INTERNATIONAL STANDARD

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Second edition
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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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Contents

Page

Foreword

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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).

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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
$\overline{f}_{fu0}$	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}	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

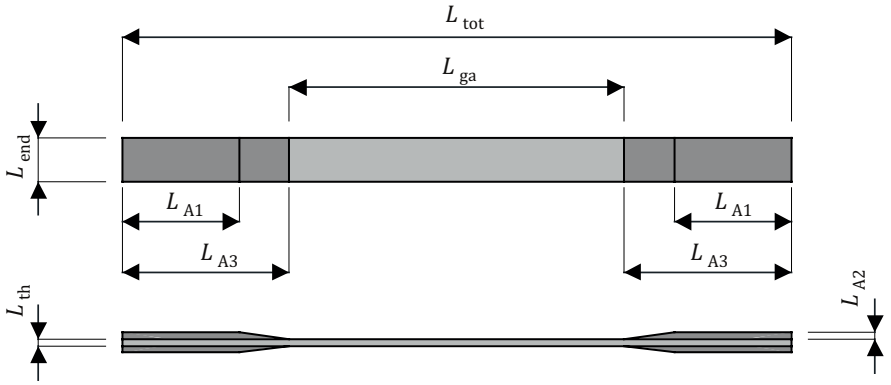
5.1 Test pieces

5.1.1 Types and dimensions

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

a) 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.

b) 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.

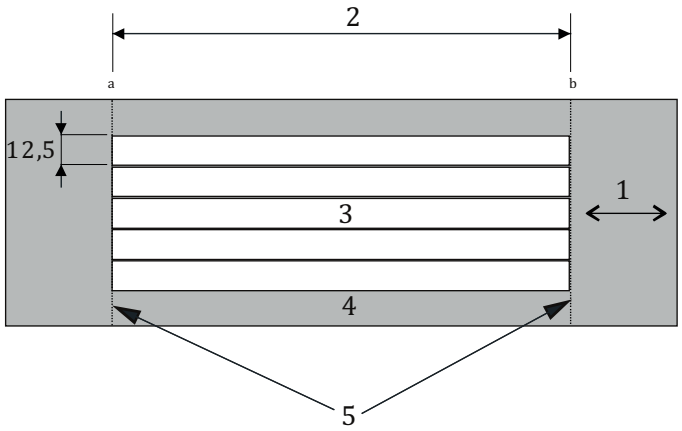
c) Apply the top coat of impregnation resin, then smooth the surface so that the thickness of the impregnation resin layer is even, to form a plate. Covering with separation film and smoothing would be best.

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.

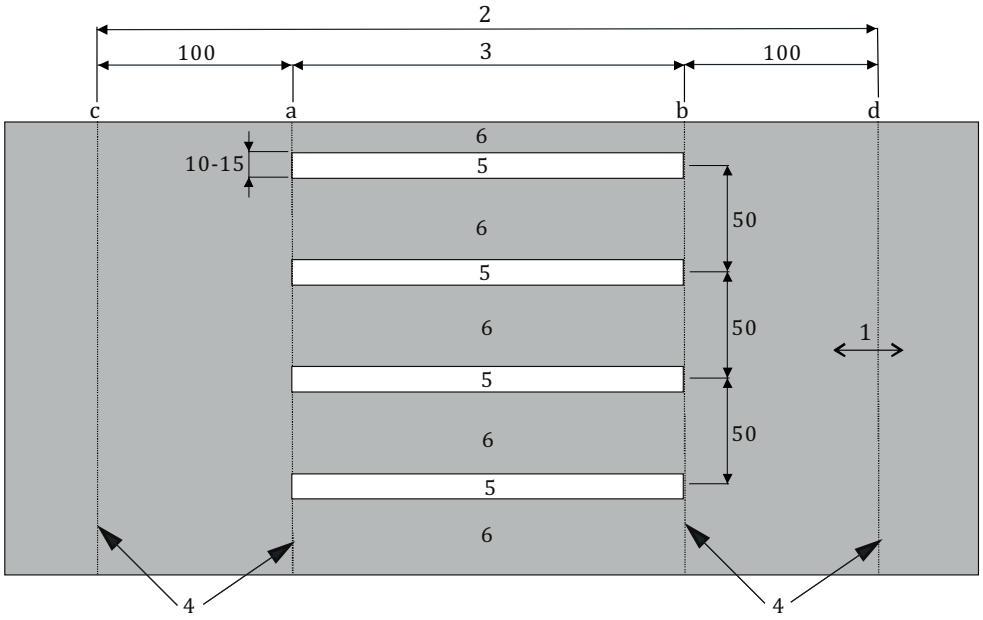
d) Apply the bottom coat of impregnation resin to the separation film and attach the aforementioned sheet onto the film.

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.

Dimensions in millimetres



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).