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European Assessment Document for

Carbon, glass, basalt and aramid fibre reinforced polymer bars as reinforcement of structural elements

Contents

1 SCOPE OF THE EAD

1.1 Description of the construction product

Carbon, glass, basalt and aramid FRP (Fibre Reinforced Polymer) bars (hereinafter referred to as “FRP bars”) are made of high strength filaments (carbon, glass, basalt or aramid fibres), in the axial direction, impregnated with special thermoplastic or thermosetting resins, to be applied as reinforcement of inorganic matrixes (like concrete, lime-stone based mortars, Portland, CSA cement, hydraulic reactive powder, light-weight concrete, etc.) to build and repair beams, columns, slabs and other structural elements.

Bars covered by his EAD have diameters ranging from 5 to 32 mm and with no limitations of length. Assessment methods (e.g., bond strength in concrete) have been developed for the range of diameters here indicated, therefore larger or smaller diameter are out of the scope of the EAD. They can be straight or bent into different shapes.

Straight bars and stirrups used as reinforcements for concrete structures can be either almost circular or flat with a maximum width of 4 cm, in order to avoid interfering during the cast of the matrix. Stirrups can be produced in single shapes with internal overlapping or in a helicoidal continuous shape.

Surface enhancement can be provided through protrusions, lungs, sand coatings, deformations or any additional surface treatments that provide means of mechanically transmitting force between the bar and the inorganic matrix surrounding the bar. Flat bars can be either smooth or sand coated.

The product is not covered by a harmonised European standard (hEN).

Concerning product packaging, transport, storage, maintenance, replacement and repair it is the responsibility of the manufacturer to undertake the appropriate measures and to advise his clients on the transport, storage, maintenance, replacement and repair of the product as he considers necessary.

It is assumed that the product will be installed according to the manufacturer’s instructions or (in absence of such instructions) according to the usual practice of the building professionals.

Relevant manufacturer’s stipulations, e.g., with regard to the intended end use conditions, having influence on the performance of the product covered by this European Assessment Document shall be considered for the determination of the performance and detailed in the ETA as long as the details of the assessment methods as laid down in this EAD are respected.

1.2 Information on the intended use(s) of the construction product

1.2.1 Intended use(s)

FRP bars are intended to be used as reinforcement of construction works and elements made of reinforced concrete (beams, columns, panels, slabs and other structural elements) and as post-installed rebars.

1.2.2 Working life/Durability

The assessment methods included or referred to in this EAD have been written based on the manufacturer’s request to take into account a working life of the FRP bars for the intended use of 100 years when installed in the works (provided that the FRP bars are subject to appropriate installation). These provisions are based upon the current state of the art and the available knowledge and experience.

When assessing the product, the intended use as foreseen by the manufacturer shall be taken into account. The real working life may be, in normal use conditions, considerably longer without major degradation affecting the basic requirements for works[1].

The indications given as to the working life of the construction product cannot be interpreted as a guarantee neither given by the product manufacturer or his representative nor by EOTA when drafting this EAD nor by the Technical Assessment Body issuing an ETA based on this EAD, but are regarded only as a means for expressing the expected economically reasonable working life of the product.

1.3 Specific terms used in this EAD

1.3.1 Definitions

Effective cross-sectional area	Measured cross-sectional area of the bar, according to 2.2.1 (ISO 10406-1[2], clause 5)
Nominal diameter	Declared value of the bar diameter from the manufacturer, corresponding to the bar size
Nominal cross-sectional area	Value of cross-sectional area calculated from the nominal diameter
Accuracy	Squared sum of the systematic error and of the expanded measurement uncertainty.

1.3.2 Abbreviations

FRP	Fibre Reinforced Polymer
DSC	Differential Scanning Calorimetry
RH	Relative Humidity

1.3.3 Symbols

Latin upper-case symbols

A_{nom}	[mm²]	Nominal bar cross-sectional area
A_{eff}	[mm²]	Effective measured bar cross-sectional area
B_s	[mm]	Width of FRP stirrups
C_c	[-]	Reduction factor for creep rupture (EN1992-1-1, clause R.5.3)
C_e	[-]	Reduction factor for environmental attack (EN1992-1-1, clause R.5.3)
E_c	[GPa]	Elastic modulus in compression
E_f	[GPa]	Tensile modulus of elasticity
F	[N]	Failure load
F_1	[N]	Reduced load in the thermomechanical data processing
$F_{1,\alpha}$	[N]	Reduced load corresponding to T_α in the thermomechanical diagram
F_{fb}	[N]	Ultimate force measured in the bend test
F_i	[N]	Force values in the thermomechanical diagram
F_{rc}	[N]	Million-hour creep failure capacity (sustained load only, case 1)

1 The real working life of a product incorporated in a specific works depends on the environmental conditions to which that works is subject, as well as on the particular conditions of the design, execution, use and maintenance of that works. Therefore, it cannot be excluded that in certain cases the real working life of the product may also be shorter than referred to above.

2 All undated references to standards in this EAD are to be understood as references to the dated versions listed in chapter 4.

$F_{rc,a}$	[N]	Million-hour creep failure capacity (alkali environment, case 2 or case 3)
H_s	[mm]	Length of FRP stirrups
L_g	[mm]	Length of the anchorage tube in the tensile test
L_t	[mm]	Tail length of FRP bent bars
R	[-]	Load (stress) ratio in the tensile fatigue test
$R_{et,t}$	[%]	Tensile capacity retention rate after alkali conditioning
$R_{et,i}$	[%]	Interlaminar capacity retention rate after alkali conditioning
R_{cb}	[%]	Reduction in bond strength from centric tests to eccentric tests
R_{Yc}	[N/N]	Creep failure load ratio
$R_{Yc,a}$	[N/N]	Creep failure load ratio for test in alkali solution (case 2) or with concrete cylinder (case 3)
$R_{\Delta m}$	[%]	Rate of percentage mass loss after alkali conditioning
T_c	[°C]	Temperature at which the first derivative of the function F_1 (T) has a minimum value
T_g	[°C]	Glass transition temperature
$T_{g,I}$	[°C]	Glass transition temperature obtained in the first heating cycle (DSC)
$T_{g,II}$	[°C]	Glass transition temperature obtained in the second heating cycle (DSC)
T_i	[°C]	Temperature values in the thermomechanical diagram
T_{max}	[°C]	Maximum service temperature
T_{pm}	[°C]	Fusion temperature (thermoplastic and semi-crystalline materials)
$T_{\alpha 1}$	[°C]	Temperature at which the second derivative of the function F_1 (T) has a maximum value
T_{α}	[°C]	Temperature at which the second derivative of the function F_1 (T) has a minimum value
V_x	[-]	Coefficient of variation
Y_c	[%]	Load-ratio in the creep test
Y_r	[%]	Relaxation rate
Y_{10}, Y_{120}, Y_{1000}	[%]	Relaxation rates at 10 h, 120 h and 1,000 h
$Y_{million}$	[%]	Million-hour relaxation rate

Latin lower-case symbols

b	[mm]	Nominal bar width (flat bars)
b_{eff}	[mm]	Effective bar width (flat bars)
b_s	[mm]	Specimen width in the interlaminar shear strength test
c_b	[mm]	Concrete cover for eccentric bond tests
d	[mm]	Nominal bar diameter (circular bars)
d_c	[mm]	Diameter of concrete cylinder in the creep test (case 3)
d_{eff}	[mm]	Effective bar diameter (circular bars)
d_{sh}	[mm]	External diameter of the spiral reinforcement
f_b	[MPa]	Flexural tensile strength
f_c	[MPa]	Compressive strength
$f_{fatigue}$	[MPa]	Fatigue strength obtained at $2x10^6$ cycles
f_{ft}	[MPa]	Tensile strength of FRP bars
$f_{ft,c}$	[MPa]	Million-hour creep failure strength (sustained load only, case 1)
$f_{ft,ca}$	[MPa]	Million-hour creep failure strength (alkali environment, case 2 or case 3)
f_{ft0}	[MPa]	Average short-term tensile strength of FRP bars
f_{ftk0}	[MPa]	Characteristic short-term tensile strength of FRP bars
$f_{ftk,c}$	[MPa]	Characteristic long-term strength of FRP bars (sustained load only, case 1)

$f_{ftk,ca}$	[MPa]	Characteristic long-term strength of FRP bars (alkali environment, case 2 or case 3)
$f_{ftk,100a}$	[MPa]	Characteristic long-term strength of FRP bars considering the effects of time, temperature and environmental influence (EN 1992-1-1, clause 3.7.2 and clause R.5.3)
f_{ub}	[MPa]	Bend capacity
k_a, k_b	[-]	Empirical constants of the creep-failure trend line
k_n	[-]	Coefficient for the evaluation of the characteristic value
l_c	[mm]	Length of concrete cylinder in the creep test (case 3)
l_p	[mm]	Length of the working part of the specimen (distance between the supports) in the three-point lateral bending test under temperature
l_i	[mm]	Span length in the interlaminar shear strength test
l_s	[mm]	Specimen length in the interlaminar shear strength test
r^2	[-]	Coefficient of determination in the linear regression
r_t	[mm]	Bend radius of FRP bent bars
t	[h]	Time
w	[mm³]	Section modulus or moment of resistance (circular cross-section)

Greek lower-case symbols

$\alpha_{sp,L}$	[°C^{-1}]	Coefficient of longitudinal thermal expansion
$\alpha_{sp,T}$	[°C^{-1}]	Coefficient of transverse thermal expansion
ε_{ft}	[mm/mm]	Tensile failure strain
ε_{ft0}	[mm/mm]	Average value of the tensile failure strain
ε_{ftk0}	[mm/mm]	Characteristic value of the tensile failure strain
θ	[rad]	Angle to be calculated with Equation C6.2
τ_b	[MPa]	Bond strength in concrete by pull-out testing
$\tau_{b,cb}$	[MPa]	Eccentric bond strength in low strength concrete C20/25 for the tested concrete cover c_b
τ_{Tmax}	[MPa]	Bond strength at maximum service temperature
τ_i	[MPa]	Interlaminar shear strength
τ_{ret}	[MPa]	Retained bond strength after bond test at maximum service temperature
τ_s	[MPa]	Transverse shear strength
χ	[%]	Strength-reduction factor of FRP bent bars

2 ESSENTIAL CHARACTERISTICS AND RELEVANT ASSESSMENT METHODS AND CRITERIA

2.1 Essential characteristics of the product

Table 2.1.1 shows how the performance of the FRP bars is assessed in relation to the essential characteristics.

Table 2.1.1 Essential characteristics of the product and methods and criteria for assessing the performance of the product in relation to those essential characteristics

No	Essential characteristic	Assessment method	Type of expression of product performance
	Basic Works Requirement 1: Mechanical resistance and stability		
1	Cross-sectional properties	2.2.1	Level Effective cross-sectional area, A_{eff} [mm^2] Effective diameter, d_{eff} [mm] *or* Effective width, b_{eff} [mm]
2	Tensile strength	2.2.2	Level and description f_{ft0} [MPa], f_{ftk0} [MPa]
3	Tensile modulus of elasticity	2.2.2	Level and description E_f [GPa]
4	Tensile failure strain	2.2.2	Level and description ε_{ft0} [mm/mm], ε_{ftk0} [mm/mm]
5	Compressive strength	2.2.3	Level and description f_c [MPa]
6	Compressive modulus	2.2.3	Level and description E_c [GPa]
7	Bond strength in concrete by pull-out testing	2.2.4	Level and description τ_b [MPa] and failure mode (pre- and post- alkali exposure) Reduction in bond strength R_{cb} [%]
8	Transverse shear strength	2.2.5	Level and description τ_s [MPa] and failure mode
9	Interlaminar shear strength	2.2.6	Level and description Span to diameter ratio, l_i/d [-] τ_i [MPa] and failure mode
10	Tensile fatigue	2.2.7	Level and description S-N curve Fatigue strength for 2 .10^6 cycles, $f_{fatigue}$ [MPa]
11	Creep failure	2.2.8	Level and description Load ratio/creep failure time curve Creep failure load ratio R_{Yc} *and/or* $R_{Yc,a}$ [-] (test in alkali solution/concrete cylinder) Million-hour creep failure capacity, F_{rc} [N] *and/or* $F_{rc,a}$ [N] (test in alkali solution/concrete cylinder) Million-hour creep failure strength, $f_{ftk,c}$ [MPa] *and/or* $f_{ftk,ca}$ [MPa] (test in alkali solution/concrete cylinder)

No	Essential characteristic	Assessment method	Type of expression of product performance
12	Coefficient of longitudinal thermal expansion	2.2.9	Level $\alpha_{sp,L}$ [°C^{-1}]
13	Coefficient of transverse thermal expansion	2.2.10	Level $\alpha_{sp,T}$ [°C^{-1}]
14	Glass transition temperature or fusion temperature	2.2.11	Level T_g [°C] *or* T_{pm} [°C] Cure ratio [°C]
15	Long-term relaxation	2.2.12	Level and description Relaxation rates Y_{10}, Y_{120}, Y_{1000} [%] Average relaxation curve Million-hour relaxation rate $Y_{million}$ [%]
16	Maximum service temperature	2.2.13	Level T_{max} [°C]
17	Bond strength at maximum service temperature	2.2.14	Level and description τ_{Tmax} [MPa] Retained bond strength, τ_{ret} [%]
18	Strength of FRP bent bars	2.2.15	Level and description Bend capacity, f_{ub} [MPa] (pre- and post-alkali exposure) Strength-reduction factor, χ (pre- and post-alkali exposure)
Basic Works Requirement 2: Safety in case of fire			
19	Reaction to fire	2.2.17	Class
Aspects of durability			
20	Alkali resistance (*)	2.2.16	Level and description Rate of percentage mass loss, $R_{\Delta m}$ [%] Tensile $R_{et,t}$ [%] and interlaminar $R_{et,i}$ [%] capacity retention rate

Note:
(*) The aspect of durability as described in 2.2.16 is specifically linked to Essential Characteristics No 2 and No 9. However, conditioning to alkali is also foreseen in clauses 2.2.4, 2.2.8 and 2.2.15.

2.2 Methods and criteria for assessing the performance of the product in relation to essential characteristics of the product

This chapter is intended to provide instructions for TABs. Therefore, the use of wordings such as “shall be stated in the ETA” or “it has to be given in the ETA” shall be understood only as such instructions for TABs on how results of assessments shall be presented in the ETA. Such wordings do not impose any obligations for the manufacturer and the TAB shall not carry out the assessment of the performance in relation to a given essential characteristic when the manufacturer does not wish to declare this performance in the Declaration of Performance.

The general principles for statistical evaluations according to EN 1990, Annex D, D.6 shall be fulfilled.

Where not explicitly indicated, the bar size is intended here as effective bar diameter for circular bars and effective bar width for flat bars. Different thicknesses of flat bars define a new product typology.

The effective (measured) cross-sectional area A_{eff} [mm^2] as assessed in Section 2.2.1 shall be used for the assessment of all the essential characteristics which directly involve it.

For all the assessment methods, the number of specimens to be tested is summarized in the Annex A. Compared to ISO 10406-1, to which many of the assessment methods refer to, the number of test specimens has been increased and extended to several production lots to discover fluctuation of homogeneity of the product.

2.2.1 Cross-sectional properties

Purpose of the assessment

The assessment is performed to determine the effective cross-sectional properties of the FRP bars.

Assessment method

Cross-sectional properties shall be determined according to the test method specified in ISO 10406-1, Clause 5 for circular bars, and according to EN ISO 527-1, clause 9.2 for flat bars.

Specimens are obtained from the same batch of specimens for tensile testing according to clause 2.2.2.

Expression of results

The average value and coefficient of variation of the effective cross-sectional area A_{eff} [mm^2] and the corresponding effective diameter d_{eff} [mm] (circular bars) or effective width b_{eff} [mm] (flat bars) shall be determined and given in the ETA.

2.2.2 Tensile properties

Purpose of the assessment

Tensile tests are performed to evaluate the tensile strength, the elastic modulus and the tensile failure strain of the FRP bars.

Assessment method

The tensile mechanical properties of specimens shall be determined according to ISO 10406-1, Clause 6.

For flat bars, the provisions of ISO 10406-1 clause 6.1.2 apply, where the bar effective width is meant instead of the effective diameter. The apparatus for tensile testing on flat bars shall comply with the indications given in EN ISO 527-1 clause 5, while its clamping system shall comply with the indications given in § 9.3 of EN ISO 527-1.

Usually failure starts with splitting (fibres delamination) and ends with rupture of the bar due to tensile rupture of the fibres. A broom-like failure is generally experienced.

Specifications for anchorages to testing machine for circular bars

In case of circular bars, particular attention shall be paid to the centring of the bar with respect to the anchorage to testing machine. In the following, some indications are given for the preparation of the anchorages to testing machine. The terms used here are coherent with those recorded in Figure 1 of ISO 10406-1. Other types of anchorage to testing machine may be used provided that (a) failure of the bar occurs outside the anchorages, (b) the anchorages prevent slip of the bar prior to tensile failure (no crack have been observed in flash of resin visible at the edge of tube), and (c) only the axial load is transmitted.

Conical anchorage (cylindrical with a conical transition section as the one shown in Figure 2.2.2.1) may be preferred to prevent premature ruptures in the anchor for bar nominal diameters up to 10 mm. Steel threaded cylindrical tubes may be used for larger diameters. Recommended dimensions of the steel tubes are given in Table 2.2.2.1. Tube lengths shorter than those recommended in Table 2.2.2.1 may be used if no slip is observed and the specimen fails within the gauge length as required.

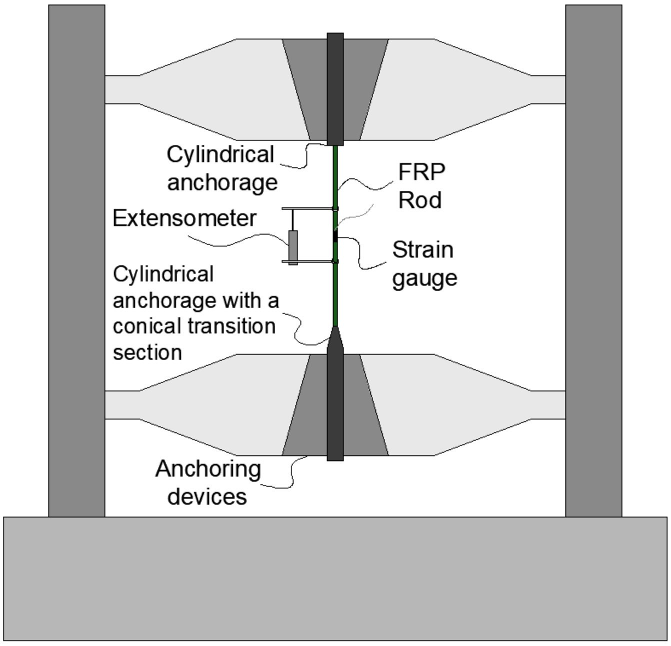

Figure 2.2.2.1: Outline of the tensile test

Table 2.2.2.1. Dimensions of the anchoring steel tube

FRP bar nominal diameter, d [mm]	Minimum outside diameter of the steel tube [mm]	Minimum length of the steel tube, L_g [mm]
5 < d < 10	21 (*)	125
12 < d < 18	27	400
20 < d < 24	35	600
25 < d < 30	50	800
32	72	1000

(*) diameter of the cylindrical portion

The tube may be filled with either polymer resin or a 1:1 mixture by weight of resin and clean sand or an expansive cement grout. A filler material compatible with the resin of which the specimen is made shall be used. The steel tubes and the FRP bar shall be axially aligned before the grout or resin is applied. Whenever possible, the anchorage shall be cast in a vertical position and at least 12 h shall elapse before the first anchorage is flipped to cast the other anchorage.

Expression of results

A description of the type of failure or combination of failure types shall be given in the ETA.

The average value (arithmetic mean) (f_{ft0}) and characteristic value (f_{ftk0}) of the tensile strength f_{ft} [MPa], the average value of the modulus of elasticity E_f [GPa] and the average (ε_{ft0}) and characteristic value (ε_{ftk0}) of the tensile failure strain ε_{ft} [mm/mm] shall be determined and given in the ETA.

The characteristic value will be determined, by using the appropriate value of k_n for unknown V_x reported in EN 1990, Annex D, Table D1.

2.2.3 Compressive properties

Purpose of the assessment

Compressive tests are performed to evaluate the compressive strength and the compressive modulus of the FRP bars.

Assessment method

The compressive properties of specimens shall be determined according to the method reported in EN ISO 604, by replacing the hardened-steel blocks of the test setup with flat and paralleled high strength steel plates. Specimens shall be cut from the bars to the desired length taking care not to overheat the material during the operation (clause 6.2.1 of EN ISO 604 does not apply). The length of the specimens is defined on the basis of the prescriptions given by § 6.1.1 of EN ISO 604, while test speed is fixed in accordance with § 9.5 of EN ISO 604.

The failure mode may be brooming, transverse or through-thickness shear, longitudinal splitting, or delamination, among possibly other forms.

Expression of results

A description of the type of failure or combination of failure types shall be given in the ETA.

The average value (arithmetic mean) and characteristic value of the compressive strength f_c [MPa] and average compressive modulus of elasticity E_c [GPa] shall be determined and given in the ETA.

The characteristic value will be determined by using the appropriate value of k_n for unknown V_x reported in EN 1990, Annex D, Table D1.

2.2.4 Bond strength in concrete by pull-out testing

Purpose of the assessment

The pull-out test is performed to determine the bond strength of FRP bars used as reinforcing bars in concrete.

Assessment method

1. *Centric bond tests*

The bond strength shall be determined according to the method indicated in ISO 10406-1, Clause 7, with the following deviations:

- the bonded length of the FRP bar shall be five times the effective diameter or the effective width of the FRP bar;
- two concrete strength grades shall be considered: "low strength concrete C20/25" and "high strength concrete C50/60" according to EN 206;
- the concrete cube shall have a size of 200 mm for all diameters;
- the external diameter of the spiral reinforcement d_{sh} [mm] shall be in the range 160-200 mm.

- concrete members shall be chosen such that splitting of the concrete is avoided (see Clause 7.1.5 of ISO 10406-1);
- for flat bars, the gripping system shall comply with the provisions indicated in EN ISO 527-1 clause 5.

Centric bond strength tests in low strength concrete C20/25 shall also be performed with bars previously conditioned in the alkali environment of clause 2.2.16 and, specifically, in an alkaline solution with initial pH≥13, temperature for immersion of 60 °C ± 3 °C, for 3,000 h without sustained tensile stress.

The failure mode shall be characterised by sliding of the bar from the concrete specimen (pull-out). If a specimen ruptures in tension, or slips at the anchoring section, or splits the concrete cover, an additional test shall be performed on a separate specimen taken from the same batch as the failed specimen (see also Clause 7.4 of ISO 10406-1).

2. Eccentric bond tests

The eccentric bond strength shall be determined according to the general method indicated in ISO 10406-1, Clause 7, considering the deviations indicated in the previous paragraph and with the following further indications. Eccentric bond tests shall be performed only in low strength concrete C20/25, by considering a concrete cover c_b equal to 1.5 d_{eff} (see Figure 2.2.4.1). In addition, other values of concrete cover may be considered as indicated by the manufacturer. In this type of test, no additional reinforcement shall be used in the concrete cube specimen.

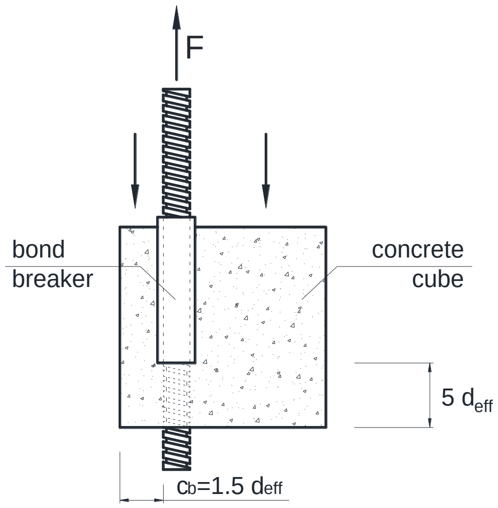

Figure 2.2.4.1: Example for test setup for eccentric bond test

Expression of results

A description of the type of failure or combination of failure types shall be recorded.

Values to be given in the ETA for not tested bar sizes shall be kept equal to the lowest results among the tested ones closest to the non-tested sizes. The extension of results is not possible if experimental results are referred to only one diameter.

1. Centric bond test

The average value (arithmetic mean) and characteristic value of the bond strength τ_b [MPa] shall be determined and given in the ETA together with the compressive strength of the substrate, before and after exposure to alkali. The failure mode shall also be given in the ETA. The characteristic value will be determined by using the appropriate value of k_n for unknown V_x reported in EN 1990, Annex D, Table D1.

2. Eccentric bond test

The reduction in bond strength R_{cb} [%] from centric tests to eccentric tests shall be given in the ETA for the tested values of concrete cover c_b, according to the following:

$$R_{cb} = \left(1 - \frac{\tau_{b,\mathrm{cb}}}{\tau_b}\right) \cdot 100 \qquad (2.2.4.1)$$

Where

$\tau_{b,\mathrm{cb}}$ eccentric bond strength in low strength concrete C20/25 for the tested concrete cover c_b, MPa;

τ_b centric bond strength in low strength concrete C20/25, MPa.

The failure mode shall also be given in the ETA.

2.2.5 Transverse shear strength

Purpose of the assessment

FRP bars are often loaded in transverse shear when these elements are used, for example, as stirrups in concrete beams. This test method specifies the test requirements for determining the transverse shear strength of FRP bars via a double shear fixture.

Assessment method

The transverse shear strength shall be determined according to the method indicated in ISO 10406-1, Clause 13. All the options for shapes of contact surfaces indicated in Figure 8 of ISO 10406-1 are equivalent.

The failure mode is characterised by cleavage of the bar (transversal shear) under test into three pieces.

Expression of results

A description of the type of failure or combination of failure types shall be given in the ETA.

The average value (arithmetic mean) and characteristic value of the transverse shear strength τ_s [MPa] shall be determined and given in the ETA.

The characteristic value will be determined by using the appropriate value of k_n for unknown V_x reported in EN 1990, Annex D, Table D1.

2.2.6 Interlaminar shear strength

Purpose of the assessment

The test method herein reported covers the determination of the apparent horizontal (interlaminar) shear strength of FRP bars. The specimen is a short beam in the form of lengths of FRP bars.

Assessment method

For circular bars, the interlaminar shear strength shall be determined according to the method reported in Annex B.

For flat bars, interlaminar shear strength shall be determined according to EN ISO 14130. The specimen dimensions shall comply with § 6.1.2 of EN ISO 14130, i.e., the specimen length l_s shall be ten times the thickness, with the only exception that the specimen width b_s shall be equal to the nominal width b [mm], instead of five times the thickness.

The failure mode is characterised by shear failure in the mid-plane of the horizontally supported bar (apparent horizontal shear). For flat bars, refer to Clause 9.7 of EN ISO 14130 for the acceptable failure modes.

Expression of results

The span to diameter ratio l_i/d used for the test and the description of the type of failure or combination of failure types shall be given in the ETA.

The average value (arithmetic mean) and characteristic value of the interlaminar shear strength τ_i [MPa] shall be determined and given in the ETA.

The characteristic value will be determined by using the appropriate value of k_n for unknown V_x reported in EN 1990, Annex D, Table D1.

2.2.7 Tensile fatigue

Purpose of the assessment

The test method herein reported covers the determination of the S-N curve and the fatigue strength for FRP bars.

Assessment method

The tensile fatigue of bars shall be determined according to the general method indicated in ISO 10406-1, Clause 10 and the indications given in Section 2.2.2 for flat bars.

Particular attention shall be paid to the centring of the bar with respect to the anchorage to testing machine. See Section 2.2.2 for further details.

Usually failure starts with splitting (fibres delamination) and ends with rupture of the bar due to tensile rupture of the fibres. A broom-like failure is generally experienced.

1. Determination of the S-N curve

For the purpose of determining the S-N curve, fix the load (stress) ratio R=0.1 and set the maximum and minimum load according to method *c)* of Clause 10.4.2 of ISO 10406-1.

At least three load levels shall be set such that the number of cycles to failure is between 10^3 and $2x10^6$.

The following procedure may be followed to choose the first load level:

a) select an appropriate maximum stress in the range of 20 to 60 percent of the quasi-static tensile strength, and commence fatigue testing with this value as the repeated maximum load;

b) If the specimen does not fail after 10^4 cycles at this repeated maximum stress, add 5 percent of the quasi-static tensile strength and perform the test uninterrupted using the same specimen;

c) If failure does not occur after 10^4 cycles following Step b, a further 5 percent should be added to the repeated maximum load;

d) Repeat Step c until the specimen fails;

e) The initial maximum stress applied to an untested specimen can be set at the previously found maximum load minus 5 percent of the quasi-static tensile strength.

The other load levels may differ one another of about 10 percent of the quasi-static tensile strength.

Other procedures can be followed that guarantee compliance with the requirement given above (number of cycles to failure between 10^3 and $2x10^6$).

The S-N curve shall be represented with the maximum repeated stress, stress range or stress amplitude on the vertical axis and the number of cycles on a logarithmic scale in the horizontal axis.

2. Experimental determination of fatigue strength

For the purpose of determining the fatigue strength, at least 6 tests up to a minimum of $2x10^6$ cycles with a stress ratio R=0.1 at the maximum stress level shall be performed. As a first attempt value, a maximum stress level of 0.2 f_{fk0} shall be fixed. If $2x10^6$ cycles are reached without failure, the experimental attempt value may be assumed on the safe side as the fatigue strength for the tested diameter. Otherwise, the test may be repeated with new specimen(s) with the maximum stress level increased by 0.1 f_{fk0} (any other reasonable steps may be used).

If a failure is observed before $2x10^6$ cycles were reached, then the maximum stress of one step lower which reached $2x10^6$ cycles is presented in the ETA as the performance value of the product.

Expression of results

A description of the type of failure or combination of failure types shall be given in the ETA.

The S-N curve shall be given in the ETA.

The fatigue strength $f_{fatigue}$ [MPa], obtained experimentally at $2x10^6$ cycles, shall be given in the ETA.

Values to be given in the ETA for not tested bar sizes shall be kept equal to the lowest results among the tested ones closest to the non-tested sizes. The extension of results is not possible if experimental results are referred to only one diameter.

2.2.8 Creep failure

Purpose of the assessment

This paragraph specifies procedures to determine the influence of sustained load on the performance of FRP bars commonly used as tensile elements in reinforced concrete.

Assessment method

Creep failure of bars shall be determined according to the method indicated in Annex E and the indications given in Section 2.2.2 for flat bars. Annex E provides multiple force levels and a given set of controlled environmental conditions (case 1, 2 and 3) so that a relationship between load and time-to-failure can be derived.

Case 2 and case 3 are alternative methods. Case 3 shall be used as the reference method to determine the creep failure performance values.

For case 1 and 2 (see Annex E), usually failure starts with splitting (fibres delamination) and ends with rupture of the bar due to tensile rupture of the fibres (broom-like failure). For case 2 and 3 and longer times to failure, the broom-like failure is less developed.

Expression of results

The type of failure or combination of failure types shall be recorded and given in the ETA.

Case 1

The creep failure load ratio R_{Yc} shall be given in the ETA, together with the million-hour creep failure capacity, F_{rc} [N] and the characteristic value of the million-hour creep failure strength, $f_{ftk,c}$ [MPa].

Values to be given in the ETA for not tested bar sizes shall be kept equal to the lowest results among the tested ones closest to the non-tested sizes. The extension of results is not possible if experimental results are referred to only one diameter.

Case 2 or 3

The creep failure load ratio $R_{Yc,a}$ shall be given in the ETA, together with the million-hour creep failure capacity, $F_{rc,a}$ [N] and the characteristic value of the million-hour creep failure strength, $f_{ftk,ca}$ [MPa]. The values shall be accompanied by the reference to the test method used.

Values to be given in the ETA for not tested bar sizes shall be kept equal to the lowest results among the tested ones closest to the non-tested sizes. The extension of results is not possible if experimental results are referred to only one diameter.

2.2.9 Coefficient of longitudinal thermal expansion

Purpose of the assessment

This test method covers the procedure for evaluating the coefficient of longitudinal thermal expansion of FRP bars.

Assessment method

The coefficient of longitudinal thermal expansion of bars shall be determined according to the method indicated in ISO 10406-1, Clause 15. For the calibration of the temperature gauge, reference shall be made to ISO 11359-1 clause 7.1.1.

Expression of results

The average coefficient of longitudinal thermal expansion, $\alpha_{sp,L}$ [°C^{-1}], shall be given in the ETA.

Values to be given in the ETA for not tested bar sizes shall be kept equal to the lowest results among the tested ones closest to the non-tested sizes. The extension of results is not possible if experimental results are referred to only one diameter.

2.2.10 Coefficient of transverse thermal expansion

Purpose of the assessment

This test method covers the procedure for evaluating the coefficient of transverse thermal expansion of FRP bars.

Assessment method

The coefficient of transverse thermal expansion of bars shall be determined according to the method indicated in ISO 10406-1, Clause 15, in the orthogonal direction with respect to the fibre axis. In this case, the strain gauge will be placed on the bar's surface, in the transverse direction.

For the calibration of the temperature gauge, reference shall be made to ISO 11359-1 clause 7.1.1.

Expression of results

The average coefficient of transverse thermal expansion, $\alpha_{sp,T}$ [°C^{-1}], shall be given in the ETA.

Values to be given in the ETA for not tested bar sizes shall be kept equal to the lowest results among the tested ones closest to the non-tested sizes. The extension of results is not possible if experimental results are referred to only one diameter.

2.2.11 Glass transition temperature or fusion temperature

Purpose of the assessment

The test methods here reported cover the procedures for evaluating the glass transition temperature of *thermosetting* and *thermoplastic* FRP bars. In addition, the procedure for the determination of the fusion temperature for *thermoplastic and semi-crystalline* FRP bars and the cure ratio for thermosetting products is also provided.

Assessment method

For *thermosetting* products, glass transition temperature of FRP bars shall be determined according to EN ISO 11357-2.

The test shall be performed on specimens - in the form of flakes or fragments - taken from the bars by mechanical cutting or removal, taking care not to overheat the material during the operation. The mass of the specimens shall be as close to 20 mg as possible and shall be taken from the core of the composite material.

Tests shall be carried out both in standard conditions and after a prescribed conditioning according to the procedure described below.

DSC in standard conditions

The procedure shall be repeated on at least three different specimens:

1. each specimen is subjected to a first conditioning cycle - lasting 48 h - in standard atmospheric conditions (23 °C ± 2 °C and 50 ± 5% RH);
2. the specimen is then subjected to a first heating cycle (I) using a heating rate of 10 °C/min. In this way a first value of the glass transition temperature $T_{g,I}^{s}$ of cycle I is determined, by applying the "equal-areas method" in accordance with EN ISO 11357-2, clause 10.1.2;
3. the same specimen is then cooled down at the same conditions of the heating cycle (temperature and rate);
4. a second heating cycle (II) is carried out on the same specimen, again using a heating rate of 10 °C/min and applying the equal-areas method in accordance with EN ISO 11357-2, thus determining a second value of the glass transition temperature $T_{g,II}^{s}$ of cycle II.

DSC after conditioning

A second group of three specimens shall be heated at a temperature of about 30 - 40 °C higher than the glass transition temperature obtained in the first cycle (min $T_{g,I}^{s}$) of the standard conditions, and holding the temperature for at least 30 min. The procedure described in the standard conditions from 2. to 4. is then performed again, to assess the $T_{g,I}^{c}$ of cycle I and $T_{g,II}^{c}$of cycle II after the new conditioning.

The difference between min $T_{g,I}^{s}$ at standard conditions and min $T_{g,I}^{c}$ after conditioning gives the cure ratio.

For *thermoplastic* products, glass transition temperature may be determined following the same procedure as for thermosetting products (point 1-4). In addition, the fusion temperature shall be determined according to EN ISO 11357-3 on 3 specimens, only if the thermoplastic product is semi-crystalline.

Expression of results

For *thermosetting products*, the minimum values of the glass transition temperature obtained in the two heating cycles at standard conditions ($T_{g,I}^{s}$ and $T_{g,II}^{s}$ [°C]) and after conditioning ($T_{g,I}^{c}$ and $T_{g,II}^{c}$ [°C]), and the cure ratio (difference between min $T_{g,I}^{s}$ at standard conditions and min $T_{g,I}^{c}$ after conditioning) [°C] shall be given in the ETA.

For *thermoplastic products*, the minimum values of glass transition temperature obtained in the two heating cycles at standard conditions $T_{g,I}^{s}$ and $T_{g,II}^{s}$ [°C] and the fusion temperature T_{pm} [°C] (for semi-crystalline products) shall be given in the ETA.

2.2.12 Long-term relaxation

Purpose of the assessment

The test method here reported covers the procedure for evaluating the long-term relaxation of FRP bars.

Assessment method

Long-term relaxation of test pieces shall be determined according to the method indicated in ISO 10406-1, Clause 9 and the indications given in Section 2.2.2 for flat bars. A strain gauge is to be fitted to the test piece. The test temperature shall be within the range of 20 °C ± 2 °C. Other temperatures may be tested according to ISO 10406-1 clause 9.3; in this case, the results reported in the ETA shall be accompanied by the test temperature.

The guaranteed tensile capacity referred to as in clause 9.4.3 of ISO 10406-1 shall be intended the characteristic value of the tensile strength as per 2.2.2.

Expression of results

The average relaxation rates Y_{10}, Y_{120}, Y_{1000} [%] at 10 h, 120 h and 1,000 h respectively shall be determined and the average relaxation curve shall be given in the ETA, together with the test temperature.

The relaxation rate after 1 million hours (approximately 114 years) shall be evaluated from the approximation line; this value represents the million-hour relaxation rate $Y_{million}$ [%] and it is also referred to as *hundred-year relaxation rate*. Values to be determined are shown in Figure 2.2.12.1.

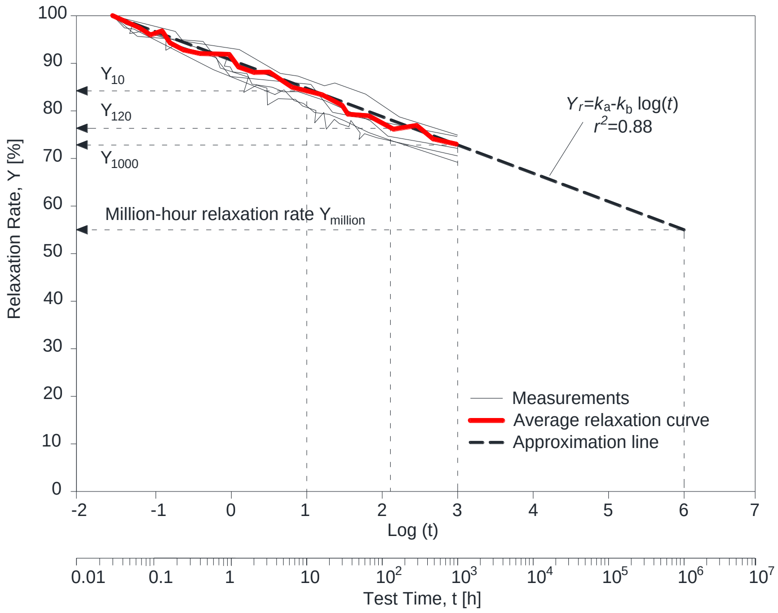

Figure 2.2.12.1: Example of relaxation curve in semi-logarithmic scale for a single diameter

Values to be given in the ETA for not tested bar sizes shall be kept equal to the lowest results among the tested ones closest to the non-tested sizes. The extension of results is not possible if experimental results are referred to only one diameter.

2.2.13 Maximum service temperature

Purpose of the assessment

This method establishes the procedure for determining the temperature at the beginning of softening of the FRP bar based on thermomechanical tests. Alternatively, it cautiously proposes a value to be set as a function of the glass transition temperature.

Assessment method

The maximum service temperature T_{max} [°C] shall be determined in accordance with the method indicated in Annex C.

The temperature T_{max} can also be determined as $T_{max}=T_{g,I}^{s}$ - 30 °C, where $T_{g,I}^{s}$ is the glass transition temperature in the first heating cycle at standard conditions (see section 2.2.11).

The experimental method indicated in Annex C shall be used as reference method to determine the maximum service temperature.

Expression of results

The lowest value of the maximum service temperature T_{max} [°C] obtained from the tests shall be given in the ETA, together with the used assessment method.

Values to be given in the ETA for not tested bar sizes shall be kept equal to the lowest results among the tested ones closest to the non-tested sizes. The extension of results is not possible if experimental results are referred to only one diameter.

2.2.14 Bond strength at maximum service temperature

Purpose of the assessment

The pull-out test under maximum service temperature is performed to determine the influence of temperature on the bond strength of FRP bars used as reinforcing bars in concrete.

Assessment method

The bond strength at maximum service temperature shall be determined on specimens prepared according to Section 2.2.4.

If the maximum service temperature according to 2.2.13 is available, the test shall be performed at such temperature, otherwise a value among 80 °C, 100 ° C, 120 °C or 140 °C shall be used.

> Note: It is suggested to use the temperature value, among the provided ones, closer to T_g - 30 °C, where T_g is the glass transition temperature of the resin constituting the FRP element (see, as technical reference, fib Bulletin 40, FRP reinforcement in RC structures. Lausanne Fédération internationale du betòn; 2007).

Test shall be performed in uncracked concrete C20/25. Splitting of the concrete shall be prevented. Spalling of concrete shall not occur during the heating.

The tests shall be performed by heating the specimens up to the selected target temperature and then performing the pull-out test at a constant slip rate according to Section 2.2.4. A special heating jacket can be used to heat the specimen, with heating rate of 5 °C/min.

Expression of results

The average value (arithmetic mean) of the bond strength τ_{Tmax} [MPa] shall be determined and given in the ETA together with the compressive strength of the substrate and the value of the temperature used in the test (selected target temperature). The characteristic value will be determined by using the appropriate value of k_n for unknown V_x reported in EN 1990, Annex D, Table D1.

The percentage of retained bond strength (τ_{ret} [%]) with respect to ambient specimens (Section 2.2.4) shall also be given in the ETA.

Values to be given in the ETA for not tested bar sizes shall be kept equal to the lowest results among the tested ones closest to the non-tested sizes. The extension of results is not possible if experimental results are referred to only one diameter.

2.2.15 Strength of FRP bent bars

Purpose of the assessment

This test method determines the quasi-static failure strength of FRP bent bars commonly used as anchorages for stirrups in reinforced concrete structures.

Assessment method

The strength capacity of the bent portion of a bar f_{ub} [MPa] shall be determined in accordance with the method indicated in Annex D, where the bar size is either the effective diameter or the effective width.

The strength capacity of the bent portion after exposure of the bent bar to the alkali environment of clause 2.2.16 and, specifically, in an alkaline solution with initial pH≥13, temperature for immersion of 60 °C ± 3 °C, for 3,000 h without sustained tensile stress, shall also be determined.

Expression of results

A description of the type of failure or combination of failure types shall be given in the ETA (see Annex D for acceptable failure modes).

The average value (arithmetic mean) and characteristic value of the bend capacity f_{ub} [MPa] and the strength reduction factor χ (percentage of the tensile strength of the straight portion of the bar that is retained in the bend location) before and after alkali exposure, shall be given in the ETA, together with the compressive strength of the substrate and the value of the bend radius r_t [mm] of the bent bar tested.

The characteristic values will be determined by using the appropriate value of k_n for unknown V_x reported in EN 1990, Annex D, Table D1.

Values to be given in the ETA for not tested bar sizes shall be kept equal to the lowest results among the tested ones closest to the non-tested sizes. The extension of results is not possible if experimental results are referred to only one diameter.

2.2.16 Alkali resistance

Purpose of the assessment

This test method covers the procedure for evaluating the alkali resistance of FRP bars used as reinforcing bars in concrete. Alkali resistance is measured by subjecting the FRP bars to an aqueous alkali environment and then testing them to failure in tension or interlaminar shear.

Assessment method

Alkali resistance of FRP bars shall be conducted on both tension and interlaminar shear specimens (*as per* Section 2.2.2 and 2.2.6, respectively) and will be determined according to the method indicated in ISO 10406-1, Clause 11 for 1,000 h and 3,000 h. For tensile specimens at 1,000 h, a sustained tensile stress, set to induce an initial tensile strain equal to 3000 microstrains ($1\mu\varepsilon = 10^{-6}\ \varepsilon$), shall be applied to the test piece. In this case, the test section of the specimen shall be immersed in the alkaline solution inside an environmental cabinet or container holding the alkaline solutions and having a constant temperature of 60 °C ± 3 °C. The specimen shall be held in a loading fixture, subjecting the bar to the said constant sustained load. After the 1,000 h, the specimens shall be unloaded and removed from the alkaline solution.

Conditioned specimens are then tested in direct tension according to ISO 10406-1, Clause 11.4 and for interlaminar shear strength according to the procedure described in 2.2.6.

Expression of results

Conditioned specimens are visually examined prior to testing using 5× magnification to describe surface changes, such as erosion, cracking, crazing, checking, and chalking.

The rate of percentage mass loss $R_{\Delta m}$ [%] and the tensile $R_{et,t}$ [%] and interlaminar $R_{et,i}$ [%] capacity retention rate shall be determined and given in the ETA for both tensile and interlaminar shear specimens, together with the exposure conditions.

> Note: The tensile retention capacity $R_{et,t}$ [%] at 3,000 h corresponds to the influence factor for environmental attack C_e according to EN 1992-1-1, clause R.5.3.

Values to be given in the ETA for not tested bar sizes shall be kept equal to the lowest results among the tested ones closest to the non-tested sizes. The extension of results is not possible if experimental results are referred to only one diameter.

2.2.17 Reaction to fire

The FRP bars shall be tested, using the test method(s) relevant for the corresponding reaction to fire class according to EN 13501-1. The FRP bars shall be classified according to the Commission Delegated Regulation (EU) No 2016/364 in connection with EN 13501-1.

The performance class obtained from the tests shall be given in the ETA.

Preparation of specimens

In addition to EN 13501-1, the following product parameters of the bars shall be considered when preparing the test specimens:

- product-type (type of fibres, type of resin, fibre/matrix ratio);
- surface structure;
- at least the product with the highest and lowest diameter.

Indications for mounting and fixing

- *EN ISO 11925-2 (Single-flame source test)*

For the relevant classes, single-flame source test shall be performed by considering the following indications for the preparation of the test specimen. The bars shall be cut to the required length (250 ±2 mm) and positioned on the specimen holder vertically close to each other by fixing them, where needed, through a non-coated steel wire to maintain them in position during the installation phase.

- *EN 13823 (SBI test)*

For the relevant classes, SBI test shall be performed by considering the following indications for the preparation of the test specimen. The bars shall be positioned vertically close to each other by tying them, where needed, through a non-coated steel wire to maintain them in vertical position during the installation phase. In accordance with EN 13823, the distance between the calcium silicate backing board and the bars shall be 80 mm. The use of a burner guard is recommended.

Extended application of test results

The results of tests considering the aforementioned parameters in fully are also valid for products:

- of the same defined product-type family;
- with the same surface structure;
- with all diameters between those evaluated, considering the worst obtained class between the adjacent diameters.

3 ASSESSMENT AND VERIFICATION OF CONSTANCY OF PERFORMANCE

3.1 System(s) of assessment and verification of constancy of performance to be applied

For the products covered by this EAD the applicable European legal act is: **Commission Decision 97/597/EC**.

Note: Although the referenced Decision refers to "Reinforcing and prestressing steel for concrete", the function of the "Carbon, glass, basalt and aramid FRP bars" in the construction work is exactly the one pursued by Decision 1997/597/EC, even if the constituting material is different. Moreover, the complex production of the "Carbon, glass, basalt and aramid FRP bars" implies an AVCP system comprising continuing surveillance, assessment and evaluation of the manufacturer's factory production control and audit testing of samples taken by the notified product certification body at the manufacturing plant or at the manufacturer's storage facilities and this is in line with the referenced Decision.

The system is: **1+**.

3.2 Tasks of the manufacturer

The cornerstones of the actions to be undertaken by the manufacturer of the product in the procedure of assessment and verification of constancy of performance are laid down in Table 3.2.1.

Table 3.2.1 Control plan for the manufacturer; cornerstones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Factory production control (FPC) [including testing of samples taken at the factory in accordance with a prescribed test plan]					
1	Incoming material	Supplier's data check	Control Plan	-	100% batch(1)
2	Effective cross-sectional area	2.2.1	Control Plan	3	100% batch(1)
3	Tensile strength	2.2.2	Control Plan	3	100% batch(1)
4	Mean tensile modulus of elasticity	2.2.2	Control Plan	3	100% batch(1)
5	Density	Control Plan	Control Plan	3	100% batch(1)
6	Glass transition temperature	2.2.11	Control Plan	3 samples of one random diameter	Every six months
7	Cure ratio	2.2.11	Control Plan	3 samples of one random diameter	Every six months
8	Fibre/matrix ratio	Control Plan	Control Plan	3	Every six months
9	Water absorption	Control Plan	Control Plan	3	100% batch(1)
10	Capillary voids (or void content)	Control Plan	Control Plan	3	100% batch(1)
11	Interlaminar shear strength	Control Plan	Control Plan	3 samples of one random diameter	Every year
12	Alkali resistance	Control plan	Control plan	3 samples of one random diameter	Every year
13	Bond strength (centric tests on low strength concrete)	2.2.4	Control Plan	3 samples of s/m/l diameter(2)	Every year
14	Strength of FRP bent bars	2.2.15	Control Plan	3 samples of one random diameter	Every year

(1) Any batch of bar produced from start to finish with the same constituent materials used in the same proportions without changing any production parameter, such as cure temperature or line speed for a maximum of 60.000 linear meters of the same diameter, also in multiple shifts of production, and at least once a year for each diameter.
(2) Among those produced in the year.

3.3 Tasks of the notified body

The cornerstones of the actions to be undertaken by the notified body in the procedure of assessment and verification of constancy of performance for the FRP bars are laid down in Table 3.3.1.

Table 3.3.1 Control plan for the notified body; cornerstones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Initial inspection of the manufacturing plant and of factory production control					
1	The Notified Body will ascertain that the factory production control with the staff and equipment are suitable to ensure a continuous and orderly manufacturing of the FRP bars.	Verification of the complete FPC as described in the control plan agreed between the TAB and the manufacturer	As defined in the control plan	As defined in the control plan	When starting the production or a new line
Continuous surveillance, assessment and evaluation of factory production control					
2	The Notified Body will ascertain that the system of factory production control and the specified manufacturing process are maintained taking account of the control plan.	Verification of the controls carried out by the manufacturer as described in the control plan agreed between the TAB and the manufacturer with reference to the raw materials, to the process and to the product as indicated in Table 3.2.1	As defined in the control plan	As defined in the control plan	1/year
Audit-testing of samples taken by the notified product certification body at the manufacturing plant or at the manufacturer's storage facilities					
1	Effective cross-sectional properties	2.2.1	As defined in the control plan	3 samples of one bar diameter and manufacturing process	Each Inspection or 2/year
2	Tensile properties	2.2.2	As defined in the control plan	3 samples of one bar diameter and manufacturing process	Each Inspection or 2/year
3	Glass transition temperature	2.2.11	As defined in the control plan	3 samples of one bar diameter(1) and manufacturing process	Each Inspection or 2/year
4	Cure ratio	2.2.11	As defined in the control plan	3 samples of one bar diameter(1) and manufacturing process	Each Inspection or 2/year
5	Tensile strength after alkali conditioning	2.2.16	As defined in the control plan	3 samples of one bar diameter and manufacturing process	Each Inspection or 2/year

4 REFERENCE DOCUMENTS

EN 206:2013+A2:2021	Concrete - specification, performance, production and conformity.
EN 705:1994 /AC:1995	Plastics piping systems - Glass-reinforced thermosetting plastics (GRP) pipes and fittings - Methods for regression analysis and their use
EN 1990:2023	Eurocode 0 - Basis of structural design and geotechnical design
EN 1992-1-1:2023	Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings, bridges and civil engineering structures
EN 13501-1:2018	Fire classification of construction products and building elements - Part 1: Classification using data from reaction to fire tests
EN 13823:2020 +A1:2022	Reaction to fire tests for building products - Building products excluding floorings exposed to the thermal attack by a single burning item
EN ISO 527-1:2019	Plastics - Determination of tensile properties - Part 1: General principles (ISO 527-1:2019)
EN ISO 604:2003	Plastics - Determination of compressive properties (ISO 604:2002)
EN ISO 7500-1:2018	Metallic materials - Calibration and verification of static uniaxial testing machines - Part 1: Tension/compression testing machines - Calibration and verification of the force-measuring system
EN ISO 11357-2:2020	Plastics - Differential scanning calorimetry (DSC) - Part 2: Determination of glass transition temperature and step height (ISO 11357-2:2020)
EN ISO 11357-3:2018	Plastics – Differential scanning calorimetry (DSC) – Part 3: Determination of temperature and enthalpy of melting and crystallization (ISO 11357-3:2018)
EN ISO 11925-2:2020	Reaction to fire tests - Ignitability of products subjected to direct impingement of flame - Part 2: Single-flame source test (ISO 11925-2:2020)
EN ISO 14130:1997	Fibre-reinforced plastic composites - Determination of apparent interlaminar shear strength by short-beam method (ISO 14130:1997)
EN ISO/IEC 17025:2017	General requirements for the competence of testing and calibration laboratories
ISO 10406-1:2015	Fiber-reinforced polymer (FRP) reinforcement of concrete – Test method. Part 1: FRP bars and grids
ISO 11359-1:2023	Plastics - Thermomechanical analysis (TMA) - Part 1: General principles

ANNEX A SUMMARY OF TEST SPECIMENS

	Essential characteristic		Clause in EAD	Minimum number of specimens	
MECHANICAL	Tensile strength		2.2.2	For each bar size: total 25 (5 from 5 separate lots)	
	Tensile modulus of elasticity				
	Tensile failure strain				
	Compressive strength		2.2.3	For each bar size: total 15 (3 from 5 separate lots)	
	Compressive modulus				
	Bond strength in concrete by pull-out testing	Centric test	2.2.4	Concrete strength C20/25	Total 15 (5 from smallest, median and largest bar size each)
			2.2.4	Concrete strength C50/60	Total 5 (max bar size)
		Eccentric test	2.2.4	Concrete strength C20/25	Total 15 (5 from smallest, median and largest bar size each)
	Bond strength at maximum service temperature		2.2.14	Total 15 (5 from smallest, median and largest bar size each)	
	Transverse shear strength		2.2.5	For each bar size: total 25 (5 from 5 separate lots)	
	Interlaminar shear strength		2.2.6	For each bar size: total 25 (5 from 5 separate lots)	
	Tensile Fatigue		2.2.7	S-N curve	At least 6 for each of the three test levels (18 from smallest, median and largest bar size each).
				Fatigue strength	At least 6 at the maximum stress level (6 from smallest, median and largest bar size each).
	Creep failure		2.2.8	For each case, at least 3 for each of the 5 test levels (for smallest, median and largest bar size each).	
	Long-term relaxation		2.2.12	Total 15 (5 from smallest, median and largest bar size each)	
	Strength of FRP bent bars		2.2.15	Total 15 (5 from smallest, median and largest bar size each)	
PHYSICAL	Effective cross-sectional properties		2.2.1	For each bar size: total 15 (5 from 3 separate lots)	
	Coefficient of longitudinal thermal expansion		2.2.9	Total 9 (3 from smallest, median and largest bar size each)	
	Coefficient of transverse thermal expansion		2.2.10	Total 9 (3 from smallest, median and largest bar size each)	
	Glass transition temperature *or* Fusion temperature		2.2.11	Total 6 specimens (3 specimens for T_{g1} *or* T_{pm} and 3 specimens for cure ratio)	
	Maximum service temperature		2.2.13	Total 15 (5 from smallest, median and largest bar size each)	
AGEING	Alkali resistance		2.2.16	Total 15 (5 from smallest, median and largest bar size each)	
	Bond strength in concrete by pull-out testing (after alkali exposure of bars)		2.2.16 and 2.2.4	Concrete strength C20/25	Total 15 (5 from smallest, median and largest bar size each)
	Strength of FRP bent bars (after alkali exposure of bars)		2.2.16 and 2.2.15	Total 15 (5 from smallest, median and largest bar size each)	
FIRE	Reaction to fire		2.2.17	According to relevant standards in alignment with Commission Delegated Regulation (EU) 2016/364.	

ANNEX B METHOD FOR DETERMINING THE INTERLAMINAR SHEAR STRENGTH FOR CIRCULAR BARS

B1. General requirements

The test method covers the determination of the apparent horizontal (interlaminar) shear strength of FRP bars by the short-beam method.

B2. Summary of test method

The test specimen is centre-loaded as shown in Figure B2.1. The ends of the specimen rest on two supports that allow the specimen to bend, the load being applied by means of a loading nose at midpoint along the support span, as shown in Figure B2.1. The specimen is deflected until a shear failure occurs at the mid-plane of the horizontally supported circular bar.

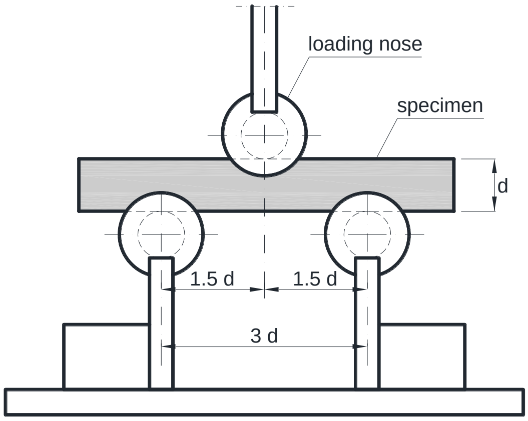

Figure B2.1: Test setup and span configuration for 3d span (span may also be 4d, 5d or 6d, as required to achieve shear mode of failure).

B3. Test specimens

The specimen shall be cut from the bars to a length of one diameter greater than the test span and to a tolerance of plus or minus 0.1 times the diameter. Suggested span-to-diameter ratios are from 3 to 1 up to 6 to 1. The obtainment of shear fractures during the test is a major consideration in determining span length.

B4. Test equipment

Testing machine - A properly calibrated testing machine that can be operated at a constant rate of crosshead motion, and in which the accuracy (see clause 1.3.1) in the load measuring system shall not exceed ±1 % of the maximum load expected to be measured.

Loading Nose and Supports - The loading nose shall be a suitable steel rod with a groove in the diameter of the pultruded bar machined in its lower end (Figure B4.1). The bottom support shall be adjustable to allow for testing at various span/diameter ratios. The surface of the groove shall be free of indentation and burrs, with all sharp edges relieved.

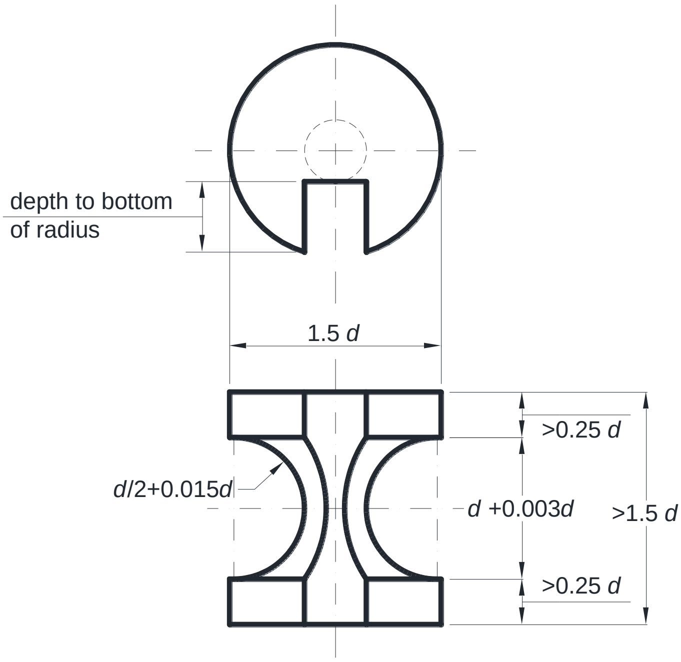

Figure B4.1: Loading nose dimension.

B5. Conditioning

Conditioning - Condition the test specimens at 23 °C ± 2 °C and 50 ± 5 % relative humidity for not less than 40 h prior to test.

Test conditions - Conduct tests in the standard laboratory atmosphere of 23 °C ± 2 °C and 50 ± 5 % relative humidity.

B6. Testing of specimens

1. Before conditioning or testing, measure the diameter of each specimen to the nearest 0.025 mm at midpoint.
2. Place the test specimen in the test fixture, as shown in Figure B2.1. Align the specimen so that its midpoint is centred and its long axis is perpendicular to the loading nose. Adjust the side supports to the span previously determined.
3. Apply the load to the specimen at the rate of crosshead motion of 1.3 mm/min.
4. Record the load to break for each specimen (maximum load on load-indicating mechanism). At times, when testing FRP bars in various environments, specimens do not consistently fail in shear, especially when the incorrect span-to-depth ratio is chosen. It is, therefore, very important to record the type of break (shear or tensile) that occurs.
5. Should a specimen fail in a manner other than horizontal shear, the value shall be discarded and a retest shall be made.

B7. Processing of test results

Calculate the apparent horizontal (interlaminar) shear strength as follows:

$$\tau_i = 0.849 \frac{F}{d_{\mathrm{eff}}^2} \qquad \text{(B7.1)}$$

where:

τ_i apparent horizontal (interlaminar) shear strength [N/mm²]

F breaking load [N]

d_{eff} effective diameter of specimen [mm].

B8. Test report

The report shall include at least the following information:

- Complete identification of the material tested, including type, source, form, principle dimensions
- Fabrication procedure
- Diameter of specimen
- Conditioning procedure used
- Atmospheric conditions in the test room
- Number of specimens tested
- Rate of crosshead motion
- Span length
- Length of specimens
- Type of failure
- Apparent horizontal shear strength of each specimen, average value, and standard deviation
- Location of failure, or method of determining failure from curve
- Average fibre content, percent by weight
- Date of test.

ANNEX C METHOD FOR DETERMINING THE MAXIMUM SERVICE TEMPERATURE

C1. General requirements

This method establishes the procedure for determining the temperature at the beginning of softening of the FRP bar based on thermomechanical tests.

C2. Summary of test method

The method is based on the thermomechanical analysis graph obtained from a three-point lateral bending test to a target value of flexure while heating the curved specimen in the heating chamber, recording the load changes with the increase of temperature. As the temperature increases, the bending resistance of the specimen decreases. This happens because the shear stress, existing for a short time in the bent specimen, reduces the resistance of the polymer matrix composite.

The rate of decrease of the specimen bending resistance has a maximum value in the moment in which the heated polymer matrix in the specimen begins to change from a glassy to a flexible state, i.e., it softens.

The subsequent differential thermal analysis of the diagram obtained during the test, which describes the dependence of the bending resistance of the specimen on temperature, determines the temperature at which the matrix softening process began.

C3. Test specimens

Test specimens are randomly selected from a controlled batch of FRP bars.

During the selection and preparation of specimens for testing, deformation and heating, exposure to ultraviolet light and other environmental influences that may lead to changes in material properties shall be avoided.

The length of test specimens shall be 12 times the bar size (effective diameter or effective width). The length of the working area (distance between the supports) of these specimens shall be within 9 times the bar size ± 2 mm.

Conditioning — the temperature shall be within the range 23 °C ± 2 °C (standard laboratory conditions).

C4. Test equipment and materials

The test equipment shall:

- provide stress greater than the strength of test specimen during the test.
- be classifiable in class 0.5 with reference to EN ISO 7500-1.
- provide measurement of the distance between crossheads with an accuracy (see clause 1.3.1) of no more than 0.5%.
- provide displacement speed of the crosshead in the range of 5 to 100 mm/min.

Example of test arrangements is shown in Figure C4.1.

The device consists of:

- heating chamber (2) mounted on the frame, which allows heating the specimen (3) to a temperature of 200° C.
- loading mechanism (5).
- supports (6) and a loading tip which shall be constituted by rollers with a diameter of minimum 1.5 the bar size (see Figure B4.1 for reference).
- force sensors with an accuracy (see clause 1.3.1) of no more than 0.5 % (4).
- temperature sensor with an accuracy (see clause 1.3.1) of no more than 1 % (1).

The device shall be equipped with a heating rate controller which provides the temperature rise in the heating chamber within (1.0 ± 0.2) °C/min and a software system for recording and processing the test results.

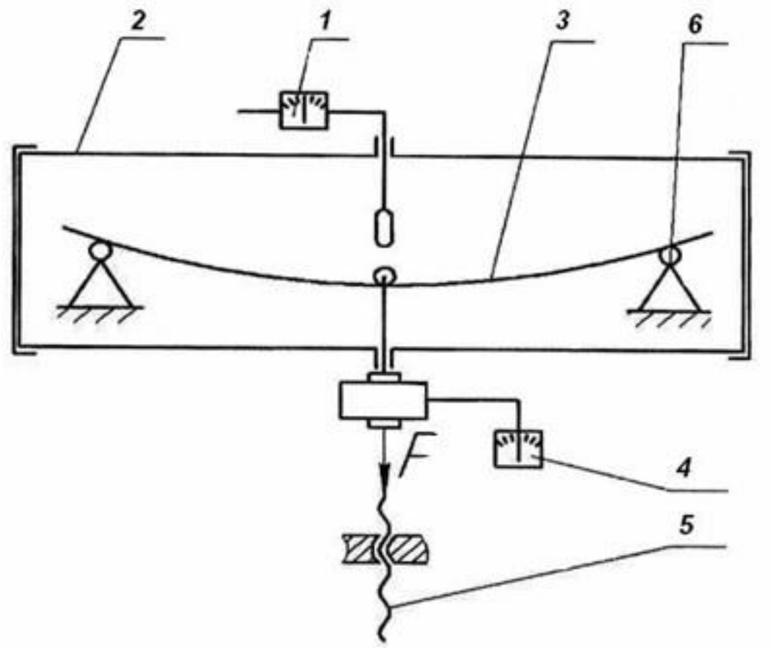

Figure C4.1: Testing scheme for the determination of the softening temperature of the test specimen (1 – temperature sensor; 2 – heating chamber; 3 – test specimen; 4 – force sensor; 5 – loading mechanism; 6 – support)

Procedure for the determination of the softening temperature of the specimen (see Figure C4.1):

1. Pre-cooled specimen (3) on supports (6) is placed in the heating chamber (2) set on room temperature;
2. The specimen is bent through the tip of the loading mechanism (5) to a predetermined deflection value associated with a target load (see clause C5);
3. The temperature in the heating chamber is recorded with sensor (1). The corresponding value of the bending strength of the specimen is recorded with sensor (4) during the test period;
4. Turn on the heating chamber to the operating mode, with a heating rate of (1.0 ± 0.2) °C/min, and gradually heat to a predetermined temperature higher than the temperature at the second α-transition point;
5. While heating the chamber, the temperature in chamber and the corresponding values of the specimen bending strength are also recorded with a frequency between 1 and 3 Hz.

C5. Testing of specimens

The applied load on the specimen shall be 10 % of the failure load for a given test base (distance between supports).

Expected value of the failure load *F* [N] is calculated through the following formula:

$$F \approx \frac{4 f_b w}{l_p} \qquad \text{(C5.1)}$$

where l_p is the length of the working part of the specimen [mm] (distance between the supports) and f_b is the flexural tensile strength [MPa].

For specimens with circular cross-section, the value of the moment of resistance *w* [mm^3] is given by:

$$w = \frac{\pi d^3}{32} \qquad \text{(C5.2)}$$

The testing device is set to a value of the test base, corresponding to the value l_p.

Force and temperature sensors are set.

The specimen is placed in the device so that the tip of the loading device applies pressure in the middle of the specimen working part, located between the supports.

Using the loading mechanism, the specimen is bent until the applied load becomes equal to the load needed according to Equation C5.1. The load is monitored by the indications of the force measuring sensor.

Maintain the specimen at a predetermined position for at least 5 minutes. Then switch the heating chamber into operating mode and monitor changes in temperature.

When the temperature in the chamber rises by 1 °C, a thermomechanical diagram – an array of temperature and force values (T_i, F_i) – is recorded. The array records temperature increments of no more than 2 °C.

After the test, the specimen is taken out of the chamber and the chamber is cooled to room temperature.

C6. Processing of test results

While processing the test results, the thermomechanical diagram of each specimen shall be analysed. Using a properly validated (following the principles of EN ISO/IEC 17025) experimental data processing software, construct a graph of the thermomechanical diagram *F(*T*)* using the array *(*T_i*,* F_i*),* where F_i are the values of the measured mechanical parameter (load), T_i are the corresponding values of the equilibrium temperature (Figure C6.1).

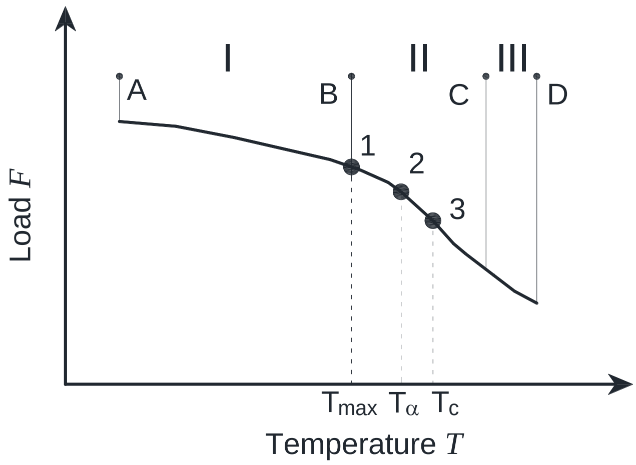

Figure C6.1: Example of thermomechanical curve

On the thermomechanical curve shown in Figure C6.1, it is possible to distinguish three zones:

- zone (I), located between points A and B;
- zone (II), located between points B and C, and
- zone (III), located between points C and D.

Within the zone I, the thermomechanical function (i.e., the resistance to bending F) decreases slightly. This is due to the fact that with increasing temperature there is a slight decrease in the rigidity of the polymer matrix, which is in the glassy state, in the absence of segmental mobility of macromolecules of the reticulated epoxy binder.

In the zone II, as the temperature rises, a gradual “softening” of the specimen occurs due to the “thawing” of the mobility of the segments of macromolecules, which causes the transition of the polymer matrix from the glassy state to the highly elastic state.

In the zone III, a significant decrease in the resistance of the specimen to transverse bending is caused by a stronger dependence of the stiffness of the polymer matrix, which is in a highly elastic state, on temperature.

In the upper section of the thermomechanical curve, select three points: 1, 2 and 3**.**

Point 1 is at the end of the initial linear portion of the thermomechanical curve, and shows the beginning of deviation from linearity caused by transient processes in the matrix. The abscissa (T_{max}) of this point determines the temperature of the beginning of the process of the transition of the polymer from the glassy state to the highly elastic state.

Point 2 shows the boundary of the α-transition and determines the corresponding temperature (T_{α}).

At point 3, the transition process proceeds most intensively (T_c).

Approximate position of the boundaries of the initial section (linear change in load with the temperature) and the working section (softening phase) are visually estimated on the graph. If necessary, such boundaries of the initial and working sections of the diagram can be refined at a second stage of data processing.

An appropriate mathematical model (for example sigmoid or polynomial) shall be used to determine such characteristic points in order to find the values of the first and second derivatives (Figure C6.2) of this reduced function $F_1(T)$.

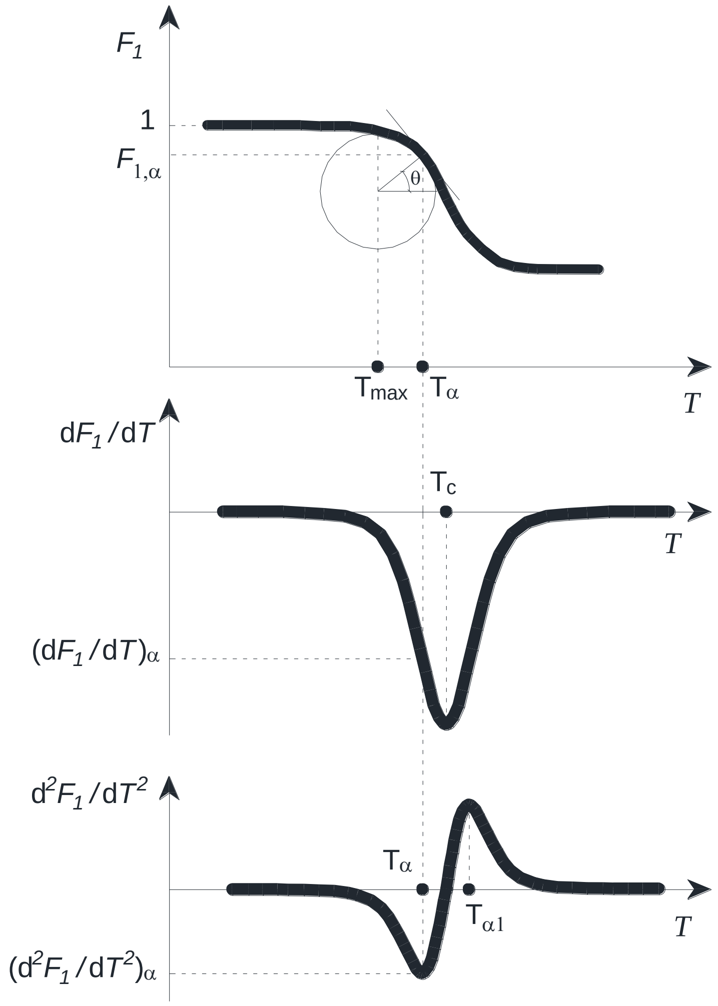

Figure C6.2: Transformed thermomechanical curve $F_1(T)$ and dependence of the first derivative dF_1/dT and second derivative d^2F_1/dT^2 on temperature.

The temperature at which the first derivative of the function F_1 (T) has a minimum value is taken as the temperature T_c [°C] (Figure C6.2, middle graph).

The temperature at which the second derivative of the function F_1 (T) has a minimum value is taken as the temperature T_α (Figure C6.2, bottom graph), for which the specific numerical value $F_{1,\alpha}$, its first derivative $(dF_1/dT)_\alpha$ and the second derivative $(d^2F_1/dT^2)_\alpha$ are found on the relative curves.

The temperature at which the second derivative of the function F_1 (T) has a maximum value is taken as the temperature $T_{\alpha 1}$ (Figure C6.2, bottom graph).

Based on the obtained values of T_α, $T_{\alpha 1}$ and T_c, the correctness of the preliminary estimation of the initial boundaries and of the working areas of the thermomechanical diagram is determined, and a decision is made about the necessity to reprocess the diagram.

The maximum service temperature T_{max} [°C] is calculated as the value of the abscissa of the centre of the circle tangent to the thermomechanical curve in the point of abscissa T_α (Figure C6.2, top graph), that is:

$$T_{\max} = T_\alpha - \frac{\left(1 - F_{1,\alpha}\right)\cos\theta}{1 - \sin\theta} \tag{C6.1}$$

where:

$$\theta = \frac{\pi}{2} + \arctan\left(\frac{\mathrm{d}F_1}{\mathrm{d}T}\right)_\alpha \tag{C6.2}$$

and represents the temperature of the transition of the polymer matrix from the glassy to the highly elastic state.

C7. Accuracy of tests

The resistance of the specimen to transverse bending shall be measured with an accuracy (see clause 1.3.1) of no more than 0.5% of the maximum value of the force produced during the test.

The values that determine the characteristics of other constants and variables that are used in intermediate calculations shall be determined with resolution of up to 0.001.

C8. Test report

The test report shall include at least the following information:

- Information on specimens
- Date of the test
- Information about conditions under which the tests are carried out
- Test results
- Values of the measured characteristics for each tested specimen
- The values of the determined characteristics of each specimen obtained by processing the test results
- The temperature corresponding to the extremes of the 1st and 2nd derivatives (T_α, $T_{\alpha 1}$, T_c) for each specimen
- The initial thermomechanical diagram of each tested specimen
- The reduced thermomechanical diagram of each tested specimen.

ANNEX D METHOD FOR DETERMINING THE STRENGTH OF FRP BENT BARS IN BEND LOCATIONS

D1. General requirements

This test method determines the quasi-static failure strength of FRP bent bars commonly used as anchorages for stirrups in reinforced concrete structures.

D2. Summary of test method

One or more FRP bent bars, cast into two blocks of concrete, are loaded in tension until failure occurs at the bent portion of the bar. An actuation device is placed in between the two concrete blocks so that the blocks are forced apart, inducing tension on the FRP bent bar.

D3. Test specimens

Geometry - The configuration of a typical specimen is shown in Figure D3.1.

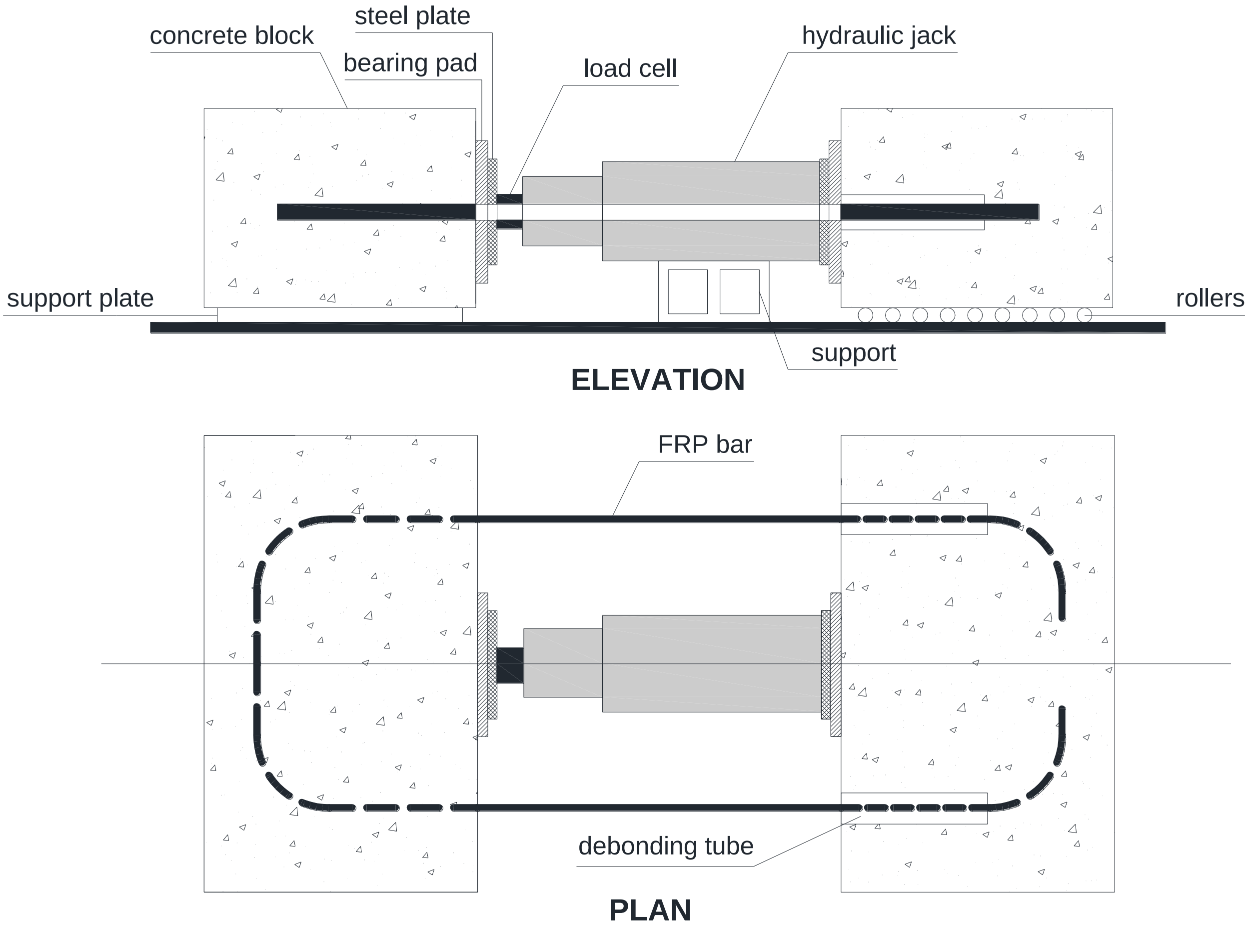

Figure D3.1: Test setup.

The dimensions of each concrete block used to anchor the FRP bar are reported in Figure D3.2.

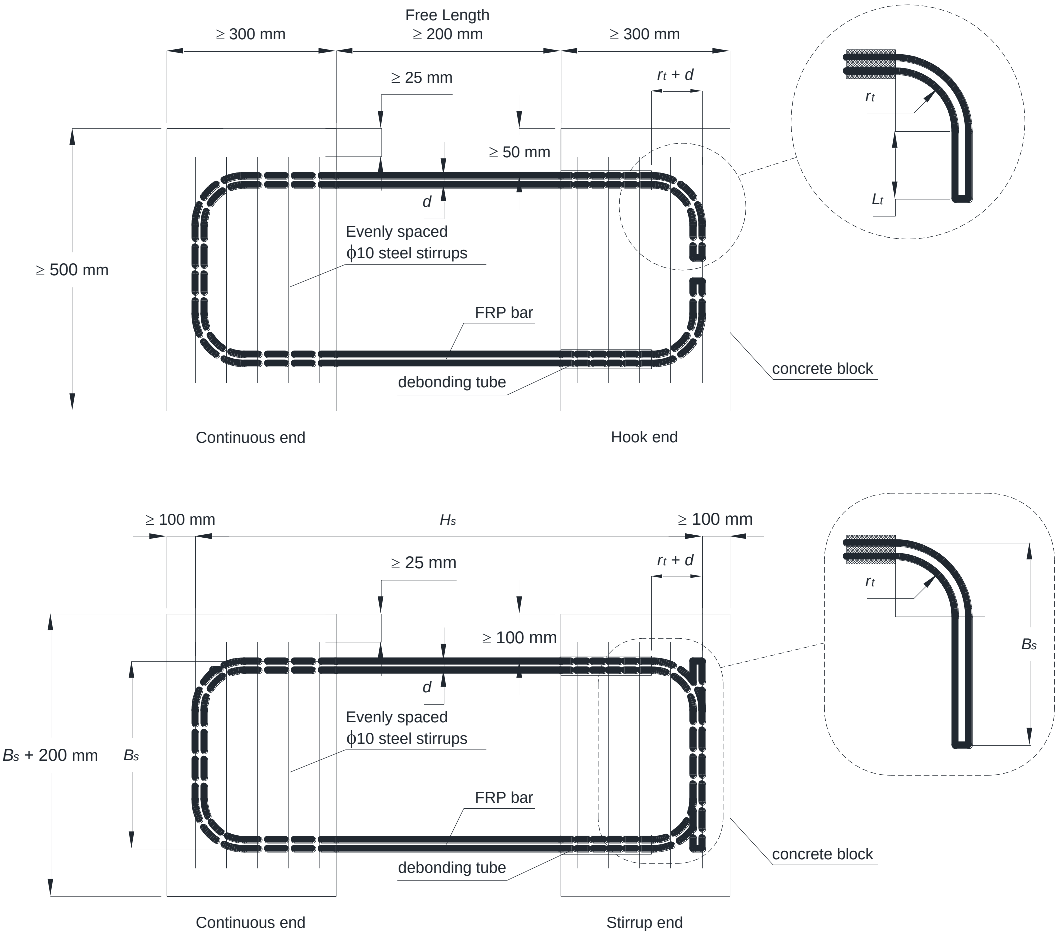

Figure D3.2: Specimen configuration

The concrete block may be reinforced using steel stirrups, as shown in Figure D3.2, to prevent splitting of the concrete block before rupture of the FRP stirrup in the bend. Steel stirrups are optional but their use shall be reported.

Bend angle of FRP bar shall be 90 ± 5 ° off of straight. The bend diameter (2 r_t) shall be at least 7 bar diameters.

The free length of the stirrup between the two blocks shall not be less than 200 mm, with 400 mm suggested.

FRP bent bar dimensions are variable, but shall have a tail length (L_t) of 12 ± 1 bar diameters per bend to minimize slippage and to help ensure a valid failure mode, in the case of bars with anchorage length. To allow for easier FRP bent bar production, two “C”-shaped bars arranged and used in the same manner as the single FRP bar shown in Figure D3.2 may be used in place of a single FRP bar (see Figure D3.3).

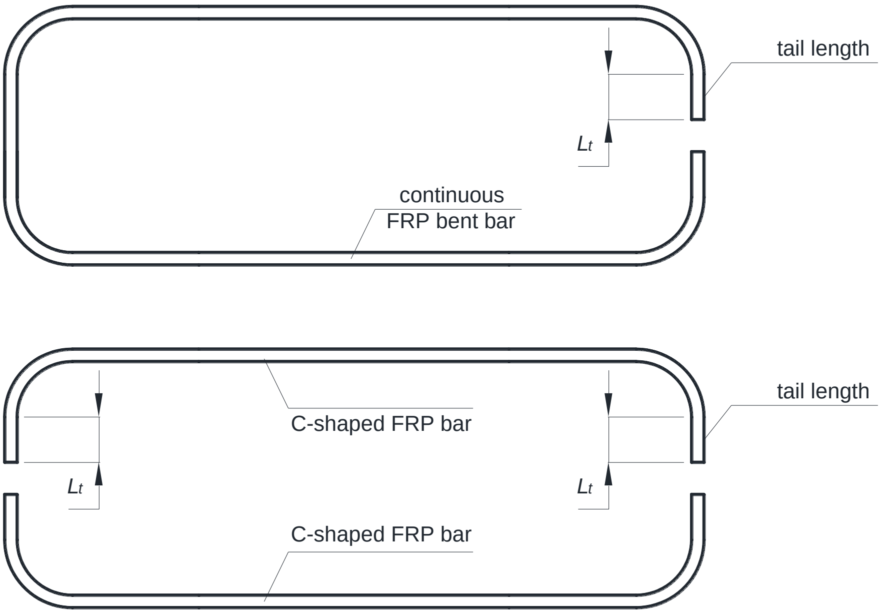

Figure D3.3 – Example of bent bar configuration inside the concrete block

In case of FRP bars used as stirrups, the tail length L_t shall be not less than the width B_s of the stirrup itself. In this last case, the lengths L_t will be in simple overlap (Figure D3.2- bottom).

A debonding tube is used to eliminate the straight-bar development of the hooked bar. The debonding tube shall fit over the reinforcing bar and cover the straight length of the FRP bar up to the bent portion, and the ends of the debonding tube shall be capped or plugged to prevent the tubes from filling with concrete during casting.

Concrete mix properties - The concrete shall be a standard mixture, with coarse aggregates having a maximum dimension of 20 to 25 mm. The concrete shall have slump corresponding to the S3 class in accordance with EN 206, and the cylinder compressive strength at 28 days shall be 30±3 MPa (C30/37 class in accordance with EN 206). A minimum of five standard control cylinders shall be made for determining compressive strength from each batch of concrete.

D4. Test equipment and materials

Hydraulic Cylinder - The hydraulic cylinder shall have force capacity in excess of the capacity of the specimen. Hand operated testing machines, electro-mechanical cylinders, or motorized pumps having sufficient volume in one or more strokes to complete a test may be used.

Force Indicator - The testing apparatus force-sensing device (a load cell or similar) shall be capable of indicating the total force being carried by the specimen. This device shall be essentially free from inertia-lag at the specified rate of testing and shall indicate the force with an accuracy (see clause 1.3.1) over the load range(s) of interest of within ± 1 % of the indicated value.

Environmental Test Chamber - An environmental chamber is required for conditioning and test environments other than ambient laboratory conditions. These chambers shall be capable of maintaining the required relative temperature to within ± 2 °C and the required relative humidity level to within 65% RH. In addition, the chambers shall be capable of maintaining environmental conditions such as fluid exposure or relative humidity during the conditioning and testing.

The test set-up, shown in Figure D3.1, consists of a hydraulic jack to distribute the applied force to the surface of the concrete. The hydraulic jack shall induce a relative displacement between the blocks at the specified rate and the load cell shall measure the corresponding force, appropriately distributed on the contact surfaces. A plywood bearing pad 200 mm square and at least 6 mm deep in conjunction with steel spreader plates 100 mm square and 6 mm deep, or similar provisions shall be used at the end of the actuator to spread the force on the concrete blocks and minimize bending forces on the bent bars. Hydraulic cylinder shall be placed in the same plane as the FRP bars, and shall be centrally located between the legs (± 6mm). The block containing the test section of the bar shall be placed on top of steel rollers to minimize the friction forces between the block and testing bed. When moving the specimens, special care shall be taken to avoid damaging or displacing the cast FRP bars.

D5. Testing of specimens

1. Unless otherwise specified as part of the experiment, the tests shall be conducted at the standard laboratory conditions, 23 °C ± 2 °C and 50 ± 5% relative humidity.
2. Increase the force in the cylinder until the specimen fails, by avoiding to subject the specimens to any shock, bending, vibration, or torsion. The strain rate shall be selected so that the specimens fail between 1 and 10 minutes from the start of the test. The suggested strain rate is 0.01 per minute [mm/mm·min]. If strain control is not available on the testing machine, a nominal piston speed of 0.01 per minute times the specimen free length selected shall be used.
3. A valid failure is achieved when an FRP rupture or FRP bar slip mode of failure is observed in at least one bent portion of the FRP bent bars. Specimens failing by way of splitting the concrete block shall be discarded and an additional test shall be performed on a separate specimen of the same lot. If splitting occurs, block dimensions may be increased and steel stirrups may be included in the blocks as necessary.
4. Record the applied force at failure and the failure mode for the specimen. If necessary to determine the failure mode, the block shall be split after the test.

D6. Processing of test results

The bend strength of the FRP bent bar shall be calculated according to Equation D6.1 and rounded to three significant digits:

$$f_{ub} = \frac{F_{fb}}{2A} \qquad \text{(D6.1)}$$

where:

f_{ub} bend strength of the FRP bent bar [MPa]

F_{fb} ultimate force measured in the bend test [N]

A cross-sectional area of single leg of the FRP bent bar [mm^2].

The percent of tensile strength retained in the bend is calculated according to Equation D6.2 and shall be rounded to three significant digits:

$$\chi = \frac{f_{ub}}{f_{ft0}} \qquad \text{(D6.2)}$$

where:

χ percentage of the tensile strength of the straight portion of the bar that is retained in the bend location;

f_{ft0} average failure tensile strength parallel to the fibres according to Section 2.2.2. Value shall be calculated using the same cross-sectional area as was used previously in Equation D6.1.

D7. Test report

The test report shall include at least the following items.

Common items

1. The trade name, shape, lot number, and, if available, date of manufacture of the FRP bent bars tested.
2. Description of the surface characteristics of the FRP bent bar.
3. If available from the bar manufacturer, fibre manufacturer, fibre description, fibre lot number, resin system manufacturer, resin system description, and resin system lot number.
4. Upon request, specific gravity, density, and fibre and void volume fractions of the FRP bent bars, and their methods of determination.
5. If available from the bar manufacturer, the process used to fabricate the bent bars.
6. FRP bent bar designation, diameter, and cross-sectional area.
7. Bend radius r_t, bend angle, and tail length L_t of FRP bent bar for each specimen.
8. Dimensions of concrete block, configuration (diameter and spacing) of steel stirrup confinement (if used), de-bonded length.

Items related to the properties of concrete:

1. The mixture proportions of cement, fine aggregate, coarse aggregate, admixture (if used), and the water-to-concrete ratio.
2. Slump of freshly mixed concrete.
3. 28-day strength of control cylinders.
4. Any deviation from the stipulated standards in such aspects as mixing, curing, dates of demoulding, and testing of control cylinders.

Items related to bend strength testing:

1. Any variations to this test method, anomalies noticed during testing or equipment problems occurring during testing.
2. Preconditioning performed on specimens.
3. Date of testing.
4. Calibration dates and methods for all measurement and test equipment.
5. Test temperature and relative humidity during testing.
6. Type and capacity of force indicator.
7. Type and capacity of force actuator.
8. Description of provisions made for: spreading the actuator force on the concrete block, minimizing bending of the specimen during loading, and eliminating drag on the block containing the test section.
9. Results of load system alignment evaluations, if any such evaluations were done.
10. Duration of test, bend strength, and strength reduction factor for each test specimen.
11. Population size, average bend strength, and average strength-reduction factor for the specimens that failed in the bend as intended. Include standard deviation and coefficient of variation.
12. Failure mode and location of failure for each specimen.

ANNEX E METHOD FOR DETERMINING THE CREEP FAILURE OF FRP BARS

E1. General requirements

This method establishes procedures to determine the influence of sustained load on the performance of FRP bars commonly used as tensile elements in reinforced concrete, also under different environmental conditions.

E2. Summary of test method

This test method consists of measuring the time to failure of a bar subjected to a constant tensile force. Multiple load levels and a given set of controlled environmental conditions are specified by the method so that a relationship between load and time-to-failure can be derived.

The general procedures of ISO 10406-1 clause 12 shall be followed with the exceptions and integrations indicated in this Annex.

The method includes three cases which are defined by different environmental conditions:

- Case 1: FRP bar in the air at a temperature of 23 °C ± 2 °C and a relative humidity of (50 ± 10) %.
- Case 2: FRP bar in an alkaline solution with pH ≥ 13 at 40 °C ± 2 °C. A second test series at 60 °C ± 2 °C shall be performed to allow extrapolation of test data (see clause E6.3).
- Case 3: FRP bar encased in a concrete cylinder stored in a tempered water bath (see Figure E3.1) at 40 °C ± 2 °C. A second test series at 60 °C ± 2 °C shall be performed to allow extrapolation of test data (see clause E6.3).

Case 1 allows to determine the creep failure load ratio R_{Yc}, which represents the load ratio at 1 million hours (approximately 114 years) determined from the creep failure line chart resulting from testing the bar in air, and the relative million-hour creep failure strength $f_{ftk,c}$ [MPa].

Case 2 and Case 3 both allows to determine the creep failure load ratio $R_{Yc,a}$, which represents the load ratio at 1 million hours (approximately 114 years) determined from the creep failure line chart resulting from testing the bar in an alkaline environment (alkali solution or concrete cylinder), and the relative million-hour creep failure strength $f_{ftk,ca}$ [MPa]. Case 3 shall be used as the reference method to determine the creep failure load ratio $R_{Yc,a}$ and the relative million-hour creep failure strength $f_{ftk,ca}$ [MPa].

E3. Test specimens

Test specimens are randomly selected from a controlled batch of FRP bars.

During the selection and preparation of specimens for testing, deformation and heating, exposure to ultraviolet light and other environmental influences that may lead to changes in material properties shall be avoided.

Case 1 and/or Case 2 – Test specimens shall be prepared according to clause 2.2.2.

Case 3 – Test specimens shall be encased in a concrete cylinder as indicated in Figure E3.1.

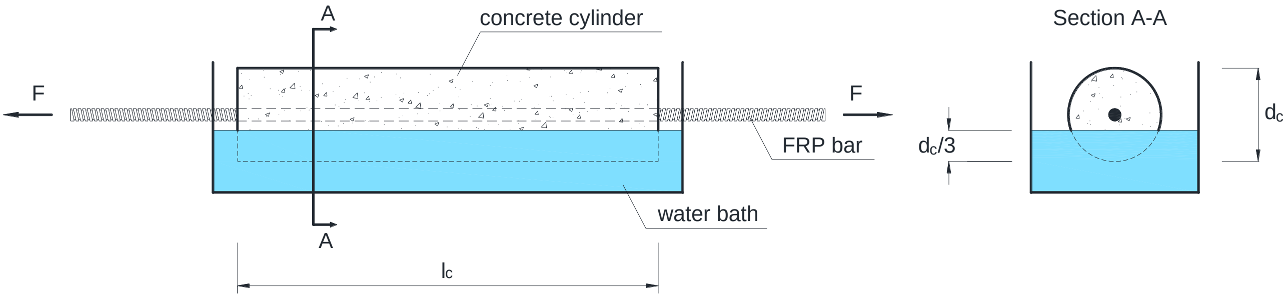

Figure E3.1 Schematic representation of the experimental setup according to case 3 with
l_c length of concrete cylinder
d_c diameter of concrete cylinder

The concrete cylinder shall be manufactured in accordance with EN 206, with dimensions as reported in Table E3.1. No additives that can change the properties of the concrete (e.g., fly ash, silica fume, limestone powder or other powders) shall be added.
The alkaline environment of the concrete cylinder shall have a pH ≥ 13 at the start of the test (this can be considered as guaranteed if the cement has an Na_2O equivalent of 1% ± 0.1%).

Table E3.1 Dimensions of the concrete cylinder according to case 3

Minimum length of the concrete cylinder l_c [mm]	180 + 2×d
Minimum diameter of the concrete cylinder in d_c [mm]	At least 60 for d > 15 mm recommended diameter 4d < d_c <8d

E4. Test equipment and devices

Test Apparatus – Use a testing apparatus with a force capacity in excess of the tensile capacity of the specimen. The testing apparatus shall be capable of applying and maintaining a force on the specimen within ±1 % of the desired sustained force. For frames using weights to load the specimen, to avoid impact forces on the specimens, weights shall be supported temporarily on a hydraulic jack or pneumatic bladder, and then the load transferred linearly to the specimen by slowly releasing the pressure on the jack or bladder.

Anchorages – Anchorages shall be in accordance with clause 2.2.2.

Extensometer and strain gauge – The extensometers and strain gauges shall be in accordance with the provisions of clause 2.2.2.

Measurement of time – The passage of time during the test shall be measured with appropriate equipment (timer, etc.) with an accuracy (see clause 1.3.1) of within 5 sec in 1 hour.

Temperature Control – The temperature of the test environment shall be maintained at the specified temperature ±2 °C during the test period.

Environmental Test Chamber – An environmental test chamber may be required for test environments other than ambient testing laboratory conditions.

E5. Testing of specimens

E5.1 Selection of sustained loads to be applied

The quasi-static tensile strength of the bars is determined in clause 2.2.2 and used as a basis for selecting the applied tensile forces for creep failure tests. At each given load ratio - for example, 80 %, 70 %, 60 % of the tensile strength - the applied load or weight shall be maintained constant until failure occurs while the time elapsed to rupture of each test specimen is recorded.

> Note: The selection of load ratios is dependent on the fibre architecture and fibre volume fraction for the bar. Material systems with a high resistance to creep rupture (for example, carbon FRP composite) will necessitate the selection of closely-spaced load ratios at stress levels approaching 100 % of the quasi-static tensile

strength. Material systems with less resistance to creep rupture (for example, glass FRP composite) will necessitate the selection of widely-spaced load ratios.

The creep tests shall be conducted for at least five sets of load ratio conditions. A minimum of three valid test results are required for each load ratio. It is suggested that additional specimens be tested at each load ratio, especially for those ratios that require long times to failure.

The highest load ratio shall be selected such that at least three specimens in this group break at a time comprised between 1 h and 10 h.

The lowest load ratio shall be selected such that at least one specimen in this group breaks at a time greater than 4,000 h.

The remaining load ratios shall be roughly equally spaced in relation to the highest and lowest load ratios determined.

E5.2 Conditioning

Case 1
Test shall be conducted in the air at a temperature of 23 °C ± 2 °C and a relative humidity of (50 ± 10) %.

Case 2
Test shall be conducted in an alkaline solution with pH ≥ 13 at 40 °C ± 2 °C. The alkali solution according to ISO 10406-1 clause 11.2.1 shall be used.

Case 3:
Specimens shall be encased in a concrete cylinder and stored in a tempered water bath (see Figure E3.1) at 40 °C ± 2 °C.

E5.3 Procedure

See clause 12.5.2 of ISO 10406-1 for the loading procedure and 12.5.4 for the measurement of creep strains.

E6. Processing of test results

E6.1 Handling of data

See clause 12.6.1 of ISO 10406-1.

E6.2 Load ratio/creep failure time curve

Case 1

The load ratio versus creep-failure time curve shall be plotted on a semi-logarithmic graph where the load ratio is represented on an arithmetic scale along the vertical axis and the creep-failure time, expressed in hours, is represented on a logarithmic scale along the horizontal axis (see Figure E6.2.1). Tests resulting in no failure (run-outs) shall be included in this plot but should not be included in the calculation of the creep failure trend line. Run outs should clearly be identified as such on the graph.

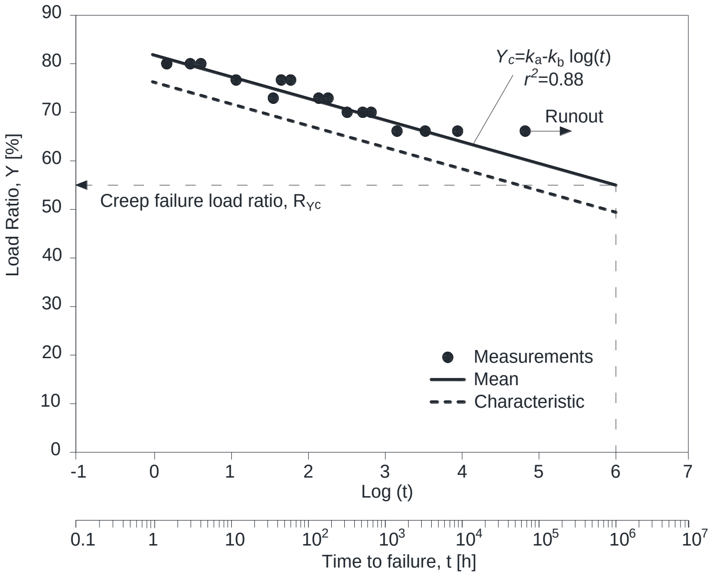

Figure E6.2.1: Example of Logarithmic Time to Failure Curve (case 1) for a single diameter

<u>Case 2 or 3</u>

The load ratio versus creep-failure time curve shall be plotted on a double-logarithmic graph where the load ratio is represented on a logarithmic scale along the vertical axis and the creep-failure time, expressed in hours, is represented on a logarithmic scale along the horizontal axis (see Figure E6.2.2). Tests resulting in no failure (run-outs) shall be included in this plot but should not be included in the calculation of the creep failure trend line. Run outs should clearly be identified as such on the graph.

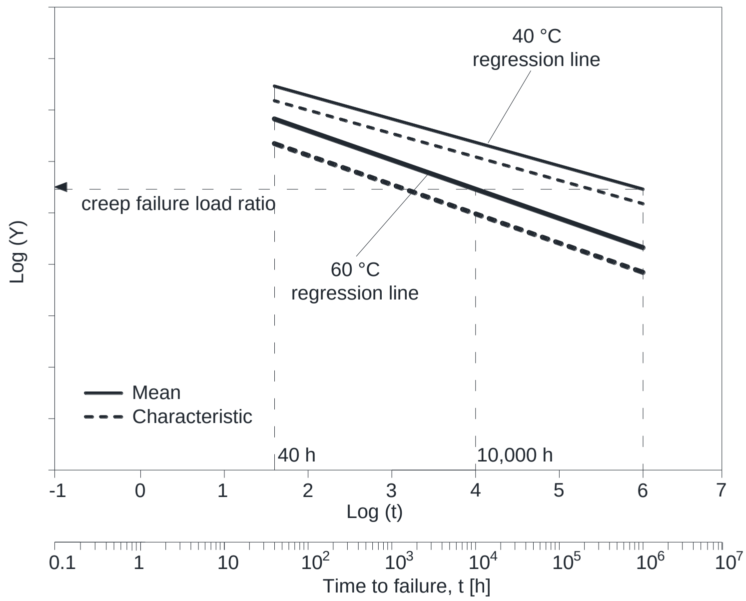

Figure E6.2.2: Example of Logarithmic Time to Failure Curve (case 2 or case 3). The creep failure load ratio at 10^6 h on the 40 °C regression line corresponds to the creep failure load ratio at 10^4 h on the 60 °C regression line (time temperature shift principle, see clause E6.3)

E6.3 Calculations

Case 1

A creep-failure trend line shall be plotted from linear regression of the data by means of the least-square method according to

$$Y_c = k_a - k_b \log t \qquad \text{(E6.3.1)}$$

where:

Y_c load ratio, expressed as a percentage of quasi-static tensile strength;

t time to failure, expressed in hours;

k_a , k_b empirical constants. The value of such constants may be determined according to EN 705 equations (8) and (9), provided that it is considered x=log(t) and y=Y_c in equation (1).

Determine the coefficient of determination r^2 of the regression line according to equation (12) of ISO 10406-1.

The load ratio at 1 million hours (10^6 hours, approximately 114 years), as determined from the linear extrapolation of the trend line (see Figure E6.2.1), shall be taken as the creep failure load ratio R_{Yc}; the load and stress corresponding to this creep failure load ratio shall be the million-hour creep failure capacity F_{rc} [N] and the million-hour creep failure strength $f_{ft,c}$ [MPa], respectively.

The million-hour creep failure strength $f_{ft,c}$ [MPa] is calculated according to equation E6.3.2:

$$f_{\mathrm{ft,c}} = \frac{F_{rc}}{A_{\mathrm{eff}}} \qquad \text{(E6.3.2)}$$

where:

F_{rc} million-hour creep failure capacity [N];

A_{eff} effective cross-sectional area of the test specimen [mm²], see clause 2.2.1.

The reference to the million hours shall not be intended, by any means, as a reference to the working life of the product, but it just represents a way to assess the essential characteristic “creep failure”.

Note: In this case, when testing occurs under sustained load only (without alkali solution – case 1), the creep failure load ratio R_{Yc} corresponds to the influence factor for service life C_c according to EN 1992-1-1, clause R.5.3.

The characteristic value of the million-hour creep failure strength $f_{ftk,c}$ [MPa], rounded off to three significant digits, shall be calculated as

$$f_{\mathrm{ftk,c}} = \frac{F_{rc,k}}{A_{\mathrm{eff}}} \qquad \text{(E6.3.3)}$$

where $F_{rc,k}$ is the characteristic value of the creep failure capacity, determined from the characteristic regression line (see Figure E6.2.2), and A_{eff} [mm²] is the effective cross-sectional area of the test piece. The characteristic value will be determined, by using the appropriate value of k_n for unknown V_x reported in EN 1990, Annex D, Table D1.

Case 2 or 3

When considering the test according to Case 2 or Case 3, the creep-failure trend line shall be plotted from linear regression of the data according to EN 705 - Method A. Extrapolation shall be done in the failure time range between 40 h and more than 4,000 h for the different load levels.

Extrapolation is allowed to 1 million hours if, for the single tested diameter, a second series at 60 °C shows linearity for the same time range in the log creep failure stress/log time graph. Linearity is seen as sufficient if the coefficient of determination r^2, calculated as indicated in EN 705 eq. 5, is greater than 0.85.

The tests at 40 °C can be omitted for the three groups of diameters foreseen by Annex A (smallest, medium, largest), if in these three groups the results of the test series at 60 °C are comparable. The test series are seen as comparable if r^2 of the regression line for the three diameters in the log creep failure stress/log time graph is greater than 0.85 and the extrapolated value at 10,000 h, representative of the 1 million hours' value for the 60 °C regression line (time temperature shift principle, see figure E6.2.2), differ less than 15% from the three values extrapolated for the regression lines of the single diameters (smallest, medium, largest).

The load ratio at 1 million hours, as determined from the linear extrapolation of the trend line at 40 °C (or at 10,000 h for the regression line at 60 °C), shall be taken as the creep failure load ratio $R_{Yc,a}$; the load and stress corresponding to this creep failure load ratio shall be the million-hour creep failure capacity $F_{rc,a}$ [N] and the million-hour creep failure strength $f_{ft,ca}$ [MPa], respectively. The million-hour creep failure strength $f_{ft,ca}$ [MPa] is calculated according to equation E6.3.2, with $F_{\mathrm{rc,a}}$ as million-hour creep failure capacity.

The characteristic value of the million-hour creep failure strength $f_{ftk,ca}$ [MPa], rounded off to three significant digits, shall be calculated according to eq. E6.3.3 by using the characteristic value of the creep failure capacity $\mathrm{F}_{rc,ka}$, which is determined from the characteristic regression line (see Figure E6.2.2).

> Note: When testing occurs in an alkali environment (case 2 or 3), the value $f_{ftk,ca}$ obtained according to Eq. E6.3.3 corresponds to the long-term tensile strength $f_{\mathrm{ftk,100a}}$, according to EN 1992-1-1, Annex R, accounting for the influence of time, temperature and environmental exposure.

E7. Test report

The test report shall include at least the following information:

- Name, shape, date of manufacture and lot number of FRP bars tested
- Type of fibre and fibre-binding material
- Designation, nominal diameter, nominal cross-sectional area
- Date of test
- Conditioning procedure used
- Type and name of testing frame and devices
- Type of anchorage
- Average tensile capacity and tensile strength for each specimen
- Initial loading time
- Failure mode and location of failure for each specimen
- Creep strain/time curve for each specimen
- Load ratio/creep failure time curve
- Formula for derivation of the approximation line (empirical constants k_a and k_b) and its coefficient of determination r^2
- Creep failure load ratio, million-hour creep failure capacity and million-hour creep failure strength