

## Recent Status of Research and Development of Concrete-Polymer Composites in Japan

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### Abstract

The present paper reviews the recent status of research and development activities of concrete-polymer composites such as polymer-modified concrete (mortar), polymer concrete (mortar) and polymer-impregnated concrete (mortar) in the Japanese construction industry. Polymer-modified concrete (mortar) comprise of repair systems for deteriorated reinforced concrete structures, strengthening (or retrofitting) methods and exfoliation (or delamination) prevention methods for existing reinforced concrete structures, liquid-applied membrane waterproofing systems, advanced polymeric admixtures such as high-grade redispersible polymer powders and hardener-free epoxy resins, intelligent repair materials, application of accelerated curing, semi flexible pavements, and drainage pavements with photo catalyst. Polymer mortar and concrete are related to new liquid resins, setting shrinkage control, thermal properties and temperature dependence, lightweight or porous polymer mortars and concretes, artificial marble products and precast products. The polymer-impregnated mortar and concrete are mainly concerned with field polymer impregnation techniques using silane-based barrier penetrants.

*Keywords: concrete-polymer composites; polymer-modified concrete (mortar); polymer concrete (mortar); polymer-impregnated concrete (mortar); research and development*

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### 1. Introduction

For the past five decades, Japan has actively researched polymer-modified concrete (mortar), polymer concrete (mortar) and polymer-impregnated concrete (mortar), and currently used as popular construction materials because of comparative high performance, multifunctionality and sustainability compared to conventional cement mortar and concrete [1-4]. Concrete-polymer composites are environment-conscious or sustainable construction materials, and confirm to concerns of saving of natural resources, the longevity of infrastructures and the environmental protection. This paper reviews recent research and development activities of the concrete-polymer composites in the Japanese construction industry.

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## **2. General trends in research and development activities in polymer-modified concrete (mortar)**

Presently popular polymeric admixtures are polymer dispersions: styrene-butadiene rubber (SBR) latex, poly(ethylene-vinyl acetate) (EVA) and polyacrylic ester (PAE) emulsions, and redispersible polymer powders: poly(vinyl acetate-vinyl versatate-acrylic ester)(VA/Veova/AE), poly(ethylene-vinyl acetate) (EVA) and poly(vinyl acetate-vinyl versatate) (VA/Veova) powders.

### ***2.1 Repair systems for deteriorated reinforced concrete structures***

Longevity of infrastructures is crucial in the development of effective repair materials and their execution systems. Repair materials for the deteriorated reinforced concrete structures include impregnants for concrete quality modification and improvement, corrosion-inhibiting coating materials for reinforcing bars, patch materials, surface preparation materials, coating materials for finish and protection, and grouts for concrete cracks.

### ***2.2 Strengthening (retrofitting) of existing reinforced concrete structures***

Recently, slabs and beams (or girders) have often been strengthened with overlays to increase their thickness (or depth) by the troweling or shotcreting work of polymer-modified mortars on the bottom surfaces. Existing reinforced concrete columns and shear walls have also recently been retrofitted with the troweling or shotcreting work of polymer-modified mortars for seismic strengthening methods.

### ***2.3 Adhesives (bonding) agents for exfoliation (delamination) prevention methods***

New exfoliation (or delamination) prevention methods using polymer-modified mortars and pastes for adhesives or bonding agents with vinylon, aramid, polyethylene and alkali-resistant glass fiber sheets are adopted due to its easy application to wet concrete substrates.

### ***2.4 Liquid-applied membrane waterproofing systems***

Generally, polymer-modified mortars or slurries for the polymer-modified cement membrane waterproofing systems are prepared at polymer-cement ratios of 20 to 300% by using PAE and EVA emulsions, and have tensile strengths of 0.7 to 8.0MPa, elongations of 25 to 400% and adhesions to the concrete substrates of 0.75 to 2.8MPa as waterproofing membranes.

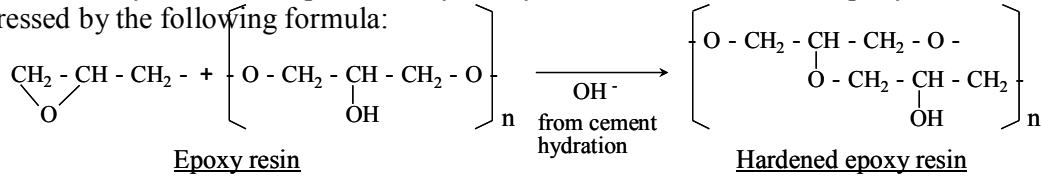
### ***2.5 High-grade redispersible polymer powders***

In the manufacture of polymer-modified mortar products, replacement of polymer dispersions by the high-grade redispersible polymer powders, i.e., the change of two-packaged systems to one-packaged systems is promoted in Japan. Commercial high-grade redispersible polymer powders are EVA, PAE, poly(styrene-acrylic ester)(SAE), VA/Veova and VA/Veova/AE powders.

## **3. Intelligent repair materials**

### ***3.1 Hardener-free epoxy-modified mortars with auto-healing or self-repairing function***

Recent research attests that even without any hardeners the epoxy resin can harden in the presence of the alkalis or hydroxide ions produced by the hydration of cement in the epoxy-modified mortars as expressed by the following formula:



Such hardener-free epoxy-modified mortars and concretes have an auto-healing or self-repairing function for the micro cracks, and may be intelligent materials as shown in Figure 1.

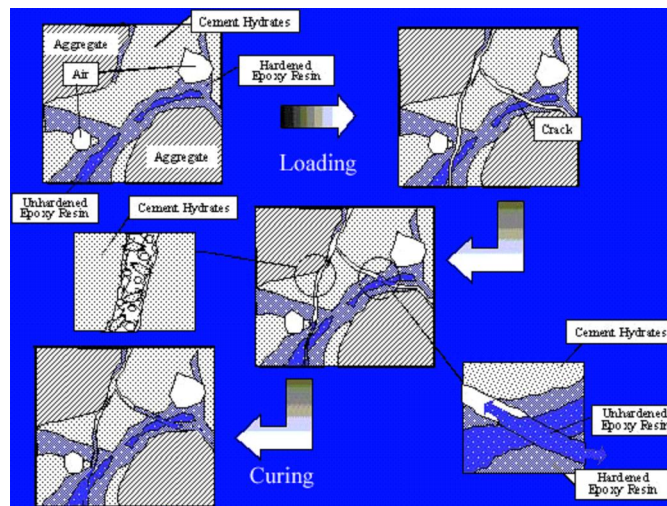
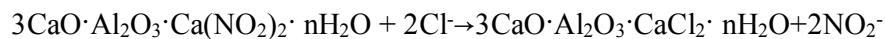


Figure 1 Simplified model for autohealing mechanism of microcracks in epoxy-modified cementitious systems.

### 3.2 Polymer-modified mortars with nitrite-type hydrocalumite

Nitrite-type hydrocalumite  $[3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Ca}(\text{NO}_2)_2 \cdot \text{H}_2\text{O} (n=11\sim 12)]$  is a corrosion-inhibiting admixture or anticorrosive admixture which can adsorb the chloride ions ( $\text{Cl}^-$ ) causing the corrosion of reinforcing bars and liberate the nitrite ions ( $\text{NO}_2^-$ ) inhibiting the corrosion as expressed by the following formula:



It provides excellent corrosion-inhibiting property to the reinforcing bars in reinforced concrete. Polymer-modified mortars using polymer dispersions and redispersible polymer powders with the nitrite-type hydrocalumite (calumite) have superior corrosion-inhibiting property and durability.

## 4. Applications of accelerated curings

The autoclave curing can be applied to SBR-modified concretes using slag for precast products. The feasibility study to examine hardener-free epoxy resin as a polymeric admixture for the accelerated curing of cement concrete shows that the application of a 120°C-autoclave curing or 90 °C –steam curing plus 120 °C –heat curing to hardener-free epoxy-modified mortars with polymer-cement ratios of 10 to 20% develops about twice to three times higher flexural strength and about twice higher compressive strength than unmodified mortar (ordinary cement mortar).

## **5. Pavement applications**

Semi flexible pavements are executed by grouting the voids of open-graded asphalt concretes with polymer-modified pastes or slurries. The pavements are applied to heavy traffic roads, intersection pavements, bus stops, parking lots and airport runways because of their excellent rutting resistance, load spreadability, abrasion resistance, oil resistance and colorability.

## **6. Recent research and development activities in polymer concrete (mortar)**

Widely used liquid resins include thermosetting resins like unsaturated polyester (UP) resin (i.e., polyester-styrene system), epoxy (EP) resin, vinyl ester (VE) resin and polyurethane (PUR), tar-modified resins and acrylic resins such as polymethyl methacrylate (PMMA) and glycerol methacrylate-styrene. Recently, new polymer concrete and mortar using waste expanded polystyrene (EPS) solution-based binders have been developed as an effective recycling method of EPS in Japan. Table 1 shows the Applications of polyester concrete in Japan.

### ***6.1 New liquid resins***

Ecologically safe EP and UP resins with low styrene contents of 30% or less for polymer mortars and concretes, and low-odor methacrylate binders for floor coatings and linings are developed for environment-conscious materials selection.

### ***6.2 Setting shrinkage control***

Low-shrinkage UP resins without any shrinkage-reducing or low-profile agents are developed for UP concretes, and PMMA concretes with low setting shrinkage are made by the combined use of a polymeric surfactant, steel fibers and vinylon fibers.

### ***6.3 Thermal properties and temperature dependence***

The thermal properties and temperature dependence of mechanical properties being most important properties for the structural uses of polymer concretes are examined for UP and EP concretes.

### ***6.4 Lightweight or porous polymer mortars and concretes***

Ultra lightweight, lightweight or ultra-lightweight porous EP concretes are produced by a prepacked concrete method, and porous acrylic concretes for drainage pavement are developed.

### ***6.5 Artificial marble products***

Recently demand for polymeric artificial marble products using polymer pastes with flame-retarding fillers such as aluminium hydroxide and magnesium hydroxide has gradually increased. The three largest markets of the artificial marble products are washstand and systematized kitchen and baths fields.

Table 1. Applications of polyester concrete in Japan

Application	Location of Work
Structural Precast Products	Manholes and handholes for telecommunication cable lines, electric power cable lines and gas pipelines, compact cable boxes for common ducts, prefabricated cellars or stockrooms, tunnel liner segments for telecommunication cable lines and sewerage systems, piles for port or hot spring construction, forms for reinforced concrete structures, FRP-reinforced frames or panels for buildings, machine tool structures, e.g., beds and saddles, works of art, e.g., carved statue and object d'art, tombs for buddhists, etc.
Nonstructural Precast Products	Gutter covers, U-shaped gutters, footpath panels, terrazzo tiles and panels, and large-sized or curved decorative panels for buildings, partition wall panels, sinks, counters, washstands, bathtubs, etc.
Cast-in-Place Applications	Spillway coverings in dams, protective linings of stilling basins in hydroelectric power stations, coverings of checkdams, foundations of buildings in hot spring areas, acid-proof linings for erosion control of dams with acidic water, etc.

## 7. Recent research and development activities in polymer-impregnated concrete (mortar)

Currently, polymer-impregnated concrete (mortar) are rarely used as construction materials because of high processing cost and cumbersomeness of manufacturing and application process despite of their excellent performance.

## 8. Standardization work

Recently the wide application of polymer-modified mortar and concrete, and polymer mortar and concrete has brought forward the standardization of test methods and their quality requirements.

## 9. Conclusions

Recently, environment-conscious concrete-polymer composites are arduously developed for sustainable development in the construction industry. Many national and institutional standards for them have been published in Japan. The concrete-polymer composites with high performance, multifunctionality and sustainability are expected to become the promising construction materials in Japan in the 21st century.

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