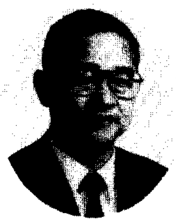
특집

콘크리트구조물의 보수 · 보강기법

일본에 있어서 철근콘크리트 구조물의 내구성 개선 및 보수용 복합재료

Composite Materials for Durability Improvement and Repair of Reinforced Concrete Structures in Japan



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1. Introduction

Reinforced concrete made up from an ideal combination of concrete and reinforcing bar has been used as main structural materials in the construction industry for many years. In recent years, the rapid deterioration of reinforced concrete structures due to alkali-aggregate reaction, rapid carbonation and chloride-induced corrosion have become a social problem in the world. This trend is similar to that in Japability-improving materials and repair materials for the reinforced concrete strucutures.
s for the reinforced concrete structures.

The present paper outlines the mechanism of the deterioration of the reinforced concrete structures and the principle of countermeasures against the deterioration, and then reviews composite materials using polymers for durability improvement and repair works for them in Japan.

2. Deterioration of Reinforced Concrete Structures

As shown in Fig.1, the deterioration of reinforced concrete structures is chiefly due to the deterioration of concrete itself and the degradation of reinforcing bars. The deterioration of the concrete is caused by chemical, physical and biological deterioration or degradation factors. Chemical degradation including alkali-aggregate reaction and chemical attack causes concrete cracks due to expansive products, and the dissolution of cement hydrates in the concrete. The actions of humidity or tempera-

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ture change, cyclic loading, freezing and thawing, abrasion and cavitation on the concrete are classified into the physical deterioration. Factors the biological deterioration factors such as bacterial attack also lead to the degradation of the concrete, On the other hand, the corrosion of the reinforcing bars is usually the result of the carbonation of the concrete and the presence of chloride ions, and induces concrete cracks due to rust expansion and a reduction in the strength of the reinforcing bars. The usual corrosion of the reinforcing bars is caused by the formation of local cells. i.e., microcells. Macrocells are sometimes formedbetween repaired and unrepaired portions of the reinforcing bars in the reinforced concrete sturctures, and such macrocells cause the corrosion of the reinforcing bars called "Repair-Induced Corrosion".

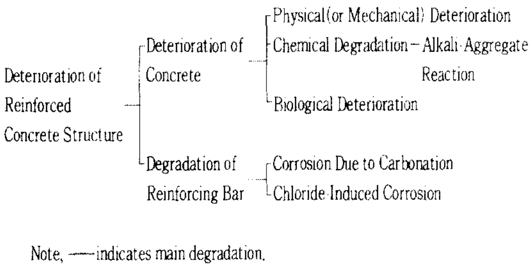


Fig.1 Deterioration of reinforced concrete structures

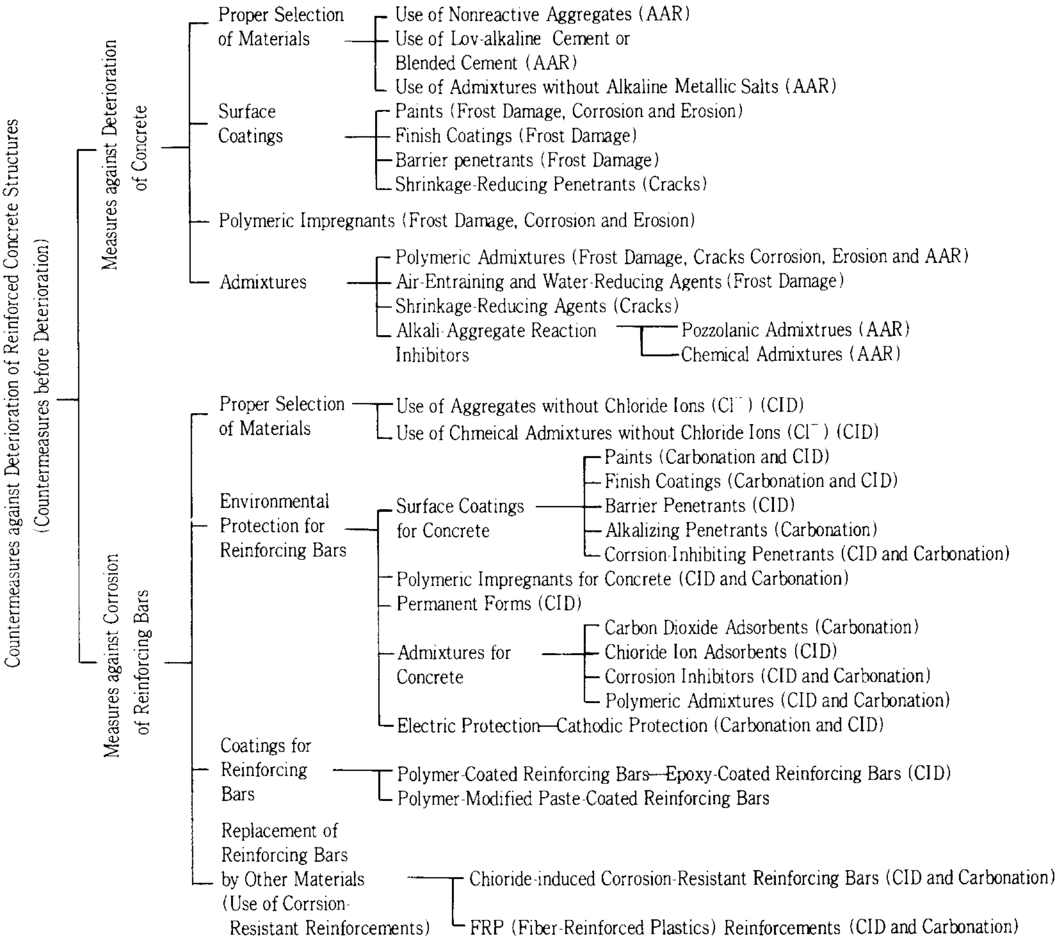
3. Countermeasures Against Deterioration of Reinforced Concrete Structures

The principle of the countermeasures against the deterioration of reinforced concrete structures is to eliminate or control their deterioration factors, i.e., the above-mentioned chemical, physical and biological deterioration or degradation factors. For example, such countermeasures involve to eliminate chloride ions and reactive aggregates from the manufacturing process of the concrete, and to prevent the diffusion of carbon dioxide, oxygen, water and chloride ions into the concrete. Fig.2 represents the countermeasures against the deterioration of the reinforced concrete structures. Two guidelines for the countermeasures against the chloride-induced damage and alkali-aggregate reaction relating to the deterioration of the reinforced concrete structures were issued in 1986 and 1989, respectively, by the Ministry of Construction in Japan. According to the guidelines, the chloride ion content and alkali content (as Na_2O equivalent) of the concrete are controlled in principle to be 0.30kg/m^3 or less and 3.0kg/m^3 or less respectively.

4. Composite Materials for Durability Improvement Work

4.1 Materials for Modification of Concrete Surfaces

The materials using polymers for the modification of concrete surfaces include finish coatings, barrier penetrants, linings, liquid-applied membrane waterproofing materials and permanent forms which are used for the elimination or control of chemical degradation factors in reinforced concrete structures. The finish coatings are applied on the concrete surfaces in the finish and repair works for reinforced concrete structures. The quality requirements for the finish coatings are specified in the following four JISs (Japanese Industrial Standards): JIS A 6909(Wall Coatings for Thin Textured Finishes), JIS A 6910 (Multi-Layer Wall Coatings for Glossy Textured Finishes), JIS A 6915 (Wall Coatings for Thick Textured Finishes) and JIS A 6917 (Lightweight Aggregate Coating Materials). The barrier penetrants pen-



Notes, ( ) indicates the type of deterioration.
AAR, Alkali-aggregate reaction; CID, Chloride-induced damage.

Fig.2 Countermeasures against deterioration of reinforced concrete structures

etrate into the concrete surfaces and improve the waterproofness and chloride ion penetration resistance of the concrete, but do not improve its carbonation resistance. Alkyl alkoxy silane-based barrier penertrants are most effective as seen in Fig.3,[1] and commonly used in Japan. The linings with thickness of 0.5 to 2.0.mm, using glass fibers (or flakes) or carbon fiber cloths as reinforcements, are applied on the concrete surfaces in the finish and repair works. As given in Table 1,[2] they have excellent chloride ion penetration resistance. Recently, the liquid-applied membrane waterproofing materials, based on polymer-cement pastes or slurries with very high polymer-cement ratios of 50% or more, sometimes 100% or more, have widely been used for the waterproofing of the reinforced concrete structures. The waterproofing materials can be applied on the wet concrete surfaces, and form flexible membaranes with thicknesses of 2.0 to 4.0 mm. Permanent forms are used instead of steel and plywood forms, and are unified with placed concrete without removing them. Polyethylene net-reinforced polymer-modified mortar, mesh-reinforced malamine-modified cementitious paste and polymer-impregnated concretepanels are practically used as the permanent forms which are mainly applied to prevent chloride ion penetration and carbonation.

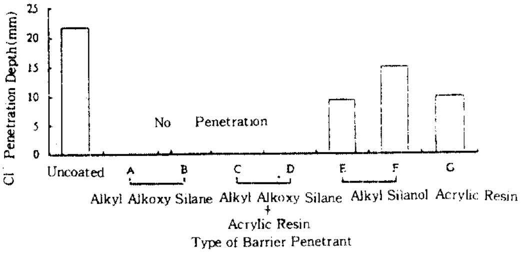


Fig.3 Chloride ion (Cl^-) penetration resistance of concretes coated with barrier penetrants

Table 1 Chloride ion (Cl^-) penetration of lining films

Type of Lining	Type of Lining Film	Thickness(μm)	Cl^- Penetration ($mg/cm^2 \cdot d$)
Epoxy Resin for Wet Substrate	Composite Layer	900	0
	Monolayer	600	0-0.48×10^{-3}
Solventless, Elastomeric Polybutadiene	Composite Layer	1000	0-0.48×10^{-3}
	Monolayer	600	0-0.48×10^{-3}
Epoxy Resin with Glass Flakes	Composite Layer	1000	0
	Monolayer	500	0-0.87×10^{-3}
Vinyl Ester Resin with Glass Flakes	Composite Layer	1500	0
	Monolayer	500	0
Epoxy Resin with Glass Rovings	Composite Layer	2000	0.48×10^{-3}-0.082
	Monolayer	800	0.48×10^{-3}

4.2 Corrosion-Resistant Reinforcements

Polymer-coated reinforcing bars such as epoxy-coated reinforcing bars and FRP (fiber-reinforced plastics) reinforcements or continuous fiber reinforcing materials are empolyed as corrosion-resistant reinforcements. A guide for quality requirements for the epoxy-coated reinforcing bars, "Recommendation for Design and Construction of Concrete Structures Using Epoxy-Coated Reinforcing Steel Bars", was published by the Japan Society of Engineers in 1986. FRP reinforcements or continuous fiber reinforcing materials are produced in various shapes by binding high-strength fibers such as carbon, aramid, galss and vinylon fibers with corrosion-resistant binders such as epoxy and vinyl ester resins at fiber contents of 60 to 70%. Fig.4 exhibits the classification of FRP reinforcements or continuous fiber reinforcing materials.[3] Table 2[3] and Fig. 5[4] show the tensile strength and elastic modulus, and tensile stress-strain relationships of FRP reinforcements, respectively.

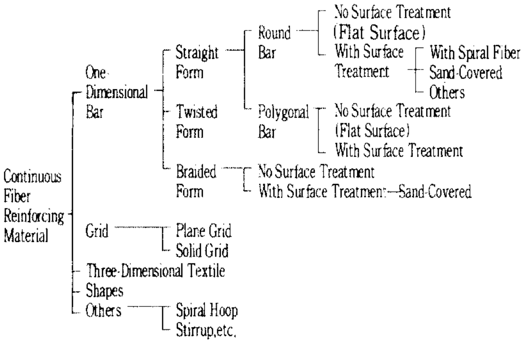


Fig.4 Classification of continuous fiber reinforcing materials

Table 2 Tensile strength and elastic modulus of FRP reinforcements

Type of Fibers	Type of Binder	Tensile Strength (kgf/mm^2)	Elastic Modulus (×$10^3 kgf/mm^2$)
Carbon(Pitch)	Epoxy Resin	80-184	10.5-21.0
	Vinyl Ester Resin	100-110	8.0-9.0
Carbon(PAN)	Epoxy Resin	155-200	12.2-15.0
	Vinyl Ester Resin	70-100	6.0-15.0
Aramid	Epoxy Resin	130-136	6.3-6.6
	Vinyl Ester Resin	125-195	4.5-5.4
Glass	Epoxy Resin	134-160	4.3-5.3
	Vinyl Ester Resin	57-90	3.0-4.5
Vinylon	Epoxy Resin	60-78	2.8-3.7
Glass/Carbon(Pitch)	Vinyl Ester Resin	50-68	3.5-4.5

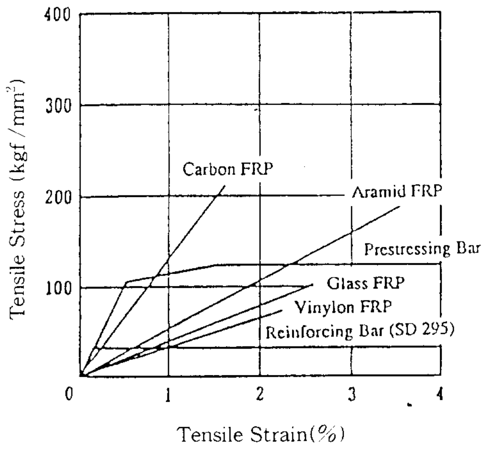


Fig.5 Tensile stress-strain relationships of FRP reinforcements

5. Composite Materials for Repair Work

Repair materials using polymers for deteriorated reinforced concrete structures include corrosion-inhibiting coatings for reinforcing bars, patch materials, coatings for surface preparation and protection, finish materials and grouts for concrete cracks. Fig. 6 illustrates typical application methods for such repair materials. The corrosion-inhibiting coatings such as epoxy resin paints, tar-epoxy resin paints and polymer-modified pastes containing corrosion inhibitors, e.g., calcium nitrite, are used for the treatment of the reinforcing bars. The patch materials are employed for the back filling of the damaged portions of the concrete. In general, polymer-modified mortars and concretes, and polymer mortars and concretes are used as the patch materials. The quality requirements for cement modifiers such as polymer latexes or emulsions for the polymer-modified mortars and concretes are specified in JIS A 6203 (Polymer Dispersions for Cement Modifiers). Sprayed and prepacked concrete techniques using such materials are sometime applied for repair work with large area. The coatings for surface preparation and protection are applied on concrete surfaces after patch work. The polymer-modified mortars and polymer mortars are usually used for this purpose. The quality requirements for the polymer-modified mortars as coatings for surface preparation are specified in JIS A 6916 (Cement Filling Compound for Surface Preparation). The finish materials are finally used in repair work for the reinforced concrete structures for improving durability and giving decorative appearance. The above-mentioned coatings and barrier penetrants are also employed as the finish materials. A specification of the finish materials for preventing chloride ion penetration for road bridge was issued by the Japan Road Association in 1984.

The chloride ion penetration resistance, carbonation resistance, oxygen diffusion coefficient and weatherability of typical polymer-modified mortars which are widely used are shown in Table 3,[5] Fig. 7,[6] 8[7] and 9[8], respectively. Epoxy resin and liquid polymers are often used as grouts for concrete cracks. The polymer-modified pastes or slurries are

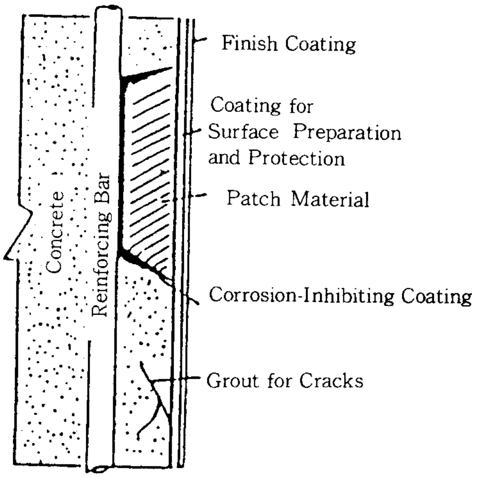


Fig.6 Typical application methods for repair materials for deteriorated reinforced concrete structures

Table 3 Apparent chloride ion (Cl^-) diffusion coefficient of polymer-modified mortars and concrete

Type of Mortar	P/C (%)	Apparent Cl^- Diffusion Coefficient (cm^2/s)	Type of Mortar	P/C (%)	Apparent Cl^- Diffusion Coefficient (cm^2/s)
Unmodified	0	6.4×10^{-8}	Unmodified	0	2.2×10^{-8}
SBR-Modified	10	6.4×10^{-8}	SBR-Modified	10	1.9×10^{-8}
	20	3.9×10^{-8}		20	9.3×10^{-9}
EVA-Modified	10	4.4×10^{-8}	EVA-Modified	10	7.9×10^{-9}
	20	2.4×10^{-8}		20	1.0×10^{-8}
PAE-Modified	10	3.8×10^{-8}	PAE-Modified	10	6.2×10^{-9}
	20	4.4×10^{-8}		20	5.8×10^{-9}

Notes, P/C, polymer-cement ratio.
SBR, styrene-butadiene rubber ; EVA, poly (ethylene-vinyl acetate) ; PAE, polyacrylic ester.

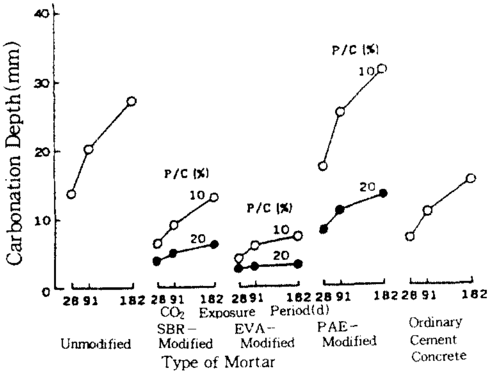


Fig.7 Carbonation resistance of polymer-modified mortars

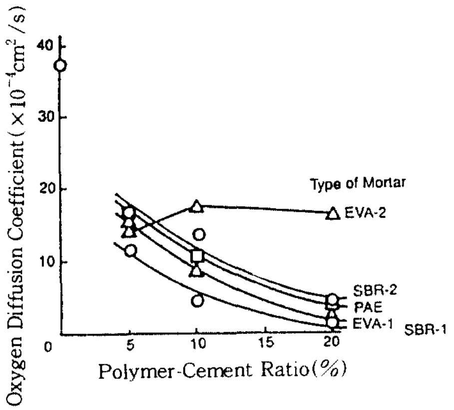


Fig.8 Oxygen diffusion coefficient of polymer-modified mortars

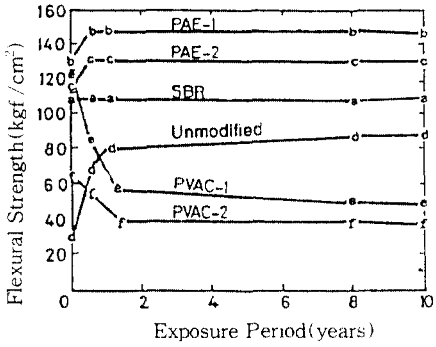


Fig.9 Weatherability of polymer-modified mortars

also applied for grouting the cracks with widths of 2.0mm or more. The quality requirements for the epoxy resin grouts for buildings are specified in JIs A 6024 (Epoxy Injection Adhesives for Repairing in Buildings).

6. Conclusions

The deterioration of reinforced concrete structures is caused by chemical, physical and biological deterioration or degradation factors for both concrete and reinforcing bars. The principle of the countermeasures against the deterioration is to eliminate or control these factors. The cementitious-polymeric composite materials which are used as durability-improving materials and repair materials in Japan at present are considered to be very effective to improve the durability of the reinforced concrete structures. The cost-performance of such composite materials should be examined further in their practical applications.

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