II. TEST METHODS FOR CONTINUOUS FIBER SHEETS

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CONTENTS

INTRODUCTION

Nine test methods are proposed to determine the properties of continuous fiber sheets for upgrading concrete structures.

(1) Test method for tensile properties of continuous fiber sheets
(JSCE-E 541-2000)
(2) Test method for overlap splice strength of continuous fiber sheets
(JSCE-E 542-2000)
(3) Test method for bond properties of continuous fiber sheets to concrete
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(8) Test method for freeze-thaw resistance of continuous fiber sheets
(JSCE-E 548-2000)
(9) Test method for water, acid and alkali resistance of continuous fiber sheets
(JSCE-E 549-2000)

These test methods are finalized by referring to the Japan Industrial Standards (JIS), the codes and specifications of the Japan Society of Civil Engineers, the test methods proposed by the research committee of the Japan Concrete Institute, the test methods used in the recommendations road and railway structures, as well as research reports research both at home and abroad. For each test method, an effort was made for it to be implemented as easily and rationally as possible for the objectives of the test. As the continuous fiber sheets used in each of the test methods shown here are generally of the same shape regardless of the materials, the methods of fabricating the test specimens have also been noted in as much detail as possible. In the review process, the preparation of other test methods was also considered, but it was decided to adopt the ones listed above after consideration of the present state of testing machines and equipment. However, test methods noted in existing research reports, etc. that should be referred to are listed separately under "Reference Test Methods."

To maintain compatibility with existing codes and specifications of the Japan Society of Civil Engineers, the same format is used: Introduction, Scope, Normative Reference, Definitions, Test specimens, Testing Machine, Test Method, Calculation and Expression of Test Results, and Report. In addition, the nature of and applicable methods, etc. for each test method can be generally categorized as follows:

a) Test methods for continuous fiber sheets as a material: (1), (2), (6), (7), (8), and (9)
b) Test methods for continuous fiber sheets as a composite material with concrete or steel: (3), (4), and (5)
c) Items directly referenced in the Recommendations for Upgrading of Concrete Structures with Use of Continuous Fiber Sheets: (1), (2), (3), (5), and (6)

In this document, two or more test methods are introduced as references:

“Test Method for Flexural Tensile Strength of Continuous Fiber Sheet (Draft)”

“Test Method for Surface Incombustibility of Protective Materials for Continuous Fiber Sheets (Draft)”

These two are not yet authorized, but may be useful for practical evaluation of the sheets.

1. TEST METHOD FOR TENSILE PROPERTIES OF CONTINUOUS FIBER SHEETS (JSCE-E 541-2000)

1. Scope

This specification describes the test method for tensile properties of continuous fiber sheets used for upgrading of concrete members.

2. Normative Reference

The following standards, by being referenced herein, form a portion of these specifications. The most recent version of each standard should be used.

JIS K 7100	Plastics-standard atmospheres for conditioning and testing
JIS B 7721	Verification of the force measuring system of the tensile testing machine
JIS Z 8401	Guide to the significant digits

3. Definitions

The following are the definitions of the major terms used in this specification in addition to the terms used in the "Recommendations for Upgrading of Concrete Structures with Use of Continuous Fiber Sheets" published by the Japan Society of Civil Engineers.

a) Test portion
    The part of a test specimen that is in between the anchoring portions and is subjected to testing

b) Anchoring portion
    The end parts of a test specimen where the anchorage is fitted to transmit loads from the testing machine to the test portion

c) Tab
    A plate made of fiber-reinforced plastic, aluminum or other material that is bonded to the test specimen to transmit loads from the testing machine to the test portion

d) Plate

The plate made of continuous fiber sheet impregnated with resin from which the test specimens are cut

e) Tensile capacity

The tensile load at the time that the test specimen fractures

f) Ultimate strain

The strain corresponding to the tensile capacity

g) Fiber bundle

Several fiber filaments bound together to form a bundle

h) Fiber mass per unit area

The fiber mass of continuous fiber sheets in the reinforced direction only, expressed as mass per square meter of the continuous fiber sheet before resin impregnation

i) Conditioning

The storage of test specimens at a prescribed temperature and humidity to keep them under identical condition before testing

4. Test specimens

4.1 Types and dimensions

Two types of test specimens may be used as described below.

a) Type A test specimen

Type A test specimens shall be manufactured in accordance with the method described in Section 4.2.1 and shall be used for a general tension test. The shape and dimensions of Type A test specimens are shown in Figure 1 and Table 1, respectively.

b) Type B test specimen

Type B test specimens shall be manufactured in accordance with the method described in Section 4.2.2. These test specimens have a greater fiber mass per unit area and shall be used for continuous fiber sheets that can be separated by individual fiber bundles. The shape and dimensions of Type B test specimens are shown in Figure 1 and Table 1, respectively.

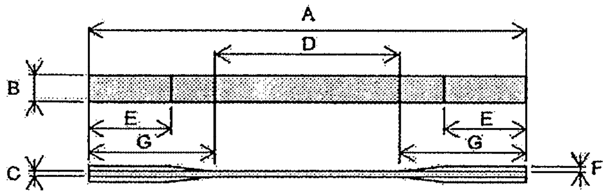

Figure 1 Shape of test specimens (Type A and Type B)

Table 1 Dimensions of test specimens (unit: mm)

Type of test specimen	Type A	Type B
A Total length	200 min.	
B Width at both ends	12.5 ±0.5	10-15
C Thickness	2.5 max.	
D Gauge length	100 min.	
E Anchoring portion length	35 min.	
F Anchorage thickness	1-2	
G Anchorage length	50 min.	

4.2 Preparation

4.2.1 Type A test specimens

Type A test specimens shall be prepared using the following method.

a) Prepare a continuous fiber sheet cut to a sufficient length for the test specimen.
b) Apply the bottom coat of impregnation resin to the separation film and attach the aforementioned sheet, fastening it so that the fiber axis of the sheet is in a straight line.
c) Apply the top coat of impregnation resin. Then smooth the surface, so that the thickness of the impregnation resin layer is even, to form a plate. Covering with separation film and smoothing would be best.
d) Cure the plate for the prescribed amount of time, then cut in widths of 12.5 mm as shown in Figure 2. The cut length should be at least 200 mm. Use a diamond cutter for cutting.
e) Attach the anchorages to the anchorage portions to form the test specimens.
f) Before testing, condition the test specimens as prescribed.

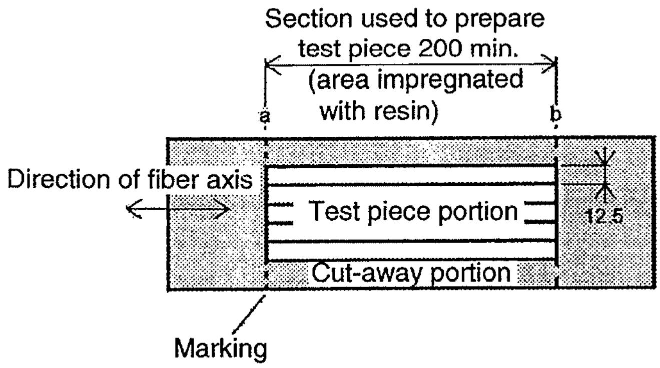

Figure 2 Dimensions of plate used to prepare Type A test specimens (unit: mm)

4.2.2 Type B test specimens

Type B test specimens shall be prepared using the following method.

a) Prepare a continuous fiber sheet cut to a sufficient length for the test specimen. Fasten the sheet so that the fiber axis is in a straight line.
b) In the center of the fastened sheet, mark two straight lines (a and b in Figure 3) perpendicular to the fiber axis that define a length of at least 200 mm. Mark two other straight lines (c and d in Figure 3) approximately 100 mm on either side of the area defined by lines a and b.
c) Working along the fiber axis between lines c and d, remove 1-3 fiber bundles from each side of the sections that are to be the test specimens. The width measures 10-15 mm. When preparing several test specimens from the same continuous fiber sheet, the portions to be used as test specimens should be separated by intervals of at least 50 mm in the direction perpendicular to the fiber axis.

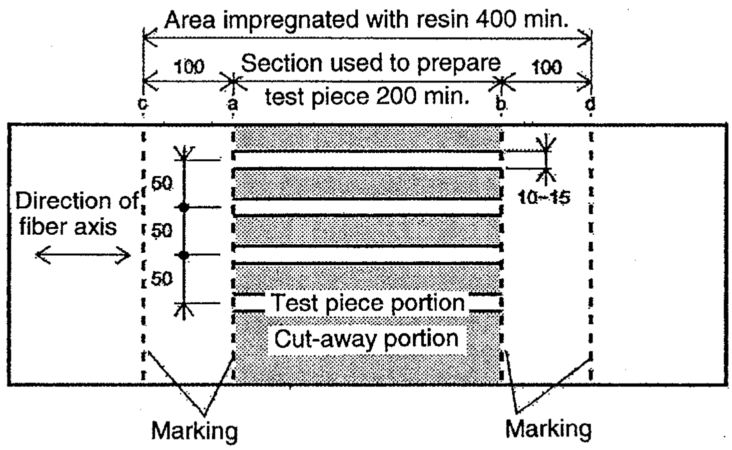

Figure 3 Dimensions of plate used to prepare Type B test specimens (unit: mm)

d) Apply the bottom coat of impregnation resin to the separation film and attach the aforementioned sheet onto the film.
e) Apply the top coat of impregnation resin. Then smooth the surface, so that the thickness of the impregnation resin layer is even, to form a plate. Covering with separation film and smoothing would be best.
f) Cure the plate for the prescribed amount of time, then cut the fiber bundle portions that are to be the test specimens at widths of 10-15 mm. The cut length should be at least 200 mm.
g) Attach the anchorages to the anchorage portions to form the test specimens.
h) Before testing, condition the test specimens as prescribed.

4.3 Curing the test specimen

A curing interval needed to give the test specimen the desired strength shall be established and the test specimen cured.[1]

4.4 Anchorage portion of test specimen

The anchorage portion of the test specimen shall not be of a shape causes the test specimen to twist or bend. An anchorage made of fiber-reinforced polymer or aluminum shall be attached to the anchorage portion using resin or adhesive at a suitable pressure so that the thickness of the adhesive layer is constant. The adhesive or resin must ensure that the adhesive layer does not experience shear fracture before the test specimen breaks.

4.5 Conditioning of test specimen

As a rule, test specimens shall be conditioned for at least 48 hours before testing in a Class 2 standard atmosphere (temperature 23 ±2°C and humidity 50 ±10%) as described in JIS K 7100.

4.6 Number of test specimens

A number of test specimens suitable for the objective of test shall be determined. However, there shall be no fewer than five test specimens

[1] The curing interval may generally be about one week.

5. Testing Machine and Measuring Devices

5.1 Testing machine

The testing machine shall conform to JIS B 7721 (Verification of the force measuring system of the tensile testing machine). The testing machine shall have a loading capacity in excess of the tensile capacity of the test specimen and shall be capable of applying loading at the required loading rate.

5.2 Strain gauges

The strain gauges shall be capable of recording all variations in gauge length or elongation during testing with an accuracy of not less than 10×10^{-6}.

6. Test Method

6.1 Dimensions of test specimens

The width and thickness of the test portion of the test specimens shall be measured as follows at three locations including the center.

Type A test specimens shall be measured to 0.01 mm.
Type B test specimens shall be measured to 0.1 mm.

6.2 Mounting the strain gauges

The strain gauges shall be properly mounted in the center of the test portion of the test specimen in order to determine the Young's modulus and ultimate strain of the test specimen.

6.3 Mounting the test specimen

The test specimen shall be set so that the longer axis of the test specimen coincides with the center line between the two chucks.

6.4 Loading rate

The standard loading rate shall be a constant strain rate equivalent to 1-3% strain per minute.

6.5 Test temperature

The test temperature shall be 20 ±5°C. However, if the test specimen is not sensitive to changes in temperature, the test may be conducted at a temperature of 5-35°C. When the specimen is to be used under special work conditions or in special environments, these shall be taken into consideration when determining the test temperature.

6.6 Scope of test

The loading test shall be performed until tensile failure, and measurements of load and strain shall be made and recorded continuously or at regular intervals until tensile capacity is reached.

7. Calculation and Expression of Test Results

7.1 Handling of data

The test data shall be assessed on the basis only of test specimens undergoing failure in the test portion. In cases where tensile failure or slippage has clearly taken place at the anchorage portion, the data shall be disregarded and additional tests shall be performed using test specimens from the same lot until the number of test specimens experiencing failure in the test portion is not less than the prescribed number.

7.2 Load-strain curve

When strain gauges are mounted, a load-strain curve depicting the relationship between the measured load and strain shall be derived.

7.3 Tensile strength

The tensile strength f_{fu} shall be calculated using Eq. (1) and rounded off to three significant digits in accordance with JIS Z 8401.

$$f_{fu} = \frac{F_u}{A} \quad \text{..........} \quad (1)$$

where

f_{fu} : tensile strength (N/mm^2)

F_u : tensile capacity (N)

A : nominal cross-sectional area of a test specimen (mm^2)

The cross-sectional area A of the test specimen shall be calculated using Eq. (2).

$$A = \begin{cases} \dfrac{w}{\rho} \cdot b_t \text{ (for Type A test piece)} \\ \dfrac{w}{\rho} \cdot \dfrac{N_t}{n_u} \text{ (for Type B test piece)} \end{cases} \quad \cdots\cdots (2)$$

where

w : fiber mass of continuous fiber sheet (g/mm^2)[2]

ρ : Density of continuous fiber sheet (g/mm^3) [3]

b_t : Minimum width of test specimen (mm)

N_t : Number of fiber bundles in test specimen

n_u : Number of fiber bundles per unit area of the continuous fiber sheet (strands / mm)

7.4 Young's modulus

Young's modulus E_f shall be calculated using Eq. (3) based on the load difference between 20% and 60% of tensile capacity of the load-strain curve, and rounded off to three significant digits in accordance with JIS Z 8401.

$$E_f = \frac{\Delta F}{\Delta \varepsilon \cdot A} \quad \cdots\cdots (3)$$

where

E_f : Young's modulus

ΔF : Difference between loads at two points at 20% and 60% of tensile capacity (N)

$\Delta \varepsilon$: Difference in strain between the two points above

A : Nominal cross-sectional area of a test specimen

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[2] Nominal fiber mass provided by material manufacturer may be used.

[3] Density provided by material manufacturer may be used.

7.5 Ultimate strain

Ultimate strain ε_{fu} is the strain corresponding to the tensile capacity F_u when strain gauge measurements of the test specimen are available up to failure. If measurements could not be made until failure, ultimate strain shall be calculated from the tensile capacity F_u and the relationship between the simultaneously measured maximum tensile load F_{last} and strain $\varepsilon_{\mathrm{last}}$, using Eq. (4), and rounded off to three significant digits in accordance with JIS Z 8401.

$$\varepsilon_{fu} = \varepsilon_{last} \cdot \frac{F_u}{F_{last}} \quad \text{.......} (4)$$

where

ε_{fu} : ultimate strain

8. Report

The report shall include the following items:

a) Name of continuous fiber sheet
b) Type of continuous fiber sheet and impregnation resin
c) Fiber mass per unit area and density of continuous fiber sheet
d) Fabrication date, fabrication method and curing interval for test specimens
e) Temperature, humidity and duration of test specimen conditioning
f) Test date, test temperature and loading rate
g) Shape and dimensions of each test specimen and calculated cross-sectional area
h) Tensile capacity of each test specimen and average and standard deviation for these values
i) Tensile strength of each test specimen and average and standard deviation for these values
j) Young's modulus of each test specimen and average and standard deviation for these values
k) Ultimate strain of each test specimen and average and standard deviation for these values
l) Load-strain curve for each test specimen

COMMENTARY ON TEST METHOD FOR TENSILE PROPERTIES OF CONTINUOUS FIBER SHEETS

Introduction

The test method for the tensile properties of continuous fiber sheets is established based on JIS K 7073 "Test method for tensile properties of carbon fiber reinforced plastic" and after reference to the test methods specified in the Guidelines for Seismic Retrofit Design and Construction of Railway Viaduct Piers Using Carbon Fiber Sheets of the Railway Technical Research Institute , Report (II) "Test method for tensile properties of continuous fiber sheets " of the Technical Committee on Continuous Fiber Reinforced Concrete Structures of the Japan Concrete Institute, and the activities of ACI 440 K.

This draft is proposed based on existing test results and covers carbon fiber sheets and aramid fiber sheets as test specimens, but it can be applied to other continuous fiber sheets as well.

1. Scope

The test specimens defined in the Test Method for Tensile Properties of Continuous Fiber Sheets are continuous fiber sheets in which the continuous fiber used to upgrade concrete members and the adhesive (impregnation resin) exhibit a monolithic mechanical behavior, and in which a single layer is used.

The test method is established mainly for carbon fiber or aramid fiber sheets, but this method may be applied to other materials if they are used in the same manner.

Tests of the tensile properties of continuous fiber strands shall be in accordance with those noted in JIS R 7601 "Testing methods for carbon fibers."

2. Normative Reference

Only the standards directly referred to in the Test Method for Tensile Properties of Continuous Fiber Sheets and forming a portion of this specification are enumerated.

3. Definitions

Among the terms used in the specification, "fiber mass per unit area" is needed to determine the cross-sectional area for calculating the tensile strength. A resin-impregnated continuous fiber plate is often used in the curing process of the test specimens, and so this is defined as "plate." "Conditioning" is defined by consulting JIS K 7100 as a reference.

4. Test specimens

4.1

The test specimens are divided into two types based on the differences in their methods of fabrication. The finished dimensions of these two types of test specimen are the same with the exception of the widths.

The Type A test specimen has the same dimensions, with the exception of thickness, as the Type I test specimen established in JIS K 7073 "Test method for tensile properties of carbon fiber reinforced plastic" which has been applied mutatis mutandis to tests of the tensile properties of continuous fiber sheets. In general, this Type A test specimen can be used for carbon fiber sheets. The Type B test specimen applies to aramid fiber sheets in particular; it has a high fiber mass per unit area and thick fiber bundles and is used for tensile test specimens made of continuous fiber sheets that can be separated by individual fiber bundles. The reason for using the Type B test specimen is to eliminate the large variations in the data for tensile strength and Young's modulus that may result if a portion of the fiber bundle is accidentally cut when fabricating the Type A test specimen from the aforementioned continuous fiber sheets.

A test specimen width of approximately 25 mm was at first considered, referring to the Type II test specimen in JIS K 7073, but finally the following widths are specified in this specification: 12.5 mm for the Type A test specimen and 10-15 mm (primarily 12.5 mm) for the Type B test specimen. This is due to the considerations of the results of past tensile property tests of continuous fiber sheets, the capacity of the testing machine being used, the uniformity of the tensile force applied to the fibers in the test specimen. If a tensile force can be uniformly applied to the fibers, a wider test specimen generally tends to minimize variations in strength; however, the wider the test specimen, the harder it is to apply tensile force uniformly to the fibers in the test specimen. If a tensile force cannot be uniformly applied, strength becomes low and variations increase. In addition, within the range of fiber mass currently being used, the 12.5 mm width is adequate to enable the test to be performed.

4.2

Since the preparation method of test specimens greatly affects the characteristic values for tensile strength, it is necessary to be fully aware of it and prepare the test specimens correctly and measure the dimensions accurately.

Type A test specimens should be prepared by applying impregnation resin directly to the continuous fiber sheet, forming a plate, and then curing the plate and cutting the test specimens from it. When cutting, be careful not to cut the continuous fiber sheet diagonally.

Type B test specimens should be prepared by removing unneeded portions of the fiber bundles in advance and adjusting the number of fiber bundles within the test specimen. This process enables accurate data to be obtained.

4.3 and 4.5

Leaving the test specimens in a controlled environment with constant temperature and humidity for a period of time necessary for their strength to be manifested is referred to as "curing." In this test method, curing is distinguished from "conditioning," the process of leaving the test specimens in a standard atmosphere for a set period just before the test is performed. However, if the curing environment is the same as the conditioning environment (atmosphere), the conditioning period may be included in the curing period.

5. Testing Machine and Measuring Devices

Only general items relating to the testing machine and fundamental items relating to the performance of the strain gauges are established.

6. Test Method

6.1

In general, continuous fiber sheets have high tensile strength. Since with Type A test specimens the difference in the width greatly affects the results, the measurement accuracy is set at 0.01 mm. For Type B test specimens, the width of the test specimens itself is treated as a reference value, so the accuracy is set at 0.1 mm.

6.2

Use strain gauges when measuring Young's modulus and ultimate strain. If only tensile strength is to be derived, the strain gauges need not be mounted.

When mounting the strain gauges, it is necessary to ensure that they are attached correctly with respect to the force direction without damaging the test specimen. The thickness of the test specimen is small compared to the length, so the strain gauges need only be mounted on one side of the test specimen. However, if the thickness of the test specimen is comparatively large, or if it may be affected by bending, strain gauges should be mounted on both sides.

6.4

When a testing machine with a strain control method is used, through consideration of past results and to avoid subjecting the test specimen to impacts, etc., the standard loading rate is a fixed strain rate equivalent to 1-3% strain per minute. If a testing machine with a load control method is used, a loading rate equivalent to the strain rate multiplied by Young's modulus should be used. With carbon or aramid fiber sheets, the standard loading rate may be such that corresponds to a stress of 500-2,500 N/mm^2 per minute.

7. Calculation and Expression of Test Results

7.3

A number of methods can be considered for deriving the cross-sectional area used to calculate the tensile strength from the tensile capacity of test specimens. Here, the adopted method for calculation is to use the fiber mass per unit area based on the mass of the continuous fiber sheet before resin impregnation. In general, the nominal fiber mass per unit area values shown in Table C1 or the values indicated in quality assurance documentation (mill sheets) may be used for fiber mass per unit area *w*. The difference between these nominal fiber mass per unit area and the actual fiber mass per unit area is generally no more than 2-5%, so the error is small.

The value derived by dividing the fiber mass per unit area *w* by the density ρ is sometimes specified by material manufacturers as the nominal thickness *t*. This value may also be used.

Table C1 Nominal fiber mass per unit area of continuous fiber sheets (carbon and aramid fibers)

Fiber sheet	Name	Nominal fiber mass per unit area (g/m^2)	Density (g/cm^3)
Carbon fiber	C245-200	200	1.80
	C245-300	300	1.80
	C390-300		1.82
	C440-300		1.84
	C540-300		2.10
	C640-300		2.10
	C245-400	400	1.80
Aramid fiber (I)	A120-280	280	1.45
	A120-415	415	
	A120-625	623	
	A120-830	830	
Aramid fiber (II)	A080-235	235	1.39
	A080-350	350	
	A080-525	525	
	A080-700	700	

Note: Aramid fiber (I) refers to all **aromatic polyamide fibers**. Aramid fiber (II) refers to **aromatic polyetheramide fibers**.

When the nominal fiber mass per unit area cannot be obtained from the quality assurance documentation or the like, measurements may be performed in accordance with the relevant sections of JIS R 7601 "Testing methods for carbon fibers" and the nominal fiber mass per unit area derived with Eq. C1 below.

$$w = \frac{W - (w_w + w_l + w_r)}{B \times L} \quad \text{...(C1)}$$

where

w	:	Fiber mass per unit area
W	:	Test specimen mass (not including impregnation resin)
B	:	Average test specimen width
L	:	Average test specimen length
w_w	:	Moisture content
w_t	:	**Weft fiber mass per unit area**
w_r	:	Other (preimpregnation resin, etc.)

8. Reports

The standard items needed to report the results of tests of the tensile properties of continuous fiber sheets are established. Other items needed to judge test results should also be noted.

2. TEST METHOD FOR OVERLAP SPLICE STRENGTH OF CONTINUOUS FIBER SHEETS (JSCE-E 542-2000)

1. Scope

This specification describes the test method for the overlap splice strength of continuous fiber sheets used for upgrading of concrete members.

2. Normative Reference

The following standards, by being referenced herein, form a portion of these specifications. The most recent version of each standard should be used.

JSCE-E 541	Test method for tensile properties of continuous fiber sheets
JIS K 7100	Plastics-standard atmospheres for conditioning and testing
JIS B 7721	Verification of the force measuring system of the tensile testing machine
JIS Z 8401	Guide to the significant digits

3. Definitions

The following are the definitions of the major terms used in this specification in addition to the terms used in the "Recommendations for Upgrading of Concrete Structures with Use of Continuous Fiber Sheets" published by the Japan Society of Civil Engineers and JSCE-E 541.

a) Overlap splice portion

The center of the test portion where the continuous fiber sheets are overlapped and spliced

4. Test specimens

4.1 Types and dimensions

The shape and dimensions of the overlap splice test specimen are shown in Figure 1 and Table 1, respectively. The method of preparing test specimens conforms to Section 4.2 "Preparation" in JSCE-E 541.

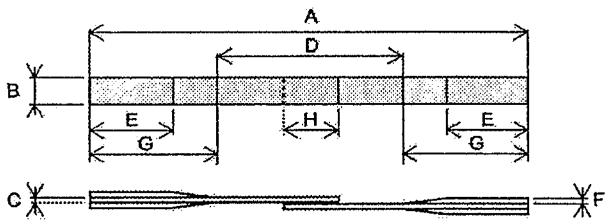

Figure 1 Shape of test specimens (Type A and Type B)

Table 1 Dimensions of test specimens (unit: mm)

Type of test specimen	Type A	Type B
A Total length	200 min.	
B Width at both ends	12.5 ±0.5	10-15
C Thickness	2.5 max.	
D Gauge length	Length of overlap splice + 100 min.	
E Anchoring portion length	35 min.	
F Anchorage thickness	1-2	
G Anchorage length	50 min.	
H Length of overlap splice portion	Necessary length	

4.2 Preparation

As a rule, test specimens shall be prepared using the same materials as those in the actual work and under constant temperature conditions. Sufficient care must be taken to ensure that fibers are not dispersed or bent in the overlap splice portion.

4.2.1 Type A test specimen

Type A test specimens are prepared by the following method.

a) Prepare a continuous fiber sheet cut to a sufficient length for the dimensions of the test specimen to be fabricated.

b) Apply the bottom coat of impregnation resin to the separation film and attach the aforementioned sheet, fastening it so that that the fiber axis of the sheet is in a straight line.
c) Overlap two sheets so that the prescribed overlap splice portion length is secured.
d) Apply the top coat of impregnation resin. Smooth the surface. Then thickness of the impregnation resin layer is even for a plate. Covering with separation film would be best.
e) Cure the plate for the prescribed period of time, then cut in widths of 12.5 mm as shown in Figure 2. The cut length should be at least 200 mm. Use a diamond cutter.
f) Attach the anchorage to the anchorage portion to form the test specimen.
g) Before performing the test, condition the test specimen as prescribed.

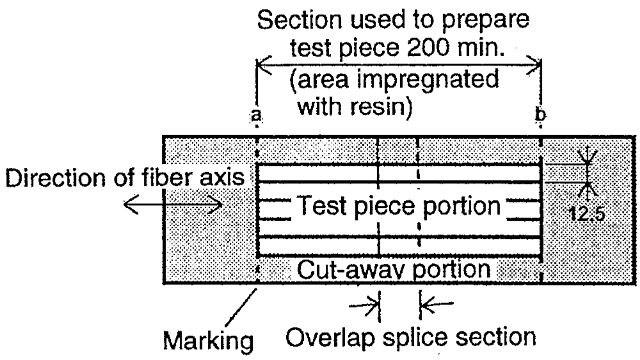

Figure 2 Dimensions of plate used to make Type A test specimens (unit: mm)

4.2.2 Type B test specimens

Type B test specimens are prepared by the following method.

a) Prepare a continuous fiber sheet cut to a sufficient length for the test specimen to be fabricated. Fasten the sheet so that the fiber axis is in a straight line.
b) In the center of the fastened sheet, mark two straight lines (a and b in Figure 3) perpendicular to the fiber axis that define a length of at least 200 mm. Mark two other straight lines (c and d in Figure 3) approximately 100 mm on either side of the area defined by lines a and b.
c) Along the fiber axis between lines c and d, remove 1-3 fiber bundles from each side of the portions so that the width measures 10-15 mm. When preparing several test specimens from the same continuous fiber sheet, the portions to be

used as test specimens should be separated by intervals of at least 50 mm in the direction perpendicular to the fiber axis. In such cases, cut along the marking on one side.

d) Apply the bottom coat of impregnation resin to the separation film and attach the aforementioned sheet to the film. The fiber bundles should be aligned in the fiber axis direction.

e) Apply impregnation resin to the top of the sheet and the overlap portion of the sheet. Then, checking the markings and making sure that the top and bottom sheets are positioned correctly, attach the sheets so that an overlap splice portion of the prescribed length is secured. The fiber bundles should be arranged in the fiber axis direction.

f) Apply the top coat of impregnation resin. Then smooth the surface so that the thickness of the impregnation resin layer is even, to form a plate. Covering with separation film would be best.

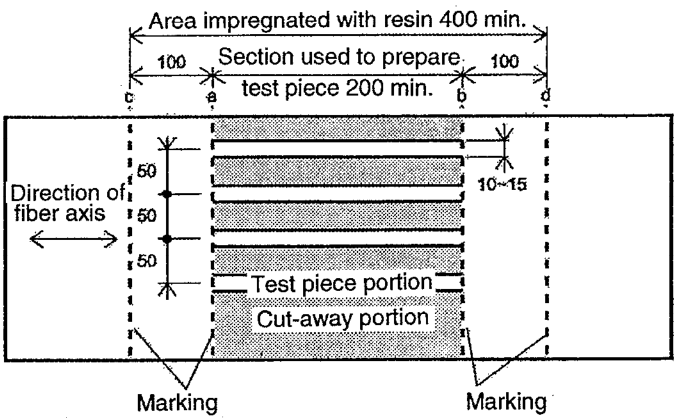

Figure 3 Dimensions of plate used to make Type B test specimens (unit: mm)

g) Cure the plate for the prescribed period of time, then cut the fiber bundle portion at widths of 10-15 mm. The cut length should be at least equivalent to 1.5 times the overlap splice length plus the anchorage length.

h) Attach the anchorage to the anchorage portion to form the test specimen.

i) Before performing the test, condition the test specimen as prescribed.

4.3 Curing the test specimen

A curing period for the test specimen to have the desired strength shall be established and the test specimen shall be cured.[1]

4.4 Anchorage portion of test specimen

The anchorage portion of the test specimen shall be of a shape that does not cause the test specimen to twist or bend. An anchorage made of fiber-reinforced plastic or aluminum shall be attached to the anchorage portion using resin or adhesive at a suitable pressure so that the thickness of the adhesive layer is constant. The adhesive or resin must ensure that the adhesive layer does not experience shear fracture before the test specimen breaks.

4.5 Conditioning of test specimen

As a rule, test specimens shall be conditioned for at least 48 hours before testing in a Class 2 standard atmosphere (temperature 23 ±2°C and humidity 50 ±10%) as described in JIS K 7100.

4.6 Number of test specimens

A number of test specimens suitable for objective of test shall be determined. However, there shall be no fewer than five test specimens for each case.

5. Testing Machine

The testing machine shall conform to JIS B 7721 (Verification of the force measuring system of the tensile testing machine). The testing machine shall have a loading capacity in excess of the tensile capacity of the test specimen and shall be capable of applying loading at the required loading rate.

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[1] The curing period shall generally be about one week.

6. Test Method

6.1 Dimensions of test specimens

The width and thickness of the test portion of the test specimens shall be measured as follows at four locations other than the overlap splice portion and two locations within the overlap splice portion.

Type A test specimens shall be measured to 0.01 mm.
Type B test specimens shall be measured to 0.1 mm.

6.2 Mounting the test specimen

The test specimen shall be mounted so that the longer axis of the test specimen coincides with the center line between the two chucks.

6.3 Loading rate

The standard loading rate shall be a fixed strain rate equivalent to 1-3% strain per minute.

6.4 Test temperature

The test temperature shall be 20 ±5°C. However, if the test specimen is not sensitive to changes in temperature, the test may be conducted at a temperature of 5-35°C. When the sheet is to be applied under special work conditions or in special environments, these shall be taken into consideration in determining the test temperature.

6.5 Scope of test

The loading test shall be performed until tensile failure, and measurements of load shall be made and recorded continuously or at regular intervals until the tensile capacity is reached.

7. Calculation and Expression of Test Results

7.1 Handling of data

The test data shall be assessed on the basis only of test specimens undergoing failure in the test portion. In cases where tensile failure or slippage has clearly taken place at the anchorage portion, the data shall be disregarded and additional tests shall be performed using test specimens from the same lot until the number of test specimens failing in the test portion is not less than the prescribed number.

7.2 Failure categories

Table 2 shows the types of overlap splice failure. Shear fracture of the impregnation resin within the overlap splice portion is called "overlap splice failure." Failure of the continuous fiber sheet in parts of the test portion other than the overlap splice portion is called "base material failure."

Table 2 Categories of overlap splice failure

Code	Type of failure
JF	Overlap splice failure
SF	Base material failure

7.3 Overlap splice strength

The overlap splice strength f_{fus} shall be calculated using Eq. (1) and rounded off to three significant digits in accordance with JIS Z 8401.

$$f_{fus} = \frac{F_u}{A} \quad \text{......} \quad (1)$$

where

f_{fus} : Overlap splice strength (N/mm^2)

F_u : Tensile capacity (N)

A : Nominal cross-sectional area of a test specimen (mm^2)

The cross-sectional area A of the test specimen shall be calculated using Eq. (2).

$$A = \begin{cases} \dfrac{w}{\rho} \cdot b_t \text{ (for Type A test piece)} \\ \dfrac{w}{\rho} \cdot \dfrac{N_t}{n_u} \text{ (for Type B test piece)} \end{cases} \qquad \text{...} (2)$$

where

w : Fiber mass per unit area of continuous fiber sheet (g/mm^2)

ρ : Density of continuous fiber sheet (g/mm^3)

b_t : Minimum width of test portion of test specimen (mm)

N_t : Number of fiber bundles in test specimen

n_u : Number of fiber bundles per unit area of the continuous fiber sheet (strands / mm)

8. Report

The report shall include the following items:

a) Name of continuous fiber sheet
b) Type of continuous fiber sheet and impregnation resin
c) Fiber mass per unit area and density of continuous fiber sheet
d) Fabrication date, fabrication method and curing period for test specimens
e) Temperature, humidity and duration of test specimen conditioning
f) Test date, test temperature and loading rate
g) Shape and dimensions of each test specimen and calculated cross-sectional area
h) Length of overlap splice for each test specimen
i) Tensile capacity of each test specimen and average and standard deviation for these values
j) Tensile strength of each test specimen and average and standard deviation for these values
k) Failure type for each test specimen

COMMENTARY ON THE TEST METHOD FOR OVERLAP SPLICE STRENGTH OF CONTINUOUS FIBER SHEETS

Introduction

The test method for the overlap splice strength of continuous fiber sheets has been prepared based on JSCE-E 541 "Test method for tensile properties of continuous fiber sheets" and after reference to the test methods specified in the "Guidelines for Seismic Retrofit Design and Construction of Railway Viaduct Pier Using Carbon Fiber Sheets" of the Railway Technical Research Institute and the activities of ACI 440 K.

This draft has been prepared based on existing test results and covers carbon fiber sheets and aramid fiber sheets as test specimens, but it can be applied to other continuous fiber sheets as well.

1. Scope

As in the "Test method for tensile properties of continuous fiber sheets," the test specimens defined in the "Test method for overlap splice strength of continuous fiber sheets" are continuous fiber sheets in which the continuous fiber used to upgrade concrete members and the adhesive (impregnation resin) exhibit a monolithic mechanical behavior, and in which a single layer is used.

The test method is established mainly for carbon fiber or aramid fiber sheets, but this method may be applied to other materials if they are used in the same manner.

2. Normative Reference

3. Definitions

Only the terms unique to overlap splice tests are established. Since many of the terms used in overlap splice tests are the same as those used in tensile properties tests, JSCE-E 541 should be consulted for other vocabulary items.

4. Test specimens

4.1

With the exception of the overlap splice portion, the dimensions of Type A test specimens and Type B test specimens are the same as those of the Type A and B test specimens used in tensile strength tests.

4.2

With the exception of the overlap splice portion, the method of preparing test specimens is generally the same as that used to prepare Type A and Type B test specimens for tensile strength tests.

5. Testing Machine and Measuring Devices

6. Test Method

7. Calculation and Expression of Test Results

7.2

The type of failure of the overlap splice strength is divided into two categories. Failure in the overlap splice portion is assumed to be primarily the shear fracture of resin between the overlapping continuous fiber sheets. However, the fracture of continuous fiber sheets within the overlap splice portion is also included in this category.

7.3

The method of calculating the overlap splice strength is basically the same as that for the tensile strength. The cross-sectional area of the test specimen is calculated using the dimensions of the section other than the overlap splice area (in other words, using the dimensions of the base material section).

8. Report

3. TEST METHOD FOR BOND PROPERTIES OF CONTINUOUS FIBER SHEETS TO CONCRETE (JSCE-E 543-2000)

1. Scope

This specification describes the method used to test the bond properties to concrete of the continuous fiber sheets used for upgrading of concrete members.

2. Normative Reference

The following standards, by being referenced herein, form a portion of these specifications. The most recent version of each standard should be used.

JSCE-E 541	Test method for tensile properties of continuous fiber sheets
JIS K 7100	Plastics-standard atmospheres for conditioning and testing
JIS B 7721	Verification of the force measuring system of the tensile testing machine
JIS Z 8401	Guide to the significant digits

3. Definitions

The following are the definitions of the major terms used in this specification in addition to the terms used in the “Recommendations for Upgrading of Concrete Structures with Use of Continuous Fiber Sheets” published by the Japan Society of Civil Engineers and JSCE-E 541.

a) Concrete block

A rectangular concrete block used to study the bond properties of continuous fiber sheets to concrete. Steel reinforcement or steel bars are embedded in the axial direction at the center of the cross-sectional area of the concrete block in order to transmit tensile strength. Concrete blocks are made up of a test block and an anchorage block.

b) Test block

The block used to study the bond properties of continuous fiber sheets

c) Anchorage block

The counterpart block to the test block prevents the bond failure of the continuous fiber sheet. An additional continuous fiber sheet jackets the block with the sheets to be tested circumferentially to provide higher bond resistance for the sheets.

d) Interfacial fracture energy

The amount of energy per unit of bond area necessary to produce interfacial fracture

e) Effective bond length

The length of the portion in which the bond stress between the continuous fiber sheet and the concrete acts effectively at the maximum load before the continuous fiber sheet comes loose from the concrete

f) Effective bond area

The area derived from the effective bond length and the bond width of the continuous fiber sheet

g) Bond strength

The strength calculated by dividing the maximum load by the effective bond area

4. Test specimens

4.1 Types and dimensions

There shall be two types of test specimens as described below.

a) Type A test specimen

Type A test specimens shall consist of two separate concrete blocks manufactured in accordance with the method described in Section 4.3.1 a). The shape and dimensions of Type A test specimen are shown in Figure 1 and Table 1, respectively.

b) Type B test specimen

Type B test specimens shall be a single concrete block manufactured in accordance with the method described in Section **4.3.1** b). The shape and dimensions of Type B test specimen are shown in Figure 2 and Table 1, respectively.

Table 1 Dimensions of test specimens (unit: mm)

Type of test specimen	Type A (separate block type)	Type B (single block type)
Block length	300 min.	600 min.
Block cross-sectional area	100 x 100	
Bond length	200 (not including section cut away from edge)	
Distinguishing characteristics	Test specimen consisting of two matching concrete blocks with the block length and cross-sectional area above	Single concrete block with the block length and cross-sectional area above and a 20 mm deep notch in the center on either side

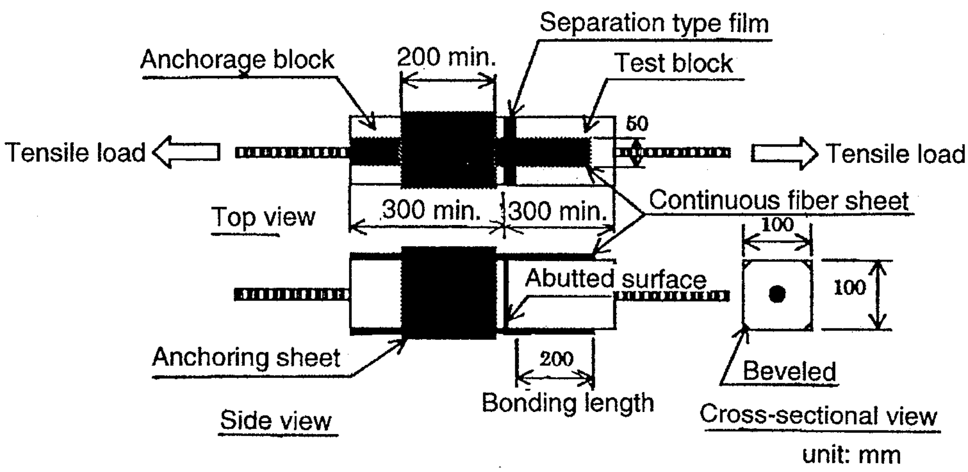

Figure 1 Shape of Type A test specimen

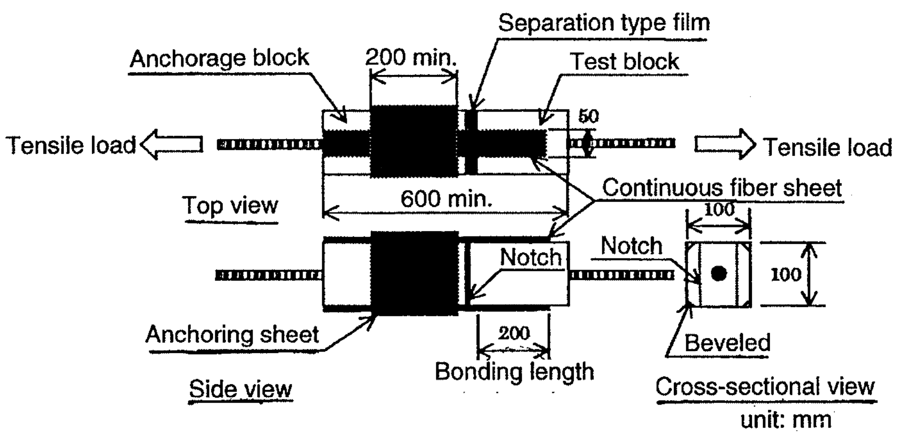

Figure 2 Shape of Type B test specimen

4.2 Quality of concrete and steel bars

4.2.1 Concrete

The standard quality of concrete shall be ordinary aggregate with maximum coarse aggregate diameter of 20 or 25 mm, slump 10 ±2 cm, and compressive strength of 30 ±3 N/mm^2 at an age of 28 days. When members to be actually upgraded are available, concrete of equivalent quality to the members may be used.

4.2.2 Steel bars

Steel bolts or bars used to transmit a tensile force shall have a strength and diameter sufficient to prevent yielding or pull-out from the concrete block before the continuous fiber sheet comes to the ultimate stage, in order to enable the load to be properly transmitted to the concrete block.

4.3 Preparation of test specimens

4.3.1 Concrete blocks

a) Type A test specimen (separate blocks)

(1) Prepare a pair of molds for concrete blocks with a cross-sectional area of 100 x 100 mm and a length of 300 mm. The dimensional error of the molds should be no more than 1/100 of the length of each side. To ensure precision, the molds should be made of steel. The four corners in the longer axis direction should be beveled using chamfering strips.

(2) The steel bolts or bars for applying tensile force should be positioned at the center axis of the concrete blocks and placed so that the ends of the bolts or bars are matched to the abutted surfaces of the concrete blocks during the test. The edge on the other side of the abutted surface should have a grip allowance long enough[1] to enable the steel bolt or bars to be gripped securely by the chuck of testing machine.

(3) Pour the concrete and cure it in the appropriate manner.[2]

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[1] The grip allowance for the tension steel bolts or bars shall be at least 200 mm from the edge of the concrete block.

[2] The concrete should be cured to give it the required strength.

(4) The steel bolts or bar should be placed so that they are not eccentric with respect to the center of the cross-sectional area. Make sure that no slippage or twisting occurs in the surfaces of the concrete blocks.

b) Type B test specimen (single block)

(1) Prepare a mold for a concrete block with a cross-sectional area of 100 x 100 mm and a length of 600 mm. The dimensional error of the mold should be no more than 1/100 of the length of each side. To ensure precision, the mold should be made of steel. The four corners in the longer axis direction should be beveled using chamfering strips. Wooden pieces for making notches on concrete surfaces after stripping off the mold should be placed on the two sides of the mold. The notch depth should be 20 mm.

(2) A pair of steel bolts or bars should be placed at the center axis of the concrete blocks so that they are abutted in the center of the longer axis. The positions of the steel bolts or bars should be placed so that they are not eccentric with respect to the center of the cross-sectional area. The edge on the other side of the abutted surface should have a grip allowance long enough[1] to enable the steel bolts or bars to be gripped securely by a chuck of testing machine.

(3) Place the concrete and cure it in the appropriate manner.[2]

4.3.2 Concrete surface treatment

The surfaces of concrete shall be given standard surface treatment using the following procedure. When a member to be actually upgraded is available, surface treatment equivalent to the actual work shall be conducted.

a) Scour the surface of concrete using a grinder to remove laitance and dirt.

b) Using a rag, wipe away powder and dust from the concrete surface. If there are oils on the surface, wipe them away using acetone.

c) Coat with primer and let it harden until it does not stick to the fingers when touched.

d) Coat with putty or other smoothing agent to even out the unevenness and bubbles on the surface, then wait for it to harden until it does not stick to the fingers when touched.

4.3.3 Attaching and anchoring continuous fiber sheets

Use the following procedure to attach the continuous fiber sheets. When a member to be actually upgraded is available, a method equivalent to the actual work shall be used.

a) Attach the separation film[3] along the abutted surfaces of the concrete blocks (for the Type A test specimen) or along the notch in the concrete block (for the Type B test specimen) to prevent between concrete and the continuous fiber sheet .
b) After coating both sides of the concrete block with resin, attach a 50 mm wide continuous fiber sheet along the axis of the steel bolts or bars as shown in Figure 1[4, 5] and then impregnate resin into the sheet without cut bubbles. During this process, adjust the length from the end of the separation film to the end of the continuous fiber sheet so that the bond length on the test block is 200 mm. On the anchorage block, extend the continuous fiber sheet to the end of the block.
c) Apply the resin on the top.
d) Cure the test specimen at the prescribed temperature and humidity for the prescribed period of time.
e) Wind a continuous fiber sheet of at least 200 mm in width once around the anchorage block perpendicular to the longer axis within 15 mm of the abutted surfaces or notch, as shown in Figure 1.
f) Cure the test specimen at the prescribed temperature and humidity for the prescribed amount of time.

4.4 Conditioning the test specimen

As a rule, test specimens shall be conditioned for at least 48 hours before testing in a Class 2 standard atmosphere (temperature 23 ±2°C and humidity 50 ±10%) as described in JIS K 7100.

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[3] To prevent spalling off of corners of the concrete blocks, attach a thin layer of separation film around the ends to prevent bond between the continuous fiber sheet and the concrete.

[4] When bonding the continuous fiber sheets, make sure the impregnation resin does not come out too much from the surface. If this happens, wipe it away completely.

[5] No more than three plies of continuous fiber sheets should be used.

4.5 Number of test specimens

A number of test specimens suitable for the test objective shall be determined. However, it shall be no fewer than three.

5. Testing Machine and Measuring Devices

5.1 Testing machine

The testing machine shall conform to JIS B 7721 and must be capable of applying the prescribed load properly.

5.2 Chucks

The chucks shall be capable of transmitting loads appropriately so that no eccentricity is created in the test specimen.

5.3 Strain gauges

The strain gauges shall be capable of recording variations during testing with an accuracy of 10×10^{-6}.

6. Test Method

6.1 Dimensions of test specimen

The width of the bonded continuous fiber sheet shall be measured, at the slit on Type A test specimens and at the notch on Type B test specimens, as well as in three additional locations on both test specimens (in the center of the bonded portion and at the ends).

6.2 Mounting the test specimen

Both Type A and Type B test specimens shall be mounted onto the testing machine so that an eccentric load is not applied by matching the center axis of the test specimen to the center axis of the testing machine.

6.3 Mounting the strain gauges

In order to measure the strain distribution in the bonded portion, strain gauges must be mounted properly on the continuous fiber sheet on the test block. The size of strain gauge and the gauge interval shall be determined to match the objective of strain measurements.[6]

6.4. Loading rate

The standard loading rate shall be at a rate of 2-5 kN per minute.

6.5 Test temperature

The test temperature shall be 20 ±5°C. However, if the test specimen is not sensitive to changes in temperature, the test may be conducted at a temperature of 5-35°C.

6.6 Scope of test

The loading test shall be performed up to the ultimate stage of the continuous fiber sheet. Measurements of load, strain and displacement shall be made and recorded continuously or at regular intervals until maximum capacity.

Reference: When strain gauges are mounted, measurements should be made about every 1 kN load.

7. Calculation and Expression of Test Results

7.1 Handling of data

The test data shall be assessed on the basis only of test specimens whose ultimate are observed as peeling off or failure of the continuous fiber sheet. In cases where

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[6] The interval between strain gauges should be no more than 20 mm.

failure has clearly taken place at the anchorage portion, the data shall be disregarded and additional tests shall be performed using test specimens from the same lot until the number of test specimens experiencing failure in the test portion is not less than the prescribed number.

7.2 Failure categories

Table 2 shows the categories for test specimen failure.

Table 2 Categories for test specimen failure

Code	Type of failure
BF	Interfacial failure
SF	Base material failure

7.3 Interfacial fracture energy

The interfacial fracture energy between the bonded surfaces G_f shall be calculated using Eq. (1) and rounded off to three significant digits in accordance with JIS Z 8401.

$$G_f = \frac{P_{\max}^2}{8b^2 \cdot E_f \cdot t} \quad \cdots\cdots (1)$$

where

G_f	:	Interfacial fracture energy (N/mm)
$P_{\max}$	:	Maximum load (N)
b	:	Average width of continuous fiber sheet (mm)
E_f	:	Young's modulus of continuous fiber sheet (N/mm^2)
t	:	Thickness of continuous fiber sheet (mm))(= n•w/p)
n	:	No. of ply of continuous fiber sheet
w	:	Fiber mass per unit area of continuous fiber sheet (g/mm^2)[7]
ρ	:	Density of continuous fiber sheet[7]

[7] Nominal fiber weight provided by material manufacturer may be used.

7.4 Bond strength

The bond strength $\tilde{\tau}_u$ shall be calculated using Eq. (2) and rounded off to three significant digits in accordance with JIS Z 8401.

$$\tilde{\tau}_u = \frac{P_{\max}}{2b \cdot l} \qquad (2)$$

where

$\tilde{\tau}_u$: Bond strength (N/mm^2)
$P_{\max}$: Maximum load (N)
b : Average width of continuous fiber sheet (mm)
l : Effective bond length in test portion of continuous fiber sheet (mm)[8]

7.5 Strain distribution diagram

When strain measurements are done, a strain distribution diagram may be drawn at each loading step.

8. Report

The report shall include the following items:

a) Name of continuous fiber sheet
b) Type of continuous fiber sheet and impregnation resin
c) Fiber mass per unit area and density of continuous fiber sheet
d) Fabrication date, fabrication method and curing period for test specimens
e) Temperature, humidity and duration of test specimen conditioning
f) Identification of test specimen
g) Test date, test temperature and loading rate
h) Test specimen dimensions and fiber mass per unit area, width, length and number of plies for continuous fiber sheets
i) Concrete mixture, slump and compressive strength at testing

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8 Effective bond length l is determined by the number of continuous fiber sheet layers, Young's modulus and the type of impregnation resin.

j) Interfacial fracture energy and bond strength for each test specimen and averages for these values
k) Type of failure for each test specimen

COMMENTARY ON TEST METHOD FOR BOND PROPERTIES OF CONTINUOUS FIBER SHEETS TO CONCRETE

Introduction

Determination of the bond properties of continuous fiber sheets to concrete is crucial for upgrading design. Conducting test to obtain accurate information on bonding behavior that matches the actual members would be ideal. Nevertheless, to specify a standard test method, it is necessary to simplify the dimensions of test specimens and the test method and to minimize the effect of differences in test conditions and human error on the evaluation results. Here a method of evaluating the bond properties of continuous fiber sheets to concrete using a uniaxial tensile strength test is adopted. This uniaxial tensile strength test method has been used by many research organizations in the past and the test can be conducted with comparative ease. The test method referenced here is "Test method for bond properties of continuous fiber sheets to concrete using tensile testing" published by the Japan Concrete Institute.

1. Scope

In this test method, the maximum load is measured in order to evaluate the bond strength, which is calculated by dividing the maximum load by the interfacial fracture energy for the bonded surfaces and the given effective bonding area (continuous fiber sheet width x effective bond length). The interfacial fracture energy derived with this test method can be used in upgrading design as the peeling resistance for flexural behaviors. It is also an important parameter determining the constitutive law of bond of continuous fiber sheets for use in calculating shear capacity. Bond strength may be used to evaluate the relative bond strengths of continuous fiber sheets and concrete, and to make comparisons with old materials when different or new continuous fiber sheet impregnation resins are used for particular applications.

2. Normative References

3. Definitions

(e)

Previous research has shown that, in the uniaxial tensile strength test method for bond strength, the maximum load at failure does not increase so much if the bond length of the continuous fiber sheet is greater than a certain level. The reason is assumed that the bond stress occurs not over the entire bonded area of the continuous fiber sheet but only in a certain limited area. Since this area is seen to be essentially the effective area for bond between the continuous fiber sheets and concrete, it was defined as the effective bond length.

4. Test specimens

4.1

Here two types of test specimens are proposed: Type A, with two separate blocks, and Type B, a monolithic block. In the Type A test specimen, which is originally separated in the center, the load is applied directly to the continuous fiber sheet starting from the initial loading step. In contrast, in the Type B test specimen, the concrete bears the tension load until the loading step at which cracks penetrate through to the notch. Accordingly, selecting the proper type of test specimen determines whether or not the consideration of the concrete contribution in tension is necessary.

4.2

Here the standard quality of concrete used specifies a slump of 10 ±2 cm and a compression strength of 30 ±3 N/mm^2 for a material age of 28 days. This quality of concrete is the standard type used in various test methods in the JSCE standards. This is done so that, by standardizing the quality of concrete, it would be easy to make relative comparisons of the test results obtained. However, if it is necessary to determine the bond properties of the actual members being studied for upgrading, concrete of the same quality as the actual members may be used for the test.

4.3

4.3.1

Eccentricity during the test has a great impact on the test results, so the test specimens must be accurately fabricated. Eccentricity during the test is affected by the positioning accuracy of the steel bolts or bars and the dimensional accuracy of the concrete test specimens themselves. Accordingly, for the Type A test specimens in particular, molds should be used so that the concrete for a pair of test specimens should be placed at the same time. The molds should be made from a thin steel plate with a guide placed in the center of the end of the test specimen, or similar measures taken, to enable the steel bolts or bars to be fastened in the proper positions in order to reduce the slippage when the blocks are fastened together. Also, since the accuracy of the molds directly affects the dimensional accuracy of the test specimens, the dimensional error of the molds should be no more than 1/100 of the side length.

For the Type B test specimens, the method calls for a notch with a depth of 20 mm to be made when the concrete is placed. However, the notch may also be made with a concrete cutter after the concrete has hardened.

4.3.2

The method noted here concerns the surface treatment that should be done in order to evaluate the standard bond properties of continuous fiber sheets. However, if a member to be actually upgraded is available, the same surface treatment may be used as that which is applied to this member.

4.3.3

The method of attaching continuous fiber sheets noted here is the one used in order to evaluate the standard bond properties. The separation film is wrapped around the ends of the test specimens to prevent the corners from being damaged. Normally a thin polyethylene film is used, but any material that does not stick to the resin that impregnates the continuous fiber sheet may be used. If a member to be actually upgraded is available, the same procedure may be used. No more than three plies of continuous fiber sheet may be used in the application of this test method. If the number of plies is greater than three, the effective bond length may exceed the bond length of 200 mm, and therefore a suitable bond length and effective bond length must be established separately.

The hardening time for the impregnation resin depends on the type of resin and the ambient temperature. Unless otherwise specified, the standard curing time is 7 days following attachment of the continuous fiber sheets to the concrete blocks, in a room with temperature and humidity regulated to 20°C ±5°C and 65% ±5%. If a member to be actually upgraded is available, curing may be done for the same duration and under the same environmental conditions as those applied under actual work conditions. However, before the test is begun, the test specimens must be conditioned for at least 48 hours at temperature 23 ±2°C and humidity 50 ±10% in accordance with JIS K 7100.

5. Testing Machine and Measuring Devices

5.1

As a rule, a tensile testing machine conforming to JIS B 7721 should be used. However, if a hydraulic jack is used to perform the test for convenience or due to difficulty in attaching test specimens, it must be confirmed that use of such methods will produce the same load control, test specimen mounting accuracy.

6. Test Method

6.3

This method notes that strain measurements should be conducted as needed. When the strain distribution is measured at each loading step, appropriate values for strain gauge length and the interval must be established to ensure that the desired data are obtained. The interval between strain gauges should be 20 mm or less.

7. Calculation and Expression of Test Results

7.3

The following values may be used for the effective bond length l when the carbon fiber sheets shown in Table C1 in JSCE-E 541 are used.

Carbon fiber sheets:

For single-ply bond	110 mm
For double ply bond	150 mm

For carbon fiber sheets other than the above and aramid fiber sheets, the effective bond length may be determined using the method prescribed in ¥the "Test method for bond properties of continuous fiber sheets to concrete using tensile testing" published by the Japan Concrete Institute.

7.5

Attaching strain gauges at appropriate intervals on the surface of the continuous fiber sheet and measuring the strain distribution enables the following method to be used to determine the bond constitutive law for the continuous fiber sheets.

7.5.1 Determining the relationship between bond stress and relative displacement

(1) From the strain distribution for the continuous fiber sheet at each loading step, determine the data after failure. Failure can be determined by the shape of the strain distribution. (Figure C1)

(2) Using the strain distribution for any loading step after failure, perform numerical integration and differentiation as shown in Figure C2 to calculate the bond stress $\tau_{(x)}$ and relative displacement $\delta_{(x)}$ between the continuous fiber sheet and the concrete at each point.

(3) Derive the relationship between the bond stress $\tau_{(x)}$ and the relative displacement $\delta_{(x)}$.

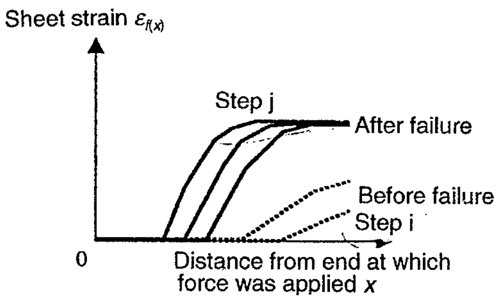

Figure C1
Calculated values for strain distribution of continuous fiber sheet

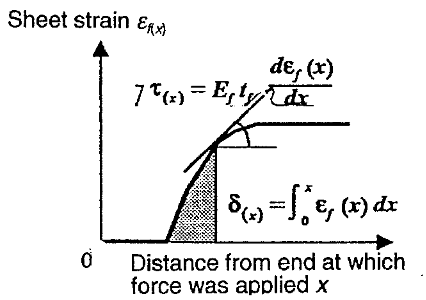

Figure C2
Calculation of bond stress and relative displacement

(4) Perform the aforementioned procedure at several load steps after failure and then average the data to determine the relationship between bond stress τ and relative displacement δ for the continuous fiber sheets and the concrete.

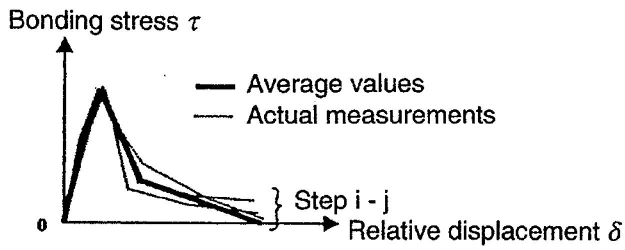

Figure C3 Relationship between τ and δ derived from strain distribution of continuous fiber sheets

7.5.2 Modeling the relationship between bond stress and relative displacement

Figure C3 shows the relationship between bond stress and relative displacement, derived from the actual measurements of the strain distribution of the continuous fiber sheets. As the figure shows, the area can be generally divided into an elastic domain and a softening domain. Modeling as shown below is done to make it easier to calculate the shear capacity of members reinforced with continuous fiber sheets.

(1) A bilinear model may be used to approximate the relationship between τ and δ obtained from the actual measurements (Figure C4).

(2) A cut-off model is identified so that the bilinear model and the fracture energy (the area enclosed by the τ and δ curves) are equivalent and the maximum bond stress is doubled (Figure C5).

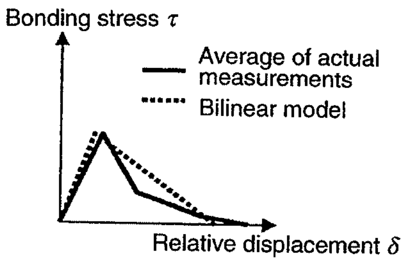

Figure C4 Bilinear model

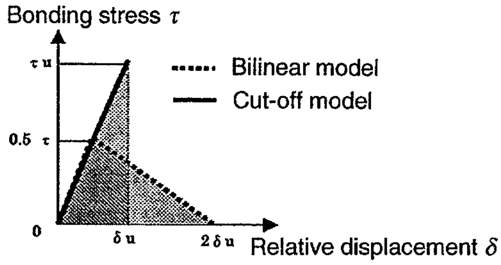

Figure C5 Cut-off model

8. Report

4. TEST METHOD FOR BOND STRENGTH OF CONTINUOUS FIBER SHEETS TO STEEL PLATE (JSCE-E544-2000)

1. Scope

This specification describes the method used to test the bond properties to steel plate of the continuous fiber sheets used for upgrading of concrete members.

2. Normative Reference

The following standards, by being referenced herein, form a portion of these specifications. The most recent version of each standard should be used.

JSCE-E 541	Test method for tensile properties of continuous fiber sheets
JSCE-E 542	Test method for overlap splice strength of continuous fiber sheets
JIS K 7100	Plastics-standard atmospheres for conditioning and testing
JIS B 7721	Verification of the force measuring system of the tensile testing machine
JIS Z 8401	Guide to the significant digits

3. Definitions

The following are the definitions of the major terms used in this specification in addition to the terms used in the "Recommendations for Upgrading of Concrete Structures with Use of Continuous Fiber Sheets" published by the Japan Society of Civil Engineers, JSCE-E 541 and JSCE-E 542.

a) Bond strength

The strength calculated by dividing the maximum load at the peeling failure of the continuous fiber sheet by the bonded area of the continuous fiber sheet to the steel plate.

b) Bonded portion

The portion of the test specimen used to test the bond strength of continuous fiber sheets to steel plate.

4. Test Specimens

4.1 Types and dimensions

There may be four types of test specimens: two Type I test specimens (I-A and I-B) and two Type II test specimens (II-A and II-B).

a) Type I test specimen

Type I test specimens are prepared using the methods prescribed in Section 4.2.1 or Section 4.2.2. These test specimens are used when the steel plate is bonded at the same time that the continuous fiber sheets are impregnated. The shape and dimensions of Type I test specimens are shown in Figure 1 and Table 1, respectively.

b) Type II test specimen

Type II test specimens are prepared using the methods prescribed in Section 4.2.3 or Section 4.2.4. These test specimens are used when the steel plate is bonded after the continuous fiber sheets are impregnated and have hardened. The shape and dimensions of Type II test specimens are the same as those for Type I as shown in Figure 1 and Table 1.

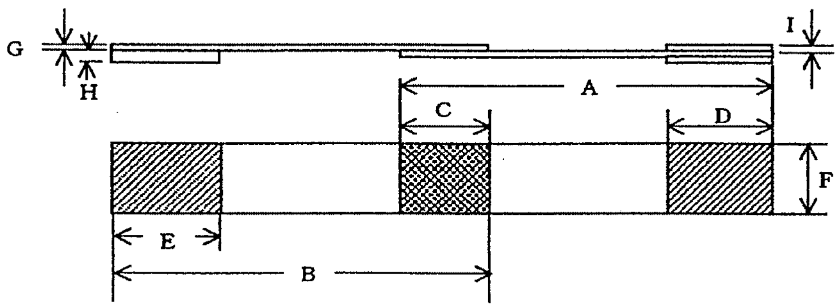

Figure 1 Shape and dimensions of test specimens used to test bond strength of continuous fiber sheets to steel plate

Table 1 Test specimen dimensions (Type I and Type II) (unit: mm)

Type of test specimen	Type A	Type B
A Length of continuous fiber sheets	≥ 200	
B Length of steel plate	≥ 200	
C Length of bonded portion	Necessary length	
D Length of anchorage for continuous fiber sheets	≥ 50	
E Length of steel plate anchorage	≥ 50	
F Width of test specimen	12.5 ±0.5	10-15
G Thickness of steel plate	Necessary thickness	
H Thickness of steel plate anchorage	≥ 1 (thickness needed to be parallel with the outer surface of the continuous fiber sheet anchorage)	
I Thickness of continuous fiber sheet anchorage	≥ 1 (thickness needed to be parallel with the outer surface of the steel plate anchorage)	

4.2 Preparation

4.2.1 Type I-A test specimen

Type I-A test specimens are prepared using the following method.

a) Line up spacers with the same thickness as the steel plate on the same surface as the steel plate of the prescribed width. Apply separation film to the spacer portion only.
b) Secure the prescribed anchorage length and then coat the steel plate portion and the spacers, to which separation film has been applied, with impregnation resin for continuous fiber sheets.
c) Apply the continuous fiber sheet and impregnate.
d) Apply the top coat of impregnation resin and remove the bubbles.
e) Cure for the prescribed period of time.
f) Cut the continuous fiber sheet portion to 12.5 mm.
g) Attach the anchorages to the steel plate and the continuous fiber sheet anchorage portions.

4.2.2 Type I-B test specimen

Type I-B test specimens are prepared using the following method.

a) Prepare a continuous fiber sheet cut to a sufficient length for the dimensions of the test specimen. Fasten the sheet so that the fiber axis is in a straight line.

b) Remove 1-3 fiber bundles from each side of the test specimens having the width of 10-15 mm. When preparing several test specimens from the same continuous fiber sheet, the portions to be used as test specimens should be separated by intervals of at least 50 mm in the direction perpendicular to the fiber axis.

c) Line up spacers with the same thickness as the steel plate on the same surface as the steel plate of the prescribed width. Apply separation film to the spacer section only.

d) Secure the prescribed anchorage length and then coat the steel plate section and the spacer, to which separation film has been applied, with impregnation resin for continuous fiber sheets.

e) Apply the aforementioned continuous fiber sheet, from which the fiber bundles have been removed, and impregnate.

f) Apply the top coat of impregnation resin and remove the bubbles.

g) Cure for the prescribed period of time.

h) Remove the portion of the continuous fiber sheet from which the fiber bundles have been removed and cut to the prescribed width.

i) Attach the anchorages to the steel plate and the continuous fiber sheet anchorage portions.

4.2.3 Type I1-A test specimen

Type II-A test specimens are prepared using the following method.

a) Prepare a continuous fiber sheet cut to a sufficient length for the dimensions of the test specimen.

b) Apply the bottom coat of impregnation resin to the separation film and fasten the aforementioned sheet so that the fibers are in a straight line.

c) Apply the top coat of impregnation resin and remove the bubbles.

d) After curing the test specimen for the prescribed period of time, cut it to a width of 12.5 mm. The cut length should be at least 200 mm.

e) Coat the prescribed bond length of the continuous fiber sheet test specimen with adhesive and attach a steel plate with the prescribed dimensions.

f) After curing the adhesive for the prescribed period of time, attach the anchorages to the steel plate to continuous fiber sheet anchorage portions.

4.2.4 Type II-B test specimen

Type II-B test specimens are prepared using the following method.

a) Prepare a continuous fiber sheet cut to a sufficient length for the dimensions of the test specimen. Fasten the sheet so that the fiber axis is in a straight line.
b) Along the fiber axis, remove 1-3 fiber bundles from each side of the test specimens having the width of 10-15 mm. When preparing several test specimens from the same continuous fiber sheet, the portions should be separated by intervals of at least 50 mm in the direction perpendicular to the fiber axis.
c) Apply the bottom coat of impregnation resin to the separation film and attach the sheet on top.
d) Apply the top coat of impregnation resin and remove bubbles. Covering with separation film and smoothing would be best to ensure that the thickness of the impregnation resin is even.
e) After curing the test specimen for the prescribed period of time, cut it to a width of 10-15 mm. The cut length should be at least 200 mm.
f) Prepare a steel plate of the same width as the cut continuous fiber sheet.
g) Coat the prescribed bond length of the cut continuous fiber sheet test specimen with adhesive and attach the steel plate.
h) After curing the adhesive for the prescribed period of time, attach the anchorages to the steel plate to continuous fiber sheet anchorage portions.

4.3 Anchorage portion of test specimen

Anchorage portion of test specimen

The anchorage portion of the test specimen shall not be of a shape that will cause the test specimen to twist or bend. Adhesive shall be used to attach an anchorage made of fiber-reinforced plastic or aluminum to the anchorage portion of the continuous fiber sheet, and to fasten an anchorage of the same type of steel to the steel plate anchorage. A suitable adhesive shall be selected so as to ensure that the adhesive layer will not experience shear fracture before the failure of test specimen.

4.4 Conditioning the test specimen

Test specimens shall be conditioned for at least 48 hours before testing in a Class 2 standard atmosphere (temperature 23 ±2°C and humidity 50 ±10%) as described in JIS K 7100.

4.5 Number of test specimens

A number of test specimens suitable for the test objective shall be determined. However, there shall be no fewer than five .

5. Testing Machine and Measuring Devices

The testing machine used for bond properties shall conform to JIS B 7721 and shall be capable of applying the maximum load for the test specimen at the prescribed loading rate.

6. Test Method

6.1 Dimensions of test specimen

The length of the bonded portion of the test specimen shall be measured to an accuracy of 0.1 mm in two locations at each side, and the average of these values shall be the length of the bonded portion. The width shall be measured in three locations (at the end of the continuous fiber sheet in the bonded portion, at the end of the steel plate, and in the center) and the average of these values shall be the width of the bonded portion.

6.2 Mounting the test specimen

The test specimen shall be mounted so that the continuous fiber sheet portion and steel plate portion of the test specimen are parallel to the center line between the two chucks of the testing machine.

6.3 Loading rate

The standard loading rate shall be a fixed strain rate equivalent to 1-10 mm elongation deformation per minute.

6.4 Test temperature

The test temperature shall be 20 ±5°C. However, if the test specimen is not sensitive to changes in temperature, the test may be conducted at a temperature of 5-35°C. When the specimen is to be used under special work conditions or in special environments, these shall be taken into consideration when determining the test temperature.

7. Calculation and Expression of Test Results

7.1 Handling of data

The test data shall be assessed on the basis only of test specimens whose failure occurred in the bonded portion and classified as one of the failure categories in Section 7.3. In cases where failure or slippage has clearly taken place at the anchorage portion, the data shall be disregarded and additional tests shall be performed using test specimens from the same lot until the number of test specimens experiencing failure in the test portion is not less than the prescribed number.

7.2 Bond strength

The bond strength $\tilde{\tau}_{su}$ shall be calculated using Eq. (1) and rounded off to three significant digits in accordance with JIS Z 8401.

$$\tilde{\tau}_{su} = \frac{P_u}{l \cdot b} \quad \cdots\cdots (1)$$

where

$\tilde{\tau}_{su}$: Bond strength (N/mm^2)

P_u : Maximum load (N)

l : Length of bonded portion (mm)

b : Width of bonded portion (mm)

7.3 Failure categories

Table 2 shows the categories for the failure of test specimens.

The determination of mode of failure is as follows: if there are continuous fibers remaining on the steel plate, it indicates a sheet failure. If the steel plate surface is exposed in its surface-treated condition, it indicates an adhesive failure. If the adhesive layer has fractured, this indicates a cohesive failure.

Table 2 Categories of failure

Code	Type of failure
BF	Adhesive failure
RF	Cohesive failure
SF	Sheet failure

Reference: Steel plates are subjected to rustproofing and other treatment. When this layer fails, it should be categorized as an adhesive failure, but it should be clearly noted that the failure occurred in the rustproofing section.

When more than one mode of failure is applicable, select the mode where the failure occurred over the widest area and include a note summarizing the proportional area applicable to each mode of failure.

8. Report

The report shall include the following items:

a) Name of continuous fiber sheet
b) Type of continuous fiber sheet and impregnation resin
c) Fiber mass per unit area and density of continuous fiber sheet
d) Type, thickness and surface processing method for bonded materials
e) Fabrication date, fabrication method and curing period for test specimens
f) Temperature, humidity and duration of test specimen conditioning
g) Test date, test temperature and loading rate

h) Shape and dimensions of each test specimen and calculated cross-sectional area
i) Tensile capacity of each test specimen and average and standard deviation of these values
j) Maximum bond strength of each test specimen and average and standard deviation of these values
k) Failure type of each test specimen
l) Other special notations

COMMENTARY ON TEST METHOD FOR BOND STRENGTH OF CONTINUOUS FIBER SHEETS TO STEEL PLATE

Introduction

This test method is used to calculate the bond length between continuous fiber sheets and steel plate in such situations as when the end of a continuous fiber sheet is anchored via a steel plate. In establishing this test method, reference was made to JIS K 6850 "Test method for tensile shearing adhesive strength of adhesives" and JIS K 6848 "Test method for shearing adhesive strength of adhesives."

1. Scope

2. Normative Reference

3. Definitions

4. Test specimens

4.1

The continuous fiber sheets and adhesives should be the same as the actual materials to be used, and the continuous fiber sheet to steel plate should be bonded using the same procedure as the one used under actual work conditions. Use the Type I test specimen when impregnating the continuous fiber sheet with impregnation resin on the steel plate to bond the continuous fiber sheet and steel plate at the site. Use the Type II test specimen when work at the site involves using adhesive to bond the steel plate to the continuous fiber sheet after the impregnation resin has hardened. The specifications for the use of Type A or Type B test specimens should conform to JSCE-E 541 and JSCE-E 542.

4.2

When the test specimen is fabricated by impregnating the continuous fiber sheet with impregnation resin and bonding it to the steel plate, the linearity of the fibers in the continuous fiber sheet must be ensured. Use spacers, etc. to which separation film has been applied and which haves the same thickness as the steel plate and perform the work carefully. If members for which the process will actually be performed are not available, use a steel plate with a thickness appropriate for the strength and estimated bond strength of the continuous fiber sheet.

4.3

Anchorages must be attached to the anchorage portions on both sides of the continuous fiber sheet for protection. To prevent eccentricity from being applied during the tensile strength test, adjust the thicknesses of the anchorages and supports to make sure that the anchorage on one side is flush with the surface of the steel plate and the anchorage on the other side is flush with the support for the steel plate, as shown in Figure C1.

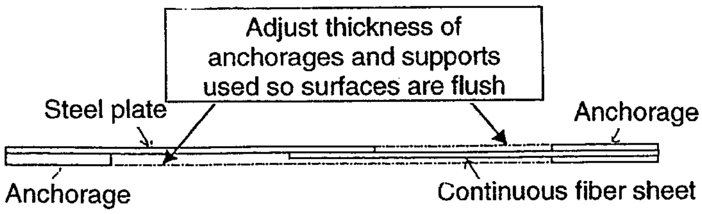

Figure C1 Side view of test specimen

5. Testing Machine and Measuring Devices

6. Test Method

When the test specimen is mounted on the testing machine, it must be parallel to the direction of applied force.

7. Calculation and Expression of Test Results

8. Report

5. TEST METHOD FOR DIRECT PULL-OFF STRENGTH OF CONTINUOUS FIBER SHEETS WITH CONCRETE (JSCE-E 545-2000)

1. Scope

This specification describes the method used to test the direct pull-off strength of the continuous fiber sheets used for upgrading of concrete members.

2. Normative Reference

The following standards, by being referenced herein, form a portion of these specifications. The most recent version of each standard should be used.

JSCE-E 541	Test method for tensile properties of continuous fiber sheets
JIS A 5304	Concrete flags
JIS A 6909	Coating materials for textured finishes of buildings
JIS Z 8401	Guide to the significant digits

3. Definitions

The following are the definitions of the major terms used in this specification in addition to the terms used in the “Recommendations for Upgrading of Concrete Structures with Use of Continuous Fiber Sheets” published by the Japan Society of Civil Engineers and JSCE-E 541.

a) Steel device

Steel device connected to a loading machine to apply tensile force. Adhesive is used to mount the device to the continuous fiber sheet attached to the concrete surface. The shape of the bond surface is either square or circular.

b) Pull-out strength

The strength calculated by dividing the maximum load by the cross-sectional area of the bond surface of the steel device

4. Test specimens

4.1 Test specimen

The test specimen is a concrete board consisting of a concrete slab measuring at least 6 cm in thickness to which a continuous fiber sheet has been attached using the method described in Section 4.3.

4.2 Quality of concrete

The concrete slabs to be used for fabricating test specimens shall be of the same quality and strength as the members to be actually upgraded. If no such members are available, the concrete slabs established in JIS A 5304 shall be used, or concrete with ordinary aggregate having a maximum coarse aggregate diameter of 20 or 25 mm, slump 10 ± 2 cm, and compression strength of 30 ± 3 N/mm^2 for a material age of 28 days shall be used.

4.3 Preparation

4.3.1 Concrete surface treatment

The surface treatment performed for the concrete test specimens onto which the continuous fiber sheets are attached shall be the same as that used for the members to be actually upgraded. If the method of surface treatment is not otherwise specified, the following procedure shall be used.

a) Scour the surface of the concrete using a disc sander to remove laitance and dirt.
b) Using a rag, wipe away powder and dust from the concrete surface. If there are oils on the surface, wipe them away using acetone.
c) Coat with primer and let it harden to the point where it does not stick to the fingers when touched.
d) Coat with a smoothing agent to even out the unevenness and bubbles on the surface, then wait for it to harden until it does not stick to the fingers when touched. The surface treatment process is now complete.

4.3.2 Attaching the continuous fiber sheets

a) Prepare a continuous fiber sheet of a size matching the concrete slab.

b) Apply the bottom coat of impregnation resin and then attach the continuous fiber sheet and remove bubbles.
c) Apply the top coat of impregnation resin and impregnate.
d) Cure for the prescribed period of time to form the test specimen.

4.4 Mounting the steel devices and notching

a) As a rule, the steel device[1] shall be the type established in 6.10 "Bond strength test" in JIS A 6909.
b) Figure 1 shows the position at which the steel devices shall be mounted. As the figure shows, the positions are determined through consideration of the distance from the edge of the concrete slab and the distance between devices. Using sandpaper or the like, rough the bond surface of the steel devices and the surface of the test specimen to which the steel device will be bonded. Be careful not to damage the continuous fibers.
c) Coat the bond surface of the steel device with adhesive and attach it carefully to the test specimen. Then attach a suitable weight[2] to the steel device and let it stand.
d) After curing the adhesive, remove the weight and, using a concrete cutter, notch the area around the device.

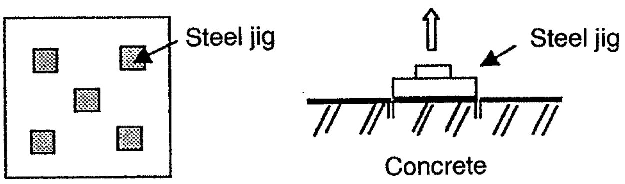

Figure 1 Mounting the steel devices on the test specimen

4.5 Number of test specimens

A number of test specimens suitable for the test objective shall be determined. However, there shall be no fewer than three.

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[1] Use a steel device whose bonding area measures 40 x 40 mm. A device with a thickness of about 10 mm is generally used.
[2] Use a weight of about 1 kg.

5. Testing Machine and Measuring Devices

The testing machine used for the direct pull-off strength test shall have the capacity larger than the maximum resistance of test specimens and shall have an indicator that enables the maximum load to be measured.

6. Test Method

6.1 Setting the testing machine

The steel devices shall be set so that the force is applied normal to the concrete surface.

6.2 Loading rate

The standard loading rate shall be a fixed rate equivalent to 5-10 kN per minute.

6.3 Test temperature

The test temperature shall be 20 ±5°C. However, if the test specimen is not sensitive to changes in temperature, the test may be conducted at a temperature of 5-35°C. When the specimen is to be used under special work conditions or in special environments, these shall be taken into consideration when determining the test temperature.

6.4 Scope of test

The test shall be performed until the steel devices come apart from the concrete slab.

7. Calculation and Expression of Test Results

7.1 Handling of data

When the steel devices have come apart from the continuous fiber sheets in the bonded portion, the data shall be disregarded and additional tests shall be performed, with steel devices mounted in advance in different locations, until the prescribed number of test specimens is obtained.

7.2 Bond strength

The bond strength f_{au} shall be calculated using Eq. (1) and rounded off to three significant digits in accordance with JIS Z 8401.

$$f_{au} = \frac{F_{au}}{A_s} \quad \text{......} \quad (1)$$

where

f_{au} : Bond strength (N/mm^2)

F_{au} : Maximum load (N)

A_s : Area of steel device (mm^2)

7.3 Failure categories

Table 1 shows the categories for the failure of test speciments.

If the failure occurred in the concrete and the steel device came apart having a piece of concrete with it, this indicates a concrete fracture. If the failure occurred in the interface between the concrete surface and the primer, or the primer and the smoothing agent, or the smoothing agent and the continuous fiber sheet, this indicates an interfacial fracture. If the failure occurred within the continuous fiber sheet or between the layers of the continuous fiber sheet, this is categorized as a "fracture between layers of continuous fiber sheet."

Table 1 Categories for the failure of test specimens

Code	Type of failure
MF	Concrete fracture
IF	Interfacial fracture
SF	Fracture between layers of continuous fiber sheet

8. Report

The report shall include the following items:

a) Name of continuous fiber sheet

b) Type of continuous fiber sheet, primer, smoothing agent and impregnation resin
c) Fiber mass per unit area and density of continuous fiber sheet
d) Number of plies of continuous fiber sheet
e) Concrete mixture, slump and compression strength at testing
f) Fabrication date and fabrication method for test specimens
g) Test date, test temperature and loading rate
h) Shape, dimensions and calculated cross-sectional area of the steel device at each test location
i) Tensile capacity at each test location and average of these values
j) Maximum bond strength at each test location and average of these values
k) Failure type at each test location
l) Other special notations

COMMENTARY ON TEST METHOD FOR DIRECT PULL-OFF STRENGTH OF CONTINUOUS FIBER SHEETS WITH CONCRETE

Introduction

This test method specifies the direct pull-off strength of the continuous fiber sheets used to upgrade concrete members. It is mainly done for quality control during construction and primarily by referring to JIS A 6909 "Coating materials for textured finishes of buildings."

1. Scope

2. Normative Reference

3. Definitions

Steel devices are also referred to as bonding terminals or attachments.

4. Test specimens

4.1

In general, the concrete slabs used in this test method may be concrete slabs for pavement, measuring 30 cm square and a thickness of 6 cm. However, it is also possible to use an actual portion of a concrete member.

4.3

There should be one ply of continuous fiber sheet. However, the test may also be conducted with a test specimen having a couple of plies actually used for upgrading. In such cases, it should be noted in the report.

4.4

JIS A 6909 "Coating materials for textured finishes of buildings" specifies a steel device with a rectangular cross-section in which each side measures 4 cm. However, one with a circular cross-section may also be used if the cross-sectional area is approximately the same. Test results with a small cross-sectional area of steel devices involve the intensive influences of the notched end, which may reduce the bond strength or change failure mode. Accordingly, as a rule such devices should not be used for the direct pull-off test of continuous fiber sheets with concrete.

The adhesive used to bond the steel device must be one with the prescribed properties; in general, an epoxy resin adhesive should be used. In order to prevent air intrusion between the steel device and the surface of the continuous fiber sheet at attaching the device, coat with adhesive until the adhesive comes out from the end when the steel device is pressed against the surface.

The depth of the notch around the steel device should be about 10 mm from the surface of the concrete slab.

5. Testing Machine and Measuring Devices

In general, when this method is used for quality control at the work site, a portable hydraulic jack is used. In such cases, the capacity of the jack should be at least 20% greater than the expected maximum load of test specimens.

6. Test Method

6.1

If the force is not applied normal to the test specimen due to unevenness in the surface of the concrete slab, the ultimate strength may be reduced. In such cases, it is important to adjust the position of the jack normal to the test specimen by inserting a thin plate between the base of the reaction frame and the concrete slab.

6.3

When using this method for quality control during construction, the test may be performed under actual environmental temperature conditions. Particularly when the temperature is low, it takes a long time for the steel devices to become firmly bonded. Therefore, care must be taken with adhesive selection and curing time.

7. Calculation and Expression of Test Results

7.3

There are three types of interfacial fracture (IF): those occurring in the interface between the concrete and primer, between the primer and smoothing agent, and between the smoothing agent and the continuous fiber sheet. In such cases, observe the fracture surface carefully and distinguish the failure mode by observing the color of the primer, the color of the smoothing agent and the color of the impregnation resin, and note this judgment in the report. If it is impossible to determine the fractured interface, note this in the report.

When a couple of failure mode are observed, report the failure mode which covers the widest area and include a note summarizing the proportional area of each failure mode.

8. Report

When the concrete slab established in JIS A 5304 "Concrete flags" is used, this should be noted, and the concrete mixture, slump and compressive strength at testing be omitted.

6. TEST METHOD FOR TENSILE FATIGUE STRENGTH OF CONTINUOUS FIBER SHEETS (JSCE-E 546-2000)

1. Scope

This specification describes the method used to test the tensile fatigue strength of the continuous fiber sheets used for upgrading of concrete members.

2. Normative Reference

The following standards, by being referenced herein, form a portion of these specifications. The most recent version of each standard should be used.

JSCE-E 541	Test method for tensile properties of continuous fiber sheets
JIS K 7083	Testing method for constant-load amplitude tension-tension fatigue of carbon fibre reinforced plastics
JIS Z 8401	Guide to the significant digits

3. Definitions

The following are the definitions of the major terms used in this specification in addition to the terms used in the "Recommendations for Upgrading of Concrete Structures with Use of Continuous Fiber Sheets" published by the Japan Society of Civil Engineers and JSCE-E 541.

a) Repeated load

Load that fluctuates periodically within a set load range

b) Maximum repeated load (P_{max})

Maximum value for repeated load

c) Minimum repeated load (P_{min})

Minimum value for repeated load

d) Load amplitude (ΔP)

Difference between the maximum repeated load (P_{max}) and the minimum repeated load (P_{min})

e) Average load (P_{mean})

Average of the maximum repeated load (P_{max}) and the minimum repeated load (P_{min})

4. Test specimens

4.1 Test specimens

The test specimens used in this test shall be the Type A and Type B test specimens established in JSCE-E 541.

4.2 Number of test specimens

A number of test specimens suitable for the test objective shall be determined. However, in order to draw the *S*-*N* curve, there shall be at least three test specimens for each of the three stress levels.

5. Testing Machine and Measuring Devices

5.1 Testing machine

The testing machine used for tensile fatigue strength tests must be capable of holding the maximum and minimum repeated load and load amplitude at a constant level with the required repetition frequency.

5.2 Strain gauges

The strain gauges shall be capable of recording variations during test with an accuracy of not less than 10×10^{-6}.

6. Test Method

6.1 Dimensions of test specimens

The dimensions shall be those established in JSCE-E 541.

6.2 Setting the strain gauges

The strain gauges shall be mounted as established in JSCE-E 541.

6.3 Mounting the test specimens

The jaw block shall be one that does not break the anchorage of the test specimen during the test, and that can hold the test specimen with a constant clamping pressure, and on which the clamping pressure can be adjusted. When setting the test specimen to the testing machine, make sure that the longer axis of the test specimen coincides with the loading axis.

6.4 Setting the load

Regarding the load amplitude, a suitable value for the minimum repeated load shall be determined that matches the objective of the test. However, when drawing the *S-N* curve, at least three levels shall be set so that the number of repetitions before failure is distributed between 10^3 and 2×10^6.

6.5 Loading rate

The standard repetition frequency is 2-10 Hz, and the standard waveform is a sine wave.

6.6 Test temperature

The test temperature shall be 20 ±5°C. However, if the test specimen is not sensitive to changes in temperature, the test may be conducted at a temperature of 5-35°C. When an actual member to be upgraded is available, the work conditions or use environments for this member may be taken into consideration for determining the test temperature.

6.7 Starting the test

After increasing the load up to the average load statically, load repetition shall be commenced enlarging the load amplitude up to the prescribed load, rapidly but without any shock. The maximum and minimum repeated loads shall remain constant for the duration of the test. Counting of the number of repetitions shall begin from the point at which the load on the test specimen reaches the prescribed load.

6.8 Ending the test

The test shall be continued until failure, and the number of repetitions up to failure shall be recorded. Unless otherwise specified, the test may be ended after the repetitions of 2 x 10^6.

6.9 Pausing the test

As a rule, the test should not be paused from the start to the end. If the test must be interrupted due to unavoidable circumstances, the number of repetitions before the pause and the paused period shall be recorded.

7. Calculation and Expression of Test Results

7.1 Handling of data

The test data shall be assessed on the basis only of test specimens undergoing failure in the test portion and specimens taking the prescribed number of repetitions. In cases where tensile failure or slippage has clearly taken place at the anchorage portion, the data shall be disregarded and additional specimens shall be tested until the number of test specimens failing in the test portion exceeds the prescribed number.

7.2 *S-N* curve

The *S-N* curve shows the relationship between the maximum repeated stress, the stress range or the stress amplitude and the number of repetitions. When some test results come at the same point in the *S-N* diagram, the number of data shall be noted. Right-facing arrows shall be used to indicate that the test specimen did not fracture at that number of repetitions.

7.3 Fatigue strength after 2 million repetitions

The fatigue strength after 2 x 10^6 repetitions shall be derived from the *S-N* curve. Fatigue strength values shall be rounded off to three significant digits in accordance with JIS Z 8401.

8. Report

The report shall include the following items:

a) Name of continuous fiber sheet
b) Type of continuous fiber sheet and impregnation resin
c) Fiber mass per unit area and density of continuous fiber sheet
d) Fabrication date, fabrication method, curing period and conditioning temperature / humidity for test specimens
e) Test date, test temperature and humidity (from start to end of test)
f) Shape, dimensions and calculated cross-sectional area for each test specimen
g) Type of testing and recording machine (notations regarding the method of load [stress] amplitude control, etc.)
h) Maximum load (stress), minimum load (stress), load (stress) range, number of repetitions until failure, and repetition frequency for each test specimen
i) Records of observation of the type of failure for each test specimen
j) *S*-*N* curve

COMMENTARY ON TEST METHOD FOR TENSILE FATIGUE STRENGTH OF CONTINUOUS FIBER SHEETS

Introduction

This test method may be used when the fatigue strength must be confirmed for the use of continuous fiber sheets in concrete structures subject to repeated loads by running vehicles or high surf. This is prepared by referring to JIS K 7083 "Testing method for constant-load amplitude tension-tension fatigue of carbon fiber reinforced plastics" and JSCE-E 535 "Test method for tensile fatigue strength of continuous fiber reinforcing materials" published by the Japan Society of Civil Engineers.

To confirm the fatigue strength of continuous fiber sheets used to upgrade concrete structures, it would be ideal to perform the test on concrete members to which continuous fiber sheets are attached. However, as concrete members may require a large-scale test, the fatigue strength test on continuous fiber sheet itself is established to make the test comparatively easy to perform.

1. Scope

There are many methods for examining the fatigue strength, including the loading types of tension-tension, tension-compression, and compression-compression. In this specification, a tension-tension fatigue strength test under constant cyclic loading is adopted as the most basic method of evaluating material characteristics.

2. Normative Reference

3. Definitions

In addition to the terms used in the “Recommendations for Upgrading of Concrete Structures with Use of Continuous Fiber Sheets” and JSCE-E 541, JIS K 7083 "Testing method for constant-load amplitude tension-tension fatigue of carbon fibre reinforced plastics" is also used as a reference for the definitions of terms.

a)-e)

These definitions refer to loads but the word "stress" may be used in place of "load."

4. Test specimens

4.1

Except for the repetition of load, the method of load application to test specimens is the same as that of the tensile strength test in JSCE-E 541. Accordingly, the test specimens established in JSCE-E 541 are used.

4.2

In order to draw an *S-N* curve properly as shown in Figure C1, at least three specimens should be tested for at least three stress levels. However, if the *S-N* relationships cannot be clearly plotted due to unsuitable stress level settings, wide variations in data or other reason, additional specimens must be tested as needed. If the static tensile strength is required as the basis for setting the loading levels for the test, the static tensile strength test should be performed using the same lot and same shape of test specimen as the fatigue strength test, in accordance with JSCE-E 541 "Test method for tensile properties of continuous fiber sheets."

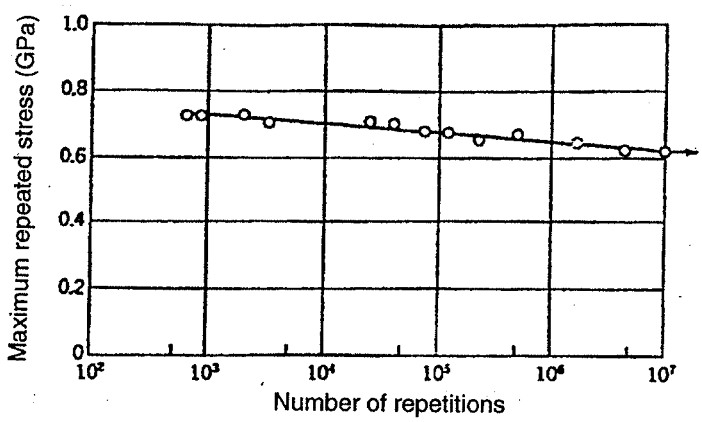

Figure C1 *S-N* curve

5. Testing Machine and Measuring Devices

5.1

The testing machine should be capable of controlling the load to a constant level automatically. If a testing machine with electrohydraulic control is to be used, care must be taken so that minute rotations are not happening in the knobs on the excitation side.

6. Test Method

6.3

If the clamping pressure of the knob is too great or too small, appropriate test results may not be obtained, so care is needed. If any slight horizontal movement or rotation of the knob on the excitation side of the testing machine is noticed, a guide should be fitted before testing to prevent such movement or rotation.

6.4

If the effects of creep on the tensile fatigue strength are known in advance, this should be taken into consideration in the setting of the test load and repetition frequency. In general, the number of repetitions before fatigue fracture occurs is affected not only by the maximum stress ratio but the stress amplitude. Therefore, different results may be obtained when the maximum and minimum stress ratios are different. In actual concrete structures subject to variable loads, the design load should be set as the maximum load.

The static tensile test should be performed in advance for test specimens from the same lot as the fatigue test in accordance with JSCE-E 541. If it is difficult to determine the maximum load for the initial test, use the following procedure.

a) From stresses equivalent to 5-55% of the static tensile strength, select the appropriate stress level and start the test with this value as the maximum repeated load.
b) If the test specimen does not fracture after 10^4 repetitions with this maximum repeated load, increase the maximum repeated load by 5% of the static tensile

strength and continue the test using the same test specimen. In such cases, the test should be conducted quickly without interruption, with the maximum repeated load incorporating 5% of the static tensile strength.

c) If the test specimen does not fracture after another 10^4 repetitions of the test in b) above, use the same procedure to increase the maximum repeated load again by 5% of the static tensile strength.

d) Repeat the procedure in (c) above until the test specimen fractures.

e) Set the maximum repeated load for the initial tensile-tensile fatigue test to the level at which the test specimen fractured, minus 5% of the static tensile strength.

6.5

The repetition frequency should be about 2-10 Hz. The upper limit for the repetition frequency should be one at which the test specimen does not get heated excessively.

6.6

The temperature and humidity for the test should conform to JSCE-E 541 and the test should be performed under the same conditions.

6.7

After the test starts, check and adjust the load level as needed to keep it at the prescribed level.

6.8

The number of repetitions should be expressed as a multiple of 10^n, such as 2.34×10^5, and rounded off to three significant digits.

7. Calculation and Expression of Test Results

7.2

For repeated loading, the stresses corresponding to the maximum load and minimum load represent the maximum repeated stress (σ_{max}) and minimum repeated stress (σ_{min}), respectively. The terms "load" or "stress" may be chosen depending on the context. In the fatigue test with a constant average load or constant minimum repeated load, the relationship is generally sought between the maximum repeated stress (or stress amplitude) and the number of repetitions until failure (*S*-*N* curve). Depending on the test objective, however, a fatigue strength curve for the prescribed number of repetitions may be plotted with the vertical axis showing the stress amplitude and the horizontal axis showing the average stress, or with the vertical axis showing the maximum stress and the horizontal axis showing the minimum stress.

In the test, it is difficult to draw a distinction between tensile fatigue strength and creep failure strength, and this issue awaits further study. In the calculation and expression of test results, therefore, the number of repetitions and the repetition frequency, i.e. the length of time that the repeated load is applied, must be clearly identified. Where the creep failure strength is known, this may be plotted on a fatigue strength diagram.

8. Report

If the test specimen does not fracture or the test is halted after the prescribed number of revolutions, this should be noted in the report. If the failure of test specimen is other than a separation rupture, the condition of the test specimen during the test and the failure mode should be noted.

7. TEST METHOD FOR ACCELERATED ARTIFICIAL EXPOSURE OF CONTINUOUS FIBER SHEETS (JSCE-E 547-2000)

1. Scope

This specification describes the method used to perform the accelerated artificial exposure test for the continuous fiber sheets used for upgrading of concrete members.

2. Normative Reference

The following standards, by being referenced herein, form a portion of these specifications. The most recent version of each standard should be used.

JSCE-E 541	Test method for tensile properties of continuous fiber sheets
JSCE-E 542	Test method for overlap splice strength of continuous fiber sheets
JIS A 1415	Methods of exposure to laboratory light sources for polymeric material of buildings
JIS Z 8401	Guide to the significant digits

3. Definitions

The following are the definitions of the major terms used in this specification in addition to the terms used in the "Recommendations for Upgrading of Concrete Structures with Use of Continuous Fiber Sheets" published by the Japan Society of Civil Engineers, JSCE-E 541 and JSCE-E 542.

a) Weathering

Physical and chemical changes of material properties due to exposure to sunlight, rain, snow and other outdoor natural conditions

b) Accelerated artificial exposure testing machine

A machine that creates reproducible standard test conditions to accelerate weathering artificially

c) Coupon test specimen

A test specimen selected from the same lot that is unexposed and subjected to the tensile strength and overlap splice strength tests

d) Tensile strength retention

The ratio of the tensile strength after accelerated artificial exposure compared with the tensile strength before accelerated artificial exposure, expressed as a percentage of one hundred (%)

e) Overlap splice strength retention

The ratio of the overlap splice strength after accelerated artificial exposure compared with the overlap splice strength before accelerated artificial exposure, expressed as a percentage of one hundred (%)

4. Test specimens

4.1 Accelerated artificial exposure plate

The method of preparing accelerated artificial exposure plates shall conform to the methods in JSCE-E 541 and JSCE-E 542. However, as a rule, the dimensions shall be no less than 300 mm in length nor 70 mm in width, and the plates shall be those that can be mounted to the accelerated artificial exposure test sample holder.

4.2 Number of accelerated artificial exposure plates

As a rule, no fewer than two accelerated artificial exposure plates shall be subjected to accelerated artificial exposure tests simultaneously.

4.3 Types and dimensions

The test specimens shall be cut from the plate that has undergone accelerated artificial exposure, and the method of preparing these test specimens shall conform to either the JSCE-E 541 or the JSCE-E 542. When making test specimens, the edge of the accelerated artificial exposure plate shall be avoided.

4.4 Number of test specimens

A number of test specimens suitable for the test objective shall be determined. It shall be no fewer than five.

5. Testing Machine and Measuring Devices

5.1 Accelerated artificial exposure testing machine

a) Two types of testing machines are available.
   - Type WV: Testing machine using an ultraviolet carbon arc lamp
   - Type WS: Testing machine using a sunshine carbon arc lamp

b) The configuration of the light source, filter and testing machine is specified in JIS A 1415.

c) The tensile testing machine is established in JSCE-E 541 and JSCE-E 542.

6. Test Method

6.1 Accelerated artificial exposure test

In addition to JIS A 1415, the following shall be considered in the test.

a) An appropriate test period shall be established. However, unless otherwise specified, the maximum values shall be 2000 hours for the Type WV testing machine and 1000 hours for the WS testing machine, in accordance with JIS A 1415.

6.2 Tensile strength test and overlap splice strength test

The tensile strength, modulus of elasticity and ultimate strain shall be obtained for the test specimens before and after the accelerated artificial exposure test, in accordance with JSCE-E 541. The overlap splice strength shall be obtained for the test specimens before and after the accelerated artificial exposure test, in accordance with JSCE-E 542.

7. Calculation and Expression of Test Results

7.1 Visual inspection

A visual inspection of the accelerated artificial exposure plate shall be conducted before and after the accelerated artificial exposure test, comparing the color and surface condition. If necessary, the accelerated artificial exposure plate shall be cut and ground and its section observed with a microscope.

7.2 Handling of data

In the tensile strength test, the test data shall be assessed on the basis only of test specimens undergoing failure in the test portion. In cases where tensile fracture or slippage has clearly taken place at the anchorage portion, the data shall be disregarded and additional specimens shall be tested until the number of test specimens fracturing in the test portion exceeds five.

7.3 Tensile strength retention

The tensile strength retention shall be calculated using Eq. (1) and rounded off to three significant digits in accordance with JIS Z 8401.

$$R_{ett} = \frac{\bar{f}_{fu1}}{\bar{f}_{fu0}} \times 100 \quad \text{.......... (1)}$$

where

R_{ett} : Tensile strength retention (%)

$\bar{f}_{fu0}$: Average value for tensile strength before accelerated artificial exposure (N/mm^2)

$\bar{f}_{fu1}$: Average value for tensile strength after accelerated artificial exposure (N/mm^2)

7.4 Overlap splice strength retention

The overlap splice strength retention shall be calculated using Eq. (1) and rounded off to three significant digits in accordance with JIS Z 8401.

$$R_{ets} = \frac{\bar{f}_{fus1}}{\bar{f}_{fus0}} \times 100 \quad \text{.......... (2)}$$

where

R_{ets} : Overlap splice strength retention (%)

$\bar{f}_{fus0}$: Average value for overlap splice strength before accelerated artificial exposure (N/mm^2)

$\bar{f}_{fus1}$: Average value for overlap splice strength after accelerated artificial exposure (N/mm^2)

8. Report

The report shall include the following items:

a) Common items
  (1) Name of continuous fiber sheet
  (2) Type of continuous fiber sheet and impregnation resin
  (3) Fiber mass per unit area and density of continuous fiber sheet
  (4) Identification of test specimen
b) Items relating to accelerated artificial exposure test
  (1) Type and model of testing machine and test conditions (black panel temperature, spray cycle, with or without humidity control unit, test period, location of test specimens, conditions for changing of test specimens, filter use conditions)
  (2) Date that accelerated artificial exposure test starts and ends
  (3) Observation records for appearance inspection
c) Items relating to tensile strength test
  (1) Fabrication date, fabrication method and curing period for test specimens
  (2) Temperature, humidity and duration of test specimen conditioning
  (3) Test date, test temperature and loading rate
  (4) Shape, dimensions and calculated cross-sectional area for each test specimen
  (5) Tensile capacity of each test specimen and average for these values
  (6) Maximum tensile strength of each test specimen and average for these values
  (7) Young's modulus of each test specimen and average for these values
  (8) Ultimate strain of each test specimen and average for these values
  (9) Load-strain curve for each test specimen
  (10) Tensile strength retention
d) Items relating to overlap splice strength test
  (1) Fabrication date, fabrication method and curing period for test specimens
  (2) Temperature, humidity and duration of test specimen conditioning

(3) Test date, test temperature and loading rate

(4) Shape, dimensions and calculated cross-sectional area for each test specimen

(5) Tensile capacity of each test specimen and average for these values

(6) Maximum tensile strength of each test specimen and average for these values

(7) Mode of failure for each test specimen

(8) Overlap splice strength retention

COMMENTARY ON TEST METHOD FOR ACCELERATED ARTIFICIAL EXPOSURE OF CONTINUOUS FIBER SHEETS

Introduction

The use of continuous fiber sheets to upgrade concrete structures is based on the premise that these structures are used for a long time, and that the effects of upgrading must be lasting and the materials used must be durable.

Accelerated artificial exposure tests are generally used as a means of predicting the durability of materials, and they are also thought to be an effective means of estimating the durability of continuous fiber sheets used as upgrading materials.

This test method evaluates the durability of continuous fiber sheets by determining changes in their mechanical properties through measurement of the tensile strength and overlap splice strength of continuous fiber sheets following accelerated artificial exposure tests.

1. Scope

This method applies to the tensile strength tests and overlap splice strength test for continuous fiber sheets during and after the period in which they are subjected to accelerated artificial exposure tests. This method may also be applicable as
to "bond strength," which is an important factor affecting the durability of concrete structures upgraded using continuous fiber sheets. However, when concrete is involved in test specimens, the test would become more complex in terms of devising a way to attach the test specimen to the sample holder and devising the sample holder itself. Accordingly, the bond strength test is not included within the scope of this test method.

2. Normative Reference

3. Definitions

4. Test specimens

4.1

The dimensions of the accelerated artificial exposure plate are determined through consideration of the shape and dimensions of the sample holders in general use and the specifications in JSCE-E 541 and JSCE-E 542. The width of 70 mm means that five Type A test specimens measuring 12.5 mm in width may be sampled.

5. Testing Machine and Measuring Devices

6. Test Method

6.1

Details of the accelerated artificial exposure test method are noted in JIS A 1415. The test period necessary to determine durability is generally longer for continuous fiber sheets than for plastic materials Therefore, a longer time than the maximum value specified in JIS A 1415 may be used.

7. Calculation and Expression of Test Results

8. Report

8. TEST METHOD FOR FREEZE-THAW RESISTANCE OF CONTINUOUS FIBER SHEETS (JSCE-E 548-2000)

1. Scope

This specification describes the method used to test the freeze-thaw resistance of the continuous fiber sheets used for upgrading of concrete members.

2. Normative Reference

The following standards, by being referenced herein, form a portion of these specifications. The most recent version of each standard should be used.

JSCE-E 541	Test method for tensile properties of continuous fiber sheets
JSCE-E 542	Test method for overlap splice strength of continuous fiber sheets
JIS A 1435	Test methods for frost resistance of exterior wall materials of buildings (freezing and thawing method)
JIS Z 8401	Guide to the significant digits

3. Definitions

The following are the definitions of the major terms used in this specification in addition to the terms used in the “Recommendations for Upgrading of Concrete Structures with Use of Continuous Fiber Sheets” published by the Japan Society of Civil Engineers, JSCE-E 541 and JSCE-E 542.

a) Tensile strength retention

The ratio of the tensile strength after freezing-thawing divided by the tensile strength before freezing-thawing, expressed as a percentage of one hundred (%)

b) Overlap splice strength retention

The ratio of the overlap splice strength after freezing-thawing divided by the overlap splice strength before freezing-thawing, expressed as a percentage of one hundred (%)

4. Test specimens

4.1 Types and dimensions

There shall be two types of test specimens as described below.

a) Type A or Type B test specimen in accordance with JSCE-E 541
b) Type A or Type B test specimen in accordance with JSCE-E 542

4.2 Number of test specimens

A number of test specimens suitable for the test objective shall be determined. However, there shall be no fewer than five test specimens for the tensile strength test and overlap splice strength test before and after freezing-thawing.

5. Testing Machine and Measuring Devices

5.1 Freeze-thaw testing machine

The testing machine used for the freeze-thaw resistance test shall consist of the heating and cooling unit needed to subject the test specimen to the prescribed freezing and thawing cycles, a testing tank, a spray unit, a temperature measurement unit and a control unit. The temperature measurement unit shall be capable of measuring the surface temperature of the control test specimen in the testing tank to an accuracy of within 1.0°C and shall be equipped with a recording unit, in accordance with the specification in JIS A 1435.

5.2 Tensile testing machine

The tensile testing machine shall be the machine specified in JSCE-E 541.

6. Test Method

6.1 Freezing and thawing method

The test method shall conform to the air freezing and thawing method specified in JIS A 1435, as follows.

a) Before the freeze-thaw resistance test, soak the test specimen in water for 24 hours.

b) The conditions for the freeze-thaw resistance test shall be as follows: the surface temperature of the test specimen shall be-20 ±2°C during freezing and 30 ±2°C during thawing (spraying). The temperature begins from room temperature for one cycle immediately after the start or the restart after interruption.

c) The period for each freeze-thaw cycle shall be 100 minutes, an 80-minute cooling period and a 20-minute thawing period. The test specimen shall reach the prescribed temperature within each of these time periods.

d) As a rule, the test shall consist of 300 freeze-thaw cycles.

6.2 Control of freezing and thawing temperatures

The freezing and thawing temperatures shall be controlled through measurement of the surface temperature of the continuous fiber sheet.

6.3 Tensile strength test and overlap splice strength test

The tensile strength, modulus of elasticity and ultimate strain shall be obtained before and after the freeze-thaw resistance test in accordance with JSCE-E 541. The overlap splice strength shall be measured before and after the freeze-thaw resistance test in accordance with JSCE-E 542.

7. Calculation and Expression of Test Results

7.1 Tensile strength retention

The tensile strength retention shall be calculated using Eq. (1) and rounded off to three significant digits in accordance with JIS Z 8401.

$$R_{ett} = \frac{\bar{f}_{fu1}}{\bar{f}_{fu0}} \times 100 \qquad (1)$$

where

R_{ett} : Tensile strength retention (%)

$\bar{f}_{fu0}$: Average value for tensile strength before freezing and thawing (N/mm^2)

$\bar{f}_{fu1}$: Average value for tensile strength after freezing and thawing (N/mm^2)

7.2 Overlap splice strength retention

The overlap splice strength retention shall be calculated using Eq. (2) and rounded off to three significant digits in accordance with JIS Z 8401.

$$R_{ets} = \frac{\bar{f}_{fus1}}{\bar{f}_{fus0}} \times 100 \quad \text{.......} \quad (2)$$

where

R_{ets} : Overlap splice strength retention (%)

$\bar{f}_{fus0}$: Average value for overlap splice strength before freezing and thawing (N/mm^2)

$\bar{f}_{fus1}$: Average value for overlap splice strength after freezing and thawing (N/mm^2)

8. Report

The report shall include the following items:

a) Common items
   (1) Name of continuous fiber sheet
   (2) Type of continuous fiber sheet and impregnation resin
   (3) Fiber mass per unit area and density of continuous fiber sheet
   (4) Identification of test specimen
b) Items relating to freeze-thaw resistance test
   (1) Type and model of testing machine and test conditions
   (2) Date that freeze-thaw resistance test starts and ends
c) Items relating to tensile strength test
   (1) Fabrication date, fabrication method and curing period for test specimens
   (2) Temperature, humidity and duration of test specimen conditioning
   (3) Test date, test temperature and loading rate
   (4) Shape, dimensions and calculated cross-sectional area for each test specimen
   (5) Tensile capacity of each test specimen and average for these values

(6) Maximum tensile strength of each test specimen and average for these values
(7) Young's modulus of each test specimen and average for these values
(8) Ultimate strain of each test specimen and average for these values
(9) Load-strain curve for each test specimen
(10) Tensile strength retention

d) Items relating to overlap splice strength test
(1) Fabrication date, fabrication method and curing period for test specimens
(2) Temperature, humidity and duration of test specimen conditioning
(3) Test date, test temperature and loading rate
(4) Shape, dimensions and calculated cross-sectional area for each test specimen
(5) Tensile capacity of each test specimen and average for these values
(6) Maximum tensile strength of each test specimen and average for these values
(7) Mode of failure for each test specimen
(8) Overlap splice strength retention

COMMENTARY ON TEST METHOD FOR FREEZE-THAW RESISTANCE OF CONTINUOUS FIBER SHEETS

Introduction

To determine the resistance of continuous fiber sheets to the effects of freezing and thawing, it is necessary to establish a proper test method. The method must evaluate the durability of continuous fiber sheets after they have experienced the range from low temperatures to high temperatures anticipated under the environmental conditions in which they are used. As a means of accomplishing this, the test specimens are subjected to repeated hot-cold temperature cycles between approximately -20°C-30°C, after which the tensile strength and overlap splice strength of the continuous fiber sheets are measured to determine changes in their mechanical properties. The following standards are referenced in the preparation of this test method:

JIS A 1435	Test methods for frost resistance of exterior wall materials of buildings (freezing and thawing method)
JIS A 6204	Chemical admixtures for concrete (Supplement 2: Test method for concrete freeze-thaw resistance)
JIS A 5209	Ceramic tiles

Of these specifications, the freeze-thaw resistance test method noted in the supplement of JIS A 6204 can be applied to bond tests using concrete test specimens in water, performed by rapidly alternating between freezing and thawing. However, a large-scale equipment is needed to evaluate the properties for individual continuous fiber sheets with concrete blocks, so this method is not necessarily applicable. Accordingly, a freeze-thaw resistance test method for continuous fiber sheets is established different from the ordinary freeze-thaw resistance test method for concrete.

The freeze-thaw resistance test method for continuous fiber sheets takes the test temperature range of -20°C and +30°C which is used for exterior wall construction materials, since this is a normal external environment for fiber sheets. The method conforming to the air freezing and thawing method is also taken into consideration because the continuous fiber sheets have a comparatively low water absorption coefficient.

1. Scope

2. Normative Reference

3. Definitions

4. Test specimens

4.1

For durability evaluation it is necessary to determine frost resistance with regard to the mechanical properties of continuous fiber sheets and their bond properties to concrete.

In general, the damage due to frost depends on the temperatures and duration of repeated freezing and thawing, the velocity gradient, and without or without water.

The types of test in this specification are categorized according to test specimen. The tensile strength test and overlap splice strength test of continuous fiber sheets conform to the air freezing and thawing method, one of the methods in JIS A 1435.

As a rule, the determination of frost resistance of materials combined with concrete should be done using the test methods for concrete and is outside the scope of this specification.

5. Testing Machine

5.1

The testing machine specified in JIS A 1435 houses the test specimen inside a testing tank. The machine should be capable of controlling the temperature in the tank from a humid state of 30°C to -20°C within 50 minutes and holding it there for a set period of time. As for the heating systems, rapid spraying with warm water having a temperature of 30°C, or a combination of spray and heater, must be equipped to increase the temperature to +30°C within 10 minutes. As a rule, the cooling capability of the testing machine must exceed 1°C/minute under load conditions.

During the thawing process, the nozzles to spray 30°C over the entire surface of the test specimen evenly must be provided on the top or side or both of the inside of the tank.

6. Test Method

6.1

a) In test methods for freeze-thaw resistance, the initial water content of test specimens affects the test results. Materials with a low coefficient of water absorption come to an almost completely saturated state after immersion in water for 24 hours. Therefore, continuous fiber sheets should be immersed in water for 24 hours prior to the start of the test.

b) and c) The air freezing and thawing method applied to this specification has generally been studied for use in evaluating the frost resistance of tile, a material with a low coefficient of water absorption. Through comparison with the frost resistance test in JIS A 5209, the number of freeze-thaw repetitions is more important than the freezing period or thawing period. Thus, in this test method, the period for each cycle is made as short as possible.

d) The number of freeze-thaw cycles should be 300 in accordance with the test method for the freeze-thaw resistance of concrete.

7. Calculation and Expression of Test Results

8. Report

9. TEST METHOD FOR WATER, ACID AND ALKALI RESISTANCE OF CONTINUOUS FIBER SHEETS (JSCE-E 549-2000)

1. Scope

This specification describes the method used to test the water, acid and alkali resistance of the continuous fiber sheets used for upgrading of concrete members.

2. Normative Reference

The following standards, by being referenced herein, form a portion of these specifications. The most recent version of each standard should be used.

JSCE-E 541	Test method for tensile properties of continuous fiber sheets
JSCE-E 542	Test method for overlap splice strength of continuous fiber sheets
JSCE-E 543	Test method for bond properties of continuous fiber sheets to concrete
JIS Z 8401	Guide to the significant digits

3. Definitions

The following are the definitions of the major terms used in this specification in addition to the terms used in the “Recommendations for Upgrading of Concrete Structures with Use of Continuous Fiber Sheets” published by the Japan Society of Civil Engineers, JSCE-E 541, JSCE-E 542 and JSCE-E 543.

a) Strength retention

The ratio of the strength (tensile strength, overlap splice strength and bond strength) after immersion divided by the strength before immersion, expressed as a percentage of one hundred (%)

b) Change in mass

The difference of mass before and after immersion, expressed as a percentage of one hundred (%)

4. Test specimens

4.1 Types and dimensions

The test specimens to match the test objectives shall be chosen among the following three types.

a) Type A or Type B test specimen established in JSCE-E 541
b) Type A or Type B test specimen established in JSCE-E 542
c) Test specimen established in JSCE-E 543

The test specimens for both the tensile strength test and the overlap splice strength test may be immersed in plate form. After immersion, the test specimens shall be cut from the plate and provided for each of the tests.

4.2 Preparation

The preparation of test specimens shall comply with the methods of preparation in each of the test methods. The edges of each of the test specimens shall be protected, and appropriate protection work shall be performed for the concrete block test specimen established in JSCE-E 543 to prevent the concrete components from being washed away in the immersion fluid.

4.3 Number of test specimens

A number of test specimens suitable for the test objective shall be determined. However, in each of the tests, there shall be no fewer than five test specimens for before and after immersion.

5. Testing Machine and Measuring Devices

5.1 Immersion container

The immersion container shall be a glass tank or other suitable container of a sufficient size to contain immersion fluid and to accommodate the test plates for immersion. The immersion container shall have a cover which is not impaired by the immersion fluid.

5.2 Constant-temperature unit

The constant-temperature unit shall maintain the prescribed temperature to an accuracy of within ±2°C.

5.3 Tensile strength test and overlap splice strength test

These tests shall comply with JSCE-E 541 and JSCE-E 542.

5.4 Bond strength test

This test shall comply with JSCE-E 543.

6. Test Method

6.1 Types of test fluid

Table 1 shows the standard types of test fluid that shall be used for immersion.

Table 1 Test fluid used for immersion

Test	Type of immersion fluid
Water resistance test	Distilled water
Acid resistance test	10% sulfuric acid solution (pH 1)
Alkali resistance test	10% sodium hydroxide solution (pH 14)

6.2 Immersion temperature

The immersion temperature shall be 20 ±5°C.

6.3 Immersion period

The standard immersion period shall be 60 days.

6.4 Immersion of test specimens

Each of the test specimens shall be immersed completely in the solution or water. Care must be taken to ensure that the water in the solution does not evaporate and that carbon dioxide in the air is not absorbed during immersion.

6.5 Procedure after immersion

After acid or alkali immersion, the test specimens shall be rinsed with water.

6.6 Tensile strength test and overlap splice strength test

These tests shall comply with JSCE-E 541 and JSCE-E 542.

6.7 Bond strength test

This test shall comply with JSCE-E 543.

7. Calculation and Expression of Test Results

7.1 Concentration of acid and alkali solution before and after test

In the acid and alkali resistance tests, the pH level of the acid and alkali solutions shall be measured before the beginning and after the end of immersion and the figures noted in the report.

7.2 Visual inspection

The test specimens shall be visually inspected before and after immersion and compared in terms of color, surface condition and change in shape. If necessary, the test specimen shall be cut and ground and its cross-section observed with a microscope.

7.3 Handling of tensile strength test data

In the tensile strength and overlap splice strength tests, the test data shall be assessed on the basis only of test specimens undergoing failure in the test portion.

7.4 Change in mass

The change in mass α for the tensile strength and overlap splice strength test specimens shall be calculated using Eq. (1) and rounded off to two significant digits in accordance with JIS Z 8401. However, both types of test specimen shall be dried and their mass measured until their weight is constant.

$$\alpha = \frac{w_0 - w_e}{w_0} \times 100 \quad \text{(1)}$$

where

α : Change in mass (%)

w_0 : Mass before immersion (g)

w_e : Mass after immersion (g)

7.5 Strength retention

The tensile strength retention, overlap splice strength retention and bond strength retention shall be calculated using Eq. (2), (3) and (4), respectively, and rounded off to two significant digits in accordance with JIS Z 8401.

7.5.1 Tensile strength retention

$$R_{ett} = \frac{\bar{f}_{fue}}{\bar{f}_{fu0}} \times 100 \quad \text{(2)}$$

where

R_{ett} : Tensile strength retention (%)

$\bar{f}_{fu0}$: Average value for tensile strength before immersion (N/mm^2)

$\bar{f}_{fue}$: Average value for tensile strength after immersion (N/mm^2)

7.5.2 Overlap splice strength retention

$$R_{ets} = \frac{\bar{f}_{fuse}}{\bar{f}_{fus0}} \times 100 \quad \text{(3)}$$

where

R_{ets} : Overlap splice strength retention (%)

$\bar{f}_{fus0}$: Average value for overlap splice strength before immersion (N/mm^2)

$\bar{f}_{fuse}$: Average value for overlap splice strength after immersion (N/mm^2)

7.5.3 Bond strength retention

$$R_{etb} = \frac{\bar{\tilde{\tau}}_{ue}}{\bar{\tilde{\tau}}_{u0}} \times 100 \quad \text{.......} (4)$$

where

R_{etb} : Bond strength retention (%)

$\bar{\tilde{\tau}}_{u0}$: Average value for bond strength before immersion (N/mm^2)

$\bar{\tilde{\tau}}_{ue}$: Average value for bond strength after immersion (N/mm^2)

Note: In each case, the width of the continuous fiber sheets is measured before immersion. Also, the same value should be used for effective bond strength before and after immersion.

8. Report

The report shall include the following items:

a) Common items
   (1) Name of continuous fiber sheet
   (2) Type of continuous fiber sheet and impregnation resin
   (3) Fiber mass per unit area and density of continuous fiber sheet
   (4) Identification of test specimen

b) Items relating to immersion in water, acid or alkali solution
   (1) Content, pH level and temperature of acid or alkali solution
   (2) Dates of starting and ending of immersion
   (3) Observation records for visual inspections and change in mass (%)

c) Items relating to tensile strength test
   (1) Fabrication date, fabrication method and curing period for test specimens
   (2) Temperature, humidity and duration of test specimen conditioning
   (3) Test date, test temperature and loading rate
   (4) Shape, dimensions and calculated cross-sectional area for each test specimen (immersed / not immersed)
   (5) Tensile capacity of each test specimen (immersed / not immersed) and average for these values
   (6) Maximum tensile strength of each test specimen (immersed / not immersed) and average for these values

(7) Young's modulus of each test specimen (immersed / not immersed) and average for these values
(8) Ultimate strain of each test specimen and average for these values
(9) Load-strain curve for each test specimen
(10) Tensile strength retention

d) Items relating to overlap splice strength test
(1) Fabrication date, fabrication method and curing period for test specimens
(2) Temperature, humidity and duration of test specimen conditioning
(3) Test date, test temperature and loading rate
(4) Shape, dimensions and calculated cross-sectional area for each test specimen (immersed / not immersed)
(5) Tensile capacity of each test specimen (immersed / not immersed)
(6) Maximum tensile strength of each test specimen (immersed / not immersed) and average for these values
(7) Mode of failure for each test specimen
(8) Overlap splice strength retention

e) Items relating to bond strength test
(1) Fabrication date, fabrication method and curing period for test specimens
(2) Temperature, humidity and duration of test specimen conditioning
(3) Test date, test temperature and loading rate
(4) Dimensions of each test specimen (immersed / not immersed), average values for width and length of continuous fiber sheet before immersion, and number of plies
(5) Concrete mixture, slump and compressive strength testing
(6) Tensile capacity of each test specimen (immersed / not immersed)
(7) Bond strength of each test specimen (immersed / not immersed) and average for these values
(8) Mode of failure for each test specimen
(9) Bond strength retention

COMMENTARY ON TEST METHOD FOR WATER, ACID AND ALKALI RESISTANCE OF CONTINUOUS FIBER SHEETS

Introduction

JSCE-E 538 "Test method for alkali resistance of continuous fiber reinforcing materials" is the only test method shown for the chemical resistance of continuous fiber reinforcing materials. This test method is established because continuous fiber reinforcing materials comprise mainly bars, and in most cases these are embedded in concrete and so alkali resistance is the most important aspect of durability.

The continuous fiber sheets dealt with here, on the other hand, are mainly attached to the surface of existing concrete members for upgrading. Therefore, in addition to alkali resistance presumed necessary due to contact with the concrete, it is also necessary to show test methods for water resistance presumed necessary due to leakage of water from cracks in the concrete and acid resistance through consideration of their application in sewer facilities.

Each of these three types of test methods has a different objective. However, the test results are organized together since they are similar in many aspects.

In the preparation of these test methods, reference is made to JIS K 7114 "Testing method for evaluation of the resistance of plastics to chemical substances" and JIS K 7070 "Test method for chemical resistance of fiber reinforced plastic."

1. Scope

2. Normative Reference

3. Definitions

4. Test specimens

4.1

Three types of test specimens are established for use in each of the tests. The tensile strength, overlap splice strength and bond strength test specimens should conform to JSCE-E 541, JSCE-E 542 and JSCE-E 543, respectively.

4.2

In the tensile strength and overlap splice strength test methods, the solution may seep into the test specimen from the edges, reducing the strength of the continuous fiber sheet. Therefore, impregnation resin or the like is used to seal the test specimen completely and prevent the solution from seeping in from the edges. Due to concern that the concrete components of the test specimen for the bond strength test may dissolve into the immersion solution, the entire surface of the concrete is protected in the same manner.

5. Testing Machine and Measuring Devices

5.1

Care must be taken to ensure that the test specimens in the immersion container do not come in contact with one another or with the container. The test specimens must be immersed at all times.

6. Test Method

6.1

The test solutions given as examples in JIS K 7114 should be used. The standard solutions should be distilled water for the water resistance test; a 10% sulfuric acid solution (equivalent to pH 1) for the acid resistance test, and a 10% sodium hydroxide solution (equivalent to pH 14) for the alkali resistance test.

The concentrations for the solutions conform to the sheet lining method, which has the highest concentrations among the quality test methods for anticorrosion covering layers indicated in the quality standard in the Recommendations for Corrosion Protection of Concrete.

When the purpose of use for the continuous fiber sheets differs from that of the test method, test solution types and concentrations other than these test solutions must be determined.

During long-term immersion testing, there is a possibility of water in the solution evaporating or absorbing carbon dioxide from the air, resulting in changes in the composition and pH level of the test solution or in sedimentation. Therefore, the immersion test should be conducted in a container that can be sealed from the outside air.

6.2

When chemical resistance is required, alkali resistance tests of continuous fiber reinforcing materials are often conducted at a temperature of 60°C since these materials are embedded in new concrete. This method, on the other hand, is intended primarily for waterworks and sewer facilities where the environment is thought to be at an almost constant temperature. Accordingly, reference is made to Class 2 standard atmosphere and the test temperature in JIS K 7114, and, as a rule, the immersion temperature is set to 20 ±5°C. However, when the environment is different, a temperature different from the one in this test method must be determined.

6.3

In the same manner, the immersion period conforms to 60 days, which is the maximum period for acid and alkali resistance tests indicated in the anticorrosion covering method noted in the Recommendations for Corrosion Protection of Concrete. However, depending on use conditions, the immersion period may be set anywhere between seven days and approximately one year. For longer immersion periods, sampling tests should be conducted during immersion.

7. Calculation and Expression of Test Results

7.2

Elution of the fiber bond into the acid or alkaline solution may cause changes in the surface condition, color or shape of the continuous fiber sheet. Accordingly, a visual comparison of the continuous fiber sheets before and after immersion is required. If a more detailed inspection is needed, the sides and ground sections of the test specimen should be inspected using an optical or electron microscope, and the test specimen should also be subjected to physical and chemical analysis if necessary.

7.4

The test specimens should be rinsed thoroughly to remove any acid or alkali adhering to the surface after immersion in acid or alkali solution, then dried until their mass is constant. Drying should preferably be carried out in a short time while avoiding thermal degradation of the test specimen by drying in a vacuum at no more than 60°C. After drying, the test specimens should be left in a constant-temperature, constant-humidity environment for 24 hours and then weighed to an accuracy of 0.1 g. Naturally, the mass and length of the test specimens must also be measured prior to immersion using the same procedure.

8. Report

Reference test methods :

The test method depends greatly on the skill of the test personnel. Methods that are almost identical to the methods indicated in other standards are not taken up in the test methods in the codes and specifications of the Japan Society of Civil Engineers. However, the following two test methods are sometimes needed in actual practice, so that they are presented here as reference test methods.

10. TEST METHOD FOR FLEXURAL TENSILE STRENGTH OF CONTINUOUS FIBER SHEETS (DRAFT)

1. Scope

This test method specifies the flexural tensile strength of continuous fiber sheets used to upgrade concrete members.

2. Normative Reference

T The following standards, by being referenced herein, form a portion of these specifications. The most recent version of each standard should be used.

JSCE-E 541	Test method for tensile properties of continuous fiber sheets
JIS Z 8401	Guide to the significant digits

3. Definitions

a) Test portion
The section of the test specimen on which the test is conducted, between the anchorage portion and the fastening portion

b) Anchorage portion
The section on the end of the test specimen to which the anchorage is attached in order to transmit the load from the testing machine to the test portion

c) Fastening portion
The section on the end of the test specimen to which the pin anchorage is attached in order to transmit the load from the testing machine to the test portion

d) Anchorage
A device attached to the anchorage portion on the test specimen in order to transmit the load from the testing machine to the test portion

e) Pin anchorage
A device, provided with an aperture to accommodate a fastening pin, that is attached to the fastening portion on the test specimen in order to transmit the load from the testing machine to the test portion

f) Maximum flexural capacity

The maximum tensile load applied to the test portion during the flexural tensile strength test

g) Loading rate

The rate at which the knobs move during the test

4. Test specimens

4.1 Preparation

The tensile strength test specimen, with a bent portion at the prescribed curvature, is made by impregnating continuous fiber sheets with impregnation resin and is prepared using the following procedure.

a) Prepare continuous fiber sheets coated and impregnated with impregnation resin in accordance with the preparation for the Type A or Type B test specimens specified in Section 4.2 of JSCE-E 541 [Section 4.2.1 a)-b) in JSCE-E 541 for Type A test specimens; Section 4.2.2 a)-e) in JSCE-E 541 for Type B test specimens].

b) Cut the semi-hardened test specimen to a width of 12.5 mm (for Type A test specimens) or in fiber bundles measuring 10-15 mm (for Type B test specimens). The cut test specimens shall be cured and hardened for not less than seven days on a plate with corners at the prescribed curvature at room temperature (23 ±2°C). The standard corner angle shall be 90°.

4.2 Anchorage portion

As a rule, the anchorage portion of the test specimen shall conform to Section 4.2 in JSCE-E 541 and shall be capable of accommodating a suitable anchorage.

4.3 Fastening portion

The fastening portion of the test specimen shall be provided with an aperture to accommodate a fastening pin inserted after a steel anchorage measuring no less than 1-2 mm (depth) x 50 mm (width) x 100 mm (length) has been fastened so that the continuous fiber sheet is in the center. If the flexural tensile strength is high and the anchorage comes apart from the fastening portion, a steel pipe shall be used for the anchorage and the end of the test specimen fastened using expansive concrete.

4.4 Number of test specimens

A number of test specimens suitable for the test objective shall be determined. However, there shall be no fewer than five.

5. Testing Machine

The testing machine used for the flexural tensile strength test shall be one that has a load capacity greater than the maximum tensile capacity of the test specimen and is capable of applying loads at the prescribed loading rate. As shown in Figure 1, its configuration shall enable tensile force to be applied by pressing with a bending device at the prescribed curvature on the test specimen bent to a 90° angle.

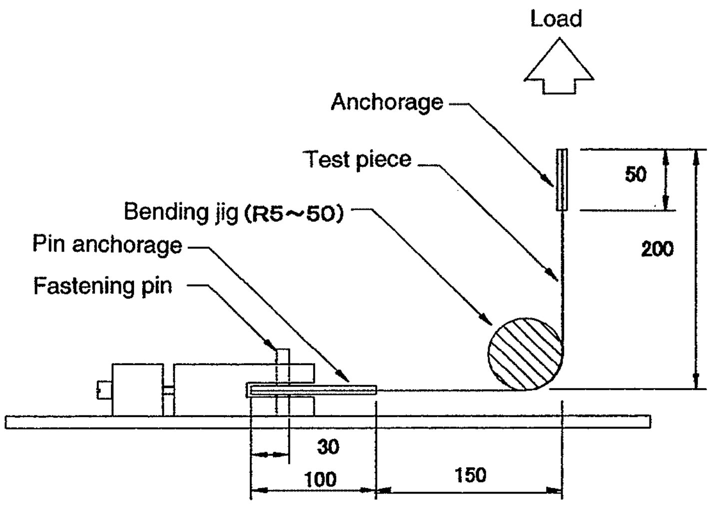

Figure 1 Outline of test method (unit: mm)

6. Test Method

6.1 Dimensions of test specimens

The width of the straight portion of the test specimen shall be measured to within approximately 0.1 mm at two locations on the anchoring side and two locations on the fastening side.

6.2 Attaching test specimens

The test specimen shall be attached by fastening the pin anchorage in the fastening portion to a special device and applying a bending device with the same curvature as the bending portion of the test specimen to the bending portion of the test specimen, and then fastening the anchorage of the anchorage portion to the device of the tensile testing machine. The test specimen shall be fastened so that the longer axis of the test specimen coincides with the loading axis, and that the bending portion of the test specimen and the bending portion of the device overlap. However, from past results it is known that the bending portion of the test specimen moves a minute distance toward the anchorage portion before failure, due to expansion of the test specimen itself, loosening of the device, etc. Therefore, the test specimen should be positioned on the fastening portion side so that the bending portion of the test specimen comes in contact with the device during failure.

6.3 Test temperature

The test temperature shall be 20 ±5°C. However, if the test specimen is not sensitive to changes in temperature, the test may be conducted at a temperature of 5-35°C. When the specimen is to be used under special work conditions or in special environments, these shall be taken into consideration when determining the test temperature.

6.4 Loading rate

The loading rate shall be adjusted so that the strain rate in the test portion is approximately 1.0-2.0% per minute.

6.5 Scope of test

The loading test shall be performed until the test portion fractures and measurements shall be made and recorded continuously or at regular intervals until the maximum capacity.

7. Calculation and Expression of Test Results

7.1 Handling of data

The test data shall be assessed on the basis only of test specimens undergoing failure in the test portion. In cases where failure or slippage has clearly taken place at the anchorage portion, the data shall be disregarded and additional specimens from the same lot shall be tested until the number of test specimens experiencing failure in the test portion exceeds the prescribed number.

7.2 Flexural tensile strength

The flexural tensile strength shall be calculated using Eq. (1) and rounded off to three significant digits in accordance with JIS Z 8401.

$$f_{fur} = \frac{F_u}{A} \qquad \text{(1)}$$

where

f_{fur} : Flexural tensile strength (N/mm^2)

F_u : Maximum flexural tensile capacity (N)

A : Cross-sectional area of test specimen (mm^2) (calculated with the method specified in Section 7.3 of JSCE-E 541)

8. Report

The report shall include the following items.

a) Type of continuous fiber sheet
b) Type of impregnation resin
c) Radius of curvature of bending portion

d) Fabrication method for test specimen (dimensions of each test specimen, dimensions of bonded portion, hardening conditions, etc.)
e) Number of test specimens
f) Loading rate or rate of crosshead movement during test
g) Flexural tensile strength for each test specimen and average of these values
h) Failure status
i) Other special notes

11. TEST METHOD FOR SURFACE INCOMBUSTIBILITY OF PROTECTIVE MATERIALS FOR CONTINUOUS FIBER SHEETS (DRAFT)

1. Scope

This test method specifies the method used to evaluate the incombustibility of the surface protection materials that provide continuous fiber sheets with resistance to flame.

2. Normative Reference

The following standards, by being referenced herein, form a portion of these specifications. The most recent version of each standard should be used.

JIS A 5430	Fiber reinforced cement boards
JIS A 1321	Testing method for incombustibility of internal finish material and procedure of buildings

3. Definitions

a) Furnace

A unit that heats the surface-protected side of the test specimen from one direction with electrical or gas heat

b) Smoke collector

A container used to collect the smoke emitted by the furnace and measure the smoke emission coefficient

c) Actinograph

A unit, made up of a white light source and a sensor, that measures the amount of light absorbed between the light source and the sensor

d) Smoke emission coefficient

A coefficient derived from the ratio between the start of overheating by the actinograph and the light transmittance when smoke is produced

e) Set exhaust temperature curve

The exhaust temperature curve when a 10 mm thick pearlite board is used as the test specimen. The heating conditions are set so that the temperature in the furnace is the same as the exhaust temperature curve.

f) Standard temperature curve

A temperature curve with 50°C added to the set exhaust temperature curve. The actual test specimen is tested under identical heating conditions and must be at or below the standard temperature curve in order to pass the test.

4. Test specimens

4.1 Test specimen materials and configuration

The test specimen materials and configuration shall be the asbestos slate board or concrete slab specified in JIS A 5430, to which are applied primer, putty, impregnation adhesive and continuous fiber sheets to form base test specimens. The incombustible covering materials to be evaluated are applied to these base test specimens, forming the test specimens for the incombustibility test. The flame retardant covering materials are processed in accordance with the specifications of the applicable manufacturers.

4.2 Number of test specimens

A number of test specimens suitable for the test objective shall be determined. However, there shall be no fewer than three test specimens.

4.3 Dimensions of test specimens

Test specimens shall measure 22 cm both vertically and horizontally.

4.4 Curing of test specimens

After fabrication, test specimens shall be cured by drying them for at least 24 hours in a dryer at 35-45°C and then leaving them in a dessicator for at least 24 hours.

5. Testing Machine

The testing machine shall be in accordance with the one established in Section 3 "Surface test" in JIS A 1321.

6. Test Method

For the heating test, the heat reception surface of the test specimen shall measure 18 cm both vertically and horizontally. After heating for three minutes with a secondary heat source, the primary heat source shall be added and the test specimen heated for seven hours.

A standard board (10 mm pearlite board) shall be used as the test specimen to set the heating conditions so that the exhaust temperature can be reproduced to an error of within 20°C of the temperature shown in Table 1. Otherwise, the heating conditions shall be in accordance with JIS A 1321.

7. Calculation and Expression of Test Results

Each of the test specimens shall be considered to pass the heating test specified in Section 6 above if a)-e) below are applicable:

a) The test specimen is not melted through its entire thickness and shows no other conspicuous harmful deformation from flame

Table 1 Set exhaust temperature curve

Elapsed time (minutes)	1	2	3	4	5	6	7	8	9	10
Exhaust temperature (°C)	70	80	90	155	205	235	260	275	290	305

Note: The measurements of light passing through the smoke shall be conducted within 15 seconds for each measurement.

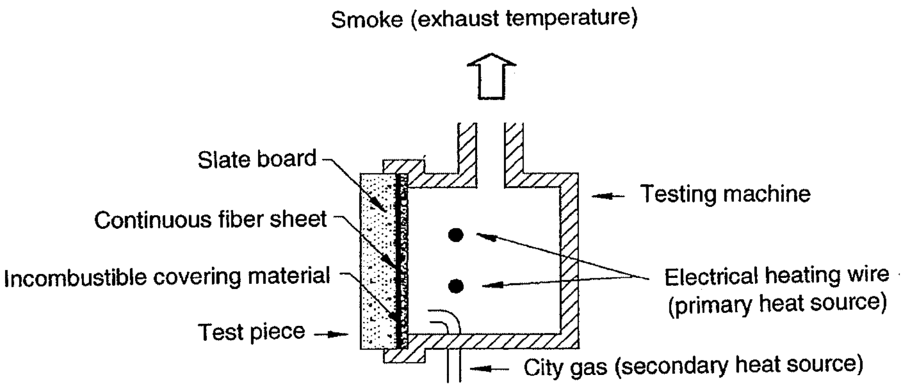

Figure 1 Overview of testing machine

b) There is no flame remaining 30 minutes or more after heating has ended.

c) In the test results, the exhaust temperature curve (the curve indicated by the recording thermometer specified in JIS A 1321; hereafter the same) does not exceed the standard temperature curve (the curve formed by adding 50°C to each of the set exhaust temperatures and connecting these values; hereafter the same) during the heating test. However, after three minutes has elapsed following the start of the test, the exhaust temperature curve may exceed the standard temperature curve within the range of the conditions noted in (d) below.

d) The calculated area (unit °C x minutes) in which the exhaust temperature curve exceeds the standard temperature curve, plus the section enclosed by the exhaust temperature curve and standard temperature curve, is 100 or less.

e) The smoke emission coefficient per unit area (C_A) derived according to Eq. (1) is less than 60.

$$C_A = 240 \log_{10} \frac{I_0}{I} \qquad (1)$$

where

I_0 : Light intensity at beginning of heating test (lx)

I : Minimum light intensity during heating test (lx)

8. Report

The report shall include the following items:

a) Pass / fail evaluation for surface incombustibility test
b) Material name, shape, dimensions, configuration, weight, content, surface finishing, and summary of other specifications
c) Heating conditions
d) Test specimen conditions
e) Summary of test results (exhaust temperature, smoke emission curve, cumulative temperature, amount of smoke emitted, amount of time flame remained, melting and other deformation, etc.)
f) Test date, name of testing institution, name of person in charge and name of person implementing test