Sustainable Solutions in Structural Engineering and Construction
Edited by Chantawarangul, K., Suanpaga, W., Yazdani, S., Vimonsatit, V., and Singh, A.

ISBN: 978-0-9960437-0-0

BOND STRENGTH OF STEEL-CONCRETE COMPOSITE ELEMENTS USING A CEMENTITIOUS ADHESIVE

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Steel-concrete composite slabs have been used for bridge deck construction in Japan because of several advantages, e.g., safety construction and high fatigue durability. On the other hand, these slabs may cause negative influences such as overweight, increasing costs and low constructability, due to many mechanical shear connectors. The quantities of shear connectors may be reduced by gluing steel-plate and concrete with a cementitious adhesive. The present study aims at examining shear bond strength and quantifying the dispersion of the strength. To investigate the dispersion, a double-lap shear test is conducted, in addition to a simple direct shear test, to examine surface treatment. A Monte Carlo Simulation using the Weibull distribution of the strength is performed to evaluate the effect of dispersion. The simulation implies that the shear stress due to the traffic load may be negligible, indicating the applicability of the composite system for highway bridge decks.

Keywords: Steel-concrete composite system, Adhesive, Bond, Simple shear test, Double-lap shear test, Monte Carlo Simulation.

1 INTRODUCTION

Steel-concrete composite slabs are often employed in highway bridges because of rationalization and labor-saving during construction. Most steel-concrete composite slabs use many mechanical shear connectors, e.g., headed studs. The connectors may cause negative influences such as dead load, costs, and constructability. The shear connector is a possible cause of concrete cracking at an early age because it restricts the volume change of concrete. To improve constructability and simplify the connecting structure, a composite-slab system using a cementitious adhesive as alternative shear connectors has been developed in previous studies (Yoshitake *et al*., 2012; 2013). The adhesive has been employed in various structures as an anti-rust material for steel. The adhesive includes much micro-carbon fibers arranged randomly at the concrete interface, gluing strongly to concrete. This paper presents the shear strength of the adhesive, and discusses bond characteristics between the concrete and steel plate.

2 MATERIALS

2.1 Adhesive

The adhesive used in all tests is “Mighty CF”, usually used as a rust preventive, consists of compound powder and liquid emulsion (Mighty-Kagaku 2011). Table 1 gives the properties of the adhesive. The powder and liquid were mixed using a handy mixer, with a ratio of 2.3 by mass. The material mixed with both was sprayable, so preparing the steel plate with the adhesive was relatively easy. The adhesive has a remarkable property that it can bond steel and concrete even after a curing period of approximately 2 weeks. The adhesive also waterproofs and prevents rust.

Table 1. Component and property of the adhesive.

	Component	**Improvement**	**Mass ratio**
Compound powder	White cement	Flexural strength	25%
	Quartz sand	Compressive strength	38%
	Carbon fiber	Tensile strength	2%
	Additive	Bond strength	5%
Liquid emulsion	Water	-	22%
	Acrylic ester	Bond strength	8%
	Additive	High-temperature endurance	<1 %

2.2 Concrete

The Japan Bridge Association recommends the use of expansive concrete for composite slabs of steel bridges to prevent cracks at an early age. Table 2 gives a mixture proportion of expansive concrete used in this study (JBA 2007). The mixture was designed by referring to a mixture proportion of typical composite slab. Table 3 presents fresh and mechanical properties of the concrete. The compressive strength of the concrete was 48.5MPa at the 28 days.

Table 2. Mixture proportion of expansive concrete.

Water-cementitious material ratio (***w*/*cm***)	0.51
Water	161 kg/m^3
Ordinary portland cement	316 kg/m^3
Expansive additive	20 kg/m^3
Fine aggregate	840 kg/m^3
Coarse aggregate	1002 kg/m^3
Water reducing admixture	3.36 kg/m^3

Table 3. Properties of expansive concrete.

Fresh concrete		Hardened concrete at age of 28 days	
Slump	Air	Comp. strength	Young's modulus
7.5cm	4.1%	48.5MPa	36.1GPa

3 THE SIMPLE SHEAR TEST

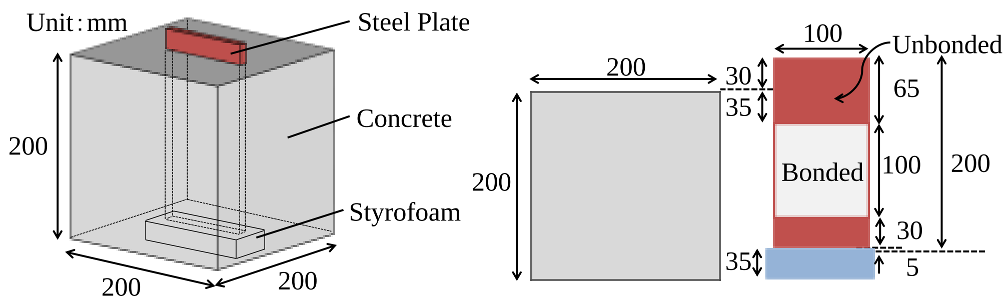

Figure 1. Schematic of specimen.

Table 4. Test parameters.

No.	Surface treatment	Thickness
1	Blast	—
2	Rust preventive agent	75 $x10^{-6}$m
3	Adhesive	280 $x10^{-6}$m
4	Adhesive	560 $x10^{-6}$m
5	Waterproofing	820 $x10^{-6}$m
6	Coating film formation	820 $x10^{-6}$m

3.1 Specimen

Figure 1 shows a schematic of test specimen in the simple shear test. Six kinds of specimen were prepared, and 3 specimens were used in each test. The dimensions of the steel plate were 200 mm L x 100 mm W x 9 mm T. Table 4 gives the surface treatment for the steel plate.

3.2 Test Method of Simple Direct Shear Test

The loading method performed compression-loading statically in the top surface of the steel plate, projecting from specimens as shown in Figure 2. The load was statically increased up to the maximum load. The loading speed was 50kN/min. After loading, specimens were split, and examined for the ratio that the adhesive attached to concrete.

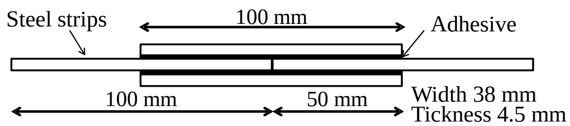

Figure 4. Double-lap shear test.

Figure 5. Specimen.

3.3 Results and Discussion

Figure 3 shows results of shear capacity. The shear capacity of No. 3 of 280 micrometers thick was 1.6 times higher than the strength of No. 1. The observation confirmed the mechanical properties improved by the adhesive. Even if the shear capacity of No. 3 Adhesive (thickness: 280 micrometers) was compared with No. 6 Coating film formation by another other processing method, it is approximately 1.5 times. The result shows the shear-bond capacity was higher than other applications.

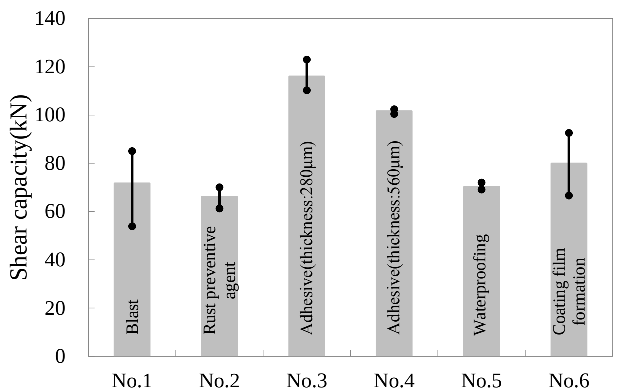

Figure 3. Kinds of surface treatment.

Furthermore, the result confirmed that there was little influence from the film thickness of the adhesive, because the shear capacity of No. 3 is equivalent to the capacity of No. 4. The adhesive glued to the concrete was evaluated by an image analysis using the tested steel plate (No. 3 and No. 4). The bond ratios were 66% and 58%, respectively. The observations emphasize that slip failure occurred between steel and adhesive.

4 DOUBLE-LAP SHEAR TEST

4.1 Specimen

To examine the variation of shear strength, 372 steel strips with dimensions of 100 mm L x 38 mm W x 4.5mm T were prepared for the double-lap shear test (Kim et al. 2013). The surface of the steel plate was treated by a mechanical grinder to improve bond performance. A schematic of the test and specimen are presented in Figure 4 and Figure 5, respectively. The bond thickness was controlled as 500 micrometers by using a spacer. All specimens were cured for at least 2 weeks at room temperature prior to the test. 93 specimens were prepared to examine the variation of shear strength.

4.2 Results and Discussion

The test result indicates the shear strengths are in the range of 0.80 to 1.80 MPa. Figure 6 shows the shear strength variation agrees well with the Weibull distribution function. The accuracy of the distribution was confirmed by using Kolmogorov-Smirnov official approval (K-S official approval). The test results and maximum D_{max} of the difference with the Weibull distribution function was 0.102, and the rejection limit $D_{n\alpha}$ provided from 5% of levels of significance with 93 specimens numbers was 0.141.

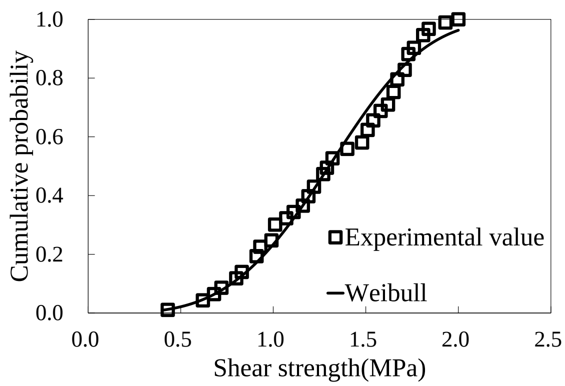

Figure 6. Weibull distribution.

4.3 Finite Element (FE) Simulation

An FE simulation was performed to quantify the shear stress between steel and concrete. Figure 7 shows the dimensions of bridge deck slab and FE modeling, respectively. The composite slab model was based on a typical twin-girder bridge with 2 traffic lane. To simplify the model, the slab thickness was assumed to be 260mm. As for Japanese specifications, the applied load (*T*-load: 200mm x 500mm of 100 kN) was used.

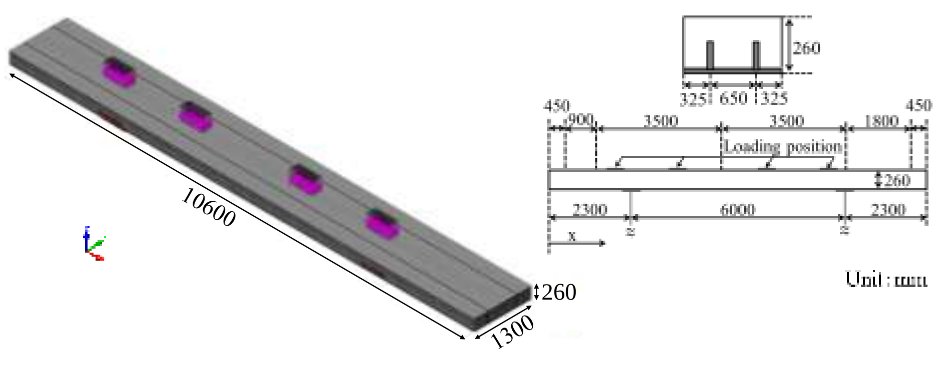

Figure 7. FE model of composite beam with adhesive.

4.4 Probabilistic Considerations

The shear strength was randomly distributed to 213 elements using a Weibull distribution and Monte Carlo simulation. Figure 8 shows the ratio of shear stress and shear strength. In the event of 1.0 or higher, shear failure may occur between steel and adhesive. The comparative result indicated the maximum ratio of 0.36, with possibility of failure negligible. The result confirmed that the composite system had little shear failure, and the system may be applicable for twin-girder bridges assumed in the study.

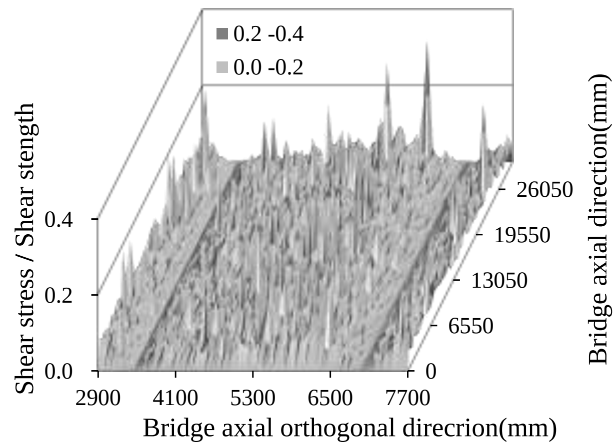

Figure 8. Ratio of shear strength and shear stress.

5 SUMMARY

This paper describes the simple direct shear test and double-lap shear test of new composite slab using a cementitious adhesive. The shear capacity of specimen with the adhesive was 160% greater than the strength of the specimen without the adhesive. The shear strength varies in the range of 0.80-1.80 MPa, agreeing well with a Weibull distribution. Applicability of the composite system was confirmed by comparing it with the Monte Carlo simulation using the distribution and FE numerical analysis.

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