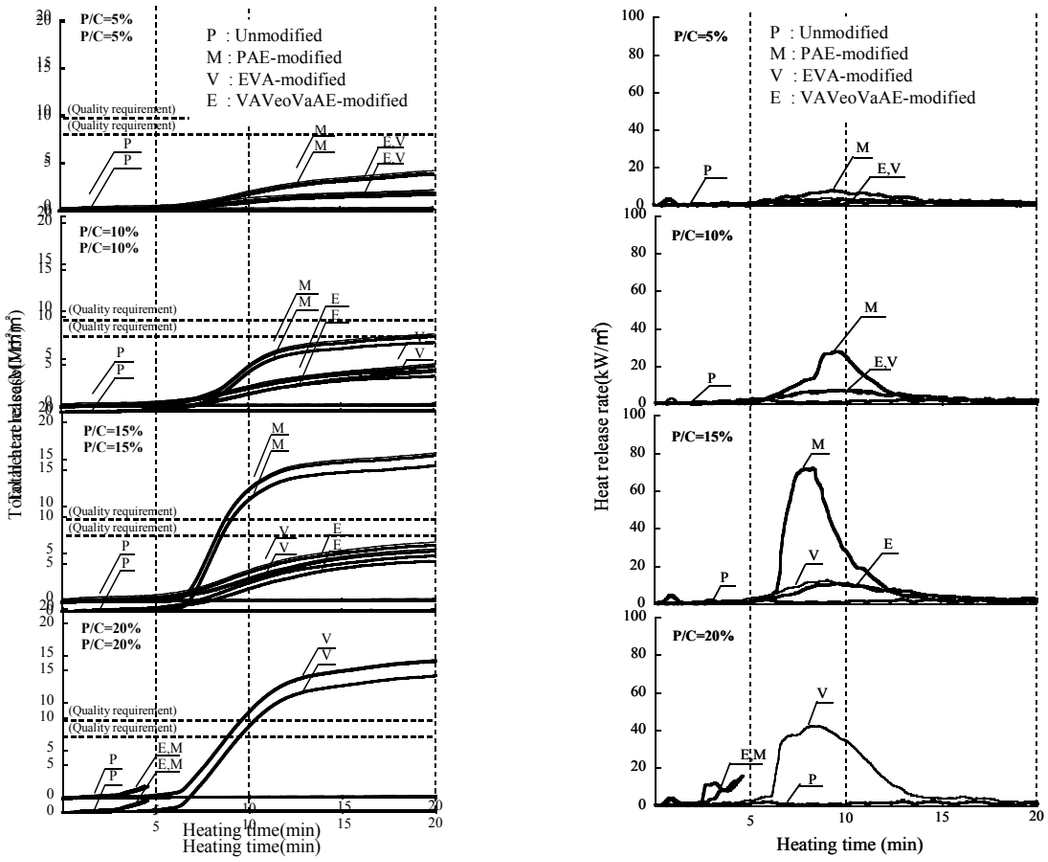

Fig. 2. Heating time vs. total heat release (a) and heat release rate (b) of polymer-modified mortars using redispersible polymer powders

a polymer-cement ratio of 20%, only EVA-modified mortar reaches a maximum without explosive fracture at heating times 5 to 10 min.

Table 6 exhibits the grading for fire-preventive materials by the Building Standards Law for noncombustibity of polymer-modified mortars using redispersible polymer powders. All the polymer-modified mortars with polymer-cement ratios of 0, 5 and 10% can be evaluated to be noncombustible materials. EVA- and VAVeo-VaAE-modified mortars with a polymer-cement ratio of 15% also are acceptable as noncombustible materials. PAE-modified mortar with a polymer-cement ratio of 15% and EVA-modified mortar with a polymer-cement ratio of 20% are evaluated to be flame-retardant materials. PAE- and VAVeoVaAE-modified mortars with a polymer-cement ratio of 20% cannot be graded for any of fire-preventive materials because of the occurrence of explosive fracture.

5. Conclusions

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

Table 6

GRADINGS FOR FIRE-PREVENTIVE MATERIALS BY THE BUILDING STANDARDS LAW FOR NONCOMBUSTIBILITY OF POLYMER-MODIFIED MORTARS

Type of mortar	Polymer-cement ratio, %	Grading for fire-preventive material
Unmodified	0	Noncombustible material
PAE-modified	5	Noncombustible material
	10	Noncombustible material
	15	Flame-retardant material
	20	Out of grading
EVA-modified	5	Noncombustible material
	10	Noncombustible material
	15	Noncombustible material
	20	Flame-retardant material
VAVeoVaAE-modified	5	Noncombustible material
	10	Noncombustible material
	15	Noncombustible material
	20	Out of grading

– In general, the fire-protecting performance of polymer-modified mortars using redispersible polymer powders tends to become worse with increasing polymer-cement ratio. All the polymer-modified mortars using redispersible polymer powders with polymer-cement ratios of 0, 5 and 10% can be evaluated to be noncombustible materials.
– The fire-protecting performance of polymer-modified mortars using redispersible polymer powders with polymer-cement ratios of 15% or more is generally affected by the polymer type. The fire-protecting performance of PAE-modified mortars is the worst of three types of polymer-modified mortars. It seems that EVA-modified mortars have a relatively good fire-protecting performance.

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