QUALITY SPECIFICATIONS FOR CONTINUOUS FIBER REINFORCING MATERIALS

1. SCOPE

These specifications shall apply to continuous fiber reinforcing materials used for reinforcement or prestressing tendons in concrete.

2. REPRESENTATION

The following items shall be included in the representation of specifications. Item 14) "Relaxation rate" may be excluded for materials intended for use as reinforcement only.
Calculation methods for each category are given in section 8. below.

1) Fiber category and identification
2) Configuration and identification
3) Binding material
4) Strength and modulus of elasticity
5) Volume ratio of axial fiber
6) Nominal cross sectional area
7) Nominal diameter
8) Maximum size
9) Nominal mass density
10) Guaranteed capacity
11) Tensile rigidity
12) Elongation
13) Creep failure capacity
14) Relaxation rate

3. CATEGORY, IDENTIFICATION, DESIGNATION

3.1 Fiber type and identification

Five categories of fiber may be used in CFRMs, with identification symbols as given in Table 1.

Table 1: Fiber type and identification

Fiber type	Identification
Carbon fiber	C
Aramid fiber	A
Glass fiber	G
Vinylon fiber	V
Composite	*)

*) two letters of two fibers with the first letter indicating a dominant fiber content.
eg. GC (glass fiber and carbon fiber composite with a larger volume of glass fiber)

3.2 Configuration and identification

Configuration of CFRMs is categorized as one of the five types, with identification symbols as given in Table 2.

Table 2: Configuration categories and identification symbols

Category	Rod	Strand	Braided	Lattice	Rectangular
Symbol	R,D *)	S	B	L	P
Configuration					

*) D = deformed

3.3 Designations

Designations for CFRM fiber / configuration combinations are given in Table 3.

Table 3: Designations

Fiber type	Configuration	Designation
Carbon	Rod	CR,CD
	Strand	CS
	Braided	CB
	Lattice	CL
	Rectangular	CP
Aramid	Rod	AR,AD
	Strand	AS
	Braided	AB
	Lattice	AL
	Rectangular	AP
Glass fiber	Rod	GR,GD
	Strand	GS
	Braided	GB
	Lattice	GL
	Rectangular	GP
Vinylon	Rod	VR,VD
	Strand	VS
	Braided	VB
	Lattice	VL
	Rectangular	VP
Composite	Rod	*)R,*)D
	Strand	*)S
	Braided	*)B
	Lattice	*)L
	Rectangular	*)P

*) = initial letters of two fiber types, e.g. GC (glass fiber + carbon fiber composite)

4. QUALITY OF FIBER AND BINDING MATERIAL

4.1 Fibers

Fibers used in CFRMs shall satisfy the quality specifications given in Table 4.

Table 4: Specifications for fiber

Fiber type	Specification	Definition
Carbon fiber	*)	Carbon content not less than 92%, normally non-graphitic
Aramid fiber	*)	All aromatic series polyamide fiber
Glass fiber	JIS R 3412, JIS R 3413	Fibers satisfying the JIS standards, left
Vinylon fiber	*)	Fibers of long chain synthetic polymers containing not less than 65% by weight of vinyl alcohol units(-CH_2-CHOH-)

*) = No Japanese or overseas standard available

4.2 Binding materials

Binding materials used in CFRMs shall be either epoxy or vinyl ester types, satisfying the quality specifications given in Table 5.

Table 5: Specifications for binding materials

Resin type	Specification
Epoxy	Conforming to standards for epoxide resins given in JIS K 7238
Vinyl ester	Conforming to standards for UP-CEE given in JIS K 6919

5. MECHANICAL PROPERTIES

Required mechanical properties for CFRM are given in Table 6.

Table 6: Mechanical properties

Identification symbol	Volume ratio of axial fibers V_f (%)	Guaranteed tensile strength [2),4)] f_0 (N/mm^2)	Young's Modulus E (kN/mm^2)	Elongation e_0 (%)	Creep failure strength [2)] f_r (N/mm^2)	Relaxation rate [3)] g (%)	Durability
CR65,CD65	63 - 66	1240	99 – 170	1.0 - 1.5		2 - 3	
CR50A,CD50A	49	960*	200	0.5			
CR50B,CD50B	49 - 52	780	190	0.4 - 0.5			
CS65A	64 - 66	980	73 – 210	0.5 - 1.5		1.04-1.06	
CS65B	64 - 66	790	84 – 170	0.5 - 1.4			
CL40	43	1200*	100	1.2			

C3D	60	1490*	130	1.1			
AR65,AD65	65	1720	59 – 60	2.9 - 3.1		7 - 14	
AS65A	60 - 69	1710	42 – 47	3.5		8.0 - 8.6	
AS65B	60 - 69	1830*	44 – 45	3.5			
AB65	66	1400	63 – 78	2.0		10	
AP50	49	1330	62	2.15		11	
AL40	43	1300*	57	2.2			
GR65,GD65	65 - 68	1130	37 - 49	2.5 - 2.7		1.82	
GL40	40	590	30	2.0			
GCL40A	40	530	37	1.4			
GCL40B	40	530*	37	1.4			
Remarks	Section 8.1	Section 8.6	Section 7.2	Section 8.8	Section 7.3, 8.9	Section 7.4, 8.10	

1) A or B following identification symbol refers to nominal diameter D:
   A : $D \leq 20$ mm; B : $D \geq 20$ mm
2) Strength, such as guaranteed tensile strength and creep failure strength, is obtained by dividing capacity, such as guaranteed capacity and creep failure capacity, by nominal cross sectional area
3) Not official values because test method was not identical
4) Data marked * refer not to average of many products but to average of one product
5) A blank cell indicates insufficient data available at present

6. NOMINAL DIAMETER AND MAXIMUM SIZE

Nominal diameter and maximum size are tested according to sections 8.3 and 8.4; the maximum size ranges are given in table 7 and 8. Blank cells indicate data unavailable.

Table 7: Nominal diameters and maximum size ranges (1)

Symbol	D (mm)	Dmax (mm)	Remarks (Designation)
CD(D) (20 types)	3.0		CFCC
	5.0		
	9.0	9.0 - 9.4	Hiful CF (SNCP)
	10.0	10.2 - 10.6	
	12.0	12.5 - 12.8	
	8.0	9.0 - 9.4	Hiful CF (ANCP)
	10.0	10.9 - 11.3	
	12.0		
	5.0		Leadline PC-5
	7.9		PC-D8
	9.8		PC-D10
	12.0		PC-D12
	5.0		Leadline PC-R5
	7.9		PC-R8
	9.8		PC-R10
	12.0		PC-R12
	12.5	14.0 - 16.0	CFRP rod
	20.0		
	25.0		

	30.0		
CS (23 types)	5.0		CFCC
	7.5		
	10.5		
	12.5	12.4 - 13.4	
	15.2	15.0 - 15.8	
	17.8		
	25.0		
	40.0	39.2 - 41.5	
	12.5		CFRP strand
	15.0		(standard)
	21.0		
	25.0		
	30.0		
	35.0		
	15.0		CFRP strand
	25.0		(high strength)
	30.0		
	12.5		CFRP strand
	15.0		(high elasticity)
	21.0		
	25.0		
	30.0		
	35.0		
CL (6 types)	4.7	3.0 - 5.4	Nefmac C6
	7.1	4.7 - 7.9	C10
	9.1	6.1 - 10.1	C13
	11.3	8.0 - 12.0	C16
	13.7	9.8 - 14.6	C19
	15.8	11.2 - 16.8	C22
C3D	10.0		BE3D
AR(D) (10 types)	3.0	3.33 - 3.64	Technora rod
	4.0	4.40 - 4.89	(deformed)
	6.0	6.86 - 7.36	
	7.4	8.02 - 8.56	
	8.0	8.88 - 9.87	
	3.0	2.95 - 3.05	Technora rod
	4.0	3.94 - 4.06	(round)
	6.0	5.82 - 6.01	
	8.0	7.80 - 8.01	
	7.5	7.70 - 8.10	Arapree
AS (8 types)	12.4	12.5 - 13.56	Technora strand
	12.7	12.72 - 14.1	
	15.2A	15.29 - 16.68	
	15.2B	15.31 - 16.72	
	17.8	17.92 - 19.21	
	19.3	19.32 - 20.92	
	20.3	20.51 - 22.3	
	21.8	21.93 - 22.95	
AB (10 types)	7.3	8.1 - 8.36	FiBRA RA7
	9.0	9.3 - 10.2	RA9
	10.4	11.2 - 12.3	RA11

	12.7	13.7 - 14.6	RA13
	14.7	16.1 - 16.6	RA15
	7.3	8.02 - 8.33	FiBRA FA7
	9.0	9.2 - 10.1	FA9
	10.4	11.1 - 12.2	FA11
	12.7	13.6 - 14.4	FA13
	14.7	15.9 - 16.6	FA15
AP (3 types)	5.4		Arapree
	7.6		
	10.6		
AL (5 types)	4.5	2.8 - 5.2	Nefmac A6
	6.8	4.5 - 7.5	A10
	8.7	5.8 - 9.6	A13
	10.8	7.7 - 11.5	A16
	13.2	9.4 - 14.0	A19

Table 8: Nominal diameters and maximum size ranges (2)

Symbol	D (mm)	Dmax (mm)	Remarks (Designation)
GR(D) (6 types)	8.0	8.7 - 9.0	Hiful GF(SNGP)
	10.0	10.5 - 10.9	
	12.0	12.6 - 13.1	
	8.0	8.7 - 9.0	Hiful GF(ANG)
	10.0	10.8 - 11.2	
	12.0	13.0 - 13.4	
GL (8 types)	2.4	1.1 - 2.9	Nefmac G2
	3.3	2.0 - 3.8	G3
	4.1	2.5 - 4.7	G4
	6.7	4.1 - 7.7	G6
	10.0	6.7 - 11.1	G10
	12.9	8.6 - 14.4	G13
	16.0	11.2 - 16.8	G16
	19.4	13.8 - 20.6	G19
VR(D) (2 types)	6.0		Claratec rod
	10.0		
GCL (6 types)	7.1	4.4 - 8.2	Nefmac H6
	10.6	7.0 - 11.8	H10
	13.7	9.2 - 15.2	H13
	16.9	12.0 - 18.0	H16
	20.7	15.2 - 21.4	H19
	23.8	17.4 - 24.6	H22

7. TEST

7.1 Sampling

Test pieces shall be obtained as shown in Table 9.

Table 9: Sampling standards

Nominal diameter	Sampling standard
Any nominal diameter	Sample taken from either end of a length or part of length* of CFRM

* Minimum unit : 100 m

7.2 Test for tensile strength

(1) Test for tensile strength shall be conducted in accordance with JSCE-E 531 "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials"
(2) Tensile strength shall be obtained by dividing the maximum resistant load by the nominal cross sectional area.
(3) Young's modulus shall be obtained by dividing the tensile rigidity by the nominal cross sectional area.

7.3 Test for creep failure strength

Test for creep failure strength shall be conducted in accordance with JSCE-E 533 "Test Method for Creep Failure of Continuous Fiber Reinforcing Materials".

7.4 Test for relaxation rate

Test for relaxation rate shall be conducted in accordance with JSCE-E 534 "Test Method for Long-Term Relaxation of Continuous Fiber Reinforcing Materials".

8. CALCULATION

8.1 Volume ratio of axial fiber

The volume ratio of axial fiber refers to the ratio of the volume of axial fiber to the apparent volume of CFRM, and is obtained from the following equation:

$$V_F = (v_{fa} / v_t) \times 100 \quad (\%)$$

where

V_F = volume ratio of axial fiber
v_{fa} = volume of axial fiber
v_t = apparent volume of CFRM

8.2 Nominal cross sectional area

(1) Nominal cross sectional area refers to the value in mm2 obtained by dividing the volume of the CFRM by the length, following the method given in 8.2(2) below. The standard method for obtaining test pieces shall be as shown in Table 9, and the total number of test pieces shall be not less than 5. Where the cross section is uniform, as in rod type CFRMs, the nominal cross sectional area may be

calculated from the nominal diameter and p .

(2) Calculation method of nominal cross sectional area

1) Measure the length L (mm) of one test piece (1 m approx.) accurately to the nearest 0.1 mm.
2) Fill a glass tube of cross sectional area A_g with water, and record the water level H_0 (mm).
3) Place the test piece gently in the glass tube, and record the water level H_1 (mm).
4) Calculate the volume of the test piece V (mm^3) based on the difference between water levels H_0 and H_1, and the cross sectional area of the glass tube.
5) Calculate the sectional area A according to the following equation

$$A = (H_1 - H_0) \times A_g / L \qquad (mm^2)$$

6) The average of the cross sectional areas A of not less than 5 test pieces shall be designated the nominal cross sectional area.

8.3 Nominal diameter

"Nominal diameter" is the diameter applied to the CFRM, defined as the average value in mm of twice the square root of the result of dividing the nominal cross sectional area by p . For CFRMs with a rectangular section, the cross sectional area is calculated from the breadth and depth of test pieces, and the nominal diameter is defined as twice the square root of the result of dividing this cross sectional area by p . The method of obtaining test pieces, and the number of test pieces, shall be as for 8.2(2) Calculation method of nominal cross sectional area ".

8.4 Maximum size

(1) "Maximum size" refers to the maximum dimension of the CFRM section, following the method given in 8.4(2) below.

(2) Calculation method of maximum size

1) Obtain a test piece of length 1 m.
2) For test pieces of not less than 5, measure the maximum diameter in the two orthogonal directions to the nearest 0.1 mm, at both ends and in the center of the test piece.
3) The maximum diameter of not less than 5 test pieces shall be designated as the maximum size.

8.5 Nominal mass density

(1) Nominal mass density (g/m) is obtained by dividing the mass of CFRM by the length, following the method given in 8.5(2) below. The standard method for obtaining test pieces shall be as shown in Table 9, and the total number of test pieces shall be not less than 5.

(2) Calculation method of nominal mass density

1) Measure the mass of a test piece (length 1 m) to the nearest 0.1 g.
2) Measure the length of the test piece to the nearest 0.1 mm.
3) Calculate mass density by dividing the mass by the length.
4) The average of the mass densities of not less than 5 test pieces shall be designated the nominal mass density.

8.6 Guaranteed capacity

(1) Guaranteed capacity is the characteristic value of the tensile capacity of CFRM, following the method given in 8.6(2) below. The standard method for obtaining test pieces shall be as shown in Table 9, and the total number of test pieces shall be not less than 20.

(2) Calculation method of guaranteed capacity
Guaranteed capacity shall be not more than the value which is obtained by subtracting three times the standard deviation from the average of the test results of not less than 20 test pieces conducted in accordance with JSCE-E 531 "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials", and is rounded off to the nearest 100 N. Test pieces failing at the anchorage shall be disregarded.

8.7 Tensile rigidity

(1) Tensile rigidity shall be calculated following the method given in 8.7(2) below. The standard method for obtaining test pieces shall be as shown in Table 9, and the total number of test pieces shall be not less than 20. The data for calculation of the tensile rigidity may be obtained during the test for the guaranteed capacity.

(2) Calculation method of tensile rigidity
Tensile rigidity shall be the average value of the results of not less than 20 test pieces, each result being calculated according to the following equation, using the values from the load - strain curve obtained in accordance with JSCE-E 531 "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials" at 20% and 60% of the guaranteed capacity.

$$EA = \Delta F / \Delta \varepsilon$$

where

EA = tensile rigidity (kN)
ΔF = load increment from 20% to 60% of guaranteed capacity (kN)
$\Delta \varepsilon$ = strain increment from 20% to 60% of guaranteed capacity

8.8 Elongation

(1) "Elongation" refers to the elongation corresponding to the guaranteed capacity, expressed as a percentage calculated following the method given in 8.8(2) below. The standard method for obtaining test pieces shall be as shown in Table 9, and the total number of test pieces shall be not less than 20. The data for calculation of elongation may be obtained during the tensile test for the guaranteed capacity.

(2) Calculation method of elongation
1) Calculate elongation corresponding to the guaranteed capacity of each test piece, from the test results obtained in accordance with JSCE-E 531 "Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials", for not less than 20 test pieces.
2) Elongation shall be defined as the average elongation of not less than 20 test results.

8.9 Creep failure capacity

"Creep failure capacity" is obtained by multiplying the creep failure capacity ratio at 1 million hours, which is obtained by extrapolation of the load ratio - failure time approximation curve in which data are shown up to 1000 hours obtained in accordance with JSCE-E 533 "Test Method for Creep Failure of Continuous Fiber Reinforcing Materials", by the guaranteed capacity.

8.10 Relaxation rate

The relaxation rate is defined as the estimated relaxation after 1 million hours, which is obtained by extrapolation of the time - relaxation approximation curve in which data are shown up to 1000 hours obtained in accordance with JSCE-E 534 "Test Method for Long-Term Relaxation of Continuous Fiber Reinforcing Materials".

9. INSPECTION

9.1 Mechanical properties

Mechanical properties shall be inspected following 7. TEST and 8 CALCULATION, confirming that the results conform to the mechanical properties listed in 5 MECHANICAL PROPERTIES.

9.2 Dimensions

Dimensions shall be measured according to 8 CALCULATION, confirming that the results conform to the values given in 6. NOMINAL DIAMETER AND MAXIMUM SIZE.