INTERNATIONAL STANDARD

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Fibre-reinforced polymer (FRP) reinforcement of concrete — Test methods —

Part 2: FRP sheets

Polymère renforcé par des fibres (PRF) pour l'armature du béton — Méthodes d'essai —

Partie 2: Feuilles en PRF

Reference number
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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 10406-2 was prepared by Technical Committee ISO/TC 71, *Concrete, reinforced concrete and pre-stressed concrete*, Subcommittee SC 6, *Non-traditional reinforcing materials for concrete structures*.

ISO 10406 consists of the following parts, under the general title *Fibre-reinforced polymer (FRP) reinforcement of concrete — Test methods*:

— *Part 1: FRP bars and grids*

— *Part 2: FRP sheets*

Fibre-reinforced polymer (FRP) reinforcement of concrete — Test methods —

Part 2: FRP sheets

1 Scope

This part of ISO 10406 specifies test methods applicable to fibre-reinforced polymer (FRP) sheets for the upgrading of concrete members.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 31-0:1992, *Quantities and units — Part 0: General principles*

ISO 291:2008, *Plastics — Standard atmospheres for conditioning and testing*

ISO 4892 (all parts), *Plastics — Methods of exposure to laboratory light sources*

ISO 5725 (all parts), *Accuracy (trueness and precision) of measurement methods and results*

ISO 7500-1, *Metallic materials — Verification of static uniaxial testing machines — Part 1: Tension/ compression testing machines — Verification and calibration of the force-measuring system*

JIS A 9511, *Preformed cellular plastics thermal insulation materials*

3 Definitions and symbols

3.1 Definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1
accelerated artificial-exposure testing machine
machine that creates reproducible standard test conditions to accelerate weathering artificially

3.1.2
ambient temperature
environmental conditions corresponding to the usual atmospheric conditions in laboratories with uncontrolled temperature and humidity

3.1.3
anchorage block
block corresponding to the test block to prevent bond failure of the FRP sheet

NOTE Additional FRP sheet circumferentially jackets the block with sheets being tested to provide higher bond strength (in this block).

3.1.4
anchoring portion
end parts of a test piece fitted with anchoring devices to transmit loads from the testing machine to the test portion

3.1.5
bond strength
strength calculated by dividing the maximum load by the effective bond area

3.1.6
concrete block
rectangular block of concrete used to study the bond properties of FRP sheets to concrete

NOTE Steel reinforcement or steel bars are embedded in the axial direction at the centre of the cross-sectional area of the concrete block in order to transmit tensile strength. Concrete blocks are made up of a test block and an anchorage block.

3.1.7
conditioning
storage of test pieces at a prescribed temperature and humidity to keep them under identical conditions before testing

3.1.8
coupon test piece
test piece selected from the same lot that is unexposed and subjected to the tensile strength and overlap splice strength tests

3.1.9
effective bond area
area estimated using the effective bond length and the bond width of the FRP sheet

3.1.10
effective bond length
length of the portion in which the bond stress between the FRP sheet and the concrete acts effectively at maximum load before the FRP sheet comes loose from the concrete

3.1.11
fibre bundle
several fibre filaments bound together to form a bundle

3.1.12
fibre mass per unit area
mass of fibre in the direction of reinforcement in the FRP sheets before impregnation with resin

NOTE Expressed as mass per square metre of the FRP sheet.

3.1.13
interfacial fracture energy
amount of energy per unit bond area necessary to produce interfacial fracture

3.1.14
overlap splice strength retention rate
ratio of the overlap splice strength after accelerated artificial exposure or freezing/thawing compared with the overlap splice strength before accelerated artificial exposure or freezing/thawing

NOTE The overlap splice strength retention is rate expressed as a percentage.

3.1.15
plate
FRP sheet impregnated with resin from which the test pieces are cut

3.1.16
pull-out strength
strength calculated by dividing the maximum load by the cross-sectional area of the bond surface of the steel device

3.1.17
steel device
mechanism made of steel connected to a loading machine to apply tensile force

NOTE Adhesive is used to mount the device to the FRP sheet attached to the concrete surface. The shape of the bond surface is either square or circular.

3.1.18
tab
plate made of fibre-reinforced polymer, aluminium or any other suitable material bonded to the test piece to transmit loads from the testing machine to the test portion

3.1.19
tensile capacity
maximum tensile load which the test piece bears during the tensile test

3.1.20
tensile strength retention rate
ratio of the tensile strength after accelerated artificial exposure or freezing/thawing compared with the tensile strength before accelerated artificial exposure or freezing/thawing

NOTE The tensile strength retention rate is expressed as a percentage.

3.1.21
test block
block used to study the bond properties of FRP sheets

3.1.22
test portion
part of a test piece that is in between the anchoring portions and is subjected to testing

3.1.23
ultimate strain
strain corresponding to the tensile capacity

3.1.24
weathering
physical and chemical changes of material properties due to exposure to sunlight, rain, snow and other outdoor natural conditions

3.2 Symbols

See Table 1.

Table 1 — Symbols

Symbol	Unit	Description	Reference
A	mm^2	Nominal cross-sectional area (general)	5.4
A_A	mm^2	Nominal cross-sectional area of type A test piece	5.4, 6.4
A_B	mm^2	Nominal cross-sectional area of type B test piece	5.4, 6.4
A_s	mm^2	Area of steel device	8.4
b_{av}	mm	Average width of FRP sheet	7.4
$b_{t,min}$	mm	Minimum width of test piece	5.4, 6.4
E_f	N/mm^2	Young's modulus	5.4, 7.4
f_{au}	N/mm^2	Bond strength	8.4
f_{fu}	N/mm^2	Tensile strength	5.4
$\overline{f}_{fu0}$	N/mm^2	Average value for tensile strength before treating, e.g. freezing and thawing or accelerated artificial exposure	9.4, 10.4
$\overline{f}_{fu1}$	N/mm^2	Average value for tensile strength after treating, e.g. freezing and thawing or accelerated artificial exposure	9.4, 10.4
f_{fus}	N/mm^2	Overlap splice strength	6.4
$\overline{f}_{fus0}$	N/mm^2	Average value for overlap splice strength before treating, e.g. freezing and thawing or accelerated artificial exposure	9.4, 10.4
$\overline{f}_{fus1}$	N/mm^2	Average value for overlap splice strength after treating, e.g. freezing and thawing or accelerated artificial exposure	9.4, 10.4
F_{au}	N	Maximum load	8.4
F_{last}		The load included in the last simultaneously recorded pair of values of the load and the strain when determining the ultimate strain	5.4.5
F_u	N	Tensile capacity	5.4, 6.4
G_f	N/mm	Interfacial fracture energy	7.4
L_{A1}		Anchoring portion length	5.1.1
L_{A2}		Anchorage thickness	5.1.1
L_{A3}		Anchorage length	5.1.1
L_{end}		Width at both ends	5.1.1
L_{ga}		Gauge length	5.1.1
L_{th}		Thickness	5.1.1
L_{tot}		Total length	5.1.1
l	mm	Effective bond length in test portion of FRP sheet	7.4
N_t	—	Number of fibre bundles in test piece	5.4
n	—	Number of plies of the FRP sheet	7.4
n_u	strands/mm	Number of fibre bundles per unit area of the FRP sheet	5.4
P_{max}	N	Maximum load	7.4
R_{ets}	%	Overlap splice strength retention	9.4
R_{ett}	%	Tensile strength retention	9.4

Table 1— Symbols (*continued*)

Symbol	Unit	Description	Reference
t	mm	Thickness of FRP sheet, equal to $n \cdot \rho_S / \rho_{sh}$	7.4
ΔF	N	Difference between loads at two points at 20 % and 60 % of tensile capacity	5.4
ρ_S	g/mm^2	Surface density of the fibre of the FRP sheet	5.4, 6.4, 7.4
ρ_{sh}	g/mm^3	Density of FRP sheet	5.4, 6.4, 7.4
ε_{last}		The strain included in the last simultaneously recorded pair of values of the load and the strain when determining the ultimate strain	5.4.5
ε_{fu}	—	Ultimate strain	5.4.5
$\Delta\varepsilon$	—	Difference in strain between the two points used to calculate ΔF	5.4
τ_u	N/mm^2	Bond strength	7.4

4 General provision concerning test pieces

Unless otherwise agreed, test pieces shall be taken from the bar or grid in the “as-delivered” condition.

In cases where test pieces are taken from a coil, they shall be straightened prior to any test by a simple bending operation with a minimum amount of plastic deformation.

For the determination of the mechanical properties in the tensile, bond and anchorage tests, the test piece may be artificially aged (after straightening, if applicable) depending on the performance requirements of the product.

When a test piece is “aged”, the conditions of the ageing treatment shall be stated in the test report.

5 Test method for determining tensile properties

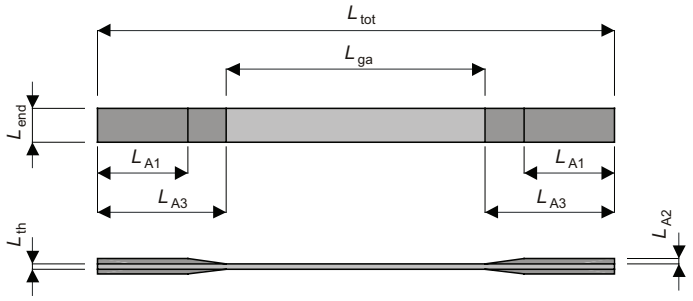
5.1 Test pieces

5.1.1 Types and dimensions

Two types of test pieces may be used (see Figure 1 and Table 1):

a) Type A test pieces: Prepare type A test pieces in accordance with the method described 5.1.2.1 and use them for the general tension test. The shape and the dimensions of type A test pieces are given in Figure 1 and Table 2, respectively.

b) Type B test pieces: Prepare type B test pieces in accordance with the method described in 5.1.2.2. These test pieces are suitable for FRP sheets in which the fibre bundles consist of a number of filaments that can be easily separated into individual bundles.



See Table 2 for definitions of symbols and dimensions.

Figure 1 — Shape of type A and type B test pieces

Table 2 — Dimensions of test pieces

Dimensions in millimetres

Symbol		Dimension for the types of test piece	
		Type A	Type B
L_{tot}	total length	$\geqslant$ 200	
L_{end}	width at both ends	12,5 $\pm$ 0,5	10 to 15
L_{th}	thickness	Recommended not to exceed 2,5	
L_{ga}	gauge length	$\geqslant$ 100	
L_{A1}	anchoring portion length	$\geqslant$ 35	
L_{A2}	anchorage thickness	1 to 2	
L_{A3}	anchorage length	$\geqslant$ 50	
When the peeling-off at tabs and the pull-out in the chuck do not occur, the thickness of the test piece can exceed 2,5 mm. When the thickness of the test piece is less than 2,5 mm and fracture at anchoring section occurs, the specification of the anchoring section should be reconsidered.			

5.1.2 Preparation

5.1.2.1 Type A test pieces

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

a) Prepare an FRP sheet cut to a sufficient length for the test piece.

b) Apply the bottom coat of impregnation resin to the separation film and attach the aforementioned sheet, fastening it so that the fibre axis of the sheet is in a straight line.

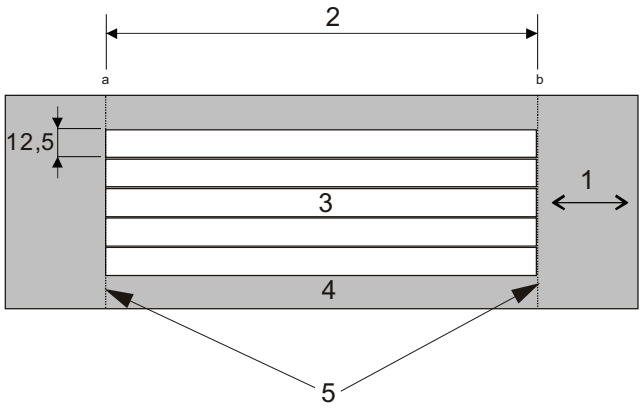
c) Apply the top coat of impregnation resin. Then smooth the surface, so that the thickness of the impregnation resin layer is even, to form a plate. Covering with separation film and smoothing would be best.

d) Cure the plate for the prescribed duration, then cut in widths of 12,5 mm as shown in Figure 2. The cut length should be at least 200 mm. Use a diamond cutter for cutting.

e) Attach the anchorages to the anchorage portions to form the test pieces.

f) Prior to testing, the test pieces shall be conditioned as prescribed in 5.1.5.

Dimensions in millimetres



Key

1 direction of fibre axis
2 section used to prepare test piece: ⩾ 200 (area impregnated with resin)
3 test piece portion
4 cut-away portion
5 marking

a, b Location of the two straight-line marks perpendicular to the fibre axis that define a length of at least 200 mm.

Figure 2 — Dimensions of plate used to prepare type A test pieces

5.1.2.2 Type B test pieces

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

a) Prepare an FRP sheet cut to a sufficient length for the test piece. Fasten the sheet so that the fibre axis is in a straight line.

b) In the centre of the fastened sheet, mark two straight lines (footnotes a and b in Figure 3) perpendicular to the fibre axis that define a length of at least 200 mm. Mark two other straight lines (footnotes c and d in Figure 3) approximately 100 mm on either side of the area defined by lines a and b.

c) Working along the fibre axis between lines c and d, remove 1 to 3 fibre bundles from each side of the test piece sections. The width measures 10 mm to 15 mm. When preparing several test pieces from the same FRP sheet, the portions to be used as test pieces should be separated by intervals of at least 50 mm in the direction perpendicular to the fibre axis.

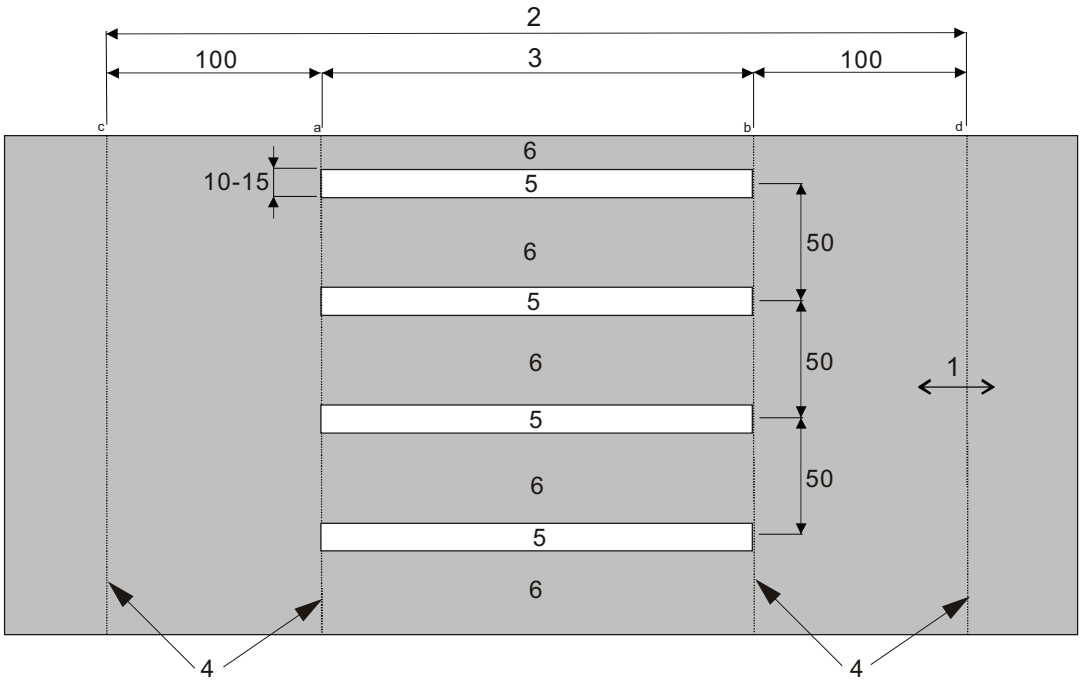
d) Apply the bottom coat of impregnation resin to the separation film and attach the aforementioned sheet onto the film.

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

f) Cure the plate for the prescribed duration, then cut the fibre bundle portions that are to be the test pieces at widths of 10 mm to 15 mm. The cut length shall be at least 200 mm.

g) Attach the anchorages to the anchorage portions to form the test pieces.

Dimensions in millimetres



Key

1 direction of fibre axis
2 area impregnated with resin: $\geqslant$ 400
3 section used to prepare test piece: $\geqslant$ 200
4 marking
5 cut-away portion
6 test piece portion

a, b Location of the two straight-line marks perpendicular to the fibre axis that define a length of at least 200 mm.
c, d Location of the two straight-line marks at least 100 mm on either side of lines a and b.

Figure 3 — Dimensions of plate used to prepare type B test pieces

Prior to testing, condition the test pieces as prescribed in 5.1.5.

A tracer thread may be added to uncured, wet-laid material to help identify the fibre direction, to somehow specify how accurately the specimens should be cut from the larger piece of material, specifically with respect to the fibre direction.

5.1.3 Curing of test pieces

Establish the curing period needed to give the test piece the desired strength and cure the test piece.

The curing period generally takes about one week.

5.1.4 Anchorage portion of test pieces

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

5.1.5 Conditioning of test pieces

The most appropriate condition from ISO 291 shall be selected, unless otherwise agreed upon by the interested parties. If humidity has a negligible or no influence on the properties being examined, it is not necessary to control the relative humidity. Similarly, if neither temperature nor humidity has any noticeable influence on the properties being examined, it is not necessary to control either the temperature or the relative humidity. In this case, the atmospheric condition is termed “ambient temperature”.

5.1.6 Number of test pieces

Determine the number of test pieces suitable for the objective of the test. It shall be no fewer than five.

5.2 Testing machine and measuring devices

5.2.1 Testing machine

The testing machine shall conform to ISO 7500-1. 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.

5.2.2 Strain gauges/extensometers

Strain gauges/extensometers used to measure the elongation of the test piece under loading should be capable of recording all variations in the gage length or elongation during testing with a strain measurement accuracy of at least 10×10^{-6}. The gauge length of the extensometer shall be not less than 100 mm.

5.3 Test method

5.3.1 Dimensions of test pieces

Measure the width and thickness of the test portion of the test pieces as follows.

a) Test pieces of type A shall be measured to 0,01 mm.

b) Test pieces of type B shall be measured to 0,1 mm.

5.3.2 Mounting of strain gauges/extensometers

Mount the strain gauges/extensometers at the centre of the test portion of the test piece in order to determine the Young's modulus and the ultimate strain of the test piece.

5.3.3 Mounting of test piece

Mount the test piece in such a way that the long axis of the test piece coincides with the centre line between the two chucks.

5.3.4 Loading rate

The standard loading rate shall be a constant strain rate equivalent to 1 %/min to 3 %/min strain.

5.3.5 Test temperature

In principle, conduct the test in the same atmosphere used for conditioning the test piece, unless otherwise agreed upon by the interested parties, e.g. for testing at elevated or low temperatures.

5.3.6 Range of test

Perform the loading test until tensile failure and record the measurements of load and strain continuously or at regular intervals at least up to two thirds of the tensile capacity.

5.4 Calculation and expression of test results

5.4.1 General

Use only results from those pieces that undergo failure in the test portion. Reject the test results from those pieces that show tensile failure or slippage at the anchorage portion and carry out additional tests using test pieces from the same lot until the number of test pieces having failed in the test portion is not less than the prescribed number.

5.4.2 Load-strain curve

When strain gauges/extensometers are mounted, plot a load-strain curve depicting the relationship between the measured load and strain.

5.4.3 Tensile strength

Calculate the tensile strength, f_{fu}, expressed in newtons per square millimetre, and rounded off to three significant digits in accordance with ISO 31-0:1992, Annex B, using Equation (1):

$$f_{fu} = \frac{F_u}{A} \tag{1}$$

where

F_u is the tensile capacity, expressed in newtons;

A is the nominal cross-sectional area of the test piece, expressed in square millimetres.

Calculate the cross-sectional area, A_A, expressed in square millimetres, of the type A test piece using Equation (2) and the cross-sectional area, A_B, expressed in square millimetres, of the type B test piece using Equation (3):

$$A_A = \frac{\rho_S}{\rho_{sh}} \cdot b_{t,min} \tag{2}$$

$$A_B = \frac{\rho_S}{\rho_{sh}} \cdot \frac{N_t}{n_u} \tag{3}$$

where

ρ_S is the surface density of the fibre of the FRP sheet, expressed in grams per square millimetre;

NOTE 1 The nominal surface density of the fibre provided by the material manufacturer can be used.

ρ_{sh} is the density of FRP sheet, expressed in grams per cubic millimetre;

NOTE 2 The density provided by the material manufacturer can be used.

$b_{t,min}$ is the minimum width of the test piece, expressed in millimetres;

N_t is the number of fibre bundles in the test piece;

n_u is the number of fibre bundles per unit area of the FRP sheet, expressed in strands per millimetre.

5.4.4 Young's modulus

Calculate the Young's modulus, E_f, using Equation (4) based on the load-strain curve at 20 % and 60 % tensile capacity and rounded off to three significant digits in accordance with ISO 5725 (all parts).

$$E_f = \frac{\Delta F}{\Delta \varepsilon \cdot A} \tag{4}$$

where

ΔF is the difference between loads at two points at 20 % and 60 % tensile capacity, expressed in newtons;

$\Delta \varepsilon$ is the difference in strain between the two points above;

A is the nominal cross-sectional area, expressed in square millimetres, calculated as A_A, using Equation (2), for a type A test piece and as A_B, using Equation (3), for a type B test piece.

5.4.5 Ultimate strain

In cases where strain-gauge measurements of the test piece are available up to the point of failure, take the ultimate strain, ε_{fu}, as the strain corresponding to the tensile capacity, F_u. In cases where the measurements are not made up to the point of failure, calculate the ultimate strain, ε_{fu}, using Equation (5), based on the tensile capacity, F_u, and the last simultaneously recorded values of the load, F_{last}, and strain, ε_{last}:

$$\varepsilon_{fu} = \varepsilon_{last} \cdot \frac{F_u}{F_{last}} \tag{5}$$

Round off the results to three significant digits in accordance with ISO 5725 (all parts).

5.5 Test report

The test report shall include the following items:

a) name of FRP sheet, date of manufacture, lot number of production run and name of manufacturer;

b) type of FRP sheet and impregnation resin;

c) surface density of the fibre and density of the FRP sheet;

d) fabrication date, fabrication method and curing duration for test pieces;

e) temperature, humidity and duration of test piece conditioning;

f) test date, test temperature and loading rate;

g) shape and dimensions of each test piece and calculated cross-sectional area;

h) tensile capacity of each test piece and average and, if required, the standard deviation for these values;

i) tensile strength of each test piece and average and, if required, the standard deviation for these values;

j) Young's modulus of each test piece and average and, if required, the standard deviation for these values;

k) ultimate strain of each test piece and average and, if required, the standard deviation for these values;

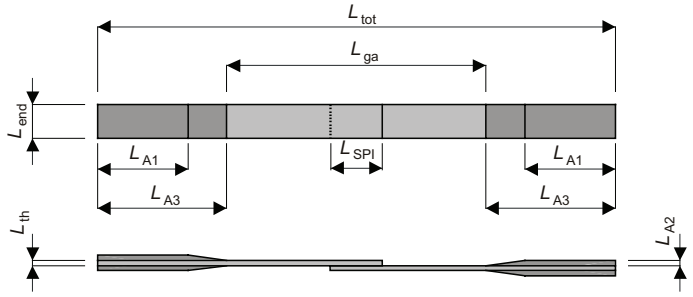
l) load-strain curve for each test piece.

6 Test method for overlap splice strength

6.1 Test pieces

6.1.1 Dimensions

The shape and the dimensions of the overlap splice test piece are shown in Figure 4 and Table 3, respectively. The method of preparing test pieces is described in 6.1.2.



See Table 3 for definitions of symbols and dimensions.

Figure 4 — Shape of test pieces

Table 3 — Dimensions of test pieces

Dimensions in millimetres

Symbol		Dimension
L_{tot}	total length	Length of splice plus a minimum of 200
L_{end}	width at both ends	$12{,}5 \pm 2{,}5$
L_{th}	thickness	Recommended not to exceed 2,5
L_{ga}	gauge length	Length of splice plus a minimum of 100
L_{A1}	anchoring portion length	$\geqslant 35$
L_{A2}	anchorage thickness	1 to 2
L_{A3}	anchorage length	$\geqslant 50$
L_{spl}	length of splice portion	Necessary length
When the peeling-off at tabs and the pull-out in the chuck do not occur, the thickness of the test piece can exceed 2,5 mm. When the thickness of the test piece is less than 2,5 mm and fracture at anchoring section occurs, the specification of the anchoring section should be reconsidered.		

6.1.2 Preparation

As a rule, prepare test pieces using the same materials as those in the actual work and under constant temperature conditions as follows, taking sufficient care to ensure that the fibres are not dispersed or bent in the overlap splice portion.

a) Prepare an FRP sheet cut to a sufficient length for the dimensions of the test piece to be fabricated.

b) Apply the bottom coat of impregnation resin to the separation film and attach the sheet mentioned in 6.1.2 a), fastening it so that that the fibre axis of the sheet is in a straight line.

c) Overlap two sheets so that the prescribed length of the overlap splice portion is secured.

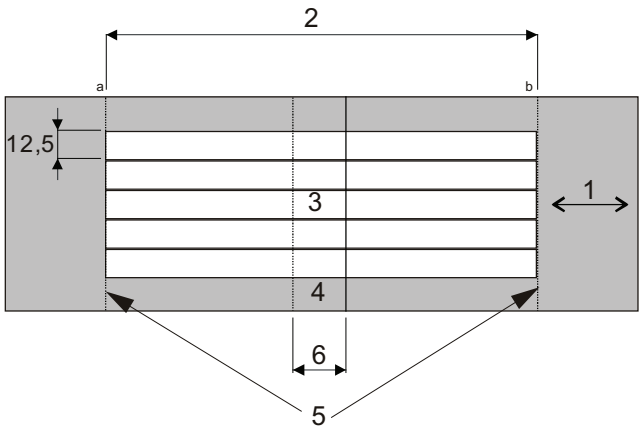
d) Apply the top coat of impregnation resin. Smooth the surface. The thickness of the impregnation resin layer should be even to form a plate. Covering with separation film is best.

e) Cure the plate for the prescribed period of time, then cut in widths of 12,5 mm as shown in Figure 5. The cut length should be at least 200 mm. Use a diamond cutter.

f) Attach the anchorage to the anchorage portion to form the test piece.

g) Before performing the test, condition the test piece as prescribed.

Dimensions in millimetres



Key

1 direction of fibre axis
2 section used to prepare test piece: ⩾ 200 (area impregnated with resin)
3 test piece portion
4 cut-away portion
5 marking
6 overlap splice section

a, b Location of the two straight-line marks perpendicular to the fibre axis that define a length of at least 200 mm.

Figure 5 — Dimensions of plate used to make type A test pieces

6.1.3 Curing of test pieces

Establish the curing period for the test piece to have the desired strength and cure the test piece.

6.1.4 Anchorage portion of test pieces

The anchorage portion of the test piece shall not have a shape that causes the test piece to twist or bend. Attach an anchorage made of fibre-reinforced plastic or aluminium to the anchorage portion using resin or adhesive at a suitable pressure so that the thickness of the adhesive layer is constant. Ensure that the adhesive or resin in the adhesive layer does not experience shear fracture before the test piece breaks.

6.1.5 Conditioning of test pieces

Select the most appropriate condition from ISO 291, unless otherwise agreed upon by the interested parties. If humidity has a negligible or no influence on the properties being examined, it is not necessary to control the relative humidity. Similarly, if neither temperature nor humidity has any noticeable influence on the properties being examined, it is not necessary to control either the temperature or the relative humidity. In this case, the atmospheric condition is termed “ambient temperature.”

6.1.6 Number of test pieces

Determine the number of test pieces suitable for the objective of the test. It shall be no fewer than five.

6.2 Testing machine

The testing machine shall conform to ISO 7500-1. 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.

6.3 Test method

6.3.1 Dimensions of test pieces

Measure the width and thickness of the test portion of the test pieces to 0,01 mm at four locations outside than the overlap splice portion and two locations within the overlap splice portion.

6.3.2 Mounting the test piece

Mount the test piece so that the long axis of the test piece coincides with the centre line between the two chucks.

6.3.3 Loading rate

The standard loading rate shall be a fixed strain rate equivalent to 1 %/min to 3 %/min strain.

6.3.4 Test temperature

In principle, conduct the test in the same atmosphere used for conditioning the test piece, unless otherwise agreed upon by the interested partied, e.g. for testing at elevated or low temperatures.

6.3.5 Range of test

Perform the loading test to the point of tensile failure, and measure and record the load continuously or at regular intervals until the tensile capacity is reached.

6.4 Calculation and expression of test results

6.4.1 General

Assess the test data only on the basis of the test pieces undergoing failure in the test portion. In cases where tensile failure or slippage has clearly taken place at the anchorage portion, disregard the data and perform additional tests using test pieces from the same lot until the number of test pieces failing in the test portion is not less than the prescribed number.

6.4.2 Failure categories

Table 4 shows the types of overlap-splice failure. Shear fracture of the impregnation resin within the overlap splice portion is called “overlap splice failure.” Failure of the FRP sheet in parts of the test portion other than the overlap splice portion is called “base material failure.”

Table 4 — Categories of overlap-splice failure

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

6.4.3 Overlap-splice strength

Calculate the overlap-splice strength, f_{fus}, expressed in newtons per square millimetre and rounded off to three significant digits, using Equation (6) in accordance with ISO 31-0:1992, Annex B:

$$f_{fus} = \frac{F_u}{A} \tag{6}$$

where

F_u is the tensile capacity, expressed in newtons;

A is the nominal cross-sectional area, expressed in square millimetres, calculated as A_A, using Equation (2), for a type A test piece and as A_B, using Equation (3), for a type B test piece.

Calculate the cross-sectional area, A, of the test piece using Equation (7):

$$A = \frac{\rho_S}{\rho_{sh}} \cdot b_{t,min} \tag{7}$$

where

ρ_S is the surface density of the fibre of the FRP sheet, expressed in grams per square millimetre;

ρ_{sh} is the density of continuous fibre sheet, expressed in grams per cubic millimetre;

$b_{t,min}$ is the minimum width of test portion of the test piece, expressed in millimetres.

6.5 Test report

The test report shall include the following items:

a) name of FRP sheet, date of manufacture, lot number of production run and name of manufacturer;

b) type of FRP sheet and impregnation resin;

c) surface density of the fibre and density of FRP sheet;

d) fabrication date, fabrication method and curing period for test pieces;

e) temperature, humidity and duration of test piece conditioning;

f) test date, test temperature and loading rate;

g) shape and dimensions of each test piece and calculated cross-sectional area;

h) length of overlap splice for each test piece;

i) tensile capacity of each test piece and average and, if required, standard deviation for these values;

j) tensile strength of each test piece and average and, if required, standard deviation for these values;

k) failure type for each test piece.

7 Test method for determining bond properties of fibre-reinforced polymer (FRP) sheets to concrete

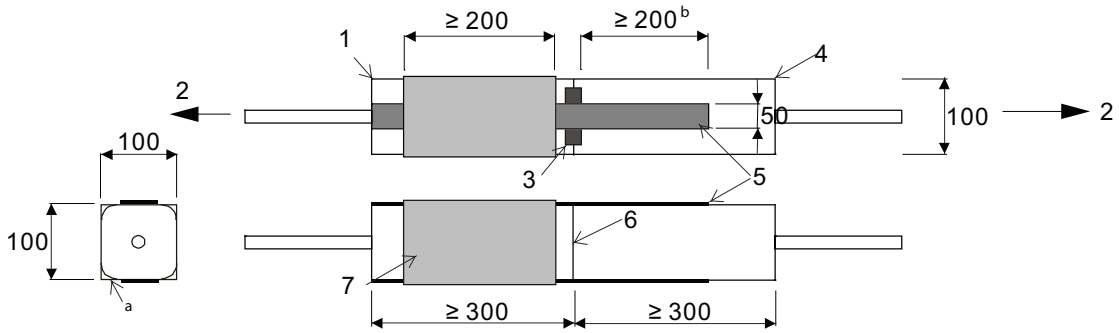
7.1 Test pieces

7.1.1 Types and dimensions

a) Type A test pieces: Type A test pieces shall consist of two separate concrete blocks manufactured in accordance with the method described in 7.1.4.2. a). The shape and the dimensions of a type A test specimen are shown in Figure 6 and Table 5, respectively.

b) Type B test pieces: Type B test pieces shall consist of a single concrete block manufactured in accordance with the method described in 7.1.4.2. b). The shape and the dimensions of a type B test specimen are shown in Figure 7 and Table 6, respectively.

Dimensions in millimetres



Key

1 anchoring block
2 tensile load
3 separation-type film
4 test block
5 continuous fibre sheet
6 abutted surface
7 anchoring sheet

a Beveled.

b Bonding length.

Figure 6 — Shape of a type A test piece

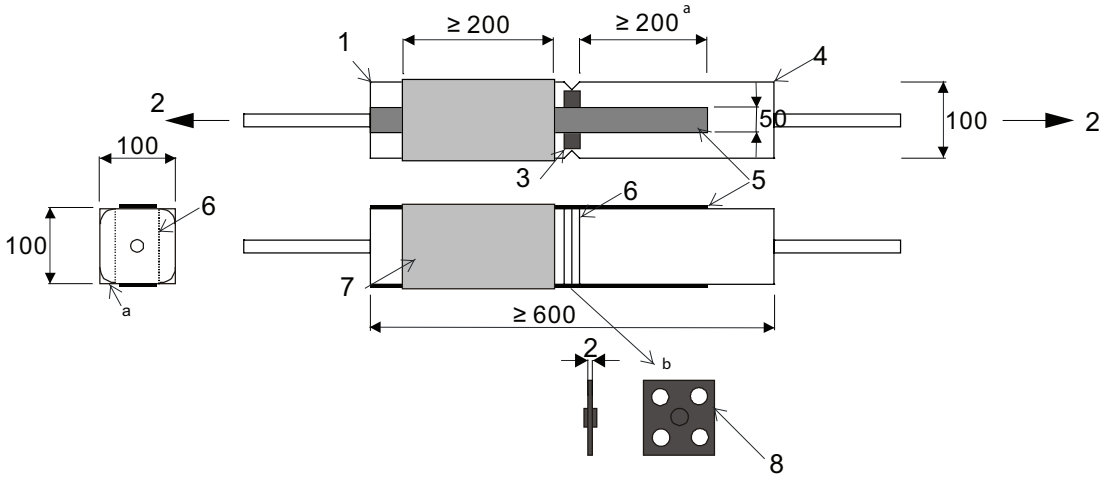
Table 5 — Dimensions of test pieces

Dimensions in millimetres

Element	Type of test piece	
	Type A (separate block type)	Type B (single block type)
Length of block	⩾ 300	⩾ 600
Cross-sectional area of the block	100 × 100	
Bond length [a]	200 (not including section cut away from edge)	
Distinguishing characteristics	Test piece consisting of two matching concrete blocks with the block length and cross-sectional area above	Single concrete block with the block length and cross-sectional area above and a 20 mm deep notch in the centre on either side

[a] The effective bond length is determined by the number of FRP layers, the layer modulus of elasticity and the type of impregnation resin. When the effective bonding length exceeds 200 mm, the bond length on the test block should be extended to at least the effective bonding length.

Dimensions in millimetres



Key

1 anchoring block
2 tensile load
3 separation-type film
4 test block
5 continuous fibre sheet
6 notch
7 anchoring sheet
8 acrylic panel

a Bonding length.

b Acrylic panel or notch should be selected.

Figure 7 — Shape of type B test piece

Table 6 — Categories for failure of test piece

Code	Type of failure
BF	Interfacial failure
SF	Base material failure

7.1.2 Quality of concrete

In cases where the structure reinforced with the FRP sheet is known, the concrete used for the test pieces shall be similar in quality and strength to that used in the structure.

In cases where the target structure is not known, the concrete shall be made using materials of good quality. The maximum diameter of coarse aggregate can be 20 mm or 25 mm and the water-to-cement ratio, between 50 % and 60 %.

The concrete pieces shall be cured in water at 20 °C ± 3 °C for 7 days, then in air for at least 7 days.

7.1.3 Steel bars

Steel bolts or bars used to transmit a tensile force shall have a strength and diameter sufficient to prevent yielding or pull-out from the concrete block before the failure of the FRP sheet, in order to ensure that the load is properly transmitted to the concrete block.

7.1.4 Preparation of test pieces

7.1.4.1 General

Prepare the test pieces indoors at 20 °C ± 15 °C.

7.1.4.2 Concrete blocks

Prepare the concrete blocks as follows.

a) Type A test specimen (separate blocks)

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

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

   3) Pour the concrete and cure it in the appropriate manner.

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

b) Type B test specimen (single block)

1) Prepare a mould for a concrete block with a cross-sectional area of 100 mm × 100 mm and a length of 600 mm. The dimensional error of the mould should be no more than 1 % of the length of each side. To ensure precision, the mould should be made of steel. The four corners in the long axis direction should be beveled using chamfering strips.

Place an acrylic panel of 2 mm thickness with four holes at the centre of the concrete blocks in the longitudinal direction, with the short acrylic pipes attached at both sides of the panel's centre to support the steel bolts or bars. One side of the piece separated by the acrylic panel is the test area and the other side is anchorage part. Otherwise, wooden pieces for making notches on concrete surfaces after stripping off the mould should be placed on the two sides of the mould. The notch depth should be 20 mm.

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

3) Place the concrete and cure it in the appropriate manner.

7.1.4.3 Concrete surface treatment

The standard treatment for the surface is as follows.

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

b) Using a rag, wipe away the powder and dust from the concrete surface. If there is oil on the surface, it should be wiped away using acetone.

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

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

7.1.4.4 Attaching and anchoring the FRP sheets

In cases where the structure reinforced with the FRP sheet is known, the method used in the piece shall be similar to that used in the structure. In cases where the target structure is not known, the standard procedure for attaching the FRP sheet shall be as follows.

a) Attach the separation film along the abutted surfaces of the concrete blocks (for the type A test piece) or along the notch in the concrete block (for the type B test piece) to prevent a bond between the concrete and the FRP sheet.

NOTE To prevent spalling off of the corners of the concrete blocks, attach a thin layer of separation film around the ends to prevent bond between the FRP sheet and the concrete.

b) After coating both sides of the concrete block with resin, attach a 50 mm wide FRP sheet along the axis of the steel bolts or bars as shown in Figure 6 or 7 and then impregnate resin into the sheet without bubbles. During this process, adjust the length from the end of the separation film to the end of the FRP sheet so that the bond length on the test block is 200 mm. On the anchorage block, extend the FRP sheet to the end of the block.

No more than three plies of FRP sheets should be used. The effective bond length is determined by the number of FRP layers, the layer modulus of elasticity and the type of impregnation resin. When effective bonding length exceeds 200 mm, bond length on the test block should be extended to at least effective bonding length.

c) Apply the resin on the top.

d) Cure the test piece at the prescribed temperature and humidity for the prescribed duration.

e) Wind an FRP sheet of at least 200 mm in width once around the anchorage block, perpendicular to the longer axis within 15 mm of the abutted surfaces or notch, as shown in Figure 6 or 7.

f) Cure the test piece at the prescribed temperature and humidity for the prescribed duration.

7.1.5 Conditioning of test pieces

Select the most appropriate condition from ISO 291, unless otherwise agreed upon by the interested parties. If humidity has no influence or a negligible influence on the properties being examined, it is not necessary to control the relative humidity. Similarly, if neither temperature nor humidity has any noticeable influence on the properties being examined, it is not necessary to control either the temperature or the relative humidity. In this case, the atmospheric condition is termed “ambient temperature”.

7.1.6 Number of test pieces

Determine the number of test pieces suitable for the objective of the test. It shall be no fewer than three.

7.2 Testing machine and measuring devices

7.2.1 Testing machine

The testing machine shall conform to ISO 7500-1 and shall be capable of applying the prescribed load appropriately.

7.2.2 Chucks

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

7.2.3 Strain gauges

The strain gauges shall be capable of recording variations during testing with an accuracy of 10^{-5}.

7.3 Test method

7.3.1 Dimensions of the test pieces

Measure the width of the bonded FRP sheet at the slit on type A test pieces and at the notch on type B test pieces, as well as at three additional locations on both test pieces (in the centre of the bonded portion and at the ends).

7.3.2 Mounting of test pieces

Mount test pieces onto the testing machine, matching the centre axis of the test piece to the centre axis of the testing machine, in order to ensure that there are no eccentric loads.

7.3.3 Mounting of strain gauges

In order to measure the strain distribution in the bonded portion, attach strain gauges appropriately to the FRP sheet on the test block. Determine the size of the strain gauge and the interval between gauges in accordance with the objective of strain measurements.

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

7.3.4 Loading rate

Apply the load at a rate of 2 kN/min to 5 kN/min.

7.3.5 Test temperature

In principle, conduct the test in the same atmosphere as used for conditioning the test piece, unless otherwise agreed upon by the interested partied, e.g. for testing at elevated or low temperatures.

7.3.6 Range of test

Carry out the loading test to the point of failure of the FRP sheet. Record the measurements of load, strain and displacement continuously or at regular intervals until the maximum load-carrying capacity is reached.

In the case where the strain gauges are fixed, measurements should be made at about every 1 kN of load.

7.4 Calculation and expression of test results

7.4.1 General

Use only the results from those test pieces that undergo failure by peeling off or by failure of the sheet. Reject the test data from test pieces where failure has clearly taken place in the anchorage portion and perform additional tests using test pieces prepared using FRP sheets from the same lot, until the number of test pieces failing in the desired manner is not fewer than the prescribed number.

7.4.2 Failure categories

Table 6 shows the categories for the failure of test pieces.

7.4.3 Interfacial fracture energy

Calculate the interfacial fracture energy, G_f, expressed in newtons per millimetre and rounded off to three significant digits, between the bonded surfaces using Equation (8):

$$G_f = \frac{P_{max}^2}{8 b_{av}^2 \cdot E_f \cdot t} \tag{8}$$

where

P_{max} is the maximum load, expressed in newtons;

b_{av} is the average width of the FRP sheet, expressed in millimetres;

E_f is the Young's modulus of the FRP sheet, expressed in newtons per square millimetre;

t is the thickness of the FRP sheet, equal to $n \cdot \rho_S / \rho_{sh}$, expressed in millimetres,

where

n is the number of plies of the FRP sheet;

ρ_S is the surface density of the fibre of the FRP sheet, expressed in grams per square millimetre;

ρ_{sh} is the density of the FRP sheet, expressed in grams per cubic millimetre.

NOTE Nominal fibre surface density provided by the material manufacturer can be used.

7.4.4 Bond strength

Calculate the bond strength, τ_u, expressed in newtons per square millimetre and rounded off to three significant digits, using Equation (9):

$$\tau_u = \frac{P_{max}}{2 b_{av} \cdot l} \tag{9}$$

where

P_{max} is the maximum load, expressed in newtons;

b_{av} is the average width of the FRP sheet, expressed in millimetres;

l is the effective bond length in the test portion of the FRP sheet, expressed in millimetres.

NOTE The effective bond length, l, is determined by the number of FRP sheet layers, Young's modulus and the type of impregnation resin.

7.4.5 Strain distribution diagram

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

7.5 Test report

The test report shall include the following items:

a) name of FRP sheet, date of manufacture, lot number of production run and name of manufacturer;

b) type of FRP sheet and impregnation resin;

c) surface density of the fibre and density of the FRP sheet;

d) fabrication date, fabrication method and curing period for test pieces;

e) temperature, humidity and duration of test piece conditioning;

f) identification of test piece;

g) test date, test temperature and loading rate;

h) test piece dimensions and surface density of the fibre, width, length, bond length and number of plies for FRP sheets;

i) concrete mixture, slump and compressive strength at testing;

j) interfacial fracture energy and bond strength for each test piece and averages for these values;

k) type of failure for each test piece.

8 Test method for direct pull-off strength of FRP sheets with concrete

8.1 Test pieces

8.1.1 Dimensions

The test piece shall be a concrete board measuring 30 cm × 30 cm with a thickness of 6 cm or an actual, or approximation of an actual, portion of a concrete member to which an FRP sheet has been attached. The concrete board shall be of the same quality and strength as the members that are actually used. If no such members are available, concrete with ordinary aggregate having a maximum coarse aggregate diameter of 20 mm or 25 mm, a slump of 10 cm ± 2 cm, and a 28 day compressive strength of 30 N/mm^2 ± 3 N/mm^2.

8.1.2 Preparation

8.1.2.1 Concrete surface treatment

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

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

b) Using a rag, wipe away the powder and dust from the concrete surface. If there is oil on the surface, wipe it away using acetone.

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

d) Coat with a smoothing agent to even out the unevenness and bubbles on the surface, then wait for it to harden until it does not stick to the fingers when touched. The surface treatment process is now complete.

8.1.2.2 Attaching the FRP sheets

a) Prepare an FRP sheet having an area of 280 mm × 280 mm.

b) Apply the bottom coat of impregnation resin and then attach the FRP sheet and remove bubbles.

c) Apply the top coat of impregnation resin and impregnate.

d) Cure for the prescribed period of time to form the test piece.

8.1.3 Mounting of steel devices and notching

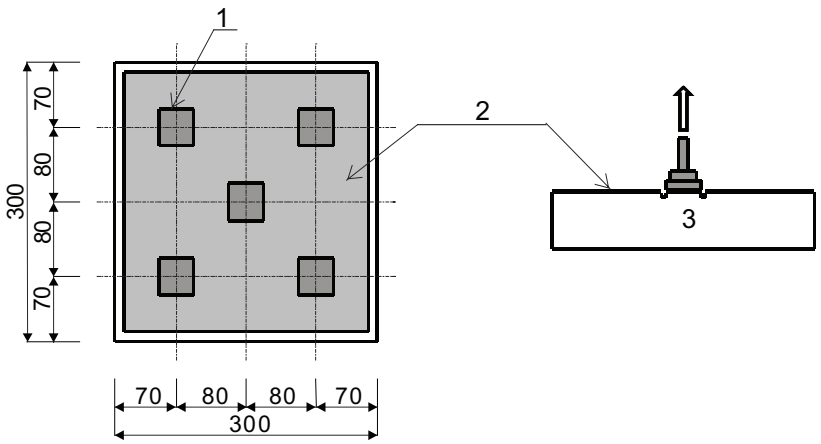
a) As a rule, use a steel device 10 mm thick with a bonding area of 40 mm × 40 mm.

b) Mount the steel devices in the position shown in Figure 8. As Figure 8 shows, the positions are determined through consideration of the distance from the edge of the concrete board and the distance between devices. Using sandpaper or the like, rough the bond surface of the steel devices and the surface of the test piece to which the steel device are bonded. Be careful not to damage the FRP sheet.

c) Coat the bond surface of the steel device with adhesive and attach it carefully to the test piece. Then attach a 1 kg weight to the steel device and let it stand.

d) After curing the adhesive, remove the weight and, using a concrete cutter, notch the area around the device.

Dimensions in millimetres



Key

1 steel device 40 × 40 × 10

2 FRP sheet

3 concrete board 300 × 300 × 60

Figure 8 — Mounting of steel devices on the test piece

8.1.4 Conditioning of test pieces

The most appropriate condition from ISO 291 shall be selected, unless otherwise agreed upon by the interested parties. If humidity has no influence or a negligible influence on the properties being examined, it is not necessary to control the relative humidity. Similarly, if neither temperature nor humidity has any noticeable influence on the properties being examined, it is not necessary to control either the temperature or the relative humidity. In this case, the atmospheric condition is termed “ambient temperature”.

8.1.5 Number of test pieces

Determine the number of test pieces suitable for the objective of the test. It shall be no fewer than five.

8.2 Testing machine and measuring devices

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

8.3 Test method

8.3.1 Setting up the testing machine

Set the steel devices so that the force is applied normal to the concrete surface.

8.3.2 Loading rate

The standard loading rate shall be a fixed rate equivalent to 2,5 kN/min to 5,0 kN/min.

8.3.3 Test temperature

In principle, conduct the test in the same atmosphere used for conditioning the test piece, unless otherwise agreed upon by the interested parties, e.g. for testing at elevated or low temperatures.

8.3.4 Scope of test

Continue the test until the point where the steel devices separate from the concrete slab.

8.4 Calculation and expression of test results

8.4.1 Handling of data

When the steel devices have come apart from the FRP sheets in the bonded portion, disregard the data and perform additional tests, with steel devices mounted in advance in different locations, until the prescribed number of test pieces is obtained.

8.4.2 Bond strength

The bond strength, f_{au}, expressed in newtons per square millimetre and rounded off to three significant digits in accordance with ISO 31-0:1992, Annex B, shall be calculated using Equation (10).

$$f_{\mathrm{au}} = \frac{F_{\mathrm{au}}}{A_{\mathrm{s}}} \tag{10}$$

where

F_{au} is the maximum load, expressed in newtons;

A_{s} is the area of steel device, expressed in square millimetres.

8.4.3 Failure categories

Table 7 shows the categories for the failure of test pieces.

If the failure occurs in the concrete and the steel device comes apart, removing a piece of concrete, this indicates a concrete fracture. If the failure occurs in the interface between the concrete surface and the primer, or the primer and the smoothing agent, or the smoothing agent and the FRP sheet, this indicates an interfacial fracture. If the failure occurs within the FRP sheet or between the layers of the FRP sheet, this is categorized as a “fracture between layers of FRP sheet”.

Table 7 — Categories for the failure of test pieces

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

8.5 Test report

The test report shall include the following items:

a) name of FRP sheet, date of manufacture, lot number of production run and name of manufacturer;

b) type of FRP sheet, primer, smoothing agent and impregnation resin;

c) surface density of the fibre and density of the FRP sheet;

d) number of plies of the FRP sheet;

e) concrete mixture, slump and compression strength at testing;

f) fabrication date and fabrication method for test pieces;

g) test date, test temperature and loading rate;

h) shape, dimensions and calculated cross-sectional area of the steel device at each test location;

i) tensile capacity at each test location and average of these values;

j) maximum bond strength at each test location and average of these values;

k) failure type at each test location;

l) other special notations.

9 Test method for freeze/thaw resistance

9.1 Test pieces

9.1.1 Types and dimensions

Test pieces shall be of the following types:

a) type A or type B test piece in accordance with Clause 5;

b) type in accordance with Clause 6.

9.1.2 Number of test pieces

Determine the number of test pieces suitable for the objective of the test. It shall be no fewer than five test pieces for the tensile strength test and the overlap splice strength test before and after freezing/thawing.

9.2 Testing machine and measuring devices

9.2.1 Freeze/thaw testing machine

The testing machine used for the freeze/thaw resistance test shall consist of the heating and cooling unit for subjecting the test piece to the prescribed freezing and thawing cycles, a testing tank, a spray unit, a temperature measurement unit and a control unit. The temperature measurement unit shall be capable of measuring the surface temperature of the control test piece in the testing tank to an accuracy of within 1,0 °C ± 2 °C and shall be equipped with a recording unit.

9.2.2 Tensile testing machine

The tensile testing machine shall be the machine specified in Clause 5.

9.3 Test method

9.3.1 Freezing and thawing method

The test method shall conform to the air freezing and thawing method as follows.

a) Before the freeze/thaw resistance test, soak the test piece in water for 24 h.

b) The conditions for the freeze/thaw resistance test shall be

   — a surface temperature of the test piece of $-20\ °C \pm 2\ °C$ during freezing and $30\ °C \pm 2\ °C$ during thawing (spraying),

   — a temperature beginning from room temperature for one cycle immediately after the start or the restart after interruption.

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

d) The test shall consist of 300 freeze-thaw cycles unless otherwise agreed.

9.3.2 Control of freezing and thawing temperatures

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

9.3.3 Tensile strength test and overlap splice strength test

The tensile strength, modulus of elasticity and ultimate strain shall be obtained before and after the freeze/thaw resistance test in accordance with Clause 5. The overlap splice strength shall be measured before and after the freeze/thaw resistance test in accordance with Clause 6.

9.4 Calculation and expression of test results

9.4.1 Tensile strength retention

The tensile strength retention, R_{ett}, expressed as a percentage and rounded off to three significant digits in accordance with ISO 31-0:1992, Annex B, shall be calculated using Equation (11):

$$R_{ett} = \frac{\bar{f}_{fu1}}{\bar{f}_{fu0}} \times 100 \tag{11}$$

where

$\bar{f}_{fu0}$ is the average value for tensile strength before freezing and thawing, expressed in newtons per square millimetre;

$\bar{f}_{fu1}$ is the average value for tensile strength after freezing and thawing, expressed in newtons per square millimetre.

9.4.2 Overlap splice strength retention

The overlap splice strength retention, R_{ets}, expressed as a percentage and rounded off to three significant digits in accordance with ISO 31-0:1992, Annex B, shall be calculated using Equation (12):

$$R_{ets} = \frac{\overline{f}_{fus1}}{\overline{f}_{fus0}} \times 100 \quad (12)$$

where

$\overline{f}_{fus0}$ is the average value for overlap splice strength before freezing and thawing, expressed in newtons per square millimetre;

$\overline{f}_{fus1}$ is the average value for overlap splice strength after freezing and thawing, expressed in newtons per square millimetre.

9.5 Test report

The test report shall include the following items:

a) common items:

- name of the FRP sheet, date of manufacture, lot number of production run and name of manufacturer;
- type of FRP sheet and impregnation resin;
- surface density of the fibre and density of the FRP sheet;
- identification of test piece;

b) items relating to freeze/thaw resistance test:

- type and model of testing machine and test conditions;
- date at which freeze/thaw resistance test starts and ends;

c) items relating to tensile strength test:

- fabrication date, fabrication method and curing period for test pieces;
- temperature, humidity and duration of test piece conditioning;
- test date, test temperature and loading rate;
- shape, dimensions and calculated cross-sectional area for each test piece;
- tensile capacity of each test piece and average for these values;
- maximum tensile strength of each test piece and average for these values;
- Young's modulus of each test piece and average for these values;
- ultimate strain of each test piece and average for these values;
- load-strain curve for each test piece;
- tensile strength retention;

d) items relating to overlap splice strength test:

- fabrication date, fabrication method and curing period for test pieces;
- temperature, humidity and duration of test piece conditioning;
- test date, test temperature and loading rate;
- shape, dimensions and calculated cross-sectional area for each test piece;
- tensile capacity of each test piece and average for these values;
- maximum tensile strength of each test piece and average for these values;
- mode of failure for each test piece;
- overlap splice strength retention.

10 Test method for exposure to laboratory light sources

10.1 Test pieces

10.1.1 Accelerated artificial-exposure plate

The method of preparing accelerated artificial exposure plates shall conform to the methods in Clauses 5 and 6. However, the dimensions shall be no less than 300 mm in length and 70 mm in width unless otherwise agreed, and the plates shall be those that can be mounted to the accelerated artificial-exposure test sample holder.

10.1.2 Number of accelerated artificial exposure plates

Subject no fewer than two accelerated artificial-exposure plates to accelerated artificial-exposure tests simultaneously unless otherwise agreed.

10.1.3 Types and dimensions

Cut the test pieces from a plate that has undergone accelerated artificial exposure and prepare the test pieces as specified in Clauses 5 and 6. When making test pieces, avoid the edge of the accelerated artificial-exposure plate.

10.1.4 Number of test pieces

Determine the number of test pieces suitable for the objective of the test. It shall be no fewer than five.

10.2 Testing machine and measuring devices

10.2.1 Two types of accelerated artificial-exposure testing machines are available:

- type WV, using an ultraviolet carbon-arc lamp;
- type WS, using a sunshine carbon-arc lamp.

10.2.2 The configuration of the light source, filter and testing machine is as specified in ISO 4892 (all parts).

10.2.3 The tensile testing machine is as specified in Clauses 5 and 6.

10.3 Test method

10.3.1 Test period

For the accelerated artificial-exposure test, establish an appropriate test period. However, consider that, unless otherwise specified, the maximum values shall be 2 000 h for the type WV testing machine and 1 000 h for the WS testing machine, in accordance with ISO 4892 (all parts).

10.3.2 Tensile strength test and overlap splice strength test

Obtain the tensile strength, modulus of elasticity and ultimate strain for the test pieces before and after the accelerated artificial-exposure test in accordance with Clause 5. Obtain the overlap splice strength for the test pieces before and after the accelerated artificial exposure test in accordance with Clause 6.

10.4 Calculation and expression of test results

10.4.1 Visual inspection

Carry out a visual inspection of the accelerated artificial-exposure plate before and after the accelerated artificial-exposure test and compare the colour and the surface condition. If necessary, cut and grind the accelerated artificial-exposure plate and observe its section with a microscope.

10.4.2 Handling of data

In the tensile strength test, assess the test data only on the basis of test pieces undergoing failure in the test portion. In cases where tensile fracture or slippage has clearly taken place at the anchorage portion, disregard the data and test additional pieces until the number of test pieces fracturing in the test portion exceeds five.

10.4.3 Tensile strength retention

Calculate the tensile strength retention, R_{ett}, expressed as a percentage with a precision of three significant digits, using Equation (13):

$$R_{\text{ett}} = \frac{\overline{f}_{\text{fu1}}}{\overline{f}_{\text{fu0}}} \times 100 \tag{13}$$

where

$\overline{f}_{\text{fu0}}$ is the average value for tensile strength before accelerated artificial exposure, expressed in newtons per square millimetre;

$\overline{f}_{\text{fu1}}$ is the average value for tensile strength after accelerated artificial exposure, expressed in newtons per square millimetre.

10.4.4 Overlap-splice strength retention

Calculate the overlap-splice strength, R_{ets}, expressed as a percentage with a precision of three significant digits, using Equation (14):

$$R_{\text{ets}} = \frac{\overline{f}_{\text{fus1}}}{\overline{f}_{\text{fus0}}} \times 100 \tag{14}$$

where

$\overline{f}_{\text{fus0}}$ is the average value for overlap-splice strength before accelerated artificial exposure, expressed in newtons per square millimetre;

$\overline{f}_{\text{fus1}}$ is the average value for overlap-splice strength after accelerated artificial exposure, expressed in newtons per square millimetre.

10.5 Test report

The test report shall include the following items:

a) common items:

- name of FRP sheet, date of manufacture, lot number of production run and name of manufacturer;
- type of FRP sheet and impregnation resin;
- surface density of the fibre and density of the FRP sheet;
- identification of test piece;

b) items relating to accelerated artificial-exposure test:

- type and model of testing machine and test conditions (black panel temperature, spray cycle with or without humidity control unit, test period, location of test pieces, conditions for changing of test pieces, filter use conditions);
- date at which accelerated artificial exposure test starts and ends;
- observation records for appearance inspection;

c) items relating to tensile strength test:

- fabrication date, fabrication method and curing period for test pieces;
- temperature, humidity and duration of test piece conditioning;
- test date, test temperature and loading rate;
- shape, dimensions and calculated cross-sectional area for each test piece;
- tensile capacity of each test piece and average for these values;
- maximum tensile strength of each test piece and average for these values;
- Young's modulus of each test piece and average for these values;
- ultimate strain of each test piece and average for these values;
- load-strain curve for each test piece;
- tensile strength retention;

d) items relating to overlap splice strength test:

- fabrication date, fabrication method and curing period for test pieces;
- temperature, humidity and duration of test piece conditioning;
- test date, test temperature and loading rate;
- shape, dimensions and calculated cross-sectional area for each test piece;
- tensile capacity of each test piece and average for these values;

— maximum tensile strength of each test piece and average for these values;

— mode of failure for each test piece;

— overlap splice-strength retention.

11 Test method for durability

11.1 Types of test methods for durability

There are three test methods for durability as shown in Table 8.

Table 8 — Test methods for durability

Test designation	Test item	Test method	
		Half-immersion test	Dry-and-wet-cycle test
A	Pull-off strength	O	O
B	Bond properties	—	O
C	Overlap splice strength	—	O

11.2 Test piece

11.2.1 Durability test for pull-off strength — Test A

The test piece shall be in accordance with 8.1.

11.2.2 Durability test for bond properties — Test B

The test piece shall be in accordance with 7.1.

11.2.3 Durability test for overlap splice strength — Test C

The test piece shall be in accordance with 6.1, with the following treatment being applied to the portion other than the tested portion in order to prevent change when subjected to dry and wet cycles.

a) The four side surfaces shall be covered with epoxy-type resin.

b) Aluminium adhesive tape shall be attached to the portion other than the gauge length shown in Figure 4 and Clause 6.

c) The heat-retention plastic foam in accordance with JIS A 9511 shall be attached to one side of the test piece.

11.3 Test method

11.3.1 Durability test for pull-off strength — Test A

11.3.1.1 Half-immersion test

a) Test tank

An example of the test tank is shown in Figure 9. The test tank shall be placed outdoors.

b) Installation of the test piece

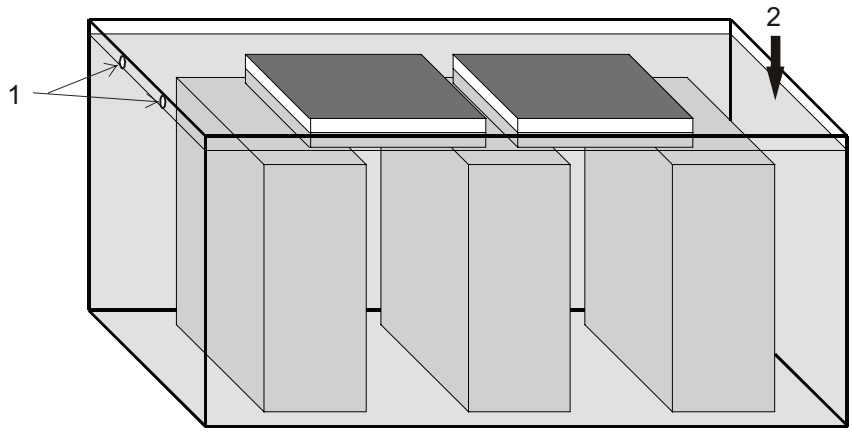
The test piece shall be installed so that the attached plane of the FRP sheet is facing upwards horizontally.

c) Test period

The test period shall be three years.

d) Pull-off strength

The test method for the pull-off strength after half-immersion shall be in accordance with 8.3.



Key

1 overflow
2 water supply

Figure 9 — Example test tank for the half-immersion test for pull-off strength

11.3.1.2 Dry-and-wet-cycle test

a) Test temperature

The temperature in dry condition shall be 60 °C ± 2 °C and that in wet condition shall be 20 °C ± 2 °C.

b) Initial water content

The test piece shall be immersed in water at 20 °C ± 2 °C for 24 h.

c) Dry and wet cycle

A cycle shall consist of a dry period of 42 h at 60 °C ± 2 °C and a wet period of 6 h in water at 20 °C ± 2 °C.

d) Number of cycles

The number of cycles shall be 50.

e) Bond properties

The test method for direct pull-off strength after dry and wet cycles shall be in accordance with 8.3.

11.3.2 Durability test for bond properties — Test B: Dry-and-wet-cycle test

Test temperature, initial water content, dry-and-wet-cycle condition and number of cycles shall be in accordance with 11.3.1.2 a) to c). Test method for the bond properties after dry and wet cycles shall be in accordance with 7.3.

11.3.3 Durability test for overlap splice strength — Test C: Dry-and-wet-cycle test

Test temperature, initial water content, dry-and-wet-cycle condition and number of cycles are according to 11.3.1.2 a) to c). The test method for the overlap splice strength after dry and wet cycles shall be in accordance with 6.3.

11.4 Calculation and expression of test results

11.4.1 Durability test for pull-off strength — Test A

The calculations and expression of test results shall be in accordance with 8.4.

11.4.2 Durability test for bond properties — Test B

The calculations and expression of test results shall be in accordance with 7.4.

11.4.3 Durability test for overlap splice strength — Test C

The calculations and expression of test results shall be in accordance with 6.4.

11.5 Test report

11.5.1 Durability test for pull-off strength — Test A

The test report shall include the following items in addition to the items listed in 8.5:

a) test item;

b) test duration or number of cycles;

c) test date.

11.5.2 Durability test for bond properties — Test B

The report shall include the following items in addition to the items listed in 7.5:

a) test item;

b) test duration or number of cycles;

c) test date.

11.5.3 Durability test for overlap splice strength — Test C

The report shall include the following items in addition to the items listed in 6.5:

a) test item;

b) test duration or number of cycles;

c) test date.

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