TEST METHOD FOR TENSILE PROPERTIES OF CONTINUOUS FIBER REINFORCING MATERIALS (JSCE-E 531-1995)

1. SCOPE

This specifications specifies mainly the test method for tensile properties of CFRM used in place of steel reinforcement or prestressing tendon in concrete.

2. DEFINITIONS

The following terms are defined for general use in this Specifications, in addition to the terms used in the "Recommendation for Design and Construction for Concrete Structures using Continuous Fiber Reinforcing Materials" and the "Quality Specifications for Continuous Fiber Reinforcing Materials":

(1) Test section: The part of a test piece subject to testing between the anchoring sections of the test piece
(2) Anchoring section: The end part of a test piece where an anchorage is fitted to transmit loads from the testing machine to the test section
(3) Gauge length: The distance between two gauge points on the test section providing a reference length for strain measurements
(4) Anchorage: Device fitted to the anchoring section of a test piece to transmit loads from the testing machine to the test piece
(5) Tensile capacity: The tensile load at the time of failure of the test piece
(6) Guaranteed tensile capacity: Guaranteed value for the tensile capacity; if none is specified, the manufacturer's guaranteed tensile capacity shall be adopted
(7) Ultimate strain: Strain corresponding to the tensile capacity

3. TEST PIECES

3.1 Preparation of test pieces

Test pieces shall as a rule not be subjected to any processing. For mesh-type CFRM, linear test pieces may be prepared by cutting away extraneous parts in such a way as not to affect the performance of the part to be tested. However, processing will be permissible for anchoring sections to be provided in the test piece.

3.2 Handling of test pieces

During the sampling and preparation of test pieces, all deformation, heating, outdoor exposure to ultraviolet light etc. causing changes to the material properties of the test section of the test piece must be avoided.

3.3 Length of test pieces

The length of the test piece shall be the length of the test section added to the length of the anchoring section. The length of the test section shall be not less than 100mm, and not less than 40 times the nominal diameter of the CFRM. For CFRM in strand form, as an additional condition, the length shall be more than 2 times the strand pitch.

3.4 Number of test pieces

The number of test pieces shall not be less than five. If the test piece is found clearly to have failed at the anchoring section, or to have slipped out of the anchoring section, an additional test shall be performed on a separate test piece taken from the same lot.

4. TESTING MACHINE AND DEVICES

4.1 Testing machine

The testing machine to be used in tensile testing shall conform to JIS B 7721 (Tensile Testing Machines). The testing machine shall have a loading capacity in excess of the tensile capacity of the test piece, and shall be capable of applying loading at the required loading rate.

4.2 Anchorage

The anchorage shall be suited to the geometry of the test piece, and shall have the capacity to transmit loads capable to cause the test piece to fail at the test section. The anchorage shall constructed so as to transmit loads reliably from the testing machine to the test section, transmitting axial loads only to the test piece, without transmitting either torsion or flexural force.

4.3 Extensometer and strain gauge

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

5. TEST TEMPERATURE

The specifications test temperature shall generally be within the range 5~35°C. The test temperature for test pieces sensitive to temperature variations shall be 20±2°C.

6. TEST METHOD

6.1 Mounting of test piece

When mounting the test piece on the testing machine, care must be taken to ensure that the longer axis of the test piece coincides with the imaginary line joining the two anchorages fitted to the testing machine.

6.2 Mounting of extensometer and strain gauge

In order to determine the Young's modulus and ultimate strain of the test piece, an extensometer or strain gauges shall be mounted in the center of the test section at a distance of at least 8 times the nominal diameter of the CFRM from the anchorages, correctly in the direction of tensioning. The gauge length when using an extensometer shall not be less than 8 times the nominal diameter of the CFRM. The gauge length for stranded CFRM shall not be less than 8 times the nominal diameter of the CFRM, and not less than the length of the stranding pitch.

6.3 Loading rate

The specifications rate of loading the test piece shall be between 100~500 N/mm^2 per minute. If a strain control type of testing machine is used, loading shall be applied to the test piece at a fixed strain rate corresponding to 100~500 N/ mm^2 per minute.

6.4 Scope of test

The loading shall be completed until tensile failure, and the measurements shall be recorded until the strain reaches at least 60% of the tensile capacity or the guaranteed tensile capacity.

7. CALCULATION AND EXPRESSION OF TEST RESULTS

7.1 Handling of data

The material properties of CFRM shall be assessed on the basis only of test pieces undergoing failure in the test section. In cases where tensile failure or slippage has clearly taken place at the anchoring section, the data shall be disregarded and additional tests shall be performed until the number of test pieces failing in the test section is not less than five.

7.2 Load-displacement curve

A load (stress) ~ displacement (strain) curve shall be derived from load or stress and strain measurements recorded.

7.3 Tensile strength

Tensile strength shall be calculated according to Eq. (1), rounded off to three significant digits.

$$f_u = F_u / A \qquad (1)$$

where

f_u = tensile strength (N/mm^2)
F_u = tensile capacity (N)
A = nominal cross sectional area of a test piece (mm^2)

7.4 Tensile rigidity and Young's modulus

Tensile rigidity and Young's modulus shall be calculated from the load difference between 20% and 60% of tensile capacity according to the load-strain curve obtained from extensometer or strain gauge readings according to Eq. (2) and (3), rounded off to three significant digits. For materials where a guaranteed tensile capacity is set, the values at 20% and 60% of the guaranteed tensile capacity may be used.

$$EA = \Delta F / \Delta e \qquad (2)$$

$$E = \frac{\Delta F}{\Delta e \cdot A} \qquad (3)$$

where

EA = tensile rigidity (N)

E = Young's modulus(N/mm^2)

ΔF = difference between loads at 20% and 60% of tensile failure capacity or guaranteed tensile capacity

Δe = strain difference between the above two points

7.5 Ultimate strain

Ultimate strain shall be the strain corresponding to the tensile failure capacity when strain gauge measurements of the test piece are available up to failure. If extensometer etc. measurements could not be made until failure, ultimate strain shall be calculated from the tensile capacity and Young's modulus according to Eq. (4), rounded off to three significant digits.

$$e_u = \frac{F_u}{EA} \qquad (4)$$

where

e_u = ultimate strain

8. TEST REPORT

The test report shall include the following items:

(1) Name of CFRM

(2) Type of fiber and fiber binding material, volume ratio of fiber

(3) Numbers or identification marks of test pieces

(4) Designation, nominal diameter, nominal cross sectional area

(5) Date of test, test temperature, loading rate

(6) Tensile capacity for each test piece, averages and specifications deviations for tensile capacity and tensile strength

(7) Tensile rigidity and Young's modulus for each test piece, and averages

(8) Ultimate strain for each test piece, and averages

(9) Stress-strain curve for each test piece

TEST METHOD FOR FLEXURAL TENSILE PROPERTIES OF CONTINUOUS FIBER REINFORCING MATERIALS (JSCE-E 532-1995)

1. SCOPE

This specifications specifies mainly the test method for flexural tensile properties of bent CFRM used in place of steel reinforcement or prestressing tendon in concrete.

2. DEFINITIONS

The following terms are defined for general use in this Specifications, in addition to the terms used in the "Recommendation for Design and Construction for Concrete Structures using Continuous Fiber Reinforcing Materials", the "Quality Specifications for Continuous Fiber Reinforcing Materials" and the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials":

(1) Deflected section: Section of a CFRM which is bent and maintained at the required bending angle and bending diameter ratio

(2) Deflector: Device used to maintain the position, alter the bending angle, or alleviate the stress concentrations in the CFRM; sometimes installed in the deflected section

(3) Bending angle: Angle formed by the straight sections of a test piece on either side of the deflector

(4) Bending diameter ratio: Ratio of the external diameter of the deflector surface in contact with the CFRM, and the nominal diameter of the CFRM

(5) Bending tensile capacity: Tensile load at the moment of failure of the test piece

3. TEST PIECES

3.1 Preparation and handling of test pieces

Test pieces shall be prepared and handled in accordance with the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

3.2 Length of test pieces

The length of the test piece shall be the length of the test section added to the length of the anchoring section. The length of the test section shall not be less than 100mm from the anchorages to the deflected section, and not less than 40 times the nominal diameter of the CFRM. For CFRM in strand form, as an additional condition, the length shall be not less than 2 times the strand pitch.

3.3 Number of test pieces

The number of test pieces shall not be less than three for each test condition (combination of bending diameters and bending angles). If the test piece is found clearly to have failed at the anchoring section, or to have slipped out of the anchoring section, an additional test shall be performed on a separate test piece taken from the same lot.

4. TESTING MACHINE AND DEVICES

4.1 Testing machine

The testing machine must include a loading device, load indicator, anchorages holder and deflector. The testing machine must also have a structure capable of continuing the test up to the tensile failure.

4.2 Loading device

The loading device shall have a loading capacity in excess of the tensile capacity of the test piece, and shall be capable of applying loading at the required loading rate.

4.3 Load indicator

The load indicator must be capable of displaying loads with an accuracy of not less than 1% of the failure load, up to failure of the test piece.

4.4 Anchorage holder

The anchorage holder must be suited to the geometry of the test piece, and must be capable of accurately transmitting loads from the testing machine to the test piece. It must be structured so as to transmit axial loads only to the test piece, without transmitting either torsion or flexural force.

4.5 Deflector

The deflector must be capable of maintaining the required bending angle and bending diameter during the test until failure of the test piece. The surface of the deflector in contact with the test piece must be robust and smooth.

5. TEST TEMPERATURE

The specifications test temperature shall generally be within the range 5~35°C. The test temperature for test pieces sensitive to temperature variations shall be 20±2°C.

6. TEST METHOD

6.1 Test preparation

The bending diameter and bending angle shall be set appropriately for the test. This combination then forms a single test condition. As a specifications configuration, only one deflected section shall be set up in the test piece.

6.2 Mounting of test piece

Care shall be taken when mounting the test piece on the testing machine to maintain the required bending angle and bending diameter at the deflected section during the test.

6.3 Loading rate

The specifications rate of loading the test piece shall be between 100~500 N/mm^2 per minute.

6.4 Scope of test

Loading shall be applied until failure of the test piece. Load and failure location shall be measured and recorded at the time of failure.

7. CALCULATION AND EXPRESSION OF TEST RESULTS

7.1 Handling of data

The material properties of CFRM shall be assessed on the basis only of test pieces undergoing failure in the test section. In cases where tensile failure or slippage has clearly taken place at the anchoring section, the data shall be disregarded and additional tests shall be performed until the number of test pieces failing in the test section is not less than three.

7.2 Bending tensile capacity

The average, maximum, minimum, and specifications deviation of the bending tensile capacity for each set of test conditions shall be calculated.

7.3 Failure patterns

The location and mode of failure shall be observed and recorded for each test piece.

8. TEST REPORT

The test report shall include the following items:

(1) Name of CFRM
(2) Type of fiber and fiber binding material, volume ratio of fiber
(3) Numbers or identification marks of test pieces
(4) Designation, nominal diameter, maximum cross sectional area
(5) Date of test, test temperature, loading rate
(6) Condition of surface of CFRM (material, thickness, configuration etc. of any coating, etc.)
(7) Bending angle, external diameter of surface position of deflected section, bending diameter ratio, material and surface configuration
(8) Bending tensile capacity for each test piece
(9) Location and mode of failure for each test piece
(10) Numbers of test pieces for each set of conditions in (7); average, maximum, minimum, and specifications deviation of the bending tensile capacity

TEST METHOD FOR CREEP FAILURE OF CONTINUOUS FIBER REINFORCING MATERIALS (JSCE-E 533-1995)

1. SCOPE

This specifications specifies mainly the test method for creep failure of CFRM used in place of steel reinforcement or prestressing tendon in concrete.

2. DEFINITIONS

The following terms are defined for general use in this Specifications, in addition to the terms used in the "Recommendation for Design and Construction for Concrete Structures using Continuous Fiber Reinforcing Materials" and the "Quality Specifications for Continuous Fiber Reinforcing Materials":

(1) Creep: Time-dependent deformation when CFRM is subjected to a sustained constant load at a constant temperature
(2) Creep strain: Strain occurring in a test piece due to creep
(3) Creep failure: Failure occurring in a test piece due a sustained load
(4) Creep failure time: Time between start of a sustained load, and failure of the test piece
(5) Creep failure capacity: Load causing failure after a specified period of time from the start of a sustained load. In particular, the load causing failure after 1 million hours is referred to as the million hour creep failure capacity.
(6) Creep failure strength: Stress causing failure after a specified period of time from the start of a sustained load. In particular, the stress causing failure after 1 million hours is referred to as the million hour creep failure strength.
(7) Load ratio: Ratio of a constant sustained load applied to a test piece, and the tensile failure load

3. TEST PIECES

3.1 Preparation, handling and dimensions of test pieces

Test pieces shall be prepared and handled in accordance with the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

3.2 Number of test pieces

The number of test pieces for each test condition shall not be less than three. If the test piece is found clearly to have failed at the anchoring section, or to have slipped out of the anchoring section, an additional test shall be performed on a separate test piece taken from the same lot.

4. TESTING MACHINE AND DEVICES

4.1 Testing machine

The testing machine must be capable of maintaining constant, sustained loading even during deformation of the test piece.

4.2 Anchorage

The anchorage must be in accordance with the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

4.3 Extensometer and strain gauge

The extensometer and strain gauge must be in accordance with the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

4.4 Hour meter

The hour meter for measuring the passage of time must be accurate to within 1% of the elapsed time .

5. TEST TEMPERATURE

The test temperature shall normally be within the range 20±2°C, except in special circumstances.

6. TENSILE CAPACITY

The tensile capacity shall be calculated in accordance with the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

7. TEST METHOD

7.1 Mounting of test piece, and gauge distance

Mounting of test pieces and gauge length shall be in accordance with the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

7.2 Loading

(1) Care must be taken during loading to prevent the test piece from being subjected to any shock or vibration.

(2) Creep test measurement is considered to start at the moment when of the prescribed load to the test piece has been completed.

7.3 Selection of sustained loads to be applied

(1) Creep tests must be conducted for not less than five sets of load ratio conditions, selected on the basis of the tensile capacity.

(2) One set of load ratio conditions must be such that three test pieces must not fail after 1000 hours of loading.

7.4 Measurement of creep strain

Creep strain shall be recorded automatically by a recorder attached to the testing machine. If no recorder is attached to the testing machine, creep strain shall be measured and recorded after the following times have elapsed:

> 1, 3, 6, 9, 15, 30, 45 minutes; 1, 1.5, 2, 4, 10, 24, 48, 72, 96, 120 hours; and in general every 24 hours subsequently, with a minimum of one measurement in every 120 hours.

8. CALCULATION AND EXPRESSION OF TEST RESULTS

8.1 Handling of data

The material properties of CFRM shall be assessed on the basis only of test pieces undergoing failure in the test section. In cases where tensile failure or slippage has clearly taken place at the anchoring section, the data shall be disregarded and additional tests shall be performed until the number of test pieces failing in the test section is not less than three.

Data for test pieces breaking at the start of loading shall be disregarded. In such cases, the applied load and the creep failure time only shall be recorded but excluded from the data, although no additional tests need be performed.

8.2 Load ratio - creep failure time curve

For each test piece subjected to creep test, the load ratio - creep failure time curve shall be plotted on a semi-logarithmic graph where the load ratio is represented on an arithmetic scale on the vertical axis, and creep failure time in hours is represented on an logarithmic scale on the horizontal axis.

8.3 Creep failure line chart

A creep failure line chart shall be prepared, calculating an approximation line from the graph data by the least-squares method according to Eq. (1).

$$Y = a - b \log T \quad (1)$$

where

Y = load ratio
a,b = empirical constants
T = time (h)

8.4 Creep failure capacity and creep failure strength

The load ratio at 1 million hours (approximately 114 years) determined from the calculated approximation line shall be the creep failure load ratio; the load and stress corresponding to this creep failure load ratio shall be the million hour creep failure capacity and the million hour creep failure strength respectively.

The million hour creep failure strength shall be calculated according to Eq. (2), rounded off to three significant figures

$$f_r = F_r / A \qquad (2)$$

where

f_r = million hour creep failure strength (N/ mm^2)
F_r = million hour creep failure capacity (N)
A = nominal cross sectional area of test piece (mm^2)

9. TEST REPORT

The test report shall include the following items:
(1) Name of CFRM
(2) Type of fiber and fiber binding material, volume ratio of fiber
(3) Numbers or identification marks of test pieces
(4) Designation, nominal diameter, maximum cross sectional area
(5) Date of test, test temperature
(6) Type and name of test machine
(7) Type and name of anchorage
(8) Tensile capacity, and average tensile capacity and tensile strength for each test piece
(9) Load ratios and creep failure time curve for each test piece
(10) Formula for derivation of approximation line
(11) Creep failure load ratio, million hour creep failure capacity and million hour creep failure strength

TEST METHOD FOR LONG-TERM RELAXATION OF CONTINUOUS FIBER REINFORCING MATERIALS (JSCE-E 534-1995)

1. SCOPE

This specifications specifies mainly the test method for evaluating the relaxation ratio for long-term relaxation under a given constant temperature and strain, for CFRM used in place of steel reinforcement or prestressing tendon in concrete.

2. DEFINITIONS

The following terms are defined for general use in this Specifications, in addition to the terms used in the "Recommendation for Design and Construction for Concrete Structures using Continuous Fiber Reinforcing Materials" and the "Quality Specific ations for Continuous Fiber Reinforcing Materials":

(1) Relaxation: Refers to stress relaxation: the time-dependent decrease in load in a CFRM held at a given constant temperature with a prescribed initial load applied and held at a given constant strain .
(2) Relaxation rate: Percentage reduction of loading relative to the initial load after a given period of time when an initial load is applied and the strain fixed. In particular, the relaxation value after 1 million hours (approximately 114 years) is referred to as the million year relaxation rate.
(3) Tensile capacity: The average of the tensile failure loads determined based on tests conducted in according with the "Test Method for Tensile Testing of Continuous Fiber Reinforcing Materials". The test temperature shall normally be within the range 20±2°C, except in special circumstances.

3. TEST PIECES

3.1 Preparation, handling and dimensions of test pieces
Test pieces shall be prepared and handled in accordance with the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

3.2 Number of test pieces
The number of test pieces for each test condition shall not be less than three. If the test piece is found clearly to have failed at the anchoring section, or to have slipped out of the anchoring section, an additional test shall be performed on a separate test piece taken from the same lot.

4. TESTING MACHINE AND DEVICES

4.1 Testing machine
The testing machine must be capable of applying a sustained load while maintaining a constant length. The machine must be capable of loading at a rate of 200±50 N/mm^2 per minute.

4.2 Anchorage

The anchorage must be in accordance with the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

4.3 Accuracy of initial load

The accuracy of the initial load applied to the test piece shall be as follows:

Test machines with loading capacity of equal to or less than 1 kN: ±1.0% of set load

Test machines with loading capacity of more than 1 kN: ±2.0% of set load

4.4 Accuracy of load measurements

The accuracy of readings or automatic recording of loads applied to the test piece shall be within 0.1% of the initial load.

4.5 Strain fluctuations

The test machine shall control strain fluctuations no greater than $\pm 25\times10^{-6}$ in the test piece throughout the test period, once the strain in the test piece has been fixed. If the CFRM slips from the anchoring section, the distance of slippage shall be compensated so as not to affect the test results.

4.6 Extensometer and strain gauge

If an extensometer or strain gauge is to be fitted to the test piece, the extensometer or strain gauge shall be in accordance with the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

4.7 Hour meter

The hour meter for measuring the passage of time must be accurate to within 1% of the elapsed time.

5. TEST TEMPERATURE

The test temperature shall normally be within the range 20±2°C, except in special circumstances. Where the test results are heavily dependent on temperature, additional tests shall be performed at 0°C and at 60°C. In either case, temperature fluctuation over the test period shall be not more than ±2°C.

6. TEST METHOD

6.1 Mounting of test piece and gauge length

Mounting of test pieces and gauge length shall be in accordance with the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

6.2 Prestretching

If a strain gauge is to be set to the test piece, the test piece shall first be stretched taut by applying a load of 10~40% of the prescribed initial load, thereafter the strain gauge shall be attached and correctly calibrated.

6.3 Initial load

The initial load shall be either 70% of the guaranteed tensile capacity, or 80% of the million hour creep failure capacity, whichever is the smaller.

6.4 Application of initial load

(1) The initial load must be applied without subjecting the test piece to any shock or vibration.
(2) The specifications rate of loading the test piece shall be between 200±50 N/ mm^2 per minute.
(3) The strain on the test piece shall be fixed after the initial load has been applied to the test piece, and maintained for 120±2 seconds. This time shall be deemed to be the test start time.

6.5 Measurement of load reduction

Load reduction shall generally be measured over a period of at least 1000 hours. Load reduction shall be recorded automatically by a recorder attached to the testing machine. If no recorder is attached to the testing machine, load reduction shall be measured and recorded after the following times have elapsed:

1, 3, 6, 9, 15, 30, 45 minutes; 1, 1.5, 2, 4, 10, 24, 48, 72, 96, 120 hours; and in general every 24 hours subsequently, at a minimum of one measurement every 120 hours.

7. CALCULATION AND EXPRESSION OF TEST RESULTS

7.1 Relaxation value

The relaxation value shall be calculated by dividing the load measured in the relaxation test by the initial load.

7.2 Relaxation curve

The relaxation curve shall be plotted on a semi-logarithmic graph where the relaxation value (%) is represented on an arithmetic scale on the vertical axis, and test time in hours is represented on an logarithmic scale on the horizontal axis. An approximation line for Eq. (1) shall be derived from the graph data using the least-square method.

$$Y = a - b \log T$$

where

Y = relaxation rate (%)
a,b = empirical constants
T = time (h)

7.4 Million hour relaxation rate

The relaxation rate after 1 million hours (approximately 114 years) shall be evaluated from the approximation line; this value represents the million hour relaxation rate. Where the service life of the structure in which the CFRM is to be used is determined in advance, the relaxation rate for the number of years of service life ("service life relaxation rate") shall also be determined.

8. TEST REPORT

The test report shall include the following items:
(1) Name of CFRM

(2) Type of fiber and fiber binding material, volume ratio of fiber
(3) Numbers or identification marks of test pieces
(4) Designation, nominal diameter, nominal cross sectional area
(5) Date of test, test temperature and temperature fluctuations
(6) Type of test machine
(7) Initial load and loading rate of initial load
(8) Guaranteed tensile capacity, and ratio of initial load to guaranteed tensile capacity
(9) Relaxation curve for each test piece
(10) Average relaxation rates at 10, 120 and 1000 hours
(11) Formula for derivation of an approximation line
(12) Million hour relaxation rate
(13) Relaxation rate corresponding to design service life allowed for in design ("service life relaxation rate"), where applicable

TEST METHOD FOR TENSILE FATIGUE OF CONTINUOUS FIBER REINFORCING MATERIALS (JSCE-E 535-1995)

1. SCOPE

This specifications specifies mainly the test method for tensile fatigue under constant tensile loading for CFRM used in place of steel reinforcement or prestressing tendon in concrete.

2. DEFINITIONS

The following terms are defined for general use in this Specifications, in addition to the terms used in the "Recommendation for Design and Construction for Concrete Structures using Continuous Fiber Reinforcing Materials", the "Quality Specifications for Continuous Fiber Reinforcing Materials", and the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials":

(1) Repeated load (stress): Load (stress) alternating simply and cyclically between fixed maximum and minimum values
(2) Maximum repeated load (stress): Maximum load (stress) during repeated loading (stressing)
(3) Minimum repeated load (stress): Minimum load (stress) during repeated loading (stressing)
(4) Load (stress) range: Difference between maximum and minimum repeated load (stress)
(5) Load (stress) amplitude: One-half of the load (stress) range
(6) Average load (stress): Average of the maximum and minimum repeated load (stress)
(7) Number of cycles: Number of times the repeated load (stress) is applied to the test piece
(8) *S-N* curve: Curve plotted in a graph with repeated stress on the vertical axis and the number of cycles to fatigue failure on the horizontal axis
(9) Fatigue strength: Maximum repeated stress at which the test piece does not fail at the prescribed number of cycles
(10) Frequency: Number of loading (stressing) cycles in one second during the test

3. TEST PIECES

3.1 Preparation, handling and dimensions of test pieces

Preparation, handling and dimensions of test pieces shall be in accordance with the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

3.2 Number of test pieces

The number of test pieces should be at least three, for each of at least three levels of loading (stress). If the test piece is found clearly to have failed at the anchoring section, or to have slipped out of the anchoring section, an additional test shall be performed on a separate test piece taken from the same lot.

4. TESTING MACHINE AND DEVICES

4.1 Testing machine

The testing machine shall be capable of maintaining a constant load (stress) amplitude, maximum and minimum repeated load (stress), and frequency. The testing machine shall be fitted with a counter capable of recording the number of cycles to failure of the test piece.

The accuracy of the load shall be within 1% of the load range.

4.2 Anchorage

The anchorage must be in accordance with the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials". Ideally the same type of anchorage should be used for all in a given series of tests.

4.3 Strain measurements

If strain measurements are required as part of the fatigue tests, an extensometer and strain gauge capable of maintaining an accuracy of ±1% of the indicated value during the test shall be used.

5. TEST TEMPERATURE

The test temperature shall generally be within the range 5~35°C. The specifications test temperature for test pieces sensitive to temperature variations shall be 20±2°C.

6. TEST METHOD

6.1 Mounting of test pieces

Mounting of test pieces shall be in accordance with the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

6.2 Load setting

Load may be set in two ways: either fixing the average load and varying the load amplitude, or fixing the minimum repeated load by partial pulsation and varying the maximum repeated load. The method adopted shall be determined according to the purpose of the test. In either case, at least three load levels shall be set within the range of number of cycles to failure 10^3 to 2×10^6.

6.3 Frequency

The frequency shall normally be within the range 1~10 Hz.

6.4 Start of test

After static loading up to the average load, repeated loading shall be commenced. The prescribed load shall be introduced rapidly and without any shock. The maximum and minimum repeated loads shall remain constant for the duration of the test. Counting of the number of cycles shall normally commence when the load on the test piece has reached the prescribed load.

6.5 End of test

Complete separation (breaking) of the test piece shall be deemed to constitute failure, and the number of cycles to failure shall be recorded. If the test piece doesn't fail after 2×10^6 cycles, the test may be discontinued. Test pieces that did not fail must not be reused.

6.6 Interruption of test

Tests shall normally be conducted without interruption for each test piece from the start of the test to the end of the test. When a test is interrupted, the number of cycles up to the time of interruption, and the period of the interruption shall be recorded.

7. CALCULATION AND EXPRESSION OF TEST RESULTS

7.1 Handing of data

Data for test pieces that slipped from the anchoring section shall be disregarded in assessing the material properties of the CFRM. In cases where tensile failure or slippage has clearly taken place at the anchoring section, the data shall be disregarded and additional tests shall be performed until the number of test pieces failing in the test section is not less than three.

7.2 *S-N* curve

The *S-N* curve shall be plotted with the maximum repeated stress, stress range or stress amplitude represented on an arithmetic scale on the vertical axis, and the number of cycles represented on a logarithmic scale on the horizontal axis. Where measurement points coincide, the number of coinciding points shall be noted. Right-facing arrows shall be added to indicate points representing test results for test pieces remaining that did not fail.

7.3 Fatigue strength

The fatigue strength after 2×10^6 cycles shall be derived from the *S-N* curve. The fatigue strength shall be rounded off to three significant digits.

8. TEST REPORT

The test report shall include the following items:

(1) Name of CFRM

(2) Type of fiber and fiber binding material, volume ratio of fiber

(3) Numbers or identification marks of test pieces

(4) Designation, nominal diameter, maximum cross sectional area

(5) Date of test, test temperature and humidity (from start to end of test)

(6) Maximum load (stress), minimum load (stress), load (stress range), number of cycles to failure, and frequency rate for each test piece

(7) Record of observed failure mode for each test piece

(8) *S-N* curve

TEST METHOD FOR COEFFICIENT OF THERMAL EXPANSION OF CONTINUOUS FIBER REINFORCING MATERIALS BY THERMO-MECHANICAL ANALYSIS (JSCE-E 536-1995)

1. SCOPE

This specifications specifies mainly the test method for measuring the coefficient of thermal expansion of CFRM used in place of steel reinforcement or prestressing tendon in concrete by thermomechanical analysis.

2. DEFINITIONS

The following terms are defined for general use in this Specifications, in addition to the terms used in the "Recommendation for Design and Construction for Concrete Structures using Continuous Fiber Reinforcing Materials" and the "Quality Specifications for Continuous Fiber Reinforcing Materials":

(1) Thermomechanical analysis (TMA): Method for measuring deformation of a material as a function of either temperature or time, by varying the temperature of the material according to a calibrated program, under a non-vibrating load
(2) TMA curve: In the context of TMA, a graph with temperature or time represented on the horizontal axis, and deformation on the vertical axis
(3) Coefficient of thermal expansion: the average coefficient of linear thermal expansion between given temperatures. The average of the given temperatures is taken as the representative temperature.

3. TEST PIECES

3.1 Pre-test curing of test pieces

Prior to testing, test pieces shall normally be kept for a minimum of 24 hours at a temperature of 20±2°C and relative humidity of 65±5%, under Specifications Temperature Conditions Class II and Specifications Humidity Conditions Class II, in accordance with JIS K 7100. The test pieces shall then normally be kept for 48 hours at the maximum test temperature, in order to eliminate strain resulting from bending, and for dehumidification and deaeration.

3.2 Dimensions of test piece

The specifications test piece cut from the CFRM shall be 20mm in length, with a round or square cross-section of diameter or breadth of not more than 5mm.

3.3 Number of test pieces

The number of test pieces shall be not less than three.

4. TESTING DEVICE

4.1 Testing device

The TMA apparatus used for testing shall be capable of measuring in compression mode, of maintaining a constant atmosphere around the test piece, and of raising the temperature of the test piece at a constant rate.

4.2 Calibration of testing device

(1) Sensitivity calibration of the displacement gauge shall be carried out periodically using either an external micrometer as defined in JIS B 7502, or a micrometer attached to the testing machine.
(2) Calibration of the temperature gauge shall be carried out using a pure substance of known melting point.

4.3 Installation of testing device

The TMA apparatus must be installed in a location not subject to vibration during testing.

5. TEST METHOD

5.1 Mounting of test piece

The test piece, gauge rod and test platform shall be cleaned, and the test piece placed upright and if possible bonded to the platform.

5.2 The gauge rod shall be placed in the center of the test piece, with no pressure applied.

5.3 The atmosphere around the test piece shall consist of dry air (water content not more than 0.1% w/w) or nitrogen (water content not more than 0.001% w/w, oxygen content not more than 0.001% w/w), maintained at a flow rate in the range of 50~100 ml/min.

5.4 The load shall be applied gently to the tip of the gauge rod at room temperature, and in general the temperature shall first be lowered to 0°C then raised to 60°C, and the full process of displacement of the test piece shall be recorded.

5.5 The rate of temperature increase shall not be more than 5°C per minute.

5.6 The compressive stress acting on the test piece shall be around 4 mN/ mm^2.

6. CALCULATION AND EXPRESSION OF TEST RESULTS

6.1 The coefficient of thermal expansion of the test piece within the measured temperature range ($T_{1\sim}T_2$) shall be calculated according to Eq. (1).

$$a_{sp} = (\Delta L_{spm} - \Delta L_{refm}) / \{L_0 \times (T_2 - T_1)\} + a_{set} \qquad (1)$$

where

a_{sp} = coefficient of thermal expansion (/°C)

ΔL_{spm} = difference in length of test piece between temperatures T_1 and T_2 (mm)

ΔL_{refm} = difference in length of specifications test piece for length calibration between temperatures T_1 and T_2 (mm)

L_{0} = length of test piece at room temperature (mm)

T_2 = maximum temperature for calculation of coefficient of thermal expansion (normally 60°C)

T_1 = minimum temperature for calculation of coefficient of thermal expansion (normally 0°C)

a_{set} = coefficient of thermal expansion calculated for specifications test piece for length calibration between temperatures T_1 and T_2 (/°C)

For apparatus in which the test piece and specifications test piece for length calibration are measured simultaneously, ΔL_{refm} shall be = 0 in the above equation.

6.2 Rounding off of numerical values

Each of the coefficients of thermal expansion shall be calculated to six decimal places (10^{-7}), and the average value rounded off to five decimal places (10^{-6}). If the average value is less than 1, it shall be expressed accurate to six decimal places (10^{-7}).

7. TEST REPORT

The test report shall include the following items:

(1) Name of CFRM
(2) Type of fiber and fiber binding material, volume ratio of fiber
(3) Numbers or identification marks of test pieces
(4) Designation, nominal diameter, nominal cross sectional area
(5) Date of test
(6) Dimensions of test pieces
(7) Pre-test curing method
(8) Type of testing machine
(9) Type of ambient atmosphere during test, and flow rate
(10) Name of substance used for temperature calibration, and measurements taken
(11) Type of specifications test piece for length calibration
(12) Temperature range for which the coefficient of thermal expansion was measured, and representative temperature
(13) TMA curve for each test piece
(14) Coefficient of thermal expansion for each test piece, and average coefficient of thermal expansion

TEST METHOD FOR PERFORMANCE OF ANCHORAGES AND COUPLERS IN PRESTRESSED CONCRETE USING CONTINUOUS FIBER REINFORCING MATERIALS (JSCE-E 537-1995)

1. SCOPE

This specifications specifies mainly the test method for performance of anchorages and couplers used with CFRM used in place of steel reinforcement or prestressing tendon in concrete.

2. DEFINITIONS

The following terms are defined for general use in this Specifications, in addition to the terms used in the "Recommendation for Design and Construction for Concrete Structures using Continuous Fiber Reinforcing Materials" and the "Quality Specifications for Continuous Fiber Reinforcing Materials":

(1) CFRM tendon: CFRM used as tendons in prestressed concrete
(2) Anchorage: Device anchoring a CFRM tendon to the concrete, transmitting prestressing force to the members
(3) Anchorage reinforcement: Latticed or spiral reinforcing steel or CFRM connected with the anchorage and arranged behind it
(4) Anchoring section: The section around the anchorage and the anchorage reinforcement, including the surrounding concrete
(5) Coupler: Device coupling tendons

3. TEST METHOD FOR PERFORMANCE OF ANCHORAGES

3.1 Purpose of test
To determine the tensile capacity when anchorage are used in conjunction with CFRM tendons

3.2 Test pieces

3.2.1 Preparation of test pieces
Test pieces shall be prepared by attaching an anchorage to one or both ends of a CFRM tendon.

3.2.2 Dimensions of test piece
The specifications length of test pieces shall be 3 meters.

3.2.3 Number of test pieces
The number of test pieces shall be no less than three.

3.3 Test temperature

The test temperature shall generally be within the range 5~35°C. Testing of test pieces which are sensitive to temperature or are to be used at high temperatures shall if necessary be tested at the service temperature.

3.4 Test method

3.4.1 Mounting of test piece

Test pieces shall be mounted supported by a tensile loading testing machine. The area and geometry of the surface supporting the anchorage, the tension in the CFRM tendons, and the manner of application of forces shall approximate the actual conditions within the prestressed concrete structure as close as possible.

3.4.2 Loading rate

CFRM tendons shall in general be loaded at a rate of 100~500 N/ mm^2.

3.4.3 Scope of test

Loading shall be continued up to the tensile failure , as determined by either failure of the CFRM tendon or excessive deformation of the anchoring device.

3.5 Calculation and Expression of test results

The tensile capacity for each test piece and the average tensile capacity shall be calculated. Modes of failure shall also be recorded. In the expression of the loading test, any deformation, damage, caving in etc. of the anchorage shall be recorded.

4. TEST METHOD FOR PERFORMANCE OF COUPLERS

4.1 Purpose of test

To determine the tensile capacity when couplers are used in conjunction with CFRM or other tendons

4.2 Test pieces

4.2.1 Preparation of test pieces

Test pieces shall be prepared by attaching CFRM or other tendons to either end or both ends of a coupler. Any other tendons and their couplers must have adequate strength as compared to the CFRM tendons being tested.

4.2.2 Dimensions of test piece

The specifications length of test pieces shall be 3 meters.

4.2.3 Number of test pieces

The number of test pieces shall be no less than three.

4.3 Test temperature

The test temperature shall generally be within the range 5~35°C. Testing of test pieces which are sensitive to temperature or are to be used at high temperatures shall if necessary be tested at the service temperature.

4.4 Test method

In accordance with 3.4, Test method for performance of anchorages

4.5 Calculation and expression of test results

The tensile capacity for each test piece and the average tensile capacity shall be calculated. Modes of failure shall also be recorded. In the expression of the loading test, any deformation, damage, caving in etc. of the couplers shall be recorded.

5. TEST METHOD FOR PERFORMANCE OF ANCHORING SECTIONS

5.1 Purpose of test

To determine the performance of the anchoring section, including the concrete in the vicinity of the anchorage and the anchorage reinforcement.

5.2 Test pieces

5.2.1 Preparation and dimensions of test pieces

The distance from the center of the anchorage to the edge of the concrete shall be the minimum allowable distance determined according to the design. The length of one side of the cross section of a concrete test piece shall be 2 times the minimum allowable distance, and the height of the section below the anchorage shall not be less than 2 times the length of the longer side.

5.2.2 Reinforcement of concrete

The section around the anchorage shall be uniformly reinforced using the anchorage reinforcement and additional bars prescribed for the anchorage. Sections other than that around the anchorage shall be reinforced with additional bars to prevent failure during the test. The material quality of the anchorage reinforcement and additional bars shall be determined according to the purpose of reinforcement.

5.2.3 Concrete quality

The concrete shall be made with normal aggregates, with coarse aggregates having a maximum dimension of 20 or 25 mm. The specifications concrete shall have a slump of 10±2 cm, and the compressive strength at 28 days shall be 30±3 N/ mm^2.

5.3 Test method

5.3.1 Loading test

Loading shall be continued up to the failure. The specifications loading method shall be application of compressive force to the anchorage, but methods applying tension to combinations of tendons may also be adopted.

5.3.2 Timing of test

Tests shall normally be performed when the compressive strength of the concrete has reached 24±3 N/ mm^2.

5.4 Calculation and Expression of test results

In the expression of the loading test, any deformation, damage, caving in etc. of the anchorage shall be recorded.

6. TEST REPORT

The test report shall include the following items:

(1) Name of CFRM
(2) Type of fiber and fiber binding material, volume ratio of fiber
(3) Numbers or identification marks of test pieces
(4) Designation, nominal diameter, maximum cross sectional area
(5) Date of test, test temperature, loading rate
(6) Dimensions of test pieces
(7) Concrete mix, slump, and compressive strength at time of testing
(8) (For anchorage and coupler performance tests:) tensile failure capacity for each test piece, average tensile failure capacity, and failure modes
(9) (For anchoring section performance test:) failure capacity
(10) Records of any deformation, damage, caving in etc. of anchorages, couplers, anchoring sections

TEST METHOD FOR ALKALI RESISTANCE OF CONTINUOUS FIBER REINFORCING MATERIALS (JSCE-E 538-1995)

1. SCOPE

This specifications specifies mainly the test method for evaluating alkali resistance of CFRM used in place of steel reinforcement or prestressing tendon in concrete by immersion in an aqueous alkaline solution.

2. TEST PIECES

2.1 Preparation of test pieces

Test pieces shall as a rule not be subjected to any processing. For mesh-type CFRM, linear test pieces may be prepared by cutting away extraneous parts in such a way as not to affect the performance of the part to be tested.

2.2 Handling of test pieces

During sampling and preparation of test pieces, all deformation, heating, outdoor exposure to ultraviolet light etc. causing changes to the material properties of the test section of the test piece must be avoided.

2.3 Length of test pieces

The length of the test section shall not be less than 100mm, and not less than 40 times the nominal diameter of the CFRM. For CFRM in strand form, as an additional condition, the length shall not be less than 2 times the strand pitch.

2.4 Number of test pieces

The number of test pieces for pre- and post-immersion tensile testing shall not be less than five. If the test piece is found clearly to have failed at the anchoring section, or to have slipped out of the anchoring section, an additional test shall be performed on a separate test piece taken from the same lot.

3. IMMERSION IN ALKALINE SOLUTION

3.1 Preparation of alkaline solution

The alkaline solution used for immersion shall have the same composition as the pore solution found in the concrete.

3.2 Prevention of infiltration of solution into test piece

In order to prevent infiltration of the solution via the ends of the test pieces during immersion, both ends of the test pieces shall be covered with epoxy resin.

3.3 Immersion temperature

The specifications temperature for immersion shall be 60°C.

3.4 Mounting of test piece

The test piece shall be mounted on the immersion apparatus. If necessary a tensioning load shall be applied to the test piece. The alkaline solution must be prevented from absorbing CO_2 from the air and from the evaporation of water during immersion.

3.5 Period of immersion

The specifications immersion period shall be one month.

3.6 Post-immersion treatment

The test piece shall be washed in water after immersion.

4. EXTERNAL APPEARANCE AND MASS CHANGE

4.1 Inspection of alkaline solution

The pH value of the alkaline solution shall be measured before and after the alkali resistance test.

4.2 External appearance

The external appearance of the test piece shall be examined before and after the alkali resistance test, for comparison of color, surface condition, and change of shape. If necessary the test piece may be sectioned and polished, and the condition of the cross-section examined using a microscope, etc.

4.3 Measurement of mass change

After immersion, the hardened epoxy resin shall be removed from the ends of the test piece, which shall then be dried and the mass measured until the mass is constant. The rate of mass loss shall be calculated according to Eq. (1).

$$\text{Rate of mass loss (\%)} = \{(W_0/L_0 - W_1/L_1)/(W_0/L_0)\}\times 100 \quad (1)$$

where

W_0 = mass before immersion (g)
L_0 = length before immersion (mm)
W_1 = mass after immersion (g)
L_1 = length after immersion (mm)

5. TENSILE TEST

5.1 Testing machine and devices

Testing machine and devices shall be in accordance with the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

5.2 Test temperature and test method

Test temperature and test method shall be in accordance with the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

6. CALCULATION AND EXPRESSION OF TEST RESULTS

6.1 Handling of data

The material properties of CFRM shall be assessed on the basis only of test pieces undergoing failure in the test section. In cases where tensile failure or slippage has clearly taken place at the anchoring section, the data shall be disregarded and additional tests shall be performed until the number of test pieces failing in the test section is not less than five.

6.2 Tensile capacity retention rate

The tensile capacity retention rate shall be calculated according to Eq. (2), and rounded off to 2 significant places.

$$\mathrm{Re}t = (F_{u1} / F_{u0}) \times 100 \qquad (2)$$

where

Ret = tensile capacity retention rate (%)
F_{u1} = tensile capacity before immersion (N)
F_{u0} = tensile capacity after immersion (N)

7. TEST REPORT

The test report shall include the following items:

7.1 Common items

(1) Name of CFRM
(2) Type of fiber and fiber binding material, volume ratio of fiber
(3) Numbers or identification marks of test pieces
(4) Designation, nominal diameter, maximum cross sectional area
(5) Date of start and end of immersion

7.2 Items related to alkaline solution immersion

(1) Composition of alkaline solution, pH, temperature, immersion period and time
(2) Tensioning load and ratio of tensioning load to nominal tensile capacity (if tensioning is not carried out, this fact should be noted)
(3) Record of observation of external appearance, and rate of mass loss

7.3 Items related to tensile testing

(1) Test temperature and loading rate
(2) Tensile capacities for immersed and non-immersed test pieces, with averages and specifications deviations of tensile capacities and tensile strength
(3) Tensile rigidity, Young's modulus and the averages of these for all immersed and non-immersed test pieces

(4) Ultimate strain for all immersed and non-immersed test pieces, and average ultimate strain
(5) Tensile capacity retention rate
(6) Stress-strain curve for all immersed and non-immersed test pieces

TEST METHOD FOR BOND STRENGTH OF CONTINUOUS FIBER REINFORCING MATERIALS BY PULL-OUT TESTING (JSCE-E 539-1995)

1. SCOPE

This standard specifies mainly the test method of determining the bond strength of CFRM used in place of steel reinforcement or prestressing tendon in concrete by pull-out testing.

2. DEFINITIONS

The following terms are defined for general use in this Standard, in addition to the terms used in the "Recommendation for Design and Construction for Concrete Structures using Continuous Fiber Reinforcing Materials" and the "Quality Specifications for Continuous Fiber Reinforcing Materials":

Nominal peripheral length: The peripheral length of the CFRM which forms the basis for calculation of bond strength; determined separately for each CFRM

3. TEST PIECES

3.1 Fabrication of test pieces

Test pieces shall normally be cube-shaped, fabricated by pouring concrete around a central CFRM. The bonded length of the CFRM shall be a typical section of the surface of the CFRM set up in the free end side. The length shall normally be 4 times the diameter of the CFRM. If the bonded length as defined above is thought not to represent the bonding characteristics of the CFRM, the bonded length may be extended as appropriate. In order to equalize the stress from the loading plate on the loaded end side, sections other than the bonded section shall be sheathed with PVC etc. to prevent bonding.

3.2 Dimensions of test piece

The dimensions of the test piece shall be determined according to the dimensions of the CFRM, as shown in **table 1**:

Table 1: Dimensions of test pieces

CFRM nominal diameter	Length of one face of test piece (cm)	Bonded length	External diameter of spiral hoop reinforcement (cm)
Less than 17 mm 17 ~ 30 mm	10×10×10 15×15×15	4×nominal diameter 4×nominal diameter	8 ~ 10 12 ~ 15

3.3 Dimensions of CFRM tendon

The CFRM tendon shall be allowed to protrude by around 10 mm at the free end side, and the end face must be structured so as to allow access for a dial gauge etc., used to measure the length of pull-out. The loading end side of the CFRM tendon must be long enough to allow the performance of the pull-out test, and must be fitted with an anchoring section, gripping device or similar apparatus to allow transmission of loads.

3.4 Arrangement of CFRM tendons

CFRM tendons shall be arranged horizontally in the center of the test piece.

3.5 Reinforcement of test pieces

Test pieces shall be reinforced with spiral hoops centered at the test piece to prevent splitting failure while the test is in progress. Spiral reinforcement hoops shall be 6 mm in diameter, with a spiral pitch of 4 cm. The ends of the spiral hoops shall be welded, or 1.5 times extra turns shall be provided.

3.6 Number of test pieces

The number of test pieces shall not be less than three. If the test piece is found clearly to have failed at the anchoring section, or to have slipped out of the anchoring section, an additional test shall be performed on a separate test piece taken from the same lot.

4. FORMS

Forms shall conform to the JSCE "Test method for bond strength of concrete by pull-out testing" (JSCE-G 503-1988).

5. CONCRETE QUALITY

The concrete shall be made with normal aggregates, with coarse aggregates having a maximum dimension of 20 or 25 mm. The standard concrete shall have slump of 10±2 cm, and the compressive strength at 28 days shall be 30±3 N/mm^2.

6. PLACING OF CONCRETE

6.1 The bonding section of the CFRM tendon shall be cleaned and rendered free from any grease, dirt etc.

6.2 Suitable measures shall be taken before placing to prevent bonding of the non-bonding sections of the tendon, and the CFRM tendon shall be placed horizontally in the form, perpendicular to the loading face.

6.3 The opening in the form through which the CFRM tendon is inserted must be sealed to prevent ingress of water etc. using oil putty or similar.

6.4 The form must be kept horizontal from the time of placing the concrete until the form is removed.

6.5 After placing, the test piece shall be smoothed off by scraping any excess concrete off the top, repeating this process again after around 2 hours to ensure that a test piece of the proper dimensions is obtained.

7. REMOVAL OF FORMS AND CURING

Forms shall be removed after 2 days, and the test pieces cured thereafter in water at a temperature of 20±3°C until the time of testing.

8. TESTING MACHINE AND DEVICES

8.1 Testing machine

The testing machine for pull-out tests must be capable of applying the prescribed load accurately.

8.2 Loading plate

The loading plate shall have a hole through which the CFRM tendon shall pass. The diameter of the hole in the loading plate shall be around 2~3 times the diameter of the continuous fiber tendon.

8.3 Anchorage

The loading end side of the CFRM tendon shall be fitted with an anchorage capable of transmitting loads accurately until the tendon pulls out due to bond failure, or because of splitting or cracking of the concrete. The load transmission device shall transmit axial loads only to the CFRM tendon, without transmitting either torsion or flexural force.

8.4 Dial gauge

The displacement meter fitted to the free end of the CFRM tendon shall be a dial gauge or similar apparatus, giving readings accurate to around 1/1000 mm.

9. TEST METHOD

9.1 Mounting of test piece

The test piece shall be placed correctly on the loading plate, with a spherical plate underneath to prevent eccentric loads from acting on the test piece.

9.2 Loading rate

The standard loading rate shall be such that the average tensile stress of the CFRM tendon increases at a rate of 10~20 N/mm^2 per minute. The loading rate must be kept as constant as possible, not subjecting the test piece to shock.

9.3 Scope of test

The slippage of the free end and the load applied shall be recorded in the increments shown in **table 2**, until either the continuous fiber tendon pulls out of the concrete, or the load decreases significantly due to splitting or cracking of the concrete.

Table 2: Measurement increments

Slippage of free end	Measurement increment
~0.1 mm	every 0.01 mm
0.1 mm ~ 0.2 mm	every 0.02 mm
0.2 mm ~ 0.5 mm	every 0.05 mm
0.5 mm ~	every 0.1 mm

9.4 Age of test piece

The age of the test piece at the time of testing shall be 28 days.

10. CALCULATION AND EXPRESSION OF TEST RESULTS

10.1 Handling of data

In cases where a test piece is judged to have undergone tensile failure at the anchoring section, or to have slipped out of the anchoring section before the CFRM has slipped from the concrete or the load is significantly reduced due to splitting or cracking of the concrete, the data shall be disregarded and additional tests shall be performed until the number of test pieces slipping from the concrete or where the load is significantly reduced due to splitting or cracking of the concrete is not less than three.

10.2

The bond strength shall be calculated according to Eq. (1) and rounded off to 3 significant digits and the curve for the pull-out load or bond stress versus slippage displacement for each test piece shall be plotted.

$$t = \frac{P}{ul} \qquad (1)$$

where

τ = bond stress (N/mm^2)
P = tensile load (N)
u = nominal peripheral length of CFRM (mm)
l = bonded length (mm)

10.3

The average bond stress causing slippage at the free end of 0.05 mm, 0.10 mm and 0.25 mm, and the maximum bond stress at the failure load shall be calculated.

11. TEST REPORT

The test report shall include the following items:
(1) Name of CFRM
(2) Type of fiber and fiber binding material, volume ratio of fiber, type of surface treatment of fibers
(3) Numbers or identification marks of test pieces
(4) Designation, nominal diameter, nominal cross sectional area
(5) Date of test, test temperature, loading rate
(6) Dimensions of test pieces, bonded length of CFRM
(7) Concrete mix, slump, and compressive strength at time of testing
(8) Average bond stress causing slippage at the free end of 0.05 mm, 0.10 mm and 0.25 mm for each test piece
(9) Maximum bond stress, failure mode and averages for each test piece
(10) Bond stress - slippage displacement curve for each test piece

TEST METHOD FOR SHEAR PROPERTIES OF CONTINUOUS FIBER REINFORCING MATERIALS BY DOUBLE PLANE SHEAR (JSCE-E 540-1995)

1. SCOPE

This specifications specifies mainly the test method for shear properties of CFRM used in place of steel reinforcement or prestressing tendon in concrete, by direct application of double shear.

2. TEST PIECES

2.1 Preparation of test pieces

Test pieces shall as a rule not be subjected to any processing. For mesh-type CFRM, linear test pieces may be prepared by cutting away extraneous parts in such a way as not to affect the performance of the part to be tested. Test pieces should be as straight as possible; severely bent pieces should not be used.

2.2 Handling of test pieces

During the obtaining and preparation of test pieces, all deformation, heating, outdoor exposure to ultraviolet light etc. causing changes to the material properties of the test section of the test piece must be avoided.

2.3 Length of test pieces

Test pieces shall be of constant length regardless of the nominal diameter of the CFRM. Length shall not be less than 5 times the shear plane interval, and not more than 30 cm.

2.4 Number of test pieces

The number of test pieces shall not be less than three. If the test piece shows significant pull-out of fibers, indicating that failure is not due to shear, an additional test shall be performed on a separate test piece taken from the same lot.

3. TESTING MACHINE AND DEVICES

3.1 Testing machine

The testing machine to be used in load testing shall conform to JIS B 7733 (Compression Testing Machines). The testing machine shall have a loading capacity in excess of the tensile capacity of the test piece, and shall be capable of applying loading at the required loading rate. The testing machine must also be capable of giving readings of loading accurate to within 1% during the test.

3.2 Shear testing apparatus

The shear testing apparatus shall be constructed so that a rod-shaped test piece is sheared on two planes more or less simultaneously by two blades (edges) converging along the faces perpendicular to the axial direction of the test piece. The discrepancy in the axial direction between the upper and lower blades shall be of the order of 0~0.5 mm, and shall be made as small as possible. The specifications distance between shear planes shall be 50 mm.

4. TEST TEMPERATURE

The test temperature shall generally be within the range 5~35°C. The specifications test temperature for test pieces sensitive to temperature shall be 20±2°C.

5. TEST METHOD

5.1 Mounting of test piece

The test piece shall be mounted in the center of the shear apparatus, touching the upper loading device. No gap should be visible between the contact surface of the loading device and the test piece.

5.2 Loading rate

The specifications loading rate shall be such that the shearing stress increases at a rate of 30~60 N/mm^2 per minute. Loading shall be applied uniformly without subjecting the test piece to shock.

5.3 Scope of test

Loading shall be continued until the test piece fails, and the failure load recorded to three significant digits. It should be noted that loading may decrease temporarily, owing to the presence of two rupture faces.

6. CALCULATION AND EXPRESSION OF TEST RESULTS

6.1 Handling of data

Whether the rupture surface is due to shear or not shall be determined by visual inspection. If pull-out of fibers etc. is obvious, the data shall be disregarded and additional tests shall be performed until the number of test pieces failing due to shear is not less than three.

6.2 Shear strength

Shear strength shall be calculated according to Eq. (1), and rounded off to 3 significant digits.

$$t = \frac{P}{2A} \qquad (1)$$

where

τ = shear strength (N/mm^2)
P = shear failure load (N)
A = nominal cross sectional area of test piece (mm^2)

7. TEST REPORT

The test report shall include the following items:

(1) Name of CFRM

(2) Type of fiber and fiber binding material, volume ratio of fiber

(3) Numbers or identification marks of test pieces

(4) Designation, nominal diameter, maximum cross sectional area

(5) Date of test, test temperature, loading rate

(6) Intervals between double shear faces

(7) Shear failure load for each test piece, average shear failure load and shear strength

(8) Failure mode of each test piece

COMMENTARY ON THE TEST METHOD FOR TENSILE PROPERTIES OF CONTINUOUS FIBER REINFORCING MATERIALS (JSCE-E 531-1995)

INTRODUCTION

A test method for tensile properties of CFRM was first set out in a proposal by the JSCE ("The application of continuous fiber reinforcement materials to concrete structures", Concrete Library No. 72), followed by another proposal from the Architectural Institute of Japan ("Research on long fiber reinforced concrete (Report No. 3)"). These documents lie behind the test method proposed here.

The test method given here focuses on the CFRM itself, excluding the performance of the anchorage. For this reason, test data clearly showing failure or pull-out at the anchoring section is to be disregarded, and test findings based solely on test pieces failing in the test section.

1. SCOPE

Test pieces shall be linear or meshed CFRM formed from continuous fibers, matrices etc. as defined elsewhere and acting mechanically as a monolithic body.

2. DEFINITIONS

Of the terms used here, nominal diameter and nominal cross sectional area are used as defined in the "Quality Standard for Continuous Fiber Reinforcing Materials". Guaranteed tensile capacity has been added to provide a basic standard for testing at some future date when a guaranteed tensile capacity has been determined.

3. TEST PIECES

Tensile test conducted by various organizations has found that tensile strength ceases to vary in test pieces longer than 30 times their nominal diameter (**Fig.C 1**). At lengths of 30 times the nominal diameter, however, the anchoring section is apt to fail, resulting in variations in strain readings. It was therefore decided to specify lengths of not less than 100 mm, and not less than 40 times the nominal diameter, with the additional condition for CFRM in strand form that the length should be not less than 2 times the strand pitch. This requirement corresponds to the requirements in JIS G 3536 (Uncoated Stress-relieved Steel Wires and Strands for Prestressed Concrete), JSCE "Standard Specification for Design and Construction of Concrete Structures" and AIJ "Prestressed Concrete Design and Construction Standards", all of which call for test pieces "not less than 100 mm for wire; not less than 200 mm for 2-core strands and deformed 3-core strands; not less than 600 mm for 7-core strands and 19-core strands; not less than 2 times the strand pitch for other types of strands; not less than 40 times the basic diameter for multiple strands". The requirement also corresponds to the AIJ "Proposal for Tensile Breaking Strength Test for Long Fiber Reinforcing Materials" requirement for test pieces to be "not shorter than 300 mm", etc.

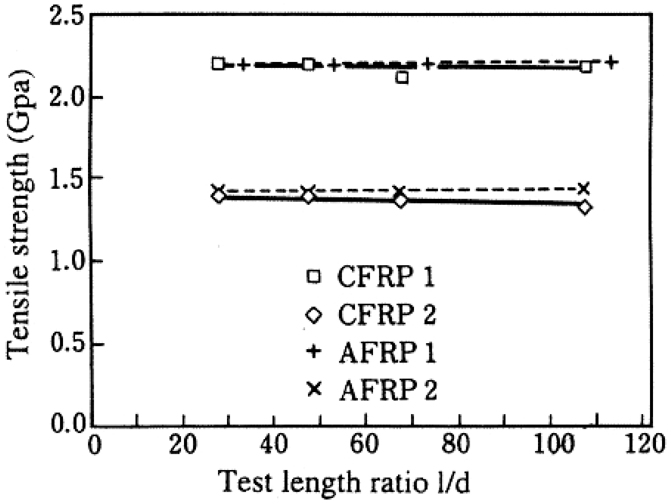

Fig. C 1　Effects of test length on tensile strength

The required numbers of test pieces were determined with reference to the statistical equation below:

$$N = (T \times CV / \mu)^2$$

where

N = number of test pieces
T = statistical value (T = 1.96 when confidence level = 95%)
μ = accuracy (%)
CV = coefficient of variation (%)

That is, when the data from the test pieces that failed in the test section in
tests conducted by the various organizations, for test pieces with a test length of not less than 38 times the nominal diameter, when N = 5~15 the coefficient of variation CV for the breaking load was less than 5.8%, with an average value of 3.0%. Applying accuracy μ = 5% with a confidence level of 95% to these results, the maximum value of N is found to be 5.2, and the average value 1.4. Based on this, the number of test pieces was set to not less than 5.

4. TEST TEMPERATURE

The standard test temperature for temperature-sensitive test pieces (i.e. test pieces showing a variation of more than 5% for failure tensile capacity, Young's modulus or ultimate strain over a temperature range of 5~35°C) was set at 20±2°C.

5. TEST METHOD

The gauge distance when using an extensometer was set at not less than 8 times the nominal diameter of the CFRM for linear materials, with an additional requirement for stranded materials that the gauge distance must be not less than the strand pitch. This sometimes results in a shorter gauge distance than that required in JIS G 3536 (Uncoated Stress-relieved Steel Wires and Strands for Prestressed Concrete), JSCE "Standard Specification for Design and Construction of Concrete Structures" and AIJ "Proposal for Tensile Breaking Strength Test for Long Fiber Reinforcing Materials", all of which call for a gauge distance of "not less than 100 mm", but the present requirement agrees with the gauge distance requirement in JIS G 3109 (Steel Bars for Prestressed Concrete) calling for a gauge distance "8 times the basic diameter of round bars, and 8 times the nominal diameter of deformed bars", and with the requirement in JIS Z 2201 (Test Pieces for Tensile Test for Metallic Materials; based on JIS G 3109) for a gauge distance of "3~8 times the diameter" of all types of rod-shaped test pieces.

When a strain gauge is used, this shall be fitted correctly in the direction of tension, without damaging the test piece. If fitting the gauge in the direction of tension is not feasible, as with stranded materials, it should be fitted in accordance with some other appropriate method.

The loading rate has been set at 100~500 N/mm^2/min, or equivalent fixed strain loading. This falls within the loading rate prescribed in the AIJ "Proposal for Tensile Breaking Strength Test for Long Fiber Reinforcing Materials" ("300~3,000 N/mm^2/min or 1%/min, whichever is the lesser"), and also falls within the ISO prescription of ("1~10 N/mm^2/sec (60~600 N/mm^2/min) for materials having a Young’s modulus not greater than 1.5×10^3 N/mm^2") in the ISO standards for test methods for metallic materials.

In AFRP rods, the range of loading rates corresponding to the above (0.2~0.9%/min), the variation in tensile strength is less than 1%, therefore these loading rates are deemed appropriate (**Fig.C 2**).

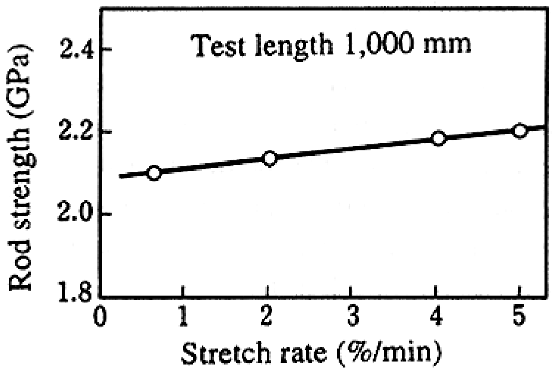

Fig. C 2 Effects of loading rate on tensile strength

6. CALCULATION AND EXPRESSION OF TEST RESULTS

(1) CFRM show elastic behavior in all zones leading to failure in many cases the Young’s modulus varies depending on the load; in carbon and Aramid fiber reinforcement materials, significant variation in the Young’s modulus is found in the region under 20% of the tensile capacity (**Fig. C 3**). Since the load range in actual service is below 60% of the tensile capacity, it was decided to derive the Young’s

modulus from the secant gradient of the strain-load curve at 20% and 60% of the tensile capacity.

If a guaranteed tensile capacity is set for the CFRM in question, or if the manufacturer can guarantee a specified tensile capacity, calculations can be based on the secant gradient at 20% and 60% of the guaranteed tensile capacity, rather than the tensile capacity. in Aramid CFRM, the Young's modulus under repeated loading is greater than that on virgin loading, although in the present test method, only the virgin loading is taken into account (**Fig. C 4**)

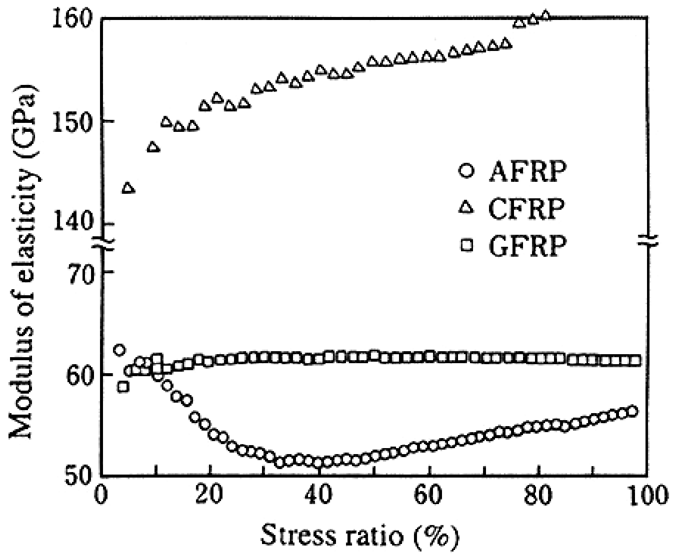

Fig. C 3 Effects of load on Young's modulus

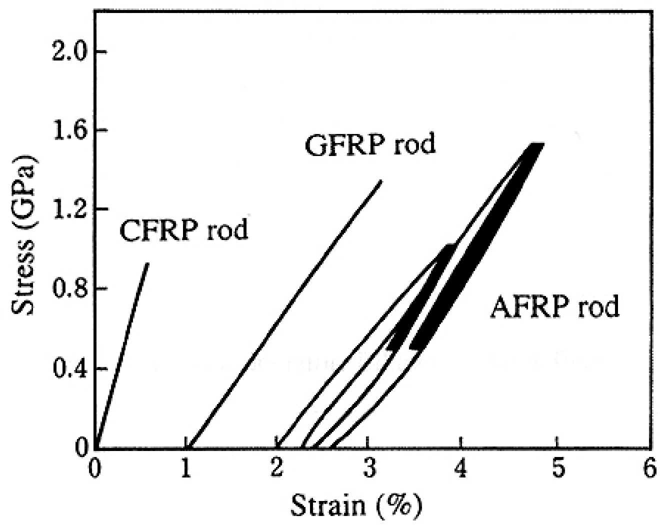

Fig. C 4 Effects of repeated loading on Young's modulus

(2) Where strain can be accurately measured up to failure using a strain gauge or similar apparatus, it was decided to identify ultimate strain with the strain corresponding to the tensile capacity. This ultimate strain corresponds to the ultimate strain used in design. Conversely, if strain cannot be accurately measured up to failure using a strain gauge or similar apparatus, ultimate strain is extrapolated based on the Young's of elasticity and the tensile capacity. This method results in errors for materials (Aramid etc.) where the Young's modulus varies with the load, and the value obtained is

around 5% greater than the measured ultimate strain. Extrapolated ultimate strain, strictly speaking, is not identical with the failure strain, but the variation is minor and the value can safely be substituted for failure strain for design purposes.

REFERENCES

1) Section III, "DOCUMENTATION" of the present volume

2) Kakibara, Kamiyoshi and Kawasaki: Dynamic Characteristics of AFRP Rods, Proceedings of Symposium on Application of CFRM to Concrete Structures, pp. 79~82, 1992

3) Uomoto and Nishimura: Static Strength and Elastic Modulus of FRP Rods, JSCE Papers, No. 472/V-20, pp.77~86, 1993

COMMENTARY ON THE TEST METHOD FOR FLEXURAL TENSILE PROPERTIES OF CONTINUOUS FIBER REINFORCING MATERIALS (JSCE-E 532-1995)

INTRODUCTION

When CFRM manufactured as straight rod is tensioned after being bent, the bending stress, added lateral pressure etc. may cause reduction of strength. When uni- directionally strengthened CFRM is bent for use as tendon in prestressed concrete, it is important to be aware of the relationship between the bending conditions and the strength characteristics. However, no standard tests of this type have been established even for steel or plastic materials. The present test method was developed for CFRM bent up as external cables, or arranged in a curved layout as internal cables. The following standards were referred to in relation to the development of this test method:

-Architectural Institute of Japan: "Annotated Design Guidelines for Cable Structures"
-New Prestressed Concrete Bridge Structures Survey & Research Committee, Expressway Survey Commission: "Report on Research into New Prestressed Concrete Bridge Structures (Findings of Study of Utility and Applicability of External Cables)", March 1993

1. SCOPE

The present test is a materials performance test designed to determine the effects of bending on CFRM manufactured as straight rod etc., as compared to the tensile capacity when the material is straight. Stirrups, spiral bars and other CFRM bent from the time of manufacture fall outside the scope of this test.

2. DEFINITIONS

The bent section is also often known as a deviator. Likewise, the deflector is also known as a saddle, or a sheave if disk-shaped.

3. TEST PIECES

(Comment on 3.1) Since the loading test on sections of the CFRM other than the bent sections is identical to the tensile test, it was decided to require simply that "Test pieces shall be prepared and handled in accordance with the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials". If sheaths, protective tubes etc. form an integrated part of the CFRM, the integrated unit shall be regarded as a single CFRM, and ideally tests shall be carried out in conditions approximating service conditions. In such cases, though, the material, thickness and geometry of the sheath or protective tubing must be clearly stated in the report.

(Comment on 3.2) In the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials", the test section length deemed unaffected by the anchoring section is specified as "... not less than 100mm, and not less than 40 times the nominal diameter of the CFRM. For CFRM in strand form, as an additional condition, the length shall not be less than 2 times the strand pitch.". For the purposes of flexural tensile test, this is the minimum distance required between the anchoring section and the bent section, therefore the specification is altered to read "The length of the test section shall not be less than 100mm from the anchorage to the bent section, and not less than 40 times the nominal diameter of the CFRM. For CFRM in strand form, as an additional condition, the length shall not be less than 2 times the strand pitch.". If the bent section is located in the center of the test section, then, the test section shall be more than twice as long as in tensile test. The length of test sections for multi-cables consisting of multiple strands of CFRM, the test length required is around 3 m, following the "Test Method for Performance of Anchorages and Couplers in Prestressed Concrete using Continuous Fiber Reinforcing Materials".

4. TESTING MACHINE AND DEVICES

(Comment on 4.5) The surface of the bent section in direct contact with the test piece must be robust and smooth, with no grooves. If the geometry and material of the deflector to be used in actual service has been decided, however, or if the present test is to be conducted for the purpose of determining the service geometry and material, the proposed deflector should be used in test. The geometry and material of the deflector must also be clearly noted in the report together with the test results. No specifications are given for the bending diameter ratio, as this should be decided according to the intended use. As a guide, the bending diameter ratios of deflectors currently in service are normally in the order of 100~150.

5. TEST TEMPERATURE

For CFRM incorporating sheathing or other protective treatment, or for deflectors with treated surfaces, the temperature effects of the protective material must be considered in the test.

6. TEST METHOD

A typical test procedure is illustrated in **Fig. C 1**.[1)~3)].

(Comment on 6.1) The dominant parameters in this test are the bending diameter, the bending angle and the nature of the contact between the CFRM and the deflector. The test conditions must therefore be determined with these parameters clearly spelled out. In addition to tests involving 1-point bending, i.e. using a single deflector, tests using multiple deflectors to bend the test piece at two, three or more points could also be considered but the standard test presented here is a 1-point bending test where the effects of a single bending diameter and bending angle are easier to determine. Three-point tests etc. may also be conducted if the results can be made consistent with those for the 1-point test.

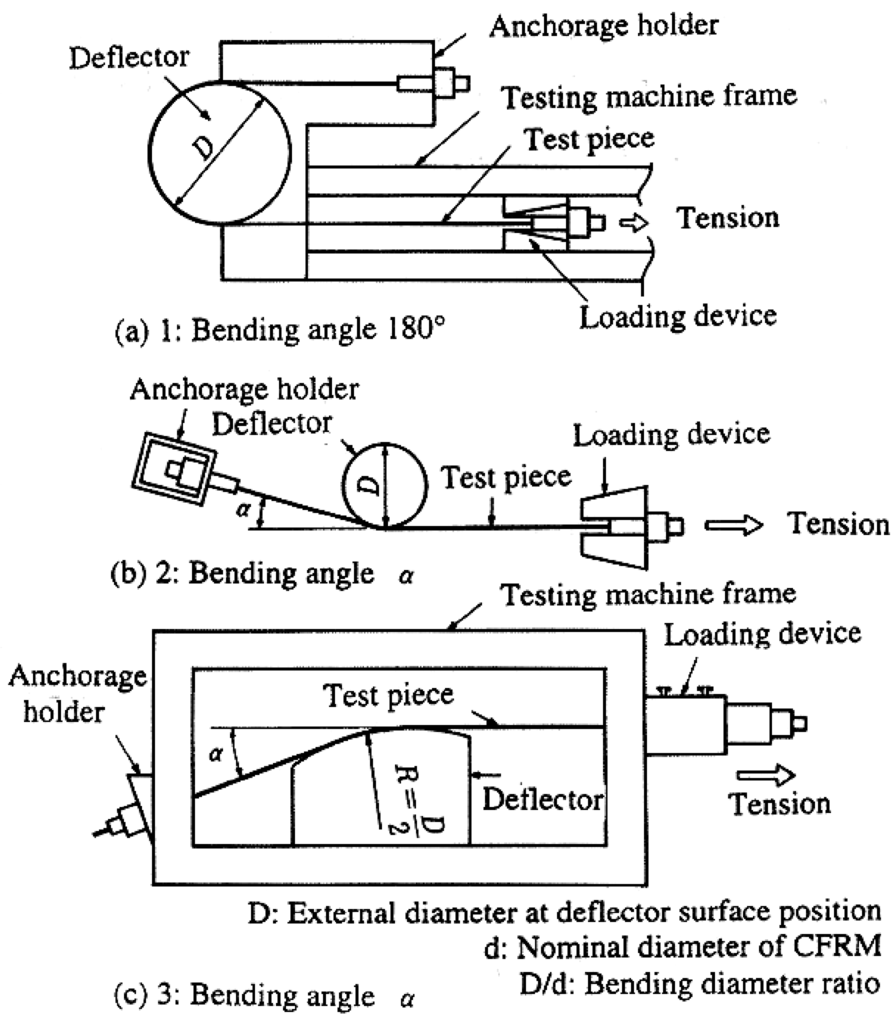

Fig. C 1 Typical bending tensile test set-ups (for reference) [1)~3)]

REFERENCES

1) Kobayashi, Kato and Enomoto: Research on sheaths for FRP Tendons, Summary of AIJ annual meeting, C Structures II, pp. 45~46, Oct. 1990

2) Enomoto and Santo: Experimental Research on Bending Tensile Capacity of CFRP Strands, Proceedings of the 46th JSCE Annual Conference, Vol. 5., pp. 232~233, Sep. 1991

3) Tokumitsu, Hino, Maruyama and Mutsuyoshi: Anchoring Systems and Tensile Properties in Flexure of Multi-type CFRM used as External Cables, Concrete Engineering Annual Papers, Vol. 15, No.2, pp. 813~816, Jun. 1993

Doc. 1: Architectural Institute of Japan: "Annotated Design Guidelines for Cable Structures", Chap. 7 "Detailing" 7.3 "Curved Sections of Cables", pp. 100~105, Jun. 1994

Doc. 2: Akimoto, Yamagata and Arakawa: Development of Practical New Techniques for Prestressed Concrete, External Cable Methods, Prestressed Concrete Structure Design & Construction Guidelines, Prestressed Concrete Technology Association, 22nd Prestressed Concrete Technology Lecture Series (Feb. 1994)

COMMENTARY ON THE TEST METHOD FOR CREEP FAILURE OF CONTINUOUS FIBER REINFORCING MATERIALS (JSCE-E 533-1995)

INTRODUCTION

Unlike reinforcement or prestressing tendon, CFRM may fail (creep failure) at strengths below the maximum static strength when subjected to a significant sustained stress for long periods. This creep failure strength varies according to the type of CFRM, therefore the creep failure strength must be evaluated when determining the level of tension in CFRM used as tendons. This is the reason for the inclusion of the present test method. The following standards were referred to in relation to the development of this test:

-JSCE standard "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials"
-JSCE standard "Test Method for Long-term Relaxation of Continuous Fiber Reinforcing Materials"
JIS K 7115-1986 "Testing Method for Tensile Creep of Plastics"
JIS K 7108-1987 "Testing Methods for Chemical Resistance of Plastics under Constant Tensile Load""

As with the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials", the object of this test is the CFRM itself, excluding the performance of the anchorage. For this reason, test data clearly showing failure or pull-out at the anchoring section is to be disregarded.

1. SCOPE

Test pieces shall be linear or meshed CFRM formed from fiber materials and matrices as defined elsewhere and acting mechanically as a monolithic body.

2. DEFINITIONS

The creep failure capacity and creep failure strength for the design of concrete structures using CFRM are defined.

3. TEST PIECES

(Comment on 3.1) Except for the fact that the load applied to the test piece is a constant, sustained load, the loading state is similar to that in tensile test, therefore the test pieces for this test are to be in accordance with the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

(Comment on 3.2) Given the long periods of time required for creep test, it has been decided to specify 3 test pieces per test condition.

4. TESTING MACHINE AND DEVICES

(Comment on 4.1) Various types of testing machine may be used, such as hydraulic servo load testers, dead-weight load testers etc. It should be noted, however, that in multiple creep testing machines the load applied to one test piece and the deformation, vibration etc. of the testing machine frame due to the load at the time of failure of one test piece are easily transmitted to other test pieces; the testing machine used should be designed and manufactured to eliminate this kind of interference.

5. TEST TEMPERATURE

Creep behavior is easily affected by temperature, therefore a test temperature of 20±2°C is required, in accordance with the specification for temperature-sensitive materials in "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

6. TENSILE FAILURE CAPACITY

This is the standard load from which the constant load to be applied continuously to the test pieces is determined; derived from the values for 5 test pieces.

7. TEST METHOD

7.3 Loads applied

(Comment on (1) & (2)) The aim of this test is to extrapolate the creep failure capacity ratio at 1 million hours from the approximation line plotted according to **8.3** on the basis of test results up to 1000 hours. This requirement is included to increase the accuracy of the approximation line.

Tensile creep failure curves for various types of FRP (fiber reinforced plastic) are shown in **Fig. C 1**. Creep failure strength is given as a stress ratio, based on the tensile strength. CFRP using carbon fibers show high creep failure strengths of around 90% at 1000 hours, while GFRP made from glass fiber show values of 65~70%. While these FRP are not used directly for reinforcement of concrete as CFRM, the values shown here are given for reference in setting the load ratio or sustained loads in creep failure test.

(Comment on 7.4) This section specifies the measurement intervals for creep strain if automatic recording is not available. The intervals specified are the same as those in the "Test Method for Long-Term Relaxation of Continuous Fiber Reinforcing Materials".

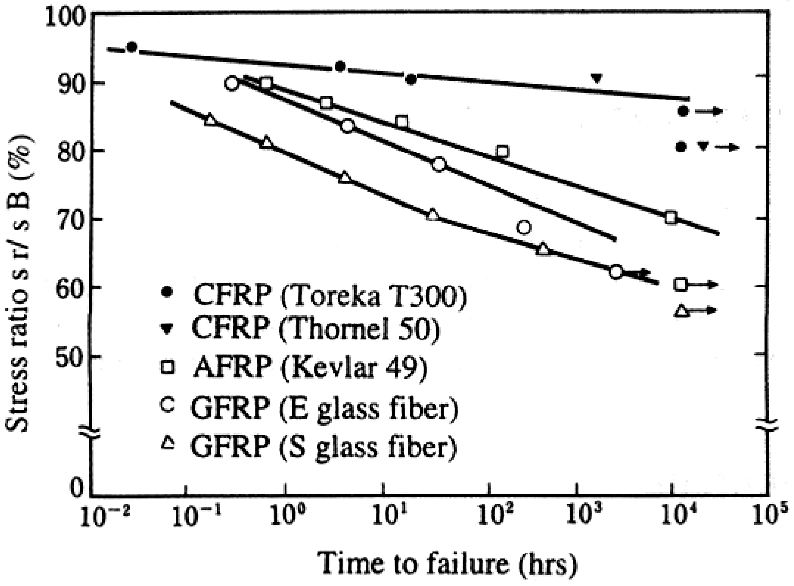

Fig. C 1 Tension creep failure curves for various FRP

8. CALCUALTION AND EXPRESSION OF TEST RESULTS

(Comment on 8.1) This provision is included to improve the accuracy of the approximation curve given in **8.3**.

(Comment on 8.2 & 8.3) A semi-logarithmic graph such as that shown in **Fig. C 2** is plotted, with a horizontal axis showing elapsed time in hours on a logarithmic scale, and a vertical axis showing stress ratio on an arithmetic scale.

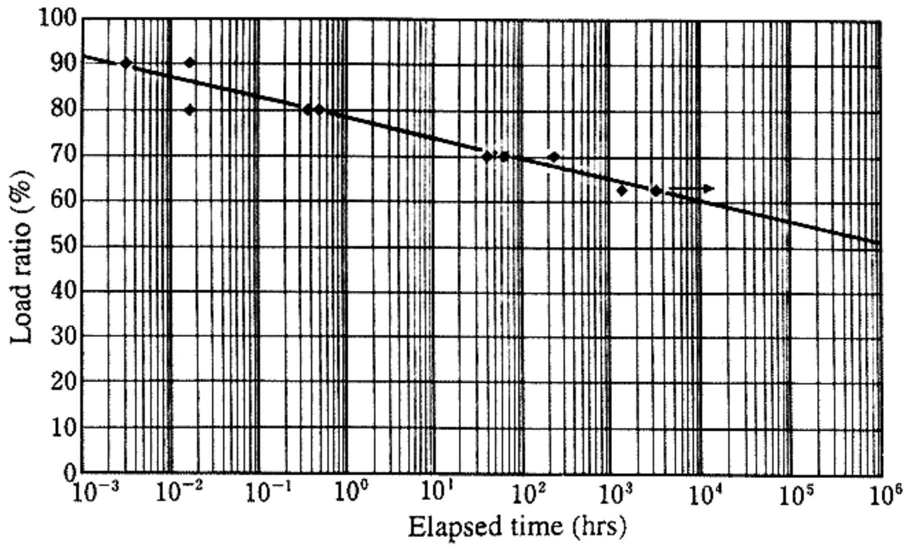

Fig. C 2 Creep failure curve

(Comment on 8.4) Creep failure capacity and creep failure strength normally refer to the values after 1 million hours (approximately 114 years), but if the service life of the proposed structure using

CFRM is determined in advance, the values correspond to this service life (i.e. the service life creep failure capacity and the service life creep failure strength).

REFERENCE

1) Introduction to FRP (revised), Reinforced Plastics Association, p.110, 1989

COMMENTARY ON THE TEST METHOD FOR LONG-TERM RELAXATION OF CONTINUOUS FIBER REINFORCING MATERIALS (JSCE-E 534-1995)

INTRODUCTION

Tendon relaxation in prestressed concrete structures is an important factor that has to be considered in the design. relaxation measurements in keeping with the intended purpose therefore must be made for CFRM, according to the method given here.

In Japan, currently the only prescriptions for relaxation test of prestressing tendon are the 10-hour tests given in JIS G 3536 (Uncoated Stress-relieved Steel Wires and Strands for Prestressed Concrete), and in JIS G 3109 (Steel Bars for Prestressed Concrete). These deal only with mechanical properties as quality standards, and do not give meaningful data for design purposes, which can only be obtained from long-term test conducted at a constant, normal temperature and with constant strain. To meet this need, the JSCE and the AIJ have conferred to produce the “Relaxation Test Method for Prestressing Steels” (AIJ/JSCE, JSEC-E 502-1990), correlated with the JIS test methods.

A provisional long-term relaxation test method for CFRM based on the JSCE standard referred to above is proposed in Vol. 72 of the Concrete Library. The method presented here incorporates subsequent amendments made to ensure consistency with other test methods for CFRM.

1. SCOPE

These provisions relate to a test method for determining levels of long-term relaxation of CFRM under a given temperature and strain, in order to give design-relevant data relating to prestressed concrete structures. Relaxation testing outside of the normal temperature range, and relaxation under variable strain, are therefore outside the scope of this test method, the purpose of which is also different from the existing 10-hour relaxation tests conducted for quality control of prestressing tendon. "Normal temperature" is defined here as a range of 20±15°C, following the Standard Temperature Class 4 given in JIS Z 8703. The test described here may be conducted at any temperature within this range, provided the temperature variation for the duration of the test is not more than ±2°C.

2. DEFINITIONS

A definition is given here for the failure capacity, since this is required as the basis for determining the initial load applied to the test piece for the purposes of relaxation test.

3. TEST PIECES

(Comment on 3.1) Except for the requirement to maintain constant strain, the dynamic conditions for test pieces are identical to those for tensile test, therefore the test pieces for this test are to be as for the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

(Comment on 3.2) Given the long periods of time required for relaxation test, it has been decided to specify 3 test pieces per test condition.

4. TESTING MACHINE AND DEVICES

(Comment on 4.1) The types of testing machine that may be used for this test include relaxation testing machines, hydraulically controlled loading machines etc.

5. TEST TEMPERATURE

Relaxation behavior is easily affected by temperature, therefore a test temperature of 20±2°C is required, in accordance with the specification for temperature-sensitive materials in "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials". As some of the constituent materials of CFRM are highly temperature-sensitive, however, provision has been made for additional tests to be carried out at 0°C and 60°C if necessary.

6. TEST METHOD

(Comment on 6.2) Prestretching is carried out prior to relaxation tests in order to attune the test piece to the testing machine and / or the strain gauge. It has been noted, however, that in Aramid fibers the relaxation rate is affected by the method of loading employed. In such cases, prestretching levels and times must be kept to a minimum.

(Comment on 6.3) The purpose of this test is to determine the relaxation rates required for design purposes, and the initial load must therefore be set to the rate in actual service conditions. This conditions may in some cases result in a load that falls within a range where creep failure occurs but not failure due to relaxation; in such cases, it must be confirmed under actual loading conditions that the load does not result in creep failure of the CFRM, increasing the initial load as necessary.

(Comment on 6.4) Application of initial load
The previous version of this proposed method gave the loading rate as a function of the fiber content by volume, but this has now been brought in line with the tensile test method.

7. CALCULATION AND EXPRESSION OF TEST RESULTS

A semi-logarithmic graph such as that shown in **Fig. C 1** is plotted, with the horizontal axis showing elapsed time in hours on a logarithmic scale, and the vertical axis showing relaxation rates on an arithmetic scale.

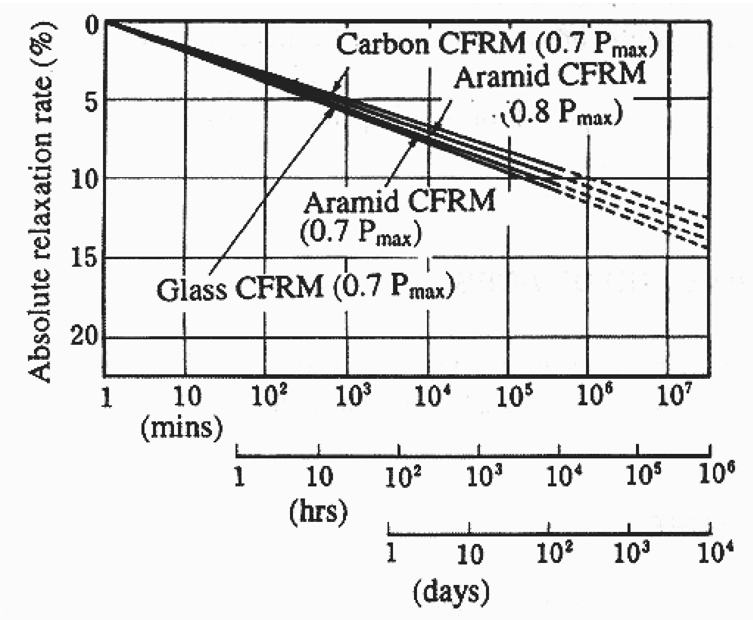

Fig. C 1 Typical relaxation test results

8. TEST REPORT

In normal testing, prestretching should not influence the results of the test, but if such influence is suspected, the report should include details of the level, time and method of prestretching.

COMMENTARY ON THE TEST METHOD FOR TENSILE FATIGUE OF CONTINUOUS FIBER REINFORCING MATERIALS (JSCE-E 535-1995)

INTRODUCTION

The test method presented here is based on the JSCE "Test Method for Fatigue of Continuous Fiber Reinforcing Material (Tentative Proposal)", published in Vol. 72 of the Concrete Library, April 1992. Given the need to confirm the fatigue characteristics of CFRM used in concrete structures subject to prevailing repeated loads due to traffic, wave action etc., the April 1992 proposal is presented as a fatigue test method for isolated CFRM, with reference to JIS K 7118 "General Rules for Testing Fatigue of Rigid Plastics", JIS K 7119 "Testing Method of Flexural Fatigue of Rigid Plastics by Plane Bending, JIS Z 2273 "General Rules for Fatigue Testing of Metals", and the JSCE standard "Proposed Method for Fatigue Testing of Reinforcement Joints". The method given here is a revised version of the April 1992 proposal, narrowed down to tensile fatigue test as this is the most fundamental test, with reference to JIS K 7083 "Testing Method for Constant-Load Amplitude Tension - Tension Fatigue of Carbon Fiber Reinforced Plastics".

Ideally the fatigue characteristics of CFRM in concrete structures should be tested on concrete members incorporating the CFRM, but as such tests would have to be done on a large scale and are unsuitable for accumulation of data, it was decided to set up a fatigue test method for isolated CFRM. Once a certain quantity of data has been accumulated, tests using concrete members to confirm fatigue characteristics will also be necessary.

1. SCOPE

Test pieces shall be linear or meshed CFRM formed from continuous fibers, matrices etc. as defined elsewhere and acting mechanically as a monolithic body. Various forms of fatigue test are possible, such as tension-tension, tension-compression, compression-compression testing etc., and various methods of loading are also possible, but it has been decided to define the present test as a tensile and tensile fatigue test under constant cycle load, this being considered the most basic method for evaluating material characteristics.

2. DEFINITIONS

Definitions of terms for this test shall follow those given in the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials", with reference also to JIS K 7083 " Testing Method for Constant-Load Amplitude Tension - Tension Fatigue of Carbon Fiber Reinforced Plastics ".

(Comment on (1)~(6)) As testing machines are load-controlled, the term load is used in the description of the test, although the term stress is more usual in reporting of results. In the context of this test, therefore, both terms are used interchangeably (see **Fig. C 1**).

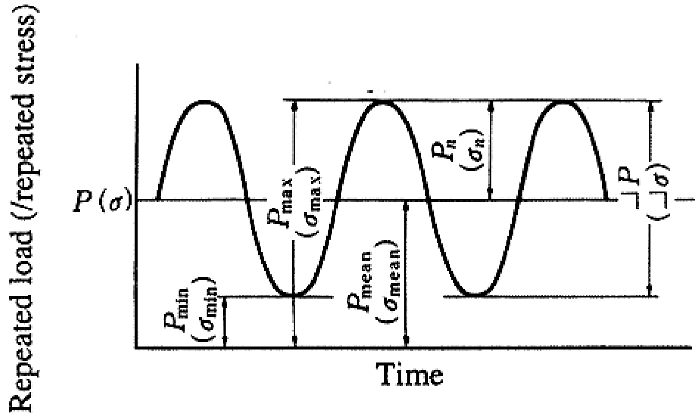

Fig. C 1 Repeated load (/repeated stress)[1)]

(Comment on 8) The number of cycles is represented by *N* or *n*, where *N* is the number of cycles to fatigue failure, and *n* is the number of cycles carried out during fatigue testing.

(Comment on 9) If the test piece has not failed by the end of the test, this fact is to be indicated by the addition of an arrow at the right-hand end of the curve (see **Fig. C 2**). The vertical axis of the *S-N* plot may represent repeated maximum stress (σ_{max}), stress range ($\Delta\sigma$), stress amplitude (σ_a) etc., depending on the purpose of the test. "Stress" may be replaced by "load" depending on the purpose of the test.

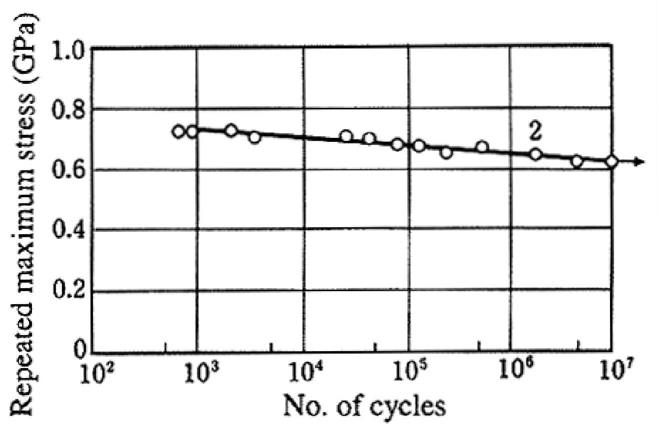

Fig. C 2 Typical *S-N* plot

(Comment on 10) Fatigue strength is generally taken to be a generic term for fatigue limit and fatigue strength at N cycles, where the fatigue limit specifically refers to the point at which the *S-N* curve becomes parallel to the horizontal axis (representing number of cycles). Fatigue strength at N cycles is the upper limit for the repeated stress that can be borne by the test piece over a specified number of cycles (N). While fatigue limits are recognized for steel materials, for plastics and FRPs the S-N curve continues to slope downwards even after 10^8 cycles. So-called fatigue limits are therefore considered not to exist for these materials, and the maximum stress at which the material does not fail after N cycles is substituted for the fatigue limit. That is, this fatigue limit is equivalent to fatigue strength at N cycles, and for CFRM also, the maximum stress at which the material does not fail after N cycles is substituted for the fatigue limit. Fatigue strength is indicated with the number of cycles N appended in parentheses, e.g. σ_m (2×10^6).

(Comment on 11) The unit normally used is Hz.

3. TEST PIECES

(Comment on 3.1) Except for the fact that the load acting on the test piece is a constant load applied repeatedly, the loading conditions for test pieces are similar to those for tensile test, therefore the test pieces for this test are to be in accordance with the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

(Comment on 3.2) The requirement for at least three (3), for each of at least three (3) levels of loading / stress is imposed to ensure proper plotting of the downward-sloping *S*-*N* curve, but if the *S*-*N* curve cannot be properly plotted because of unsuitable stress level settings or wide variations in data, additional test must be performed as necessary. The static tensile strength on which the loading levels for this test are based should be calculated on the basis of not less than five tests conducted according to the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials", using identical test pieces to those used in the fatigue test.

4. TESTING MACHINE AND DEVICES

(Comment on 4.1) The testing machine should preferably be fitted with an automatic load maintenance mechanism. If a test machine with electrohydraulic control is to be used, steps must be taken to ensure the knobs on the excitation side are fixed, i.e. cannot rotate during the test (see **Fig. C 3**).

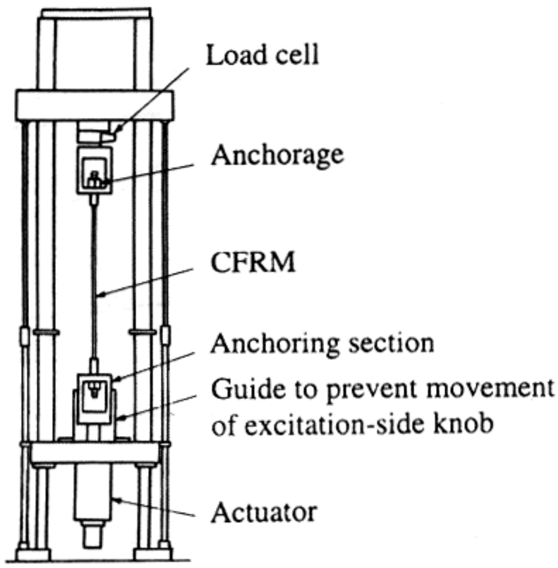

Fig. C 3   Typical testing machine

(Comment on 4.2) Some reports indicate that the type of anchorage device used has a greater effect on the test results in fatigue test than in tensile test, and this issue remains to be studied. Provisionally, therefore, the anchorage used should be identical in all tests.

5. TEST TEMPERATURE

As the effects of temperature and humidity on fatigue tests remains to be clarified, the provision given here is based on the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials".

6. TEST METHOD

(Comment on 6.1) If any slight horizontal movement or rotation of the knob on the excitation side of the test machine is noted, fitting of a guide to prevent such movement before the test is performed may minimize or eliminate any variations in data.

(Comment on 6.2) If the effects of creep failure strength on the tensile fatigue strength are known in advance, this should be taken into account in the setting of the test load and the frequency. Typical *S*-*N* curves for FRP using various types of fibers are shown in **Fig. C 4**, where the maximum-minimum stress ratio *R* is fixed at 0.1. As the fatigue life (i.e. number of cycles to fatigue failure) is generally affected not only by the maximum stress ratio, but also by the stress amplitude, different results may be obtained is the maximum and minimum stress ratios vary. In actual concrete structures subject to variable loads, permanent loads such as dead weight etc. can be considered as the minimum load, and the design load can be considered as the maximum load. In almost all cases, the maximum-minimum stress ratio *R* is greater than the value adopted in **Fig. C 4**, therefore the *S*-*N* curve obtained in such a case can be taken to be more conservative than that shown in **Fig. C 4**.

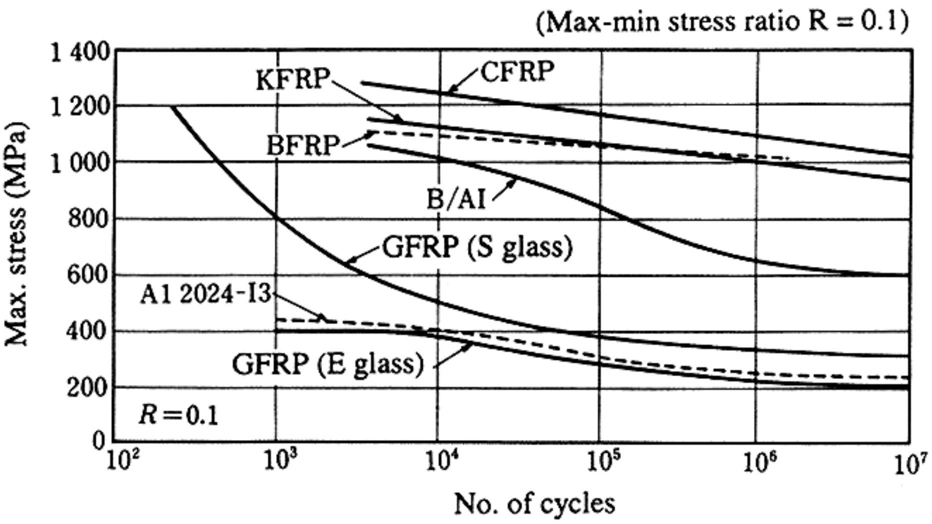

Fig. C 4 Typical *S*-*N* curves for various FRP

The following procedure may be employed where the maximum stress level for the initial test is difficult to determine:

(1) Select an appropriate stress level in the range 20~60% of the static tensile strength, and commence

fatigue test with this value as the repeated maximum stress.
(2) If the test piece ~~is~~ still did not fail after 10^4 cycles at this repeated maximum stress, add 5% of the static tensile strength to the repeated maximum stress, and perform the test using the same test piece. In this case, if possible the test should be carried on uninterruptedly, with the repeated maximum stress incorporating 5% of the static tensile strength.
(3) If the test piece still did not fail after a further 10^4 cycles following step (2), a further 5% of the static tensile strength should be added to the repeated maximum stress.
(4) Repeat step (3) until the test piece fails.
(5) The initial tensile-tensile fatigue repeated maximum stress should be set at the repeated maximum stress level where the test piece fails, minus 5% of the static tensile strength.

(Comment on 6.3) The frequency is set to eliminate the effects of inertia of the moving parts of the test machine, with an upper limit placed at the frequency to prevent excessive heating of the test piece. The entire series of tests should preferably be performed with the same frequency. If the frequency is too low the test will be prolonged accordingly, while if the frequency is too high, the effects of heating will accelerate fatigue damage of the test piece, thus reducing the number of cycles to failure. Further limitations are imposed by the capacity of standard testing machines etc. For these reasons, the frequency has been set at 1~10 Hz, based on previously conducted tensile fatigue tests on CFRM. Depending on the type of CFRM and the stress level, heating may occur even in this range. If heating is suspected, the frequency should be kept below 5 Hz, and the temperature of the test piece should be monitored.

(Comment on 6.4) It should be noted that load variation may occur during a test due to variations in the rigidity of the test piece. If the test machine is not equipped with an automatic load maintenance mechanism, the load must be checked and corrected as necessary during the test.

(Comment on 6.5) The number of cycles is expressed as a multiple of 10^n, e.g. 2.34×10^5, rounded off to three significant digits. The maximum value for the number of cycles to failure (i.e. the number of cycles at which the test may be halted) is 2×10^6.

7. CALCULATION AND EXPRESSION OF TEST RESULTS

(Comment on 7.2) In the case of repeated loading, the stresses corresponding to the maximum and minimum loads respectively are the maximum repeated stress (σ_{max}) and the minimum repeated stress (σ_{min}). Which of the terms load and stress is used will depend on the purpose of the test.

In fatigue test with constant average load or constant minimum repeated load, the relationship generally sought is that between maximum repeated stress or stress amplitude, and the number of cycles to failure (the *S-N* curve). For some test purposes, though, fatigue strength after a given number of cycles may be plotted with stress amplitude on the vertical axis and average stress on the horizontal axis, or with maximum stress on the vertical axis and minimum stress on the horizontal axis.

In the present test, it is hard to draw a distinction between tensile fatigue strength and creep failure strength; this issue awaits further study. In the calculation and expression of test results, therefore, the number of cycles and the repetition rate, i.e. the length of time the repeated load is applied, must be made clear. Where the creep failure strength is known, this may be plotted in a fatigue strength graph etc.

8. TEST REPORT

(Comment on 6) If the test piece did not fail or the test is halted after the specified number of cycles, this fact should be noted in the test report. For cases of failure other than normal failure, the condition of the test piece during the test, and the mode of failure, should also be noted.

REFERENCE

1) JIS K 7083 " Testing Method for Constant-Load Amplitude Tension - Tension Fatigue of Carbon Fiber Reinforced Plastics "

COMMNETARY ON THE TEST METHOD FOR COEFFICIENT OF THERMAL EXPANSION OF CONTINUOUS FIBER REINFORCING MATERIALS BY THERMOMECHANICAL ANALYSIS (JSCE-E 536-1995)

INTRODUCTION

The test method presented here is based on the JSCE "Test Method for Thermal Expansion Coefficient Testing of Continuous Fiber Reinforcing Material (Tentative Proposal)", published in Vol. 72 of the Concrete Library, April 1992, which was based on JIS C 2141 "Testing Methods of Ceramic Insulators for Electrical and Electronic Applications", as the coefficients of thermal expansion of CFRM are relatively close to those of ceramics. Subsequent investigations with commercially available testing machines for measuring thermal expansion coefficients revealed that the TMA machine is the most widely available machine, and furthermore requires no particular expertise in handling. JIS standards have already been established for thermal expansion coefficient test of plastics using the TMA and the technique has been confirmed to be sufficiently accurate. These facts have been borne in mind in drawing up the present test method. The following standards are referenced:

JIS R 3102-1993 "Test Method for Average Linear Thermal Expansion of Glass"
JIS K 7197-1991 "Testing Method for Linear Thermal Expansion Coefficient of Plastics by Thermomechanical Analysis"
JIS K 7100-1981 "Standard Atmospheres for Conditioning and Testing of Plastics"
JIS B 7502-1979 "Micrometer Calipers"

1. SCOPE

This test using the TMA device is to be applied to linear or meshed CFRM test pieces formed from continuous fibers, matrices etc. as defined elsewhere and acting dynamically as a monolithic body.

2. DEFINITIONS

(Comment on 1) A non-vibrating load refers to a load applied slowly enough to prevent the load changes over time from being affected by the viscoelasticity of the material.
(Comment on 3) Coefficient of thermal expansion is generally defined as a value obtained by dividing the differential of the ratio between the length change and temperature change at a given temperature (dL/dT) by the length of the test piece as measured at room temperature. Strictly speaking, however, the length of the test piece ΔL in relation to a finite temperature difference ΔT is a measured variable rather than a differential value, hence the term average coefficient of linear thermal expansion at representative temperatures.

3. TEST PIECES

(Comment on 3.1) Unlike metals, inorganic materials etc., in plastics the dimension changes due to adsorption and desorption of moisture, or to the release of residual strain during molding, processing etc. are not negligible in comparison to the linear thermal expansion. In order to ensure the reliability of measurements, provision has therefore been made for curing of CFRM based on JIS K 7100 "Standard Atmospheres for Conditioning and Testing of Plastics ", with the aim of eliminating moisture and strain resulting from molding and processing. Clearly, if pre-test curing is inadequate, the test piece will shrink due to desorption of moisture as the temperature rises, resulting in an exaggerated value being obtained for the coefficient of thermal expansion.
(Comment on 3.2) The length of the test piece is based on JIS R 3102 "Test Method for Average Linear Thermal Expansion of Glass", where out of consideration for the capacity of the testing machine the standard length is set at no more than 20±0.025 mm, and the diameter or length of one side is set at no more than 5 mm. If a test piece of such dimensions is difficult to obtain from the CFRM in question, test pieces of different dimensions may be used.

4. TESTING MACHINE

(Comment on 4.1) A standard TMA apparatus allows measurements in various modes - expansion, compression, penetration, tension etc. - depending on the choice of loading method and the geometry of the detector rod, but the test described here will normally be conducted in compression mode. A typical TMA apparatus is illustrated in **Fig. C 1**.

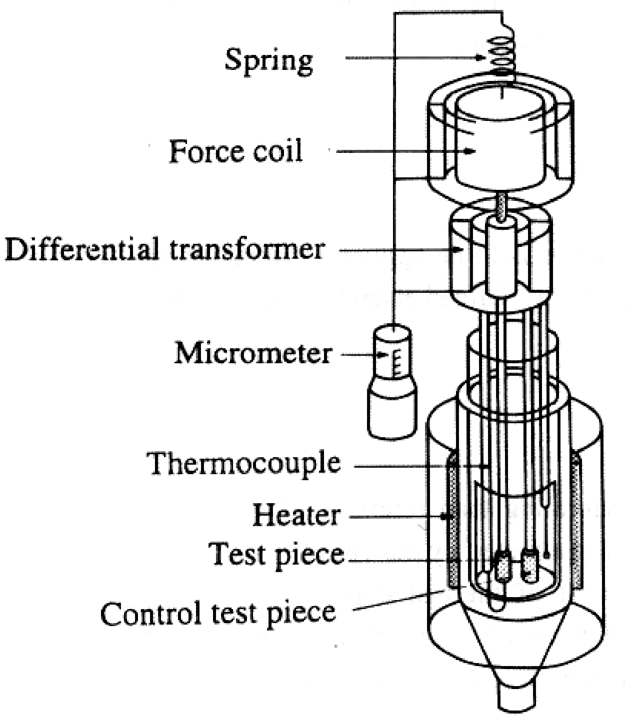

Fig. C 1 Configuration of a typical TMA apparatus

(Comment on 4.2) As the accuracy of measurements of the coefficient of thermal expansion is intimately connected with the accuracy of temperature measurements, temperature calibration is particularly important. Temperature calibration materials feasible for this test would include ice water (0°C) for low temperature calibration, and indium (melting point 156.4°C) for high temperature calibration.

(Comment on 4.3) The TMA apparatus should preferably be mounted on a vibration-proofing base during the test, to eliminate the effects of vibration.

5. TEST METHOD

(Comment on 5.1) As measurement accuracy in the order of μm is required to ascertain dimensional changes, care must be taken to remove extraneous materials such as grease, and to mount the test piece stably.

(Comment on 5.4) The service temperature range for CFRM in actual service is assumed to be 0~60°C. If service temperatures are expected to fall outside this range, the test temperature range must be extended accordingly.

(Comment on 5.5) A limit has been imposed on the rate of temperature increase to minimize temperature measurement errors resulting from the temperature increasing too rapidly.

(Comment on 5.6) According to JIS K 7197 "Testing Method for Linear Thermal Expansion Coefficient of Plastics by Thermomechanical Analysis", the compressive stress acting on the tip of the detector rod is to be in the order of 3±0.1 mN/mm^2, and this standard has been referenced in setting the compressive stress acting on the test piece at around 3 mN/mm^2. This requirement need not apply if the effects on measurements within the test temperature range of softening of the matrix are minimal.

6. CALCULATION AND EXPRESSION OF TEST RESULTS

The coefficient of thermal expansion of unidirectional fiber-reinforced plastics along the fiber axis is approximated by the following equation according to compounding:

$$\alpha_F = (E_f \alpha_f V_f + E_m \alpha_m V_m) / (E_f V_f + E_m V_m) \qquad \text{(Eq. C 1)}$$

where

α_F = coefficient of thermal expansion of unidirectional fiber-reinforced plastics along the fiber axis

α_f = coefficient of thermal expansion of fiber material

α_m = coefficient of thermal expansion of matrix

E_f = modulus of elasticity of fiber material

E_m = modulus of elasticity of matrix

V_f = fiber material content by volume

V_m = matrix content by volume

As the Young’s modulus of the fiber binding material is generally very small compared to the Young’s modulus of the fiber material, the coefficient of thermal expansion of unidirectional fiber-reinforced plastics along the fiber axis will be close to the coefficient of thermal expansion of fiber material.

Similarly, the coefficient of thermal expansion perpendicular to the fiber axis is approximated by the following equation:

$$\alpha_{Fr} = (1+V_m)\alpha_m V_m + (1+V_f)\alpha_f V_f - \alpha_F (v_f V_f + v_m V_m) \qquad \text{(Eq. C 2)}$$

where

α_{Fr} = coefficient of thermal expansion of unidirectional fiber-reinforced plastics perpendicular to the fiber axis

v_f = Poisson's ratio of fiber material

V_m = Poisson's ratio of matrix

Approximate values obtained for various fiber materials and CFRM using them are listed in **Table C 1**. It can be seen from the table that, since the coefficient of thermal expansion of unidirectional fiber-reinforced plastics along the fiber axis is approximately equivalent to that of the fiber material, the coefficient of thermal expansion of the fiber material may be substituted for that of the unidirectional fiber-reinforced plastic along the fiber axis.

As few measurements have been made of the coefficient of thermal expansion of CFRM perpendicular to the fiber axis, an example for one type of unidirectional fiber-reinforced plastic is also given in the table (1). The coefficient of thermal expansion perpendicular to the fiber axis is extremely high in relation to that in the axial direction, and tends to approach the order of magnitude of the coefficient of thermal expansion of the fiber binding material.

Table C 1: Approximate values for coefficient of thermal expansion

Material	Coefficient of Thernal Expansion ($\times 10^{-6}$/°C)		
	Fiber	CFRM or Other Materials	
		Longitudinal Direction	Transverse Direction
Carbon	-2 ~ 8	0.6 ~ 1	25
Aramid	-8 ~ -3	-6 ~ -2	30
Glass	8 ~ 10	8 ~ 10	23
Epoxy	55 ~ 60		
Unsaturated Polyester	80 ~ 100		
Steel	12		
Concrete	7 ~ 12		

REFERENCE

1) H. Miyairi et al. (ed.) Dictionary of Composite Materials, Asakura Shoten publishers, pp.278~279, 1991

COMMENTARY ON THE TEST METHOD FOR PERFORMANCE OF ANCHORAGES AND COUPLERS IN PRESTRESSED CONCRETE USING CONTINUOUS FIBER REINFORCING MATERIALS (JSCE-E 537-1995)

INTRODUCTION

Some studies have been made on test methods for anchorages for use with CFRM tendons in prestressed concrete as part of the Joint Research on New Materials for Use as Tendons in Prestressed Concrete Bridges, which in turn is a part of the Ministry of Construction Comprehensive Technology Development Project for Construction-related New Materials Utilization. The present test method references the following standards, among others:

JSCE "Standard Specification for Design and Construction of Concrete Structures" (1991 edition)
JSCE "Prestressed Concrete Design and Construction Guidelines" (Concrete Library No. 66)

1. SCOPE

The present test proposal is to be applied to anchorages and couplers for CFRM in prestressed concrete structures or members constructed by pre- or post-tensioning. Detailing of tests for special structures subject to unusual loads, located in unusual environments etc. must therefore be determined as appropriate for the structure in question, based on the test method given here.

The anchoring methods currently in use include anchoring of diagonals in cable-stayed bridges, ground anchors etc., but these are not covered in the present test. Anchorage and coupler performance after long periods of use, fatigue performance etc. are also not covered by this test, as these are expected to be influenced by relaxation of the CFRM etc.

2. DEFINITIONS

Terminology for this test is based on the "Recommendation for Design and Construction for Concrete Structures using Continuous Fiber Reinforcing Materials" and the "Quality Standard for Continuous Fiber Reinforcing Materials", with certain additions relating to CFRM used as tendons etc. CFRM used as tendons in prestressed concrete are referred to here as CFRM tendons.

3. TEST METHOD FOR PERFORMANCE OF ANCHORAGES

4. TEST METHOD FOR PERFORMANCE OF COUPLERS

5. TEST METHOD FOR PERFORMANCE OF ANCHORING SECTIONS

The test methods given are based on the JSCE "Proposed Performance Test Methods for Anchorages and Couplers used in Prestressed Concrete Construction", with extra provision being made in sections 3 and 4 for testing of anchorage and coupler performance, expressed in terms of tensile capacity. The "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials" is referenced with regard to the loading rate, test temperature, and number of test pieces.

Tests 3 and 4 are intended for newly developed devices and devices with a minimal performance record in testing the performance (capacity) of anchorages and couplers. Test 5 is intended to check the performance of an anchoring section comprising and anchorage, anchorage reinforcement etc., focusing in particular on the performance of the surrounding concrete. Test 5 is thus to be used in checking the performance of an anchoring section designed using anchorages checked according to tests 3 and 4.

The standard length of CFRM has been set at 3 meters. This is because CFRM anchorages and couplers are commonly used in so-called multi-types, where multiple CFRM are anchored or connected, and if the individual CFRM are of diverse lengths or incorrectly set at the time of tensioning, the tension will be concentrated on a small number of them which will consequently rupture (fail) before the others, giving inaccurate test results. This is best avoided by making the CFRM as long as possible, but as the test results should be on the conservative side, giving a low tensile capacity, and as the members actually used in prestressed concrete will be longer than 3 meters, this was selected as the standard length for the test. If the test does not involve multiple CFRM, the CFRM length may be shorter than 3 meters, but the minimum length given in the "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials" must be adhered to.

(Comment on 3.4, 4.4) If one end of the CFRM or other tendon is fitted with an anchorage or coupler other than the type to be tested, the performance of the other anchorage or coupler must first be confirmed to be equivalent or superior to that of the anchorage or coupler to be tested.

(Comment on 3.5, 4.5) Mode of failure here refers to the condition of the test piece at which the tensile capacity is reached, e.g. "failure of CFRM (giving location of rupture)", "pull-out of CFRM from anchorage", etc.

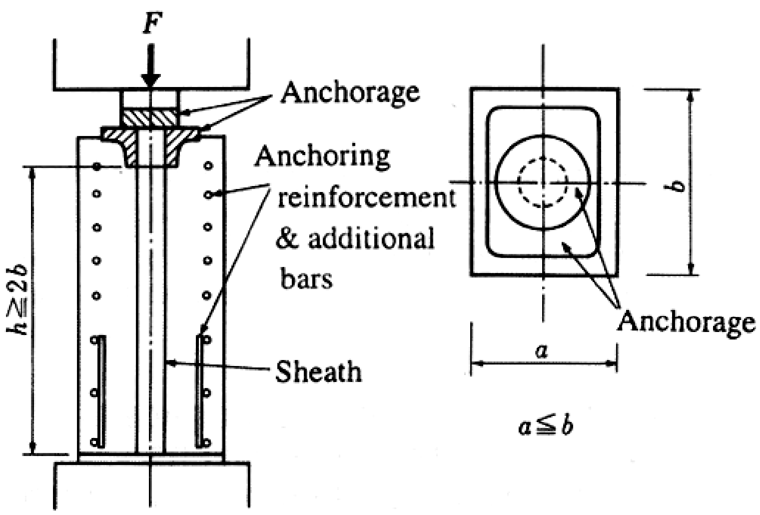

Fig. C 1 Test piece & loading method

(Comment on 5.2.1) The minimum allowable distance in determining the length of one side of the concrete test piece can be obtained by reference to "Duyvidag Method Design and Construction Guidelines", Chapter 4 "Structural Detailing", 4.1 " Minimum Layout Distances", in JSCE "Prestressed Concrete Design and Construction Guidelines".

(Comment on 5.2.2) As the proportion of steel and CFRM arranged in the anchorage reinforcement will vary depending on the design, test conditions should approximate the actual design as closely as possible. Further, as the quantities of anchorage reinforcement and additional bars installed relative to the proposed anchorage will also depend on the actual design, the quantities in the test piece should follow the actual design.

(Comment on 5.2.3, 5.3.2) JSCE "Proposed Performance Test Methods for Anchorages nad Couplers used in Prestressed Concrete Construction" requires that concrete strength at the time of test should be "... sufficient to bear the prestressing level prescribed for the anchorage. Concrete strength at time of testing must not exceed the design strength." The present test requires compressive strength at 28 days of 30±3 N/mm^2, with the test being performed when the concrete has reached a compressive strength of 24±3 N/mm^2. The reason for this is that the performance test proposed here is considered as a means of checking the performance of the anchorage, i.e. a separate test. The requirement for loading when the concrete has reached a compressive strength of 24±3 N/mm^2 is based on the general practice of prestressing at compressive strengths of 21~24 N/mm^2.

Concrete quality and the timing of loading may vary depending on the technique used, and in such a case, test conditions should be determined based on the proposed technique.

(Comment on 5.3.1) Adequate safety measures should be in place when conducting tests involving tensioning of tendons, owing to the inherent dangers of the technique.

6. TEST REPORT

Mode of failure here refers to the condition of the test piece at which the tensile failure capacity is reached, e.g. "failure of CFRM (giving location of failure)", "pull-out of CFRM from anchorage", etc.

COMMENTARY ON THE TEST METHOD FOR ALKALI RESISTANCE OF CONTINUOUS FIBER REINFORCING MATERIALS (JSCE-E 538-1995)

INTRODUCTION

The need for the test for alkali resistance as a durability test for CFRM is referred to in Concrete Library No. 72 "Application of CFRM to Concrete Structures". The alkali resistance of CFRM is determined by immersing test pieces in an aqueous alkaline solution, noting any changes in external appearance, weight and tensile failure capacity before and after immersion, if necessary also conducting microscopic examination of the sides and sections of the test piece, as well as physical and chemical analyses of the fiber bond. The present test method references the following standards:

-JIS K 7107 "Testing Methods for Chemical Resistance of Plastics under Constant Tensile Deformation"
-JIS K 7108 "Testing Methods for Chemical Resistance of Plastics under Constant Tensile Load"
-JIS K 7114 "Testing Method for Evaluation of the Resistance of Plastics to Chemical Substances"
-JIS K 7209 "Testing Methods for Water and Boiling Water Absorption of Plastics"

1. SCOPE

The purpose of this test is to evaluate the alkali resistance of CFRM.

2. TEST PIECES

(Comment on 2.1) The length of the test section of test pieces is based on the proposed tensile test method. Test pieces which have clearly failed at or slipped out from the anchoring section are to be ignored, and test continued until the number of test pieces failing in the test section is not less than three. As there is a possibility of alkaline fluid infiltrating via the ends of the test piece, causing loss of strength in the CFRM, both ends are to be completely sealed with a strong alkali-resistant resin such as epoxy.

(Comment on 2.2) The epoxy sealed ends of a test piece that has undergone immersion are to be cut off, giving a test piece for measurement of mass change. Following measurement of mass change, the test piece is to undergo tensile test.

3. IMMERSION IN ALKALINE SOLUTION

(Comment on 3.1) The alkaline solution should be at around pH 13, e.g. $Ca(OH)_2$ = 2 g/*l*, NaOH = 10 g/*l*, KOH = 14 g/*l*. During long-term testing, there is a possibility of water in the alkaline solution evaporating or absorbing CO_2 from the air, resulting in changes of composition and pH levels, as well as sedimentation. Immersion has therefore to be carried out in a sealed container. Any elution or reaction with the alkali on the part of the CFRM may be ignored, as the high pH level renders negligible the effects of elution or reaction on the pH level.

(Comment on 3.2) A high temperature is desirable as this is an acceleration test, but an upper limit of 60°C has to be imposed owing to the alkali-resistance properties of the fiber bond. 60°C is given as the standard immersion temperature, although any temperature in the range 20~60°C may be selected, depending on the expected application conditions and the properties of the CFRM. Temperature variation should be kept within ±2°C.

(Comment on 3.3) The test piece will normally be immersed untensioned, although immersion under tension is desirable if the material is intended for use as prestressing tendons.

(Comment on 3.4) The standard immersion period shall be 1 month, variable within the range 7 days ~ 1 year. For long periods of immersion, sampling test should be carried out during the test period.

4. EXTERNAL INSPECTION

Elution of the fiber bond into the alkaline solution may result in changes in the surface condition, color and geometry of the CFRM, therefore a visual comparison of immersed and non-immersed specimens is required. If more detailed inspection is necessary, the polished surface or section of the test piece is to be examined under an optical or electron microscope. A physical and/or chemical analysis of the matrix may also be required.

5. MASS CHANGE

The test piece is to be thoroughly washed after immersion to remove any alkali solution adhering to the surface or interior, and the hardened epoxy resin at the ends removed. The test piece is then dried to constant mass. Drying should preferably be carried out in a short time while avoiding thermal degradation, by drying in vacuum at a temperature of not more than 60°C. After leaving the test piece at normal temperature and humidity for 24 hours, the mass is to be measured to an accuracy of 0.1 g and the length to 1 mm. The mass and length of the test piece must of course also be measured prior to immersion.

COMMENTARY ON THE TEST METHOD FOR BOND STRENGTH OF CONTINUOUS FIBER REINFORCING MATERIALS BY PULL-OUT TESTING (JSCE-E 539-1995)

INTRODUCTION

The test method presented here is based on the JSCE "Proposed Method for Bond Testing of Continuous Fiber Reinforcing Material", published in Vol. 72 of the Concrete Library, April 1992, which was based on the draft "Pull-Out Bond Strength Testing Method" (Concrete Handbook, Japan Concrete Institute, February 1976), referencing also JSCE-G 503-1988 “Bond Strength Testing of Reinforcement and Concrete by Pull-Out (Standard Specification for Design and Construction of Concrete Structures (Standards), August 1991)” and the proposed JIS standard “Bond Strength Testing of Reinforcement and Concrete by Pull-Out”. As the standards quoted above refer to steel reinforcement, adaptations have been made to allow for the difference in materials. Revisions have also been made with reference to the draft “Long Fiber Reinforcing Material Bond Test Method” in the Long Fiber Reinforced Materials Concrete Research Report(Vol.3), March 1993”.

1. SCOPE

The present test is intended for CFRM transmitting loads solely by surface bonding, and therefore excludes grid and mesh materials etc. which have different stress transmission mechanisms. In view of the outstanding processability of CFRM, however, CFRM with no fiber binding material and slab form CFRM with rectangular sections are covered by this test.

There is currently no standardized test for bond performance, and in addition to the pull-out tests quoted above, other forms of test available include push-out testing, double sliding testing, beam testing etc. Each of these has merits and demerits, and so have not been established as standard test methods.

The pull-out test given here has been claimed to be incapable of measuring bond strength accurately owing to the differences in the stress conditions in actual members, but it does have the advantages of being simple, executable with existing test equipment, and using test pieces of convenient size. It should be borne in mind, therefore, that the evaluation of bond performance obtained from this test is a relative evaluation.

2. DEFINITION

The surfaces of CFRM are deformed in various ways to ensure bonding. Implementation of the test involves standard concepts of diameter and circumference of the CFRM, and these are therefore defined here.

Nominal peripheral length refers to the circumferential length when calculated from the nominal diameter, to the circumscribed peripheral length when calculated from the circumscribed circle diameter, and to the sum of the lengths of the sides where the section is rectangular.

3. TEST PIECES

(Comment on 3.1) CFRM may have either circular or rectangular sections, and the surface of the material is frequently subjected to various forms of deformation in order to improve the bonding characteristics. Section diameter therefore refers to the diameter of the equivalent circular section, and to the nominal diameter.

(Comments on 3.2) The standard length of one side of the test piece shall be approximately 6 times the diameter of the CFRM, with a bonded length 3 times the diameter and an unbonded length 2 times the diameter. This provision is to prevent yielding or rupture from occurring before pull-out when the concrete is not reinforced. The outline of the test specimen is shown in Fig. C 1.

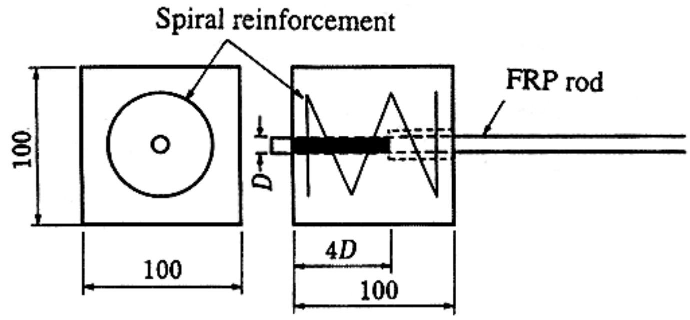

Fig. C 1   Outline of Test Piece

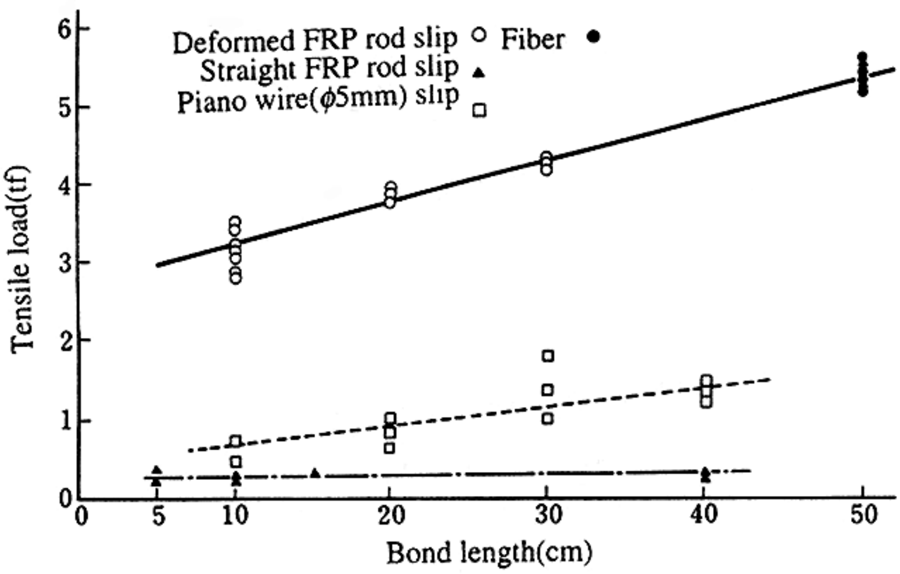

Fig. C 2   Relationship between bond length & pull-out load

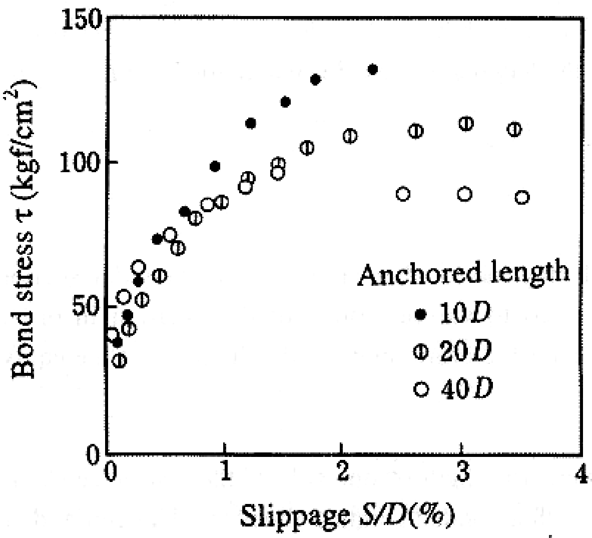

Fig. C 3　Bond characteristics for different anchored lengths

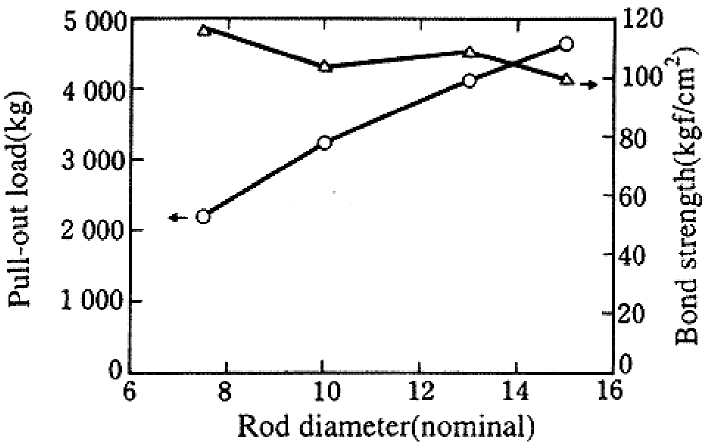

Fig. C 4　Effects of rod diameter on bond strength

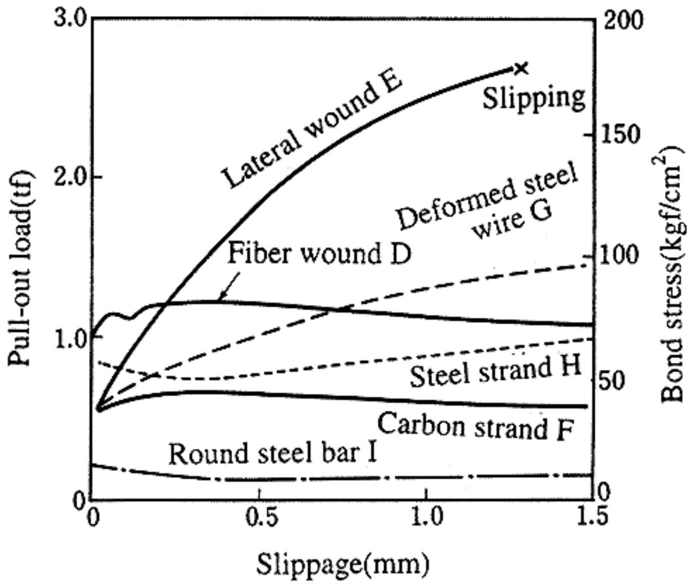

Fig. C 5　Bond behavior characteristics of rod due to differences in deformation treatment

As the length of CFRM anchored in concrete increases, the pull-out load also increases as shown in **Fig. C 2** where a more or less linear relationship is evident, but bond strength conversely tends to fall off as the anchored length increases (**Fig. C 3**). This can be taken to be a general phenomenon whereby the calculated apparent bond strength decreases as the anchored area increases, and this is the case also when the diameter of the CFRM increases (**Fig. C 4**). Consideration has to be made here for the effects of the surface treatment of the CFRM on bond strength. It has been reported, though, as shown in **Fig. C 5**, that especially for stranded materials, the bond strength may be significantly affected if the anchored length is less than one pitch of the strand. In such cases, previous tests have adopted an anchored length of 30~50 cm (10*D*~40*D*).

It has been claimed that bond strength can vary greatly due to stress disturbance within the concrete if the point of introduction of bonding into the concrete is at the end of the test piece. For this reason, the point of introduction of bonding should preferably be inside the test piece, with an unbonded section at the loading end.

(Comment on 3.3) The relationship between slippage displacement and pull-out load (bonding stress) of the CFRM is sometimes required in connection with the bonding characteristics. For this reason, a part of the CFRM has to be left protruding from the concrete, to allow measurement of slippage displacement at the free end.

In pull-out tests of steel reinforcement, the steel can be loaded mechanically by grip Cping. With CFRM, however, the use of a mechanical chuck such as that used on steel would cause a concentration of stress at that point, and could also result in rupture of the CFRM at loads far below the material strength as CFRM are generally weaker in the transverse direction than in the longitudinal direction. A gripping device to transmit loading to the CFRM at the loading end is therefore required. In practice, loading is usually carried out by connecting tie rods to the gripping device, which thus doubles as a coupler for the tie rods.

(Comment on 3.4) The surface bonding strength of an undeformed circular CFRM is considerably lower than that of steel, so the effects of concrete bleeding on bond strength are expected to be correspondingly large. In an admittedly small number of tests where CFRM cast vertically and horizontally in concrete were compared for pull-out strength, the bond strength of the horizontally cast test pieces, which are more subject to bleeding, was found to be slightly lower. In fact, however, CFRM are almost always given deformed surfaces to improve the bonding characteristics, and as **Fig. C 6** shows, bond strength test results are little different from those for deformed steel bars. As the JSCE-G 503-1988 standard also specifies the horizontal position, this has been adopted here also as it gives a conservative evaluation.

(Comment on 3.5) If the concrete undergoes splitting failure during a pull-out test, the bonding is lost instantaneously and a proper evaluation of bonding characteristics cannot be made. It is therefore necessary to reinforce the concrete to prevent splitting failure before pull-out. On the other hand, this reinforcement has to be kept to a minimum, otherwise a constraining effect will appear in the concrete. Some tests of CFRM have been performed with the pitch of the reinforcing bars reduced, or with increased reinforcement, but studies of the constraining effect in these cases are still inadequate, so the original proposal has been retained here. The arrangement of reinforcement also should be gauged accurately, as it has a significant effect on the bond strength.

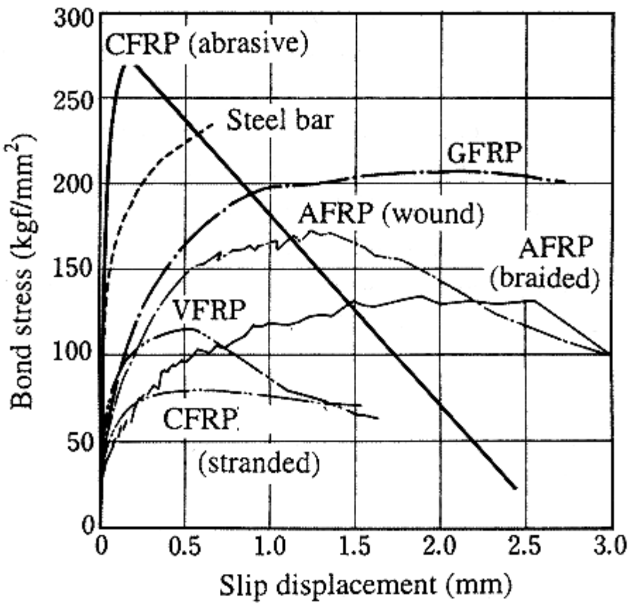

Fig. C 6   Pull-out test results for various reinforcement types

(Comment on 3.6) Three test pieces is an adequate number as the purpose of the test is to make a relative comparison of the bonding characteristics of a CFRM.

4. FORMS

The conventional type of form already in use is adopted here.

5. CONCRETE QUALITY

The effects of the maximum aggregate size, slump and concrete strength on bond strength are not clear (**Figs. C 7,8**). The concrete quality provisions of JSCE-G 503-1988 have been retained as there is no obvious reason to change them for testing of CFRM. As CFRM are used almost exclusively in prestressed concrete, if necessary the bond strength with high strength concrete should also be tested.

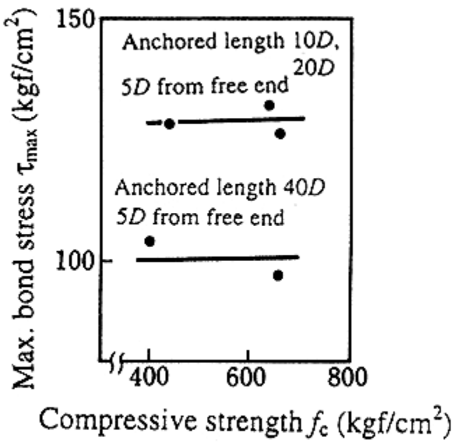

Fig. C 7   Relationship of concrete strength and bond strength

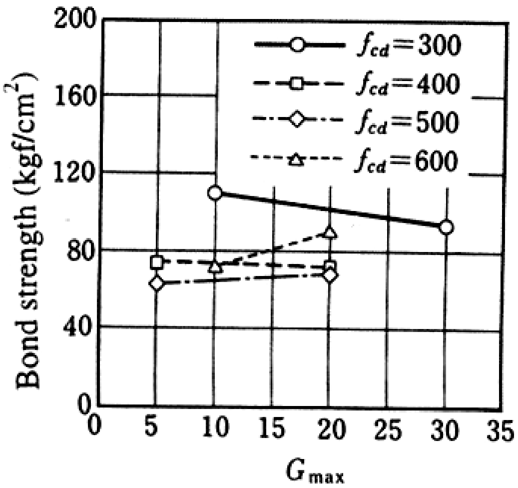

Fig. C 8 Effects of maximum aggregate size on bond strength

6. PLACING OF CONCRETE

(Comment on 6.2) The seal can consist of soft plastic tubing with an internal diameter more or less equivalent to the maximum diameter of the CFRM, in conjunction with oil putty. The external diameter of the covered section should be in the range of 1.2~1.5 times the diameter of the CFRM.

7. REMOVAL OF FORMS AND CURING

Care should be taken not to subject the CFRM to any shock.

8. TESTING MACHINE AND DEVICES

The testing machine and gauge are illustrated in **Fig. C 9**.

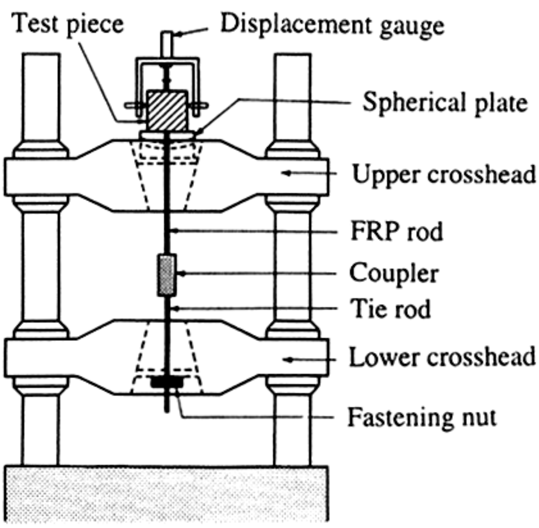

Fig. C 9 Outline of testing machine

(Comment on 8.2) Provision is made for a hole in the loading plate to allow for the diversity of CFRM likely to be tested.

(Comment on 8.3) The gripping device also serves to anchor the CFRM. A common practice is to place a sheath over the CFRM, filling the gap between the two with resin or expansive mortar. This is equivalent to the gripping device used in tensile test, and the test piece must not pull out before undergoing bond failure. The conditions for bond testing need not be as strict as those for tensile testing, and a gripping device similar to that used in tensile test is sufficient.

9. TEST METHOD

(Comment on 9.1) The spherical plate is necessary to minimize the effects of bending and torsion on the CFRM and the concrete.

10. CALCULATION AND EXPRESSION OF TEST RESULTS

JSCE-G 503-1988 stipulates adjustment of the bond stress using the concrete strength derived by dividing the pull-out load by the bonded area. While the bond strength in cases of bond splitting are governed by the concrete strength, for other cases a good correlation with the compressive strength of the concrete has not yet been established. For this reason no corrections based on concrete strength are specified here, and the compressive strength has only to be noted in the report.

COMMENTARY ON THE TEST METHOD FOR SHEAR PROPERTIES OF CONTINUOUS FIBER REINFORCING MATERIAL BY DOUBLE PLANE SHEAR (JSCE-E 540-1995)

INTRODUCTION

Shear in CFRM is investigated in relation to lifting wire rods, or to the reinforcement effect of shear reinforcement. The former case concerns shipping or transportation, storage and stages in construction and is regarded as a construction condition. The latter case concerns shear in members, and needs to be studied in order to establish design standards.

With the above in mind, the present test method is proposed as a method for determining the shear strength of materials. The test method given is simple but involves the possibility of compressive and shear deformation of test pieces. Unless test pieces are infinitely thin, the stresses causing failure are complex and do not correspond to shear in the strictest sense, but the present test is proposed nevertheless, given the current lack of a suitable alternative. “JSCE standard JSCE-G 553 1983: Shear Strength Test Method for Steel Fiber Reinforced Concrete” was referenced in drawing up this test.

1. SCOPE

The test method given here is for an average shear strength of CFRM materials by shear cutting.

There is currently no standard method for evaluating shear strength of wires such as CFRM, and so no standard have been set, but a method involving shear cutting of bar-shaped test pieces have been described [1,2]. The test method for shear given here, as stated in the Introduction above, cannot be said to evaluate shear strength in the strict sense owing to the complex stress situation, but the method has the advantage of simplicity and of using existing test apparatus.

It should therefore be noted that the test method given here evaluates average shear strength when cutting CFRM.

2. TEST PIECES

Test pieces should be longer than the shear testing apparatus, not less than 5 times the distance between shear planes and not more than 30 cm. Use of bent test pieces may result in splitting of the resin or damage to the fibers themselves when the test piece is set in the metal holders, thus test pieces must have good parallelism.

3. TESTING MACHINE AND DEVICES

The testing machine for shear test, illustrated in **Fig. C 1**, consists of a push-in cutting device and a test piece holder. The gap between the two parts must be as small as possible to enable cutting of test pieces.

The surfaces contacting the test piece, illustrated in **Fig. C 2**, may be (**a**) push-in semi-circular cutter with circular holder; (**b**) flat cutter with circular holder; or (**c**) both cutter and holder flat. A comparison using rod-shaped test pieces found that cutting strength for (**b**) and (**c**) was slightly greater than for (**a**). This is thought to be due to the smaller contact area between a rod-shaped test piece and a flat device, thus the test piece is cut while subject to compression. Type (**a**) is thus preferred for rods, and type (**c**) for strips.

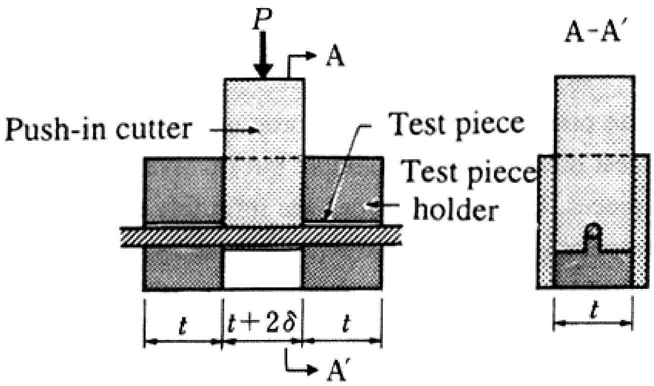

Fig. C 1 Double shear test machine

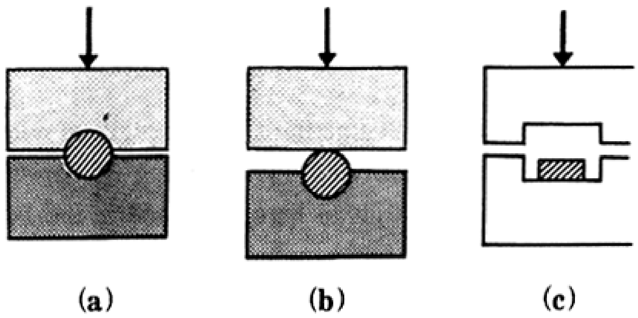

Fig. C 2 Combinations of test pieces and test machine contact surfaces

If the distance between the shear faces t is too large, flexing action takes place, which in some CFRM types was found to result in pull-out of fibers. Relatively uniform results for shear strength were obtained at shear face distances of 2~3 times nominal diameter although the value t = 50 mm that has been adopted here as the variation coefficient is small for different nominal diameters.

4. CALCULATION AND EXPRESSION OF TEST RESULTS

The ideal test apparatus for this test would have no gap between the push-in cutter and the holder, but as this is impossible for practical purposes, the test piece is subjected not only to shear stress, but also to flexural stress and the fracture face may exhibit pull-out of fibers due to flexure as well as shear. The fracture face should be examined after testing, and if significant fiber pull-out is found, the test should be treated as invalid, and repeated after adjustment of the testing machine.

This test method subjects the test piece to compression force in addition to shear force due to contact stress with the metal fittings. This compression force is not uniform along the axis of the test piece; it is thought to be distributed as shown in **Fig. C 3**. The test is in fact carried out under these stress conditions, although for practical purposes, shear strength is to be derived from the average stress calculated by dividing the maximum load *P* in the shear test by the total nominal sectional area.

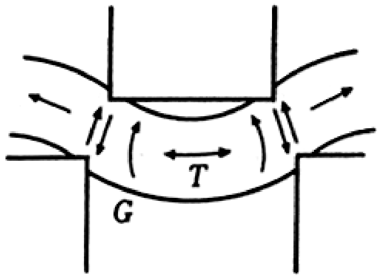

Fig. C 3　Conceptual diagram of contact stresses from the test apparatus acting on the test piece

REFERENCES

1] Kawamoto, M.: Materials Testing, Chap 5, "Shear Testing", Asakura Shoten Pub., 8th ed., pp.54~56, 1970

2] Japan Plasticity Processing Association (ed.): Plasticity Processing Series No. 12 "Shear Processing: The Basics of Press Working", Corona Pub., 1st ed., 1992