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.

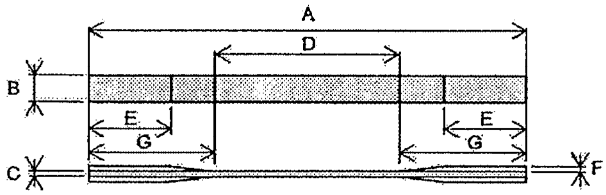

Figure 1 Shape of test specimens (Type A and Type B)

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.

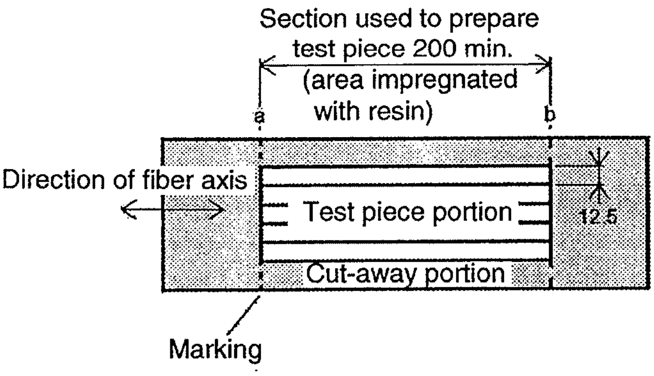

Figure 2 Dimensions of plate used to prepare Type A test specimens (unit: mm)

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.

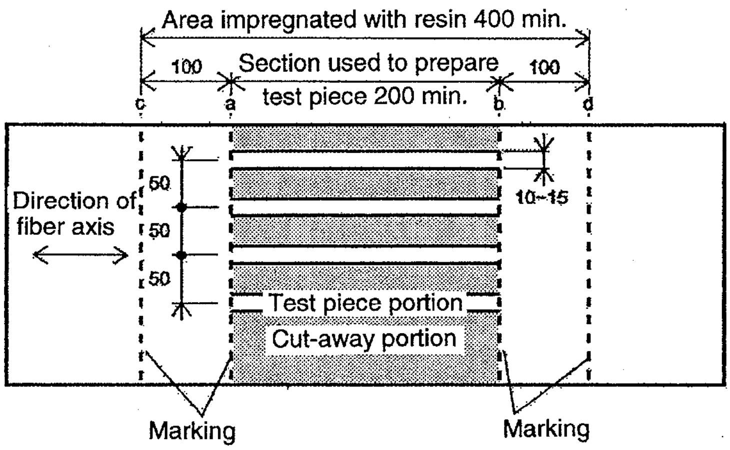

Figure 3 Dimensions of plate used to prepare Type B test specimens (unit: mm)

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.

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

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.

$$\varepsilon_{fu} = \varepsilon_{last} \cdot \frac{F_u}{F_{last}} \qquad (4)$$

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.

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

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.