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

Part 1: FRP bars

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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 document 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).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents. ISO shall not be held responsible for identifying any or all such patent rights.

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document 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*.

This third edition cancels and replaces the second edition (ISO 10406-1:2015), which has been technically revised.

The main changes are as follows:

— inclusion of thermoplastic resin for FRP bars;

— addition of the test method for fibre volume fraction of FRP bars;

— revision of test methods for alkaline resistance, long-term relaxation, tensile fatigue strength, and creep failure strength to enhance rigor and comprehensiveness;

— increase in the minimum number of test specimens from 3 to 5 for all test methods to ensure data reliability.

A list of all parts in the ISO 10406 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Introduction

Fibre reinforced polymer (FRP) bars, renowned for their high strength, lightweight nature, excellent bond behaviour, and superior durability, serve a pivotal role in reinforcing new constructions and rehabilitating existing reinforced concrete structures. As the global use of FRP bars continues to expand, the need for standardized test methods has become paramount. Unlike steel, FRP bars exhibit anisotropic behaviour and their performance is influenced by the type of fibres, resin matrix, and manufacturing processes. As such, rigorous and consistent test methods are essential to accurately evaluate the physical properties, mechanical properties, long-term durability, and reliability of FRP bars in various environmental and loading conditions.

This document provides a comprehensive framework for evaluating the physical properties, mechanical properties, durability, and long-term performance of FRP bars. It aims to promote uniformity in test methods globally, thereby ensuring consistency in product quality and facilitating international trade. By establishing these test methods, this document supports engineers, manufacturers, and regulators in the design, production, and certification of FRP reinforcement systems for safe and sustainable infrastructure.

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

Part 1: FRP bars

1 Scope

This document specifies test methods applicable to fibre-reinforced polymer (FRP) bars as reinforcement or pre-stressing tendons in concrete, including physical, mechanical, durability, and long-term properties.

FRP bars in this document are made of fibre and resin matrix. Types of fibres are aramid fibre, basalt fibre, carbon fibre or glass fibre. The matrix includes thermosetting resins, such as vinylester, unsaturated polyester resins, as well as thermoplastic resins, including polypropylene, polyamides, and polymethyl methacrylate.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 291:2008, *Plastics — Standard atmospheres for conditioning and testing*

ISO 3611, *Geometrical product specifications (GPS) — Dimensional measuring equipment — Design and metrological characteristics of micrometers for external measurements*

ISO 4788, *Laboratory glassware — Graduated measuring cylinders*

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

ISO 13385-1, *Geometrical product specifications (GPS) — Dimensional measuring equipment — Part 1: Design and metrological characteristics of callipers*

3 Terms, definition, and symbols

3.1 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1.1
average load
average of the maximum and minimum repeated load

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3.1.2
bending angle
angle formed by the straight sections of a test piece on either side of the deflector

3.1.3
bending diameter ratio
ratio of the external diameter of the deflector surface in contact with the fibre-reinforced polymer (FRP) bar, and the nominal diameter of the fibre-reinforced polymer (FRP) bar

3.1.4
bending tensile capacity
tensile load at the moment of failure of the test piece

3.1.5
coefficient of thermal expansion
average coefficient of linear thermal expansion between given temperatures

Note 1 to entry: The average of the given temperatures is taken as the representative temperature.

3.1.6
creep failure capacity
load causing failure after a specified period of time from the start of a sustained load

Note 1 to entry: In particular, the load causing failure after 1 million hours is referred to as the million-hour creep failure capacity.

3.1.7
creep failure strength
stress causing failure after a specified period of time from the start of a sustained load

Note 1 to entry: In particular, the load causing failure after 1 million hours is referred to as the million-hour creep failure strength.

3.1.8
creep failure time
time between the start of a sustained load and failure of a test piece

3.1.9
creep failure
failure occurring in a test piece due to a sustained load

3.1.10
creep strain
differential change in length per unit length occurring in a test piece due to creep

3.1.11
creep
time-dependent deformation of a fibre-reinforced polymer (FRP) bar subjected to a sustained load at a constant temperature

3.1.12
deflected section
section of a fibre-reinforced polymer (FRP) bar which is bent and maintained at the required bending angle and bending diameter ratio

3.1.13
deflector
device used to maintain the position, alter the bending angle, or alleviate the stress concentrations in the fibre-reinforced polymer (FRP) bar; sometimes installed in the deflected section

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3.1.14
fatigue strength
maximum repeated stress at which the test piece does not fail at the prescribed number of cycles

3.1.15
fibre-reinforced polymer
FRP
composite material, moulded and hardened to the intended shape, consisting of continuous fibre impregnated with a fibre-binding polymer

3.1.16
fibre-reinforced polymer bar
FRP bar
composite material, moulded and hardened to the intended shape, consisting of continuous fibres impregnated with a fibre-binding polymer

3.1.17
fibre volume fraction
the ratio of the volume of fibres to the volume of the composite

3.1.18
frequency
number of loading (stressing) cycles in one second during the test

3.1.19
gauge length
straight portion along the length of a test piece used to measure the elongation using an extensometer, or a similar device

3.1.20
load amplitude
one-half of the load range

3.1.21
minimum repeated load
minimum load during repeated loading

3.1.22
nominal cross-sectional area
value obtained upon dividing the volume of the fibre-reinforced polymer (FRP) specimen by its length

3.1.23
nominal diameter
diameter of fibre-reinforced polymer (FRP) calculated assuming a circular section

3.1.24
nominal peripheral length
peripheral length of the fibre-reinforced polymer (FRP), which forms the basis for calculation of bond strength

3.1.25
number of cycles
number of times the repeated load is applied to the test piece

3.1.26
relaxation
time-dependent decrease in load in a fibre-reinforced polymer (FRP) held at a given constant temperature with a prescribed initial load applied and held at a given constant strain

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3.1.27
relaxation rate
percentage reduction in load relative to the initial load after a given period of time, under a fixed strain

Note 1 to entry: In particular, the relaxation value after 1 million hours (approximately 114 years) is referred to as the hundred-year relaxation rate.

3.1.28
repeated load
load alternating cyclically between fixed maximum and minimum values

3.1.29
S-N curve
curve plotted on a graph with repeated stress on the vertical axis and the number of cycles to fatigue failure on the horizontal axis

3.1.30
Fibre-reinforced polymer (FRP) tendon
resin-bound construction made of continuous fibres in the shape of a tendon used to reinforce concrete uniaxially

Note 1 to entry: Tendons are usually used in prestressed concrete

3.1.31
thermomechanical analysis (TMA)
method for measuring deformation of a material as a function of either temperature or time, by varying the temperature of the material according to a calibrated program, under a non-vibrating load

3.1.32
TMA curve
a graph with temperature or time represented on the horizontal axis, and deformation on the vertical axis

3.1.33
ultimate strain
strain corresponding to the maximum tensile force

3.2 Symbols

See Table 1.

Table 1 — Symbols

Symbol	Unit	Description	Reference
A	mm^2	Nominal cross-sectional area of test piece	5.1.3, 6.1.5
a	—	Empirical constant	8.1.5
b	—	Empirical constant	8.1.5
D	mm	Nominal diameter	5.1.3
E	N/mm^2	Young's modulus	6.1.5
F_r	N	Million-hour creep rupture capacity	8.3.6
F_{u0}	N	Tensile capacity after immersion	7.1.5
F_{u1}	N	Tensile capacity before immersion	7.1.5
f_r	N/mm^2	Million-hour creep rupture strength	8.3.6
f_u	N/mm^2	Tensile strength	6.1.5
L	mm	Length of test piece at room temperature	5.3.4
L_0	mm	Length before immersion	7.1.3
L_1	mm	Length after immersion	7.1.3
l_o	mm	Length of test piece	5.1.3

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Table 1 *(continued)*

Symbol	Unit	Description	Reference
l_b	mm	Bonded length	6.2.4
M_f	—	Fibre content of FRP bar	5.2.6
m_1	g	Initial mass of the dry boat or crucible	5.2.6
m_2	g	Initial mass of the boat or crucible plus dried specimen	5.2.6
m_3	g	Final mass of the boat or crucible plus residue after calcination	5.2.6
P_{bmax}	N	Maximum pull-out load	6.2.4
P_{max}	N	Maximum tensile load	6.1.5
P_{su}	N	Shear failure load (N)	6.4.5
R_{et}	%	Tensile capacity retention rate	7.1.5
T_1	°C	Minimum temperature for calculation of coefficient of thermal expansion (normally 0 °C)	5.3.4
T_2	°C	Maximum temperature for calculation of coefficient of thermal expansion (normally 60 °C)	5.3.4
t	h	Time	8.1.5
u	mm	Nominal peripheral length of test piece	6.2.4
V_o	mm^3	Volume of water in the measuring cylinder	5.1.3
V_s	mm^3	Volume of the sum total of water and test piece	5.1.3
W_0	g	Mass before immersion	7.1.3
W_1	g	Mass after immersion	7.1.3
Y	%	Relaxation rate	8.1.5
Y_c	—	Creep load ratio	8.3.6
α_{set}	1/°C	Coefficient of thermal expansion calculated for specifications test piece for length calibration between temperatures T_1 and T_2	5.3.4
α_{sp}	1/°C	Coefficient of thermal expansion	5.3.4
ΔL_{spm}	mm	Difference in length of test piece between temperatures T_1 and T_2	5.3.4
ΔL_{refm}	mm	Difference in length of specifications test piece for length calibration between temperatures T_1 and T_2	5.3.4
ΔP	N	Difference between loads at 20 % and 50 % of maximum tensile load	6.1.5
$\Delta\varepsilon$	—	Strain difference between ΔP	6.1.5
ε_u	—	Ultimate strain	6.1.5
τ_{bu}	N/mm^2	Bond strength	6.2.4
τ_{su}	N/mm^2	Shear strength (N/mm^2)	6.4.5

4 General provision concerning test pieces

Unless otherwise agreed, test pieces shall be taken from the bar in the ‘as-delivered’ condition.

In cases when test pieces are taken from a coil, the test piece shall be straightened prior to any test by 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 can 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.

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5 Test method for physical properties

5.1 Cross-sectional area

5.1.1 Test pieces

5.1.1.1 Preparation of test pieces

Test pieces shall be cut to predetermined length and finished flat at its cut end from the mother material (FRP) for tensile test.

5.1.1.2 Length of test pieces

The length of test pieces shall be 100 mm when nominal approximate diameter is 20 mm or less, and shall be 200 mm when approximate diameter is over 20 mm.

5.1.1.3 Number of test pieces

The number of test pieces shall be five from the mother material of the same lot at least.

5.1.2 Test procedure

The test procedure is as follows:

a) The length of the test piece shall be measured using the vernier callipers specified by ISO 13385-1. Measurements shall be taken at three locations along the test piece, and the average of the three values shall be rounded off to one figure below a decimal point; it is the length of test piece.

b) The volume of the test piece shall be measured using the measuring cylinder specified by ISO-4788 according to approximate diameter of test piece. Table 2 shows the relationship between approximate diameter of test piece and capacity of measuring cylinder. When there are two or more capacities, the minimum capacity cylinder in the range that can be measured shall be chosen.

c) Put the waterworks water of a proper quantity into the measuring cylinder and measure the volume. When the air bubbles, which can cause an error of measurement, are generated on the surface of the test piece, the surface-tension-reducing solvent such as ethanol etc. may be added in water for the purpose to control generating of air bubbles. When the test piece is in the measuring cylinder, the water shall cover the test piece, and the top of the water shall be in the range of scale.

d) Insert the test piece into the measuring cylinder and measure the volume of the sum total of water and the test piece.

e) The test temperature shall be within the range 15 °C to 25 °C (or 20 °C to 30 °C for warm countries).

Table 2 — Relationship between the approximate diameter of test piece and the capacity of measuring cylinder

Approximate width of test piece (mm)	Capacity of measuring cylinder (ml)
under 10	10 or 20
11 to 13	25
14 to 20	50 or 100
21 to 25	100
over 25	300 or 500

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5.1.3 Calculations

Nominal cross-sectional area shall be calculated from Formula (1), rounded off to one figure below a decimal point.

$$A = \frac{V_s - V_0}{l_0} \tag{1}$$

where

A nominal cross-sectional area, in mm^2;
V_s volume of the sum total of water and test piece, in mm^3;
V_0 volume of water in the measuring cylinder, in mm^3;
l_0 length of test piece, in mm.

NOTE The nominal cross-section area includes the area of surface-bonded sand particles, surface-bonded transverse wraps, and other non-load-bearing area.

Nominal diameter shall be calculated from Formula (2), rounded off to one figure below a decimal point.

$$D = 2\sqrt{\frac{A}{\pi}} \tag{2}$$

where

D nominal diameter, in mm;
A nominal cross-sectional area, in mm^2.

5.1.4 Test report

The test report shall include the following mandatory information:

a) name, shape, date of manufacture and lot number of FRP tested;

b) the International Standard used (including its year of publication);

c) the method used (if the standard includes several);

d) nominal cross-sectional area, nominal diameter;

e) any deviations from the procedure;

f) any unusual features observed;

g) test temperature;

h) the date of the test;

The test report may include the following additional information:

a) capacity of measuring cylinder used in the test;

b) length of test piece;

c) volume of water in the measuring cylinder;

d) volume of the sum total of water and the test piece;

e) name of the solvent, if any solvent is used in the test.

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