KCI Concrete Journal
Vol. 13 No. 2 pp. 42-48, July 2001

Bend Resistance of Polymer Cement Slurry Coated Reinforcing Bars

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(Received June 5, 2001, Accepted July 19, 2001)

Abstract

The bend resistance of coated reinforcing bar is greatly influenced by both the adhesion strength between bar and coating materials, and the followed transformation of coating material as bars bend. Especially, tearing state or partial microscopic cracks are predicted on the inside and outside of bending angle, because tensile strength and elongation of polymer film are very different according to types of polymer dispersions in bar coating, and these damaged parts are rapidly corroded by penetration of corrosive factors. In this study, polymer cement slurry coated reinforcing bars with various polymer dispersions are prepared by following combined conditions, polymer-cement ratio of 50% and 100%, coating thickness of 250μm and 450μm, coating number, curing age of 3, 7, 14 and 28days. Then the specimens are tested for working life and bend resistance at bending angles 90°, 135° and 180° to observe the microscopic damage effect as the bars bend. Also, epoxy-coated reinforcing bars for control experiment were used with 250μm of coating thickness. The tensile strength for polymer films is performed.

From the test results, the working life of the polymer cement slurry is within 90 seconds. Among four types of polymer dispersion, polymer cement slurry coated reinforcing bar using St/BA-1 emulsion has the excellent bend resistance, which is remarkably improved than that of epoxy-coated reinforcing bar. And the bend resistance is more related to elongation than tensile strength of polymer film. Polymer cement slurry with a polymer-cement ratio of 100%, a coating thickness of 450μm and one coating using St/BA emulsion is selected as a most suitable coating material for coated reinforcing bar.

Keywords: bend resistance, coated reinforcing bars, cement modifiers, coating thickness, polymer cement slurry (PCS)

1. Introduction

Reinforced concrete structures under severe conditions such as marine structures, bridges and structures constructed with aggregates dredged from sea, can be deteriorated from corrosion of the reinforcing bars. [1,2] In order to prevent the corrosion of reinforcing bars, the method to use epoxy-coated reinforcing bars is widely used, because of their superior resistance against corrosion. However, in impact and bend test, the coated bars whose coating thickness is thinner than 250μm, do not meet the requirement of standard specification.[3]

In recent years, various polymer dispersions (latexes or emulsions) have been developed and commercialized for cement modifiers, and cementitious materials using the polymer dispersions have been widely used in the field of construction work all over the world.[4~6] However, a study on coated reinforcing bars using polymer cement slurry has hardly been proposed till now. The authors have already checked the basic properties of polymer cement slurry coated reinforcing bars.[7,8]

In applying coated reinforcing bar to reinforced concrete structure, there needs inspection of bend resistance according to bend angles because bending angles in the middle and end of reinforcing bar are different. Bend resistance of coated reinforcing bar generally depends on deformation capacity of coating substances and adhesion between reinforcing bar and coating substances. Especially, adhesion and elongation of polymer film are considerately different related to kinds of polymer dispersion used in coating reinforcing bar, and there causes tearing and partial fine cracking phenomenon on the inside and outside of bend angle

which may lead erosive factors to invade and stimulate wearing out.

In this research, four kinds of polymer dispersion are used on D13 produced in Korea to make coated reinforced bars with 50%, 100% of polymer-cement ratios and 250, 450μm of coating thickness. These bars are used to make PCS-coated reinforcing bars and epoxy-coated reinforcing bar at 3, 7, 14, 28 curing days by dipping coating and then those bars are bent as standard hook shapes of 90°, 135° and 180° to observe damage of bending coated reinforcing bars on the general construction site, bending reinforced bars for a short time conducts.

2. Experimental Program

2.1 Materials

(1) Cement

Ordinary portland cement as specified in KS (Korea Standard) was used in all the mixes for polymer cement slurry (PCS). The basic properties are listed in Table 1.

Table 1 Physical properties and chemical compositions of ordinary portland cement

Specific gravity (20°C)	Blaine's specific surface (cm^2/g)	Setting time (h-min)		Compressive strength of mortar (Mpa)		
		Initial set	Final set	3d	7d	28d
3.14	3300	2-18	3-12	15.0	25.5	43.3

Chemical compositions (%)		
MgO	SO_3	Ig.loss
1.3	1.9	0.6

(2) Cement Modifiers

Commercial cement modifiers used were two [poly(styrene-butyl acrylate)(St/BA)] emulsion, one polyacrylic (PA) emulsion and one styrene-butadiene rubber (SBR) latex. Their basic properties are listed in Table 2.

Table 2 Properties of polymer dispersions

Type of polymer	Specific gravity (20°C)	pH (20°C)	Viscosity (20°C, Pa·s)	Total solids (%)
St/BA-1	1.04	7.5	2470	56
St/BA-2	1.04	6.8	146	56
PA	1.09	4.3	1997	50
SBR	1.01	7.8	82	49

(3) Antifoamer

Before mixing, a silicone emulsion-type was added to polymer dispersion in a ratio of 2.0% of the silicone solids in the antifoamer to the total solids in the polymer dispersion.

(4) Reinforcing Bar

Reinforcing bars D13 having the quality specified in KS D 3504 (Steel Bars for Concrete Reinforcement) were used for coating with polymer cement slurry. The chemical components and mechanical properties of reinforcing bar are listed in Table 3. Also, epoxy-coated reinforcing bars for control experiment were used with 250μm of coating thickness.

Table 3 Chemical components and mechanical properties of reinforcing bar

Mn	Cu	C	Si	Cr	S	P	Sn
0.99	0.38	0.28	0.17	0.10	0.04	0.03	0.02

Tensile strength (kg/mm^2)	Yield strength (kg/mm^2)	Elongation (%)	Bend test
64.9	42.0	23.9	good

2.2 Test Procedures

When reinforcing bars are bent, expansion and adhesion should be adequate to avoid cracks of covering on bent part. This study hires KS M 5250 and ASTM A 775(Epoxy-coated Reinforcing Bars) that are more stiff and conducts short-time bend to bending angles of 90°, 135° and 180°, considering real stooping on general construction sites.

Table 4 Comparison between KS M 5250 and ASTM A 775

Standard / Test item	KS M 5250	ASTM A 775
Bend resistance	· Temperature : 20 2 C · Bend angle : 120° · Requirement : No cracking and peeling	· Temperature : 24 2 C · Bend angle : 120° (by mandrel of 150mm) · Limit time : within 90sec.

(1) Tensile Strength Test for Polymer Films

Four types of polymer dispersions were ponded on glass plates and dried at 40°C to make polymer film samples. The tensile strength of the polymer film samples was determined at a crosshead speed of 300 mm/min using an Instron universal testing machine.

(2) Preparation of Specimen

This study uses 42 PCS-coated reinforcing bars at each 3, 7, 14, 28 curing days, after one or two times of coating conducted with 50%, 100% of polymer-cement ratio and of 250μm, 450μm of coating thickness, using four kinds of

Table 5 Mix proportions of polymer cement slurry

Type of slurry	Polymer-cement ratio (%)	Water-cement ratio (%)		Antifoamer content (%)
		250μm	450μm	
St/BA-1-modified	50	47	39	2
	100	78	75	
St/BA-2-modified	50	51	49	2
	100	77	75	
PA-modified	50	96	83	2
	100	140	120	
SBR-modified	50	31	-	2
	100	-	42	

polymer dispersion. The mix proportions of polymer cement slurry are listed in Table 5.

(3) Coating Thickness

PCS-coated reinforcing bars in this study are 50cm of D13 with aimed coating thickness of 250μm, 450μm and randomly selected three of them in each size were measured to inform covering thickness. Epoxy-coated reinforcing bars are regulated to measure over 15 times per a certain length by ASTM.

(4) Working Life Test

The coating thickness according to elapsed time was measured to check the working life of polymer cement slurry. The range of permissive error, -50 m to 50 m, was considered.

(5) Bend Test

For the test of bend resistance, following conditions of specimen, 50% and 100% of polymer-cement ratio, 250μm and 450μm of covering thickness, one or two times of coating, curing ages of 3, 7, 14 and 28 days dipping coating duration, are counted in building specimen and those specimen are bent in to the angles of 90°, 135° and 180° to figure out its bending damage.

2.3 Principles of polymer modification

Polymer modification of cement mortar and concrete is governed by both cement hydration and polymer film formation processes in their binder phase. The cement hydration process generally precedes the polymer formation process.[9]

In due course, a co-matrix phase is formed by both cement hydration and polymer film formation processes. It is important to understand the mechanism of the co-matrix phase formation. The process of the polymer film formation on the cement hydrates is represented in Fig.2.[10]

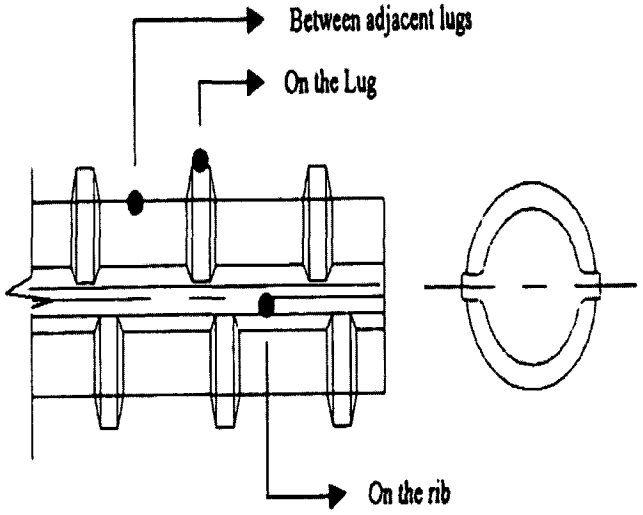

Fig. 1 Measurement of coating thickness of reinforcing bars

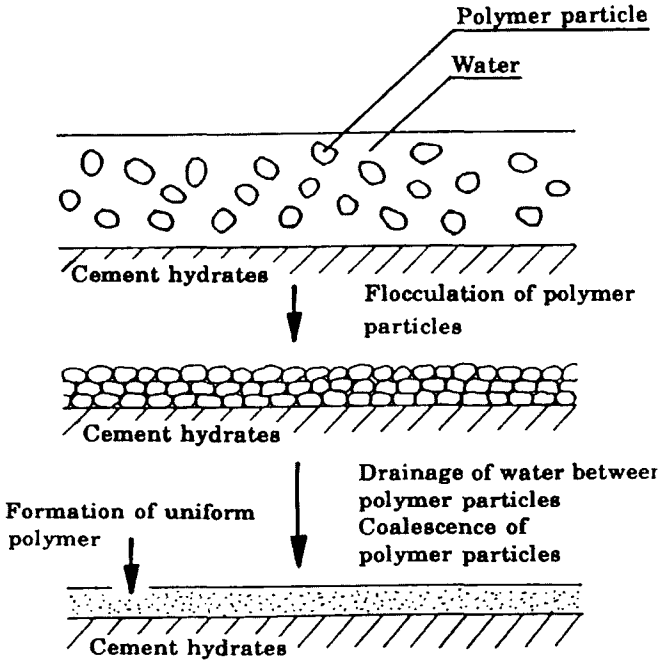

Fig. 2 Simplified model of process of polymer film formation on cement hydrates

3. Test Results and Discussion

3.1 Tensile Strength of Polymer Films

Fig.3 shows between tensile strength and elongation of polymer films made from polymer dispersions. Polymer film using St/BA emulsion releases low tensile strength but excellent elongation. On the other hand, polymer film using SBR latex has a highest tensile strength and lowest elongation among four types of polymer dispersion. It is judged that the elongation of polymer film influences the bend resistance of PCS-coated reinforcing bars.

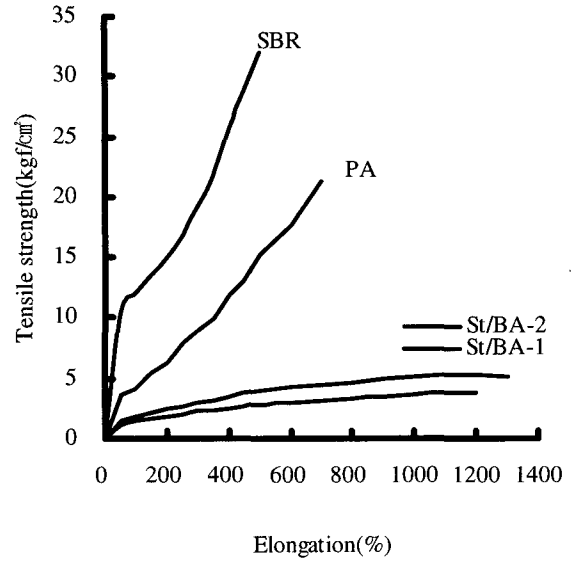

Fig. 3 Tensile strength vs. elongation of polymer films

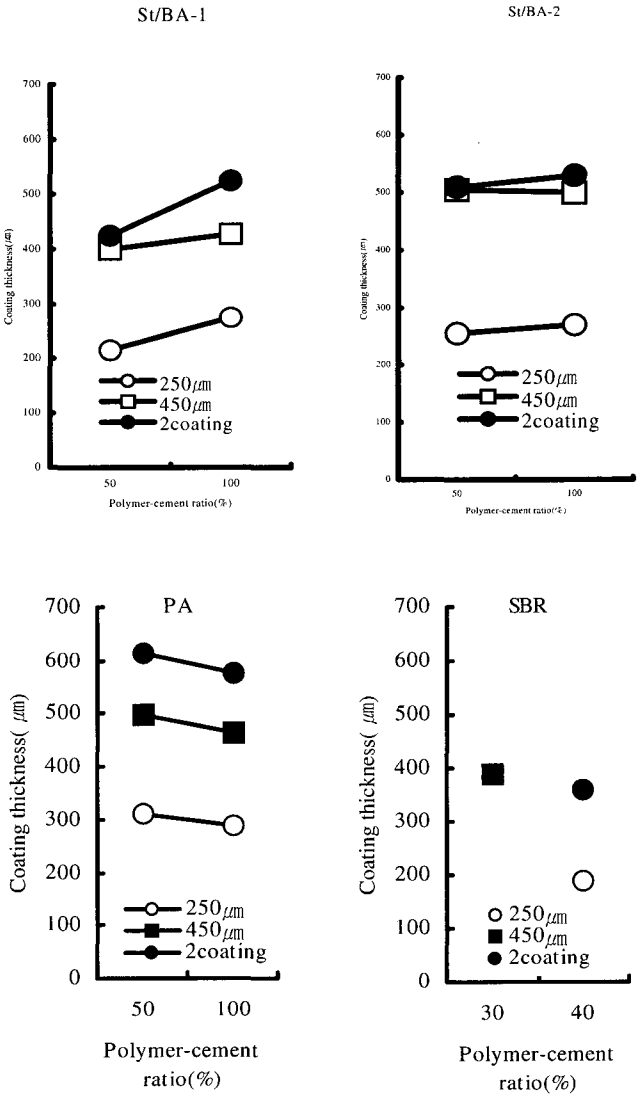

Fig. 4 Coating thickness of PCS-coated reinforcing bars

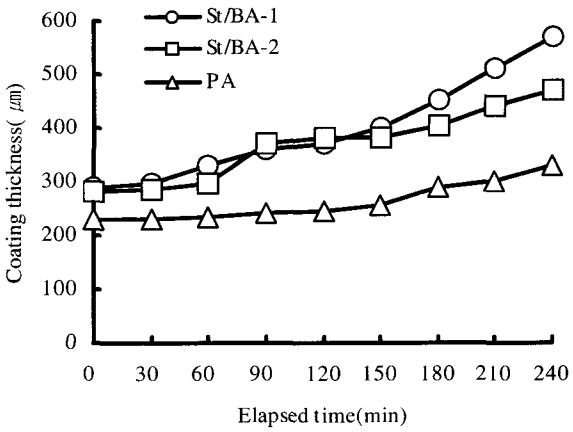

Fig. 5 Elapsed time vs. coating thickness of polymer cement slurry

Table 6 Coating thickness of polymer cement slurry

Type of slurry	Polymer-cement ratio (%)	Coating thickness		
		1 coating		2 coating
		250μm	450μm	
St/BA-1-modified	50	215	400	425
	100	275	428	525
St/BA-2-modified	50	255	505	510
	100	270	500	530
PA-modified	50	310	497	615
	100	288	465	575
SBR-modified	50	-	390	-
	100	190	-	360

3.2 Coating Thickness

The coating thickness was measured on the body of a straight length of reinforcing bar between the deformations or ribs. The results show considerable differences related to measured parts and it is thinnest on ribs and it is thickest between ribs.

3.3 Working Life

The coating thickness according to elapsed time was measured to check the working life of polymer cement slurry. Fig.5 gives the elapsed time vs. coating thickness of polymer cement slurries using polymer dispersions. The working life of the PCS-coated reinforcing bars was performed in the range of permissive error, -50μm to 50μm. The polymer cement slurries using St/BA and PA emulsions show slowly the change of coating thickness within 90 and 180 minutes respectively. After then, however they give the rapid change of coating thickness.

3.4 Bend resistance

(1) Bend Resistance of PCS-Coated Reinforcing Bars (3 days)

The PCS-coated reinforcing bars with St/BA-1-modified have cracks on the outside of the angle at 135° or 180° with 50% polymer-cement ratio and but most of them show good coating conditions. PCS-coated reinforcing bars with St/BA-2-modified are good only at condition of twice coating, however, all the rest conditions of them showed detached covering and cracks on the outside and overlaps on the inside of angles. The PCS-coated reinforcing bars with PA-modified are undamaged in condition of 100% polymer-cement ratio, 450μm's thickness and 2 coatings.

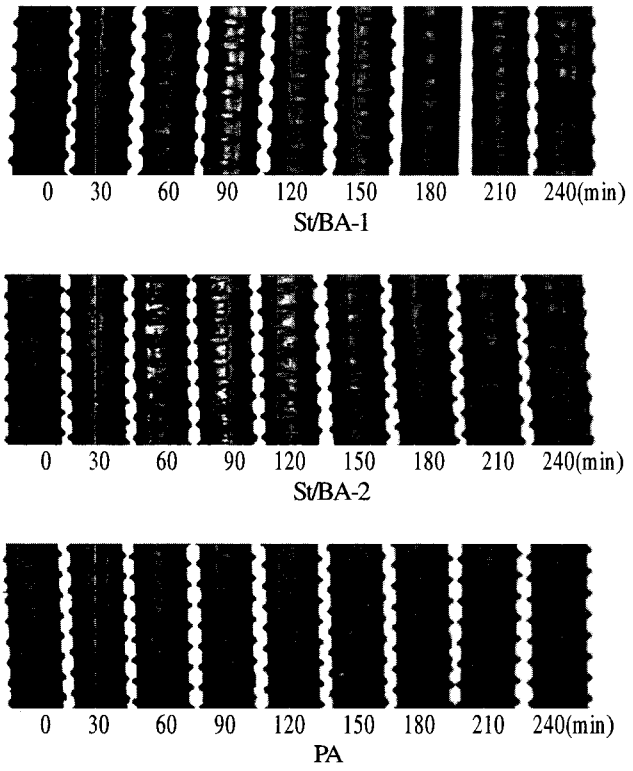

Fig.6 Change of coating thickness of PCS-coated reinforcing bars according to elapsed time

(2) Bend Resistance of PCS-Coated Reinforcing Bars (7days)

The PCS-coated reinforcing bars with St/BA-1-modified have cracks all the conditions on the outside of all angles at 50% polymer-cement ratio, regardless of covering thickness and the number of coating, however, at 100% polymer-cement ratio its covering is good except 250μm's thickness. PCS-coated reinforcing bars with St/BA-2-modified at 50% polymer-cement ratio have cracks except the bend angle of 90°. At 100% polymer-cement ratio, its coating states are fine regardless of covering thickness and coating number, however, the larger its bend angles are, the more detached covering appear, which is easy to fall away by fingers. The PCS-coated reinforcing bars with PA-modified at 100% polymer-cement ratio are undamaged only at its bend angles of 90° and 135°, however, the rest of specimen have cracks on the outside of angles regardless of coating number, bend angles, covering thickness.

(3) Bend Resistance of PCS-Coated Reinforcing Bars (14 days)

The PCS-coated reinforcing bars with St/BA-1-modified at 50% polymer cement ratio have cracks except the condition of 2 coatings. At 100% polymer-cement ratio, its coating states on the both sides of angle part are good, however, the outside of angle detachment and coating damage occur. The PCS-coated reinforcing bars with St/BA-2-modified at 50% polymer-cement ratio have cracks only in the condition of 250μm's thickness and its coating is generally good, but its outside of the hook is detached from bars and easily

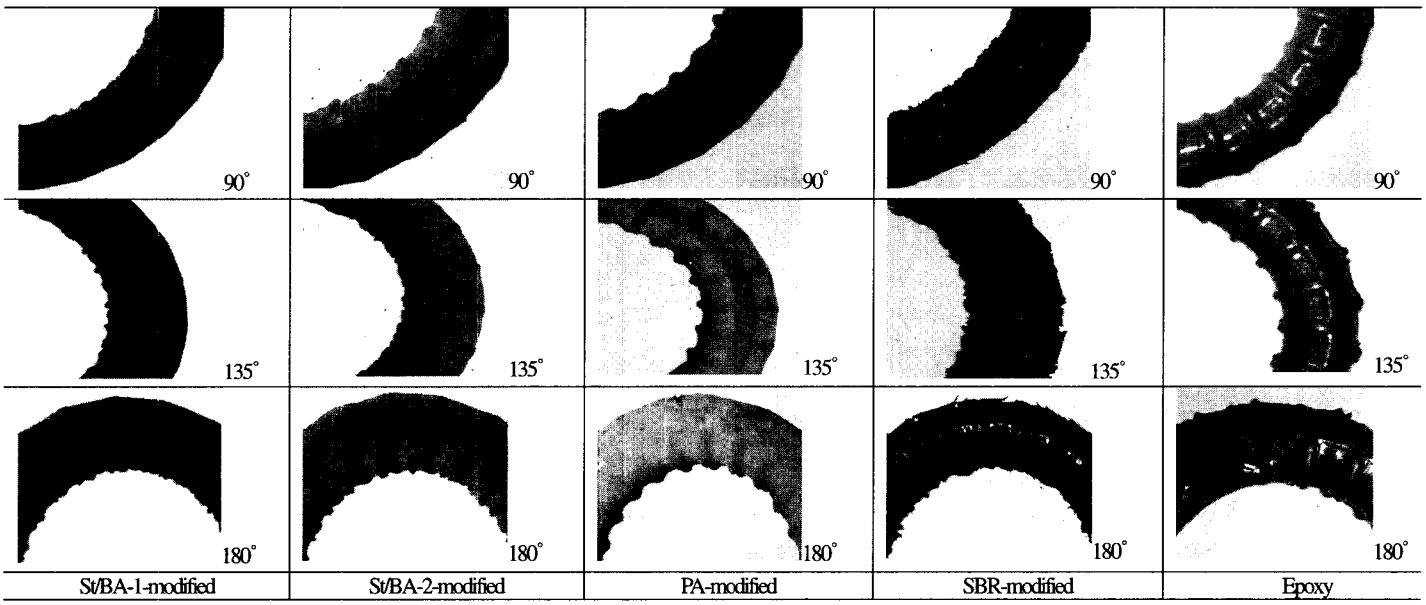

Fig. 7 Bend test results of PCS- coated reinforcing bars

Table 7 Bending test results of PCS-coated reinforcing bars after 3days

Type of slurry	Polymer-cement ratio	Bending angle									Remarks
		90°			135°			180°			
		250 ㎛	450 ㎛	2coating	250 ㎛	450 ㎛	2coating	250 ㎛	450 ㎛	2coating	
St/BA-1	50	△	△	O	×	×	△	×	×	△	
	100	O	O	O	O	O	O	O	O	O	
St/BA-2	50	×	△	O	×	×	△	×	×	△	O : Good △: Moderate × : Bad
	100	×	×	O	×	×	O	×	×	O	
PA	50	×	×	×	×	×	×	×	×	×	
	100	△	O	O	×	△	O	×	△	△	
SBR	50		×			×			×		
	100	×		×	×		×	×		×	

Table 8 Bending test results of PCS-coated reinforcing bars after 7days

Type of slurry	Polymer-cement ratio	Bending angle									Remarks
		90°			135°			180°			
		250 ㎛	450 ㎛	2coating	250 ㎛	450 ㎛	2coating	250 ㎛	450 ㎛	2coating	
St/BA-1	50	×	O	×	×	×	×	×	×	×	
	100	O	O	O	×	O	O	×	O	O	
St/BA-2	50	O	△	O	△	×	△	×	×	×	O : Good △: Moderate × : Bad
	100	O	O	O	△	△	O	△	△	O	
PA	50	×	×	×	×	×	×	×	×	×	
	100	△	O	O	×	△	O	×	△	×	
SBR	50		×			×			×		
	100	×		×	×		×	×		×	

Table 9 Bending test results of PCS-coated reinforcing bars after 14days

Type of slurry	Polymer-cement ratio(%)	Bending angle									Remarks
		90°			135°			180°			
		250 ㎛	450 ㎛	2coating	250 ㎛	450 ㎛	2coating	250 ㎛	450 ㎛	2coating	
St/BA-1	50	×	×	O	×	×	×	×	×	×	
	100	O	O	O	△	O	O	△	O	O	
St/BA-2	50	×	O	O	×	O	O	×	O	△	O : Good △: Moderate × : Bad
	100	△	O	O	O	O	O	△	O	O	
PA	50	×	×	×	×	×	×	×	×	×	
	100	△	O	O	×	O	O	×	O	O	
SBR	50		×			×			×		
	100	×		×	×		×	×		×	

Table 10 Bending test results of PCS-coated reinforcing bars after 28days

Type of slurry	Polymer-cement ratio(%)	Bending angle									Remarks
		90°			135°			180°			
		250 ㎛	450 ㎛	2coating	250 ㎛	450 ㎛	2coating	250 ㎛	450 ㎛	2coating	
St/BA-1	50	△	O	O	△	O	O	△	O	O	
	100	△	O	O	△	O	O	△	O	O	
St/BA-2	50	△	O	O	△	O	O	△	O	O	O : Good △: Moderate × : Bad
	100	△	O	O	△	O	O	△	O	O	
PA	50	×	×	×	×	×	×	×	×	×	
	100	×	×	△	×	×	△	×	×	×	
SBR	50		×			×			×		
	100	×		×	×		×	×		×	

Table 11 Bending test results of epoxy coated reinforcing bars

Type	Bending angle			Remarks
	90°	135°	180°	
Epoxy	△	×	×	O : Good △: Moderate × : Bad

pulled away by fingers. The PCS-coated reinforcing bars with PA-modified at 100% polymer-cement ratio all have cracks and 100% polymer-cement ratio show good coating states on the condition of 450μm and 2 coatings.

(4) Bend Resistance of PCS-Coated Reinforcing Bars (28days)

In case of the PCS-coated reinforcing bars with St/BA-modified, 250μm's thickness and 90° showed suspended coating on the outside of hook part. St/BA-1-modifieid showed less suspended coating than St/BA-2-modified but coatings are good. The PCS-coated reinforcing bars with PA-modified at 100% polymer-cement ratio all show cracks through all experimented angles except 2 coatings.

(5) Bend Resistance of Epoxy-Coated Reinforcing Bars

The epoxy-coated bars have a few fissures at 90° bend and more fissures at 135°, 180°.

4. Conclusions

The conclusions obtained from these results can be summarized as follows:

1) The polymer cement slurries using St/BA and PA emulsions show slowly the change of coating thickness within 90 and 180 minutes respectively. After then, however they give the rapid change of coating thickness.
2) The PCS-coated reinforcing bars have better bend resistance at 100% polymer-cement ratio than 50%, and about coating thickness show superior bend resistance with the depths of 450μm to 250μm.
3) The PCS-coated reinforcing bars in the relation to curing days have more excellent bend resistance at the age of 7, 14 curing days than 3 curing days, especially at 28 curing days its bend resistance is best among all the bars.
4) PCS-coated reinforcing bars with 2 coatings have similar bend resistance to 1 coating.
5) Judging modifiers in the view of bend resistance, St/BA emulsion-1 is supreme among St/BA emulsions. PA emulsion cause generally weak bend resistance but show excellent specimen on the conditions of P/C 100% and 2 coatings.
6) When using cement modifiers as coating materials, St/BA emulsion show better ability of expansion than PA emulsion, SBR and epoxy coated bars.

In conclusion, the bend resistance is more related to elongation than tensile strength of polymer film.

Polymer cement slurry with a polymer-cement ratio of 100%, a coating thickness of 450μm and one coating using St/BA emulsion is selected as a most suitable coating material for coated reinforcing bar.

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