
**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



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Published in Switzerland

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT), see the following URL: Foreword — Supplementary information.

The committee responsible for this document is ISO/TC 71, *Concrete, reinforced concrete and pre-stressed concrete*, Subcommittee SC 6, *Non-traditional reinforcing materials for concrete structures*.

This second edition cancels and replaces the second edition (ISO 10406:2008), which has been technically revised.

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 documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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, *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*

3 Terms and definitions

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 1 to entry: 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 1 to entry: 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 dry sheet (fibre sheets before impregnation with resin)

Note 1 to entry: Expressed as mass per square metres.

**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 1 to entry: 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 1 to entry: 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 1 to entry: 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

Table 1 (continued)

Symbol	Unit	Description	Reference
$b_{t,min}$	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
\bar{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
\bar{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
\bar{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
\bar{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}	N	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}	mm	Anchoring portion length	5.1.1
L_{A2}	mm	Anchorage thickness	5.1.1
L_{A3}	mm	Anchorage length	5.1.1
L_{end}	mm	Width at both ends	5.1.1
L_{ga}	mm	Gauge length	5.1.1
L_{th}	mm	Thickness	5.1.1
L_{tot}	mm	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 sheet	7.4
n_u	strands/mm	Number of fibre bundles per unit area of the 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
t	mm	Thickness of sheet, equal to $n \cdot \rho_s / \rho_{sh} \times 10^{-3}$	7.4
ΔF	N	Difference between loads at two points at 20 % and 50 % of tensile capacity	5.4
ρ_s	g/m ²	Fibre mass per unit area of dry sheet	5.4 , 6.4 , 7.4
ρ_{sh}	g/cm ³	Density of dry 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

Table 1 (continued)

Symbol	Unit	Description	Reference
ε_{fu}	—	Difference in strain between the two points used to calculate ΔF	5.4.5
$\Delta\varepsilon$	—	Ultimate strain	5.4
τ_u	N/mm ²	Bond strength	7.4

4 General provision concerning test pieces

Unless otherwise agreed upon, test pieces shall be taken from the sheet in the “as delivered” condition.

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.

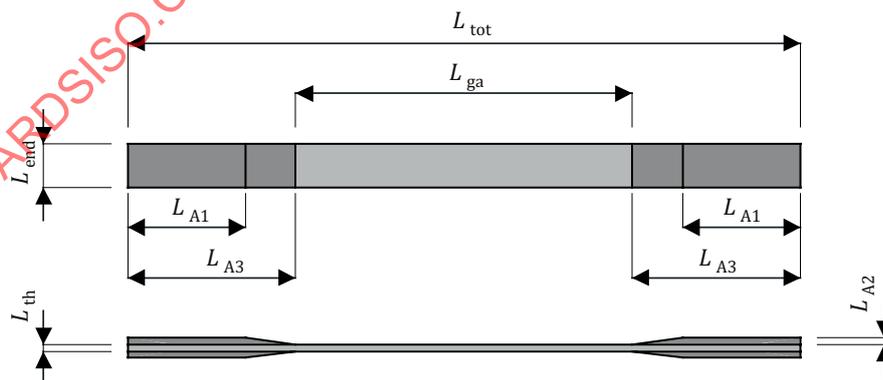
5 Test method for determining tensile properties

5.1 Test pieces

5.1.1 Types and dimensions

Two types of test pieces may be used (see Figure 1 and Table 2).

- Type A test pieces: Prepare type A test pieces in accordance with the method described in 6.1.2.1 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.
- Type B test pieces: Prepare type B test pieces in accordance with the method described in 6.1.2.2. 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.



NOTE 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	≥200	
L_{end}	width at both ends	12,5 ± 0,5	10 to 15
L_{th}	thickness	Recommended not to exceed 2,5	
L_{ga}	gauge length	≥100	
L_{A1}	anchoring portion length	≥35	
L_{A2}	anchorage thickness	1 to 2	
L_{A3}	anchorage length	≥50	
NOTE 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.			

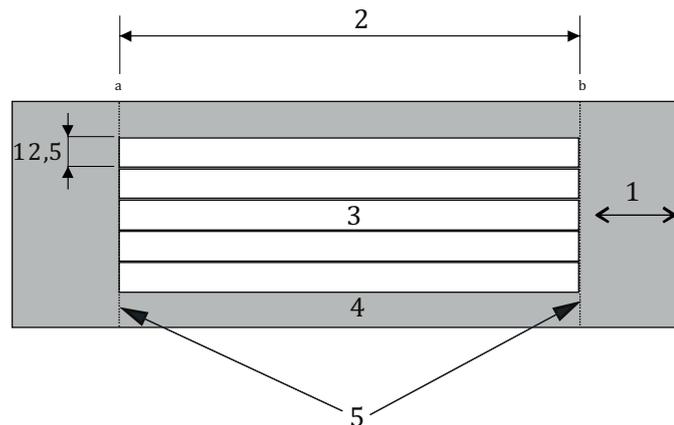
5.1.2 Preparation

5.1.2.1 Type A test pieces

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

- a) Prepare a dry 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 considering manufacturer’s instructions, 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](#) considering manufacturer’s instructions.

Dimensions in millimetres

**Key**

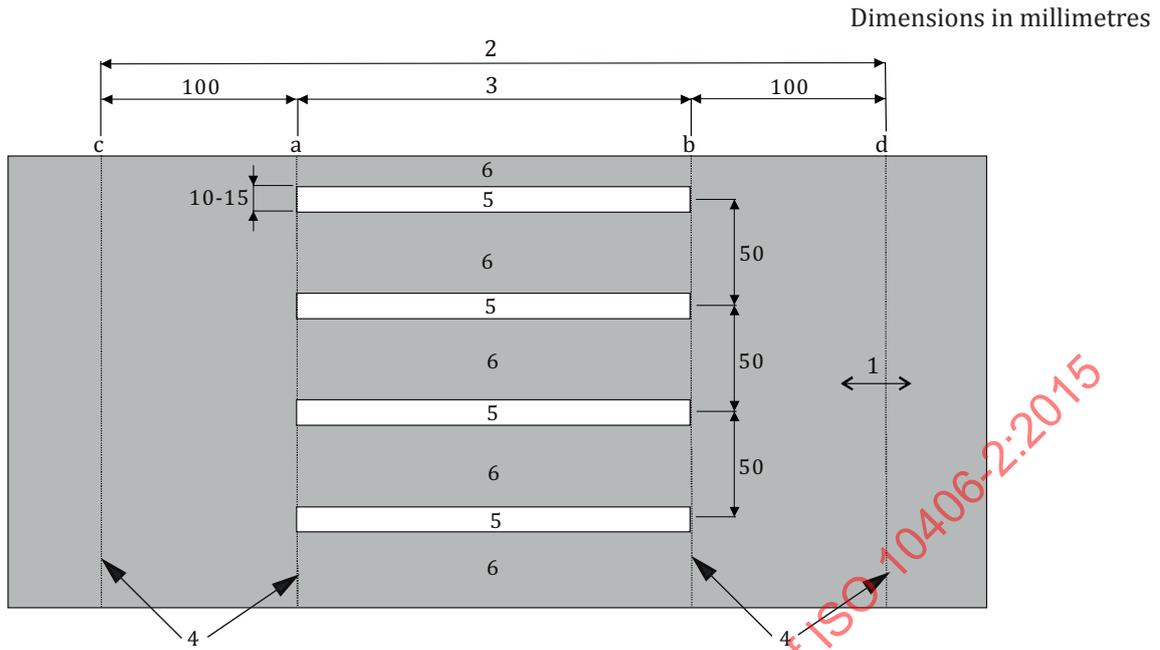
- 1 direction of fibre axis
- 2 section used to prepare test piece: ≥ 200 (area impregnated with resin)
- 3 test piece portion
- 4 cut-away portion
- 5 marking
- a, b Location of the two straight-line marks perpendicular to the fibre axis that define a length of at least 200 mm.

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 a dry 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 one to three 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.



Key

- 1 direction of fibre axis
- 2 area impregnated with resin: ≥ 400
- 3 section used to prepare test piece: ≥ 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

- h) Prior to testing, condition the test pieces as prescribed in 5.1.5 considering manufacturer’s instructions.

A tracer thread may be added to uncured, wet-laid material to help identify the fibre direction and 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 considering manufacturer’s instructions.

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 it is confirmed by prior tests under equivalence conditions at the testing room that humidity has a negligible or no influence on the properties, it is not necessary to control the relative humidity. Similarly, if it is confirmed by prior tests under equivalence conditions at the testing room that neither temperature nor humidity has any noticeable influence on the properties, 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 gauge length or elongation during testing with a strain measurement accuracy of at least 10×10^{-6} .

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. The width and thickness of the test piece shall be determined as the average of at least three readings taking from different locations on the test specimen. Measurements shall be taken to the following precision:

- 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 centreline 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_{tu} , expressed in newtons per square millimetre and rounded off to three significant digits in accordance with ISO 31-0:1992, Annex B, using Formula (1):

$$f_{tu} = \frac{F_u}{A} \quad (1)$$

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

$$A_A = \frac{\rho_S}{\rho_{sh}} \cdot b_{t,min} \times 10^{-3} \quad (2)$$

$$A_B = \frac{\rho_S}{\rho_{sh}} \cdot \frac{N_t}{n_u} \times 10^{-3} \quad (3)$$

where

ρ_S is the fibre mass per unit area of dry sheet, expressed in grams per square metres;

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

$b_{t,min}$ 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 sheet, expressed in strands per millimetre.

NOTE 1 The nominal fibre mass per unit area provided by the material manufacturer can be used.

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

5.4.4 Young's modulus

Calculate the Young's modulus, E_f , using Formula (4) based on the load-strain curve at 20 % and 50 % tensile capacity and rounded off to three significant digits in accordance with ISO 5725 (all parts).

$$E_f = \frac{\Delta F}{\Delta \varepsilon \cdot A} \quad (4)$$

where

ΔF is the difference between loads at two points at 20 % and 50 % 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 Formula (2), for a type A test piece and as A_B , using Formula (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 Formula (5), based on the tensile capacity, F_u , and the last simultaneously recorded values of the load, F_{last} , and strain, ε_{last} :

$$\varepsilon_{fu} = \varepsilon_{last} \cdot \frac{F_u}{F_{last}} \quad (5)$$

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) fibre mass per unit area of dry sheet and density of dry sheet;
- d) fabrication date, fabrication method, and curing conditions (including temperature and duration) for test pieces;
- e) temperature, humidity, and duration of test piece conditioning;
- f) test date, test temperature, and loading rate;
- g) 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.

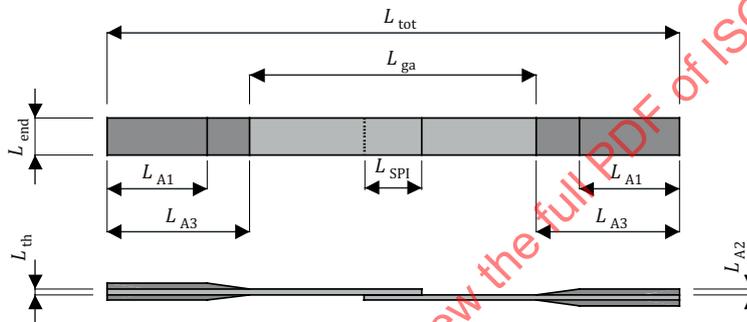
6 Test method for overlap splice strength

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](#).

NOTE Test piece corresponding to the Type A test piece in [Clause 5](#) is specified in this part of ISO 10406. Type B test piece is not specified because of difficulties of making test piece to keep axial direction of fibres linear in two FRP sheets.



NOTE See [Table 3](#) for definitions of symbols and dimensions.

Figure 4 — Shape of test pieces

Table 3 — Dimensions of test pieces

Dimensions in millimetres

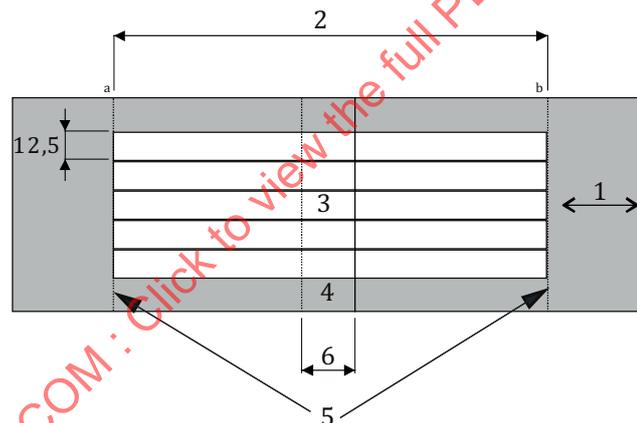
Symbol	Dimension
L_{tot}	total length Length of splice plus a minimum of 200
L_{end}	width at both ends $12,5 \pm 2,5$
L_{th}	thickness Recommended not to exceed 2,5
L_{ga}	gauge length Length of splice plus a minimum of 100
L_{A1}	anchoring portion length ≥ 35
L_{A2}	anchorage thickness 1 to 2
L_{A3}	anchorage length ≥ 50
L_{spl}	length of splice portion Necessary length
NOTE 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 is to 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.

- Prepare a dry sheet cut to a sufficient length for the dimensions of the test piece to be fabricated.
- Apply the bottom coat of impregnation resin to the separation film and attach the sheet mentioned in a), fasten it so that the fibre axis of the sheet is in a straight line.
- Overlap two sheets so that the prescribed length of the overlap splice portion is secured.
- 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.
- Cure the plate for the prescribed duration considering manufacturer's instructions, 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.
- Attach the anchorage to the anchorage portion to form the test piece.
- Before performing the test, condition the test piece as prescribed.

Dimensions in millimetres



Key

- direction of fibre axis
- section used to prepare test piece: ≥ 200 (area impregnated with resin)
- test piece portion
- cut-away portion
- marking
- 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 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 considering the manufacturer's instructions.

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 it is confirmed by prior tests under equivalence conditions at the testing room that humidity has a negligible or no influence on the properties, it is not necessary to control the relative humidity. Similarly, if it is confirmed by prior tests under equivalence conditions at the testing room that neither temperature nor humidity has any noticeable influence on the properties, 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 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 parties (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 Formula (6) in accordance with ISO 31-0:1992, Annex B:

$$f_{fus} = \frac{F_u}{A} \quad (6)$$

where

F_u is the tensile capacity, expressed in newtons;

A is the nominal cross-sectional area, expressed in square millimetres, using Formula (7).

$$A = \frac{\rho_s}{\rho_{sh}} \cdot b_{t,min} \times 10^{-3} \quad (7)$$

where

ρ_s is the fibre mass per unit area of dry sheet, expressed in grams per square metres;

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

$b_{t,min}$ 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:

- name of FRP sheet, date of manufacture, lot number of production run, and name of manufacturer;
- type of FRP sheet and impregnation resin;
- fibre mass per unit area of dry sheet and density of dry sheet;

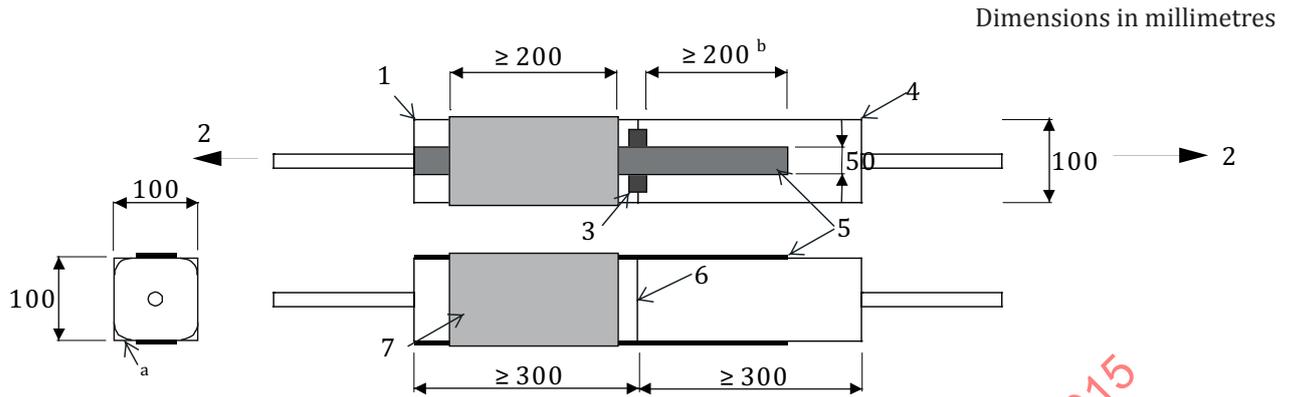
- d) fabrication date, fabrication method, and curing conditions (including temperature and duration) for test pieces;
- e) temperature, humidity, and duration of test piece conditioning;
- f) test date, test temperature, and loading rate;
- g) dimensions of each test piece and calculated cross-sectional 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 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 5, respectively.



Key

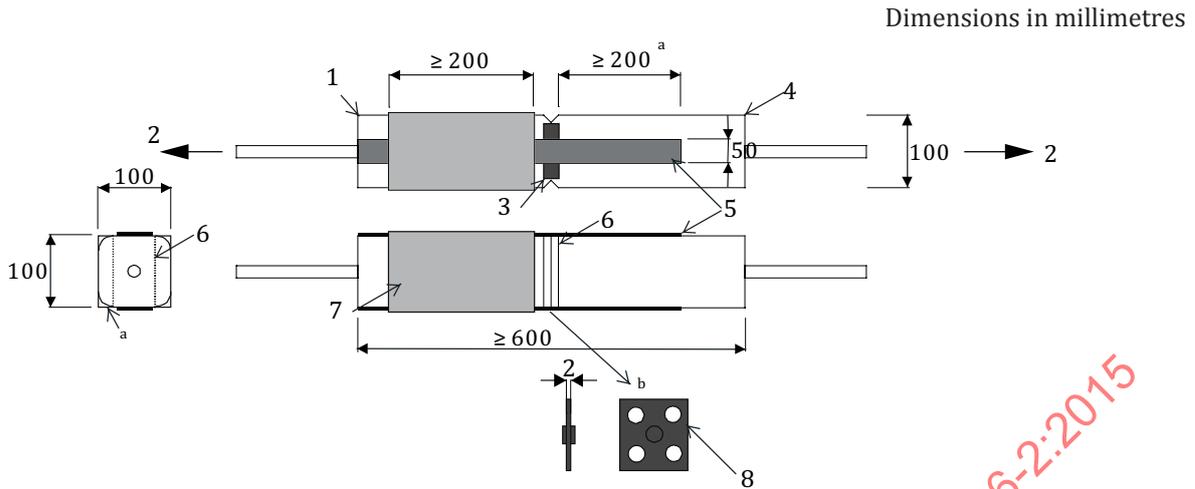
- 1 anchoring block
- 2 tensile load
- 3 separation-type film
- 4 test block
- 5 FRP sheet
- 6 abutted surface
- 7 anchoring sheet
- a Beveled.
- b Bond length.

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)	
Remarks	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 or a 20 mm deep notch in the centre on either side
^a The effective bond length varies by the number of FRP layers, Young's modulus, and the type of impregnation resin. When the effective bond length exceeds 200 mm, the bond length on the test block should be extended to at least the effective bond length.		



Key

- 1 anchoring block
- 2 tensile load
- 3 separation-type film
- 4 test block
- 5 FRP sheet
- 6 notch
- 7 anchoring sheet
- 8 acrylic panel with 4-hole of around 20 mm diameter
- a Bond 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 nominal size of coarse aggregate can be 20 mm or 25 mm and the water-to-cement ratio, between 0,5 and 0,6.

The concrete pieces shall be cured in water at 20 °C ± 3 °C for seven days, then in air for at least another seven days. The water temperature of 27 °C ± 2 °C is applicable for warm countries.

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 $20\text{ °C} \pm 15\text{ °C}$.

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 $100\text{ mm} \times 100\text{ mm}$ 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 $100\text{ mm} \times 100\text{ mm}$ 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 typical treatment for the surface is as follows. Select surfaces that are vertically-oriented during concrete pour. If the instructions of manufactures are provided, follow them.

- 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 is as follows. If the instructions of manufactures are provided, follow them.

- 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 [Figure 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 varies by the number of FRP layers, Young's modulus, and the type of impregnation resin. When effective bond length exceeds 200 mm, bond length on the test block should be extended to at least effective bond 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 [Figure 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.

7.3 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 Loading rate

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

7.3.4 Test temperature

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

7.3.5 Range of test

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

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 Formula (8):

$$G_f = \frac{P_{\max}^2}{8b_{\text{av}}^2 \cdot E_f \cdot t} \quad (8)$$

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 defined in [Clause 5](#), expressed in newtons per square millimetre;

t is the thickness of the FRP sheet, equal to $n \cdot \rho_s / \rho_{\text{sh}} \times 10^{-3}$, expressed in millimetres,

where

n is the number of plies of the sheet;

ρ_s is the fibre mass per unit area of dry sheet, expressed in grams per square metres;

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

NOTE 1 The nominal fibre mass per unit area provided by the material manufacturer can be used.

NOTE 2 The nominal 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 Formula (9):

$$\tau_u = \frac{P_{\max}}{2b_{\text{av}} \cdot l} \quad (9)$$

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 , varies by the number of FRP sheet layers, Young's modulus, and the type of impregnation resin.

7.5 Test report

The test report shall include the following:

- 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) fibre mass per unit area of dry sheet and density of dry 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, width, length, bond length, and number of plies for FRP sheets;
- i) concrete mixture 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/mm² ± 3 N/mm².

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. In cases where the target structure is not known, the standard procedure for attaching the FRP sheet is as follows. If the instructions of manufactures are provided, follow them.

- 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.

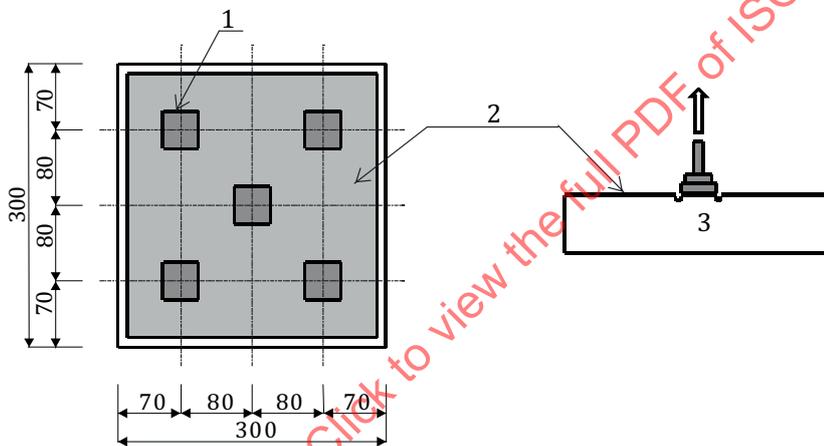
8.1.2.2 Attaching the FRP sheets

- 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 square steel device with a bonding area of 40 mm × 40 mm with 10 mm thickness or circular dollies with a diameter of 50 mm with a thickness of at least 20 mm if made of steel or with a thickness of at least 30 mm if made of aluminium.
- 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. In case of square devices, notch the area around the device using a concrete cutter. In case of circular dollies, notch the area around the device using a diamond coring barrel. The depth of the notch shall be in the range of 3 mm to 12 mm.

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 it is confirmed by prior tests under equivalence conditions at the testing room that humidity has no influence or a negligible influence on the properties, it is not necessary to control the relative humidity. Similarly, if it is confirmed by prior tests under equivalence conditions at the testing room that neither temperature nor humidity has any noticeable influence on the properties, 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 board.

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 Formula (10).

$$f_{\text{au}} = \frac{F_{\text{au}}}{A_{\text{s}}} \quad (10)$$

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:

- 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) fibre mass per unit area of dry sheet and density of dry sheet;
- d) number of plies of the FRP sheet;
- e) concrete mixture 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 $1,0\text{ °C} \pm 2\text{ °C}$ 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 with the temperature of 5 °C to 35 °C .
- b) The conditions for the freeze/thaw resistance test shall be
 - surface temperature of the test piece of $-20\text{ °C} \pm 2\text{ °C}$ during freezing and $30\text{ °C} \pm 2\text{ °C}$ during thawing (spraying), and
 - 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, Young's modulus, 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 Formula (11):

$$R_{\text{ett}} = \frac{\bar{f}_{\text{fu1}}}{\bar{f}_{\text{fu0}}} \times 100 \quad (11)$$

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 Formula (12):

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

where

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

\bar{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:

- 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;
 - fibre mass per unit area of dry sheet and density of dry 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 conditions including temperature and duration for test pieces;
 - temperature, humidity, and duration of test piece conditioning;
 - test date, test temperature, and loading rate;
 - dimensions and calculated cross-sectional area for each test piece;
 - tensile capacity of each test piece and average for these values;
 - 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;