

INVESTIGATION OF CURING PERIOD OF CEMENTITIOUS ADHESIVE AND PERFORMANCE OF RUST PREVENTION

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ABSTRACT: A steel-concrete composite structure needs generally mechanical shear connectors such as headed studs to ensure efficient load resistances. As an alternative to shear studs, a type of cementitious adhesives has been developed to connect a steel-concrete composite structure. The unique feature of this adhesive is the improved bond performance with fresh concrete which depends on the curing age of the adhesive. This paper presents the outcome of fifteen flexural tests of elemental steel-concrete composite beams with various curing ages of the adhesive to investigate the appropriate curing period. Shot blasting steel plate and the un-shot blasting steel plate were prepared to examine the bond performance from the surface condition of the steel plate. The result of the flexural tests indicates that the bond performance between the steel plate and the concrete is optimum when the curing periods are 7 - 14 days. The tests with longer curing age produce similar bond performances with the tests at 7 days. Use of steel plate without shot blasting may be undesirable for the composite structure using the adhesive. In addition to the flexural tests, 8 deformed bars with and without adhesive coating were exposed to a field condition to investigate the rust preventive performance of the adhesive. The deformed bars without the adhesive had already corroded at 5 days after exposure. The observation showed the deformed bar with the adhesive was hardly deteriorated after 200 days.

Keywords: Cementitious adhesive, Curing period, Rust prevention, Flexural test, Field exposure

1. INTRODUCTION

Steel-concrete composite structures are constructed by connecting concrete and steel and have many advantages such as excellent fatigue durability and a reduced member size compared with non-composite sections. The interaction between concrete and steel affects performances (e.g. load carrying capacities, durability, and rigidity) of composite structures. Various shear connectors such as headed studs, channels and T-connectors are currently available.

A new composite structural system using a cementitious adhesive has been developed in previous studies. The adhesive has been used in various structures as rust preventive materials. The previous study reports the composite beam using the adhesive had sufficient load carrying capacity [1] and fatigue durability [2], [3]. Herein, it should be noted that the adhesive needs an appropriate curing term before casting of concrete. According to the previous report [1], the steel substrate sprayed with the adhesive was cured for 2 weeks. However, the curing period was not discussed sufficiently. Therefore, flexural tests using elemental composite beams cured in various terms were performed in order to investigate an appropriate curing period of the adhesive. In addition, the rust prevention performance of the

adhesive was examined using coated bars exposed to a field environment for 200 days.

2. MATERIALS

2.1 Cementitious Adhesive

The carbon-fiber-blended cementitious adhesive developed in Japan consists of compound powder and liquid emulsion, as shown in Fig. 1. Table 1 and Table 2 give the components and properties of the adhesive [4]. The powder and liquid were manually mixed in the laboratory using a portable mixer at a weight ratio of 2.3 (powder/emulsion), as recommended by the manufacturer.



Fig.1 Compound powder (left) and liquid emulsion (right)

Table 1 Components of the adhesive

	Component	Composition
Compound powder	White cement	36%
	Quartz Sand	54%
	Carbon fiber	3%
Liquid emulsion	Additive	7%
	Water	73%
	Acrylic ester	27%
	Additive	<1%

Note: The manufacturer is Mighty-Kagaku [4]

Table 2 Properties of fresh and hardened adhesive

Property	Value
Fluidity	>250 mm
Air permeability	476 cm ³ /m ² (24 h)
	1455 cm ³ /m ² (72 h)
Flexural strength	5.8 MPa (7 days)
	6.9 MPa (28 days)
Compressive strength	21.0 MPa (7 days)
	36.8 MPa (28 days)
Tensile strength	3.1 MPa (7 days)
	4.0 MPa (28 days)
Strain capacity	0.4% (7 days)
	0.4% (28 days)
Drying shrinkage	0.08% (7 days)
	0.13% (28 days)
Water permeability	0.4% (water pressure: 0.1 MPa)

Note: The manufacturer is Mighty-Kagaku [4]

2.2 Concrete

The Japan Bridge Association recommends the use of expansive concrete for the composite slab to prevent cracks due to concrete contraction [5]. Table 3 gives the mixture proportion of the expansive concrete. The compressive strength and splitting tensile strength of concrete were obtained from the tests using the cylindrical specimen (100 mm diameter x 200 mm height). The concrete prisms (100 mm width x 100 mm height x 400 mm length) were used for the flexural strength. Table 4 provides the concrete strength at the age of 7 days.

2.3 Steel Plate and Deformed Bar

Rolled steel for welded structure (Grade SM400A by JIS G3106 [6]) used in flexural tests had a yield strength of 245 MPa with Young's modulus of 200 GPa. The shot blasting steel plate (Type B) and the un-shot blasting steel plate (Type N) were prepared to examine the bond performance with a different surface condition of the steel plate. Fig. 2 shows steel plates used in

this study. The steel plate with shot blasting has a rougher surface than the one without shot blasting, so the surface without shot blasting was shiny, as shown in Fig. 2. Steel plates were 100 mm width x 300 mm length x 3.2 mm thickness. The adhesive after mixing was sprayed on the steel plates by using a spray gun with a nozzle diameter of 4 mm as shown in Fig. 3. The amount of the adhesive sprayed on the steel plates was approximately 1.0 kg/m². The adhesive was sprayed on all steel plates used in flexural tests at once as shown in Fig. 3.

Table 3 Mixture design of expansive concrete

Component	Quantity
Water-binder ratio	48.0%
Water	161 kg/m ³
Ordinary Portland cement	316 kg/m ³
Expansive additive	20 kg/m ³
Fine aggregate	841 kg/m ³
Coarse aggregate	980 kg/m ³
Water-reducing admixture	2.69 kg/m ³

Table 4 Strength of expansive concrete at the age of 7 days

	Strength
Compressive strength	39.1 MPa
Splitting tensile strength	3.30 MPa
Flexural strength	5.58 MPa



(a) Un-shot blasting steel plate



(b) Shot blasting steel plate

Fig.2 Steel plates



Fig.3 Steel plates sprayed with the adhesive
Eight deformed bars with a diameter of 13 mm

were employed for field exposure. All bars (Grade SD345 by JIS G3112 [7]) had a yield strength of 345 MPa with Young's modulus of 200 GPa. Each reinforcing bar was 1940 mm long. The adhesive attached on the deformed bar was approximately 0.83 kg/m². Fig. 4 shows the surface condition of the coated and uncoated deformed bars.



(a) Deformed bar without adhesive coating



(b) Deformed bar with adhesive coating

Fig.4 Surface condition of the deformed bar

3. FLEXURAL TESTS FOR ADHESIVE CURING PERIOD

3.1 Test Detail

To examine the effect of curing time for the adhesive, the flexural test was conducted by using the specimen shown in Fig. 5. The curing periods of the adhesive on steel plates (Type B and Type N) were 2, 7, 14, 28, 140 and 168 days before casting concrete. In addition, the flexural tests using the Type B steel plates cured for 3, 4 and 5 days were also performed to further explore the trend of the failure load at the initial age. After curing of the adhesive to the desired age, concrete was cast. The concrete formwork was removed at the concrete age of 1 day, and the concrete was cured in the water with a temperature of 20 degree Celsius. The side of the steel plate without adhesive was greased in order to prevent the rust during the water curing. The test age for concrete was 7 days for all test cases.

The load by using a universal testing machine was applied statically to the test specimen. The test was a 4-point loading system, as shown in Fig. 5. Two beam specimens were tested at each age. The strain of steel plate was measured at the mid-span of the beam.

3.2 Experimental Results and Discussion

All specimens had a single line cracking due to the bending moment occurred at the loading span

regardless the experimental conditions. After concrete cracking, the steel at the area from the crack to the plate edge debonded from the concrete, as shown in Fig. 6.

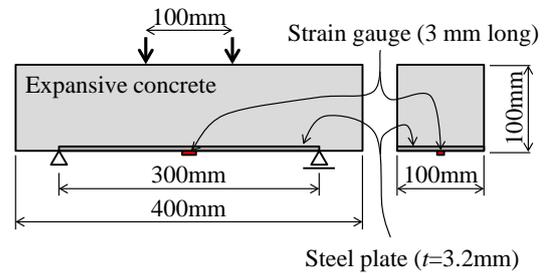


Fig.5 Schematic of specimen and loading condition for flexural test

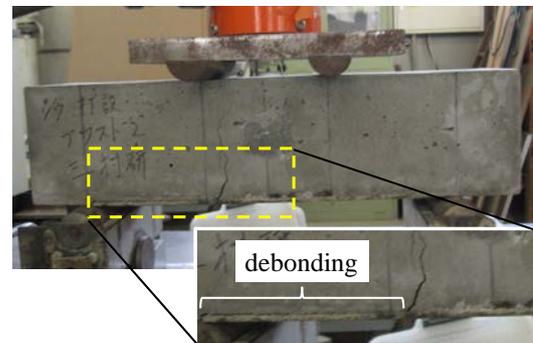


Fig.6 Concrete cracking and debonding of steel plate

Fig. 7 presents the adhesive remaining on the steel plate after flexural test with 7 days curing of the adhesive. Little adhesive remained on un-shot blasting steel plate (Type N) because the un-shot blasting steel plate had a smooth surface. The surface of shot blasting steel plate (Type B) was rougher than Type N, more adhesive remained on Type B steel plate.

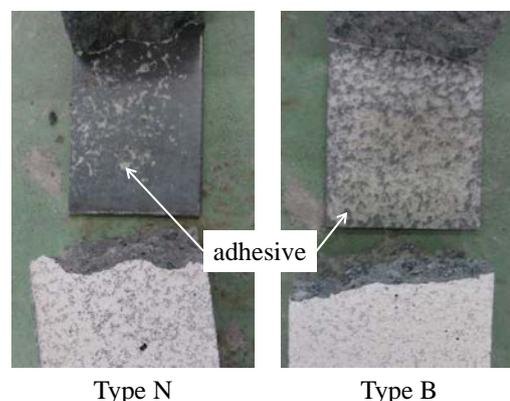


Fig.7 Adhesive remaining on steel plate after test with curing period of 7 days

Fig. 8 presents a ratio of failure load (failure load of elemental composite beam/load carrying capacity of concrete). The ratio of 2 days curing of Type N beams was almost 1.0, the adhesive cured for 2 days hardly had the bond performance with the un-shot blasting steel plate. In the test of Type B, the ratios at 28, 140 and 168 days were approximately equivalent to the ratio at 7 days. This result indicates that the bond performance between the steel plate and the concrete is optimum when the curing periods are 7 - 14 days. This appropriate curing is longer than one of typical adhesive such as epoxy resin. However, some procedures for casting concrete are needed after applying the adhesive, so the curing period of 7 - 14 days can be acceptable in actual construction. The tests with longer curing age, such as 140 or 168 days, produced similar bond performances with the tests at 7 days. A half year curing of the adhesive hardly affects the decrease in load carrying capacity of the composite beam. In the test of Type N, the ratio of the beam with 140 days curing was definitely smaller than the ratio of the one with 7 days curing. Use of steel plate without shot blasting may be undesirable for the composite structure using the adhesive.

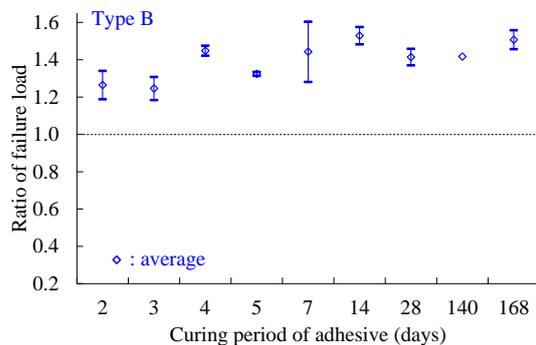
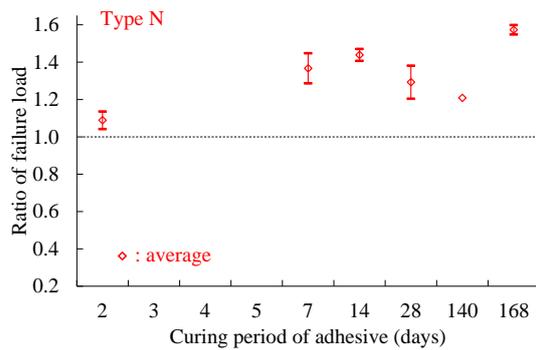


Fig.8 Ratio of failure load

Fig.9 shows the relationship between load and strain of steel plate of Type B at the curing period of 5 days and 7 days. Both strain responses were similar up to the load of around 10 kN. Under the load of more than 10 kN, the strain of steel plate

obtained from the specimen with 5 days curing was smaller than steel strain from the specimen with 7 days curing. Such smaller strain was caused by the released strain due to the slip between concrete and steel plate, as evident in Fig. 6. Higher strain such as the elemental beam with 7 days curing was induced by the development of the bond performance of the adhesive.

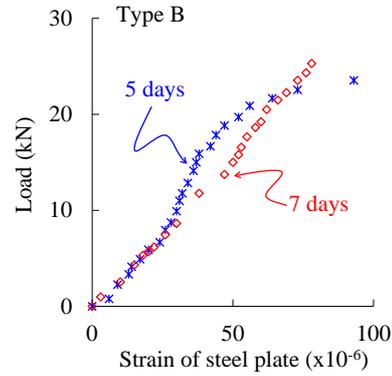


Fig.9 Load - steel strain relationship

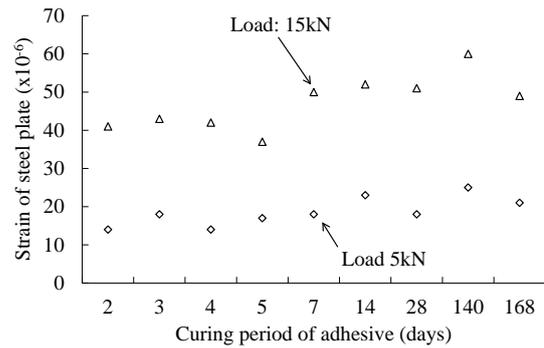


Fig.10 Strain of steel plate at the load of 5 kN and 15 kN (Type B)

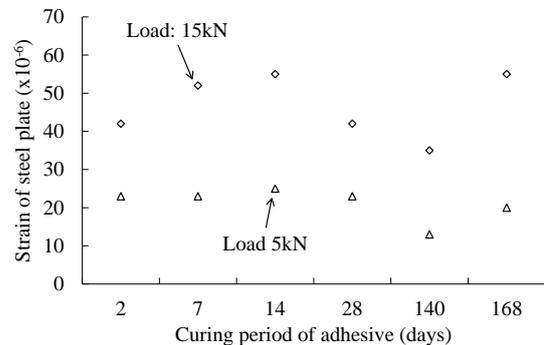


Fig.11 Strain of steel plate at the load of 5 kN and 15 kN (Type N)

Fig. 10 shows the strain of steel plate in Type B at loads of 5 kN and 15 kN. Strains at 5 kN were from 13×10^{-6} to 25×10^{-6} , and almost equivalent

at the ages of 2 - 168 days. At the load of 15 kN, the strains before 5 days and the strains after 7 days were approximately 40×10^{-6} and 50×10^{-6} , respectively. Such smaller strains before 5 days mean a slip between the steel plate and the concrete. This result also indicates that the adhesive needs the curing period of more than 7 days.

The strains of the Type N beams are as shown in Fig. 11. The strain at a load of 15 kN tended to increase until 14 days of curing but decreased at 28 days of curing period, and at 140 days, the strain was less than that at 2 days due to the slip between the steel plate and the adhesive. Such a decrease in strain at these curing days was the same as the transition of the failure load ratio shown in Fig 8.

4. FIELD EXPOSURE OF DEFORMED BARS COATED WITH ADHESIVE

4.1 Test Detail

For applying the adhesive coating to steel bars, a roller and lysing gun can be used. However, with these ways, it is difficult to uniformly apply an appropriate amount of adhesive to the reinforcing bar. Therefore, in this study, a wood formwork with an inner dimension of 50 x 50 x 2000 mm as shown in Fig. 12 was used as a mold to hold the adhesive material inside. Reinforcing bars were then coated by immersing in the adhesive in this wood formwork. In the present test, each rebar was immersed for a few seconds, and after taking it out, it was manually rotated for about 30 minutes so that the adhesive was evenly applied to the rebar.

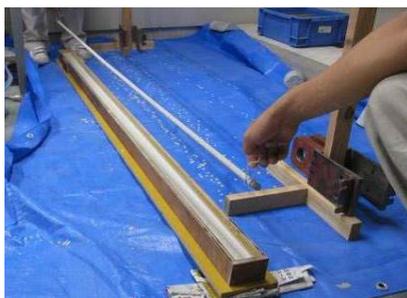


Fig.12 Coating of the adhesive on the deformed bar

Table 5 shows the amount of adhesive applied. As a result of the application, the coating amount was 0.38 kg/m^2 , and the adhesive could be applied only to the extent that a thin film was stretched over the surface of the reinforcing bar. Therefore, after the adhesive cured for around 30 minutes, the adhesive was again applied to the rebar with the same procedure. As a result of measuring the weight of the reinforcing bars after the second

application of the adhesive, as shown in Table 5, the applied amount of the adhesive was 66 g on the average of 4 bars and the average coated amount per unit area was 0.83 kg/m^2 .

Deformed bars were then exposed to a field condition to confirm the rust preventive effect of the adhesive, as shown in Fig. 13. The field exposure was performed at a site located 500 m from the seashore.

Table 5 Weight of the adhesive on the deformed bar

Bar	Bar weight (g)		Adhesive Weight (g)
	before	after	
1	1836	1899	63 (0.79 kg/m^2)
2	1830	1897	67 (0.84 kg/m^2)
3	1827	1892	65 (0.82 kg/m^2)
4	1840	1910	70 (0.88 kg/m^2)
Ave.	1833	1899	66 (0.83 kg/m^2)



Fig.13 Field exposure of the deformed bars

4.2 Experimental Results and Discussion

Fig. 14 shows the corrosion of the deformed bars exposed for 0, 5 and 42 days. The deformed bars without the adhesive had already corroded at 5 days. The rust at 5 days appeared at some lugs and ribs of the deformed bars. After 42 days of exposure, most lugs and ribs had rusted, and the rust had expanded further to other areas of the bar. On the other hands, bars with the adhesive showed no sign of rusting.

Fig. 15 shows the corrosion of the deformed bars exposed for 91, 136 and 200 days. The rust of the deformed bars without the adhesive expanded as exposure continued, and the whole of the bars deteriorated due to the rust when 200 days passed.

The deformed bars coated with the adhesive had some minor rust with the size of approximately 1 mm after 91 days exposure, as shown in Fig. 15. All such rust appeared like a pinhole at the lug which had locally thinner adhesive. The occurrence of this localized rust gradually increased with the increasing exposure period. In this study, although the bars were

rotated until the adhesive hardened roughly, the uniform adhesive was not entirely applied around the lugs of the deformed bars. The application procedure and the amount of the adhesive required on a deformed bar need further studies to prevent the rust at the lug location. However, the local rust did not expand, and even after 200 days from the start of the exposure, the reinforcing bar was sound and no significant corrosion occurred.

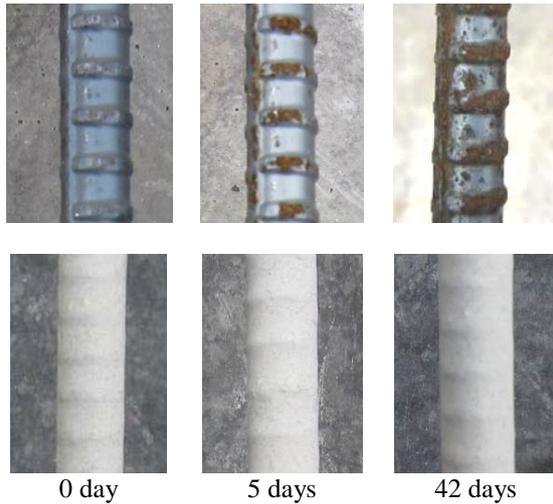


Fig.14 Corrosion of the deformed bar at 0, 5 and 42 days

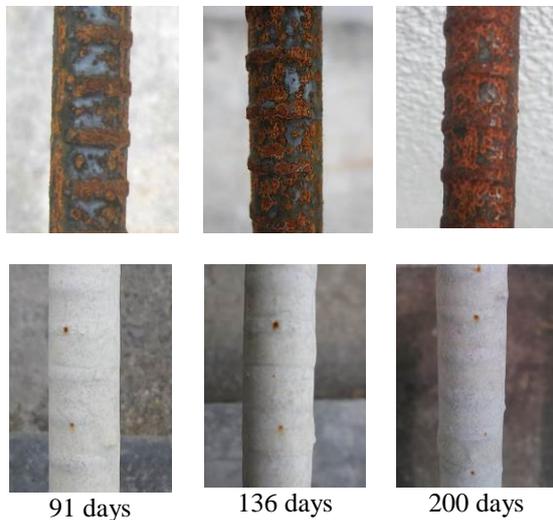


Fig.15 Corrosion of the deformed bar at 91, 136 and 200 days

5. CONCLUSION

This paper presents the investigations of the cementitious adhesive for a steel-concrete composite structure. Flexural tests using the elemental composite beams were conducted to obtain the appropriate curing period of the

adhesive. Field exposure testing of deformed bars coated the adhesive was performed to confirm the rust prevention performance. Based on the test results in this study, it can be concluded as follows:

- (1) The appropriate curing period of the cementitious adhesive can be recommended as 7 - 14 days based on the ratio of failure load and steel strain response obtained from flexural tests. In addition, the adhesive with longer curing age, such as 140 or 168 days has similar bond performances.
- (2) As a result of the field exposure test, the deformed bars without the adhesive had already corroded at 5 days, and the rust covered almost the whole surface area of the bar when 200 days passed. The deformed bar coated with the adhesive was sound and no significant corrosion occurred.

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