EAD **340351-00-0104**

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August 2020

European Assessment Document for

Fibre-reinforced polymer kits made of a pultruded carbon fibre laminate and an epoxy adhesive

This European Assessment Document (EAD) has been developed taking into account up-to-date technical and scientific knowledge at the time of issue and is published in accordance with the relevant provisions of Regulation (EU) 305/2011 as a basis for the preparation and issuing of European Technical Assessments (ETA).

Contents

1 SCOPE OF THE EAD

1.1 Description of the construction product

The fibre reinforced polymer kits made of a pultruded carbon fibre laminate and an epoxy adhesive (hereinafter referred to as “FRP kit”, see 1.3.1) consist of the following components (see Figure 1.1.1):

(A) a pultruded FRP laminate

(B) a bonding agent

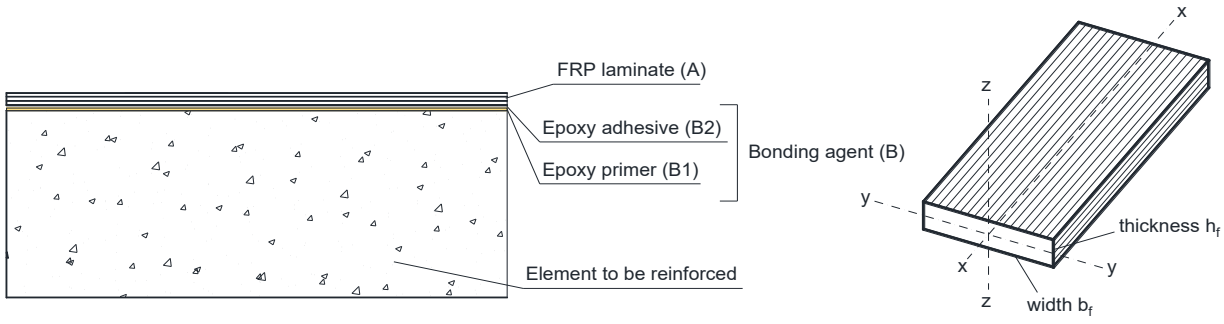


Figure 1.1.1: FRP kit made by a pultruded FRP laminate (A) and a bonding agent (B). For the FRP element the direction along the fibre direction, or axis of the profile, is defined as the “axial” direction (x-x) and the perpendicular direction is defined as the “transverse” direction (y-y).

FRP laminates (A), are made of unidirectional carbon fibres and obtained by a pultrusion process. They are produced in different widths b_f, thicknesses h_f and with different elastic moduli (see Figure 1.1.1).

This EAD is applicable to FRP laminates with thickness lower than 10 mm.

The bonding agent (B) consists of (see Figure 1.1.1)

- an epoxy primer (optional) (B1), to prepare the concrete, reinforced concrete and masonry surfaces;
- a bi-component epoxy adhesive (putty) (B2) for the structural bonding on substrates.

Application of the kit is typically handmade, i.e., the FRP laminate (A) is bonded on site on the element to be reinforced through the bonding agent (B).

The product is not fully covered by the following harmonised technical specification: EAD 340352-00-0104 which covers kit made by dry fabrics (glass or carbon), with various weights per unit area and fibre orientation, which are impregnated on site by epoxy adhesives, after having regularized the surface of the element to be reinforced. The kit object of EAD 340352-00-0104 is therefore different in composition and the overall process is handmade, i.e., the FRP material is obtained by impregnation of the dry fabric and the epoxy adhesive, therefore such systems are saturated and cured in place. Contrarily, in the kit object of this EAD, the FRP material is produced in factory by a pultrusion process and then applied on site by the bonding agent. The diversity of kit object of the current EAD reflects in the assessment of all essential characteristics, where preparation of specimens, test methods, expression of results are different and need to be differently specified. In addition, diversity of kits reflects also in 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 (see clause 3.1). Specifically, with respect to EAD 340352-00-0104:

- Tensile properties: a different reference standard has been considered related to preformed fibre-reinforced plastic composites;
- Interlaminar shear strength: the reference test procedure used for the assessment is directly applicable without need for adaptation, while small deviations from the reference standard are

needed (i.e., number of specimens) which justify the presence of a clause in the current EAD (see 2.2.2);
- Lap tensile strength: for the tensile tests, two laminates (plates) are overlapped for a definite length and bonded, instead of having overlapped layers of fabric impregnated with resin (therefore completely embedded) as in EAD 340352-00-0104;
- Bond strength: due to the different substrates on which the kit may be applied (see 1.2.1), new specifications for materials are introduced and an Annex has been added with description of the tests for different substrates (see Annex B);
- Cyclic behaviour: methods and expression of results need to be specified in more detail to be applicable to the assessment of the kit at hand;
- Glass transition temperature has to be assessed also for the pultrusion resin used to produce the FRP laminate, as representative of the whole kits' behaviour, which is not present in EAD 340352-00-0104;
- Creep aspects: preparation of specimens is included in order to consider the different components of the kit, and components' nature, and also the different substrates to which it may be applied;
- Durability aspects: while ageing procedures are common between the two EADs, preparation of specimens, tests and expression of results need to be specified in more detail considering the different components of the kit, and components' nature, which have influence on the properties as already stated in the previous points (tensile properties, interlaminar shear strength and lap tensile strength);
- Reaction to fire: preparation of specimens and indications for mounting and fixing need to be specified for the kit at hand.

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)

The FRP kit is intended to be used in highly specialized applications to strengthen structural parts of constructions. The main intended use is the flexural strengthening of reinforced concrete beams and slabs in cases where the strengthening elements can be installed straight, i.e., as linear, not foldable elements. In addition, it is used for the strengthening of analogous elements of masonry, wood and steel structures.

The increase in the load carrying capacity of structural elements (e.g., beams, slabs, vaults, walls) is achieved by bonding the FRP laminate to the external surfaces of the elements (see Figure 1.2.1.1 and Figure 1.2.1.2). In particular, flexural strengthening is obtained by bonding the FRP kit to the tension face of a flexural member with fibres oriented along the load carrying direction of the member. This will provide an increase in flexural strength (see Figure 1.2.1.1).

The FRP kit is intended to be used for reinforcement of structural elements subject to static, quasi-static and dynamic loading.

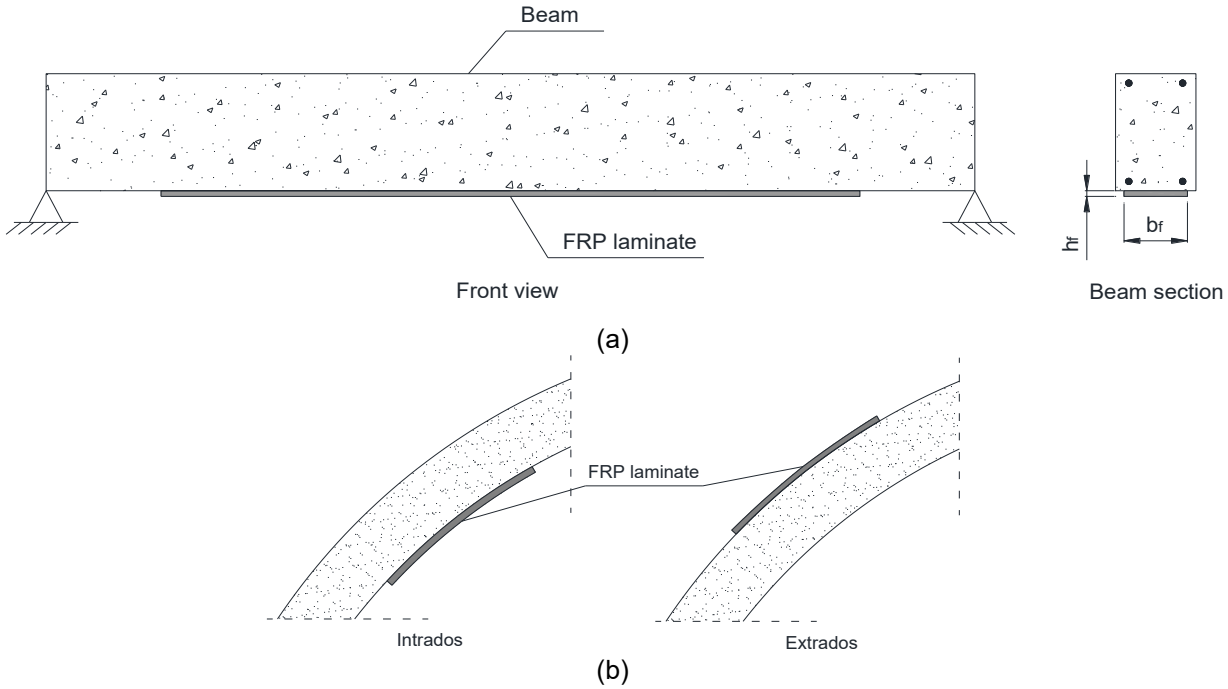


Figure 1.2.1.1: Example of flexural strengthening (a) beam; (b) vault.

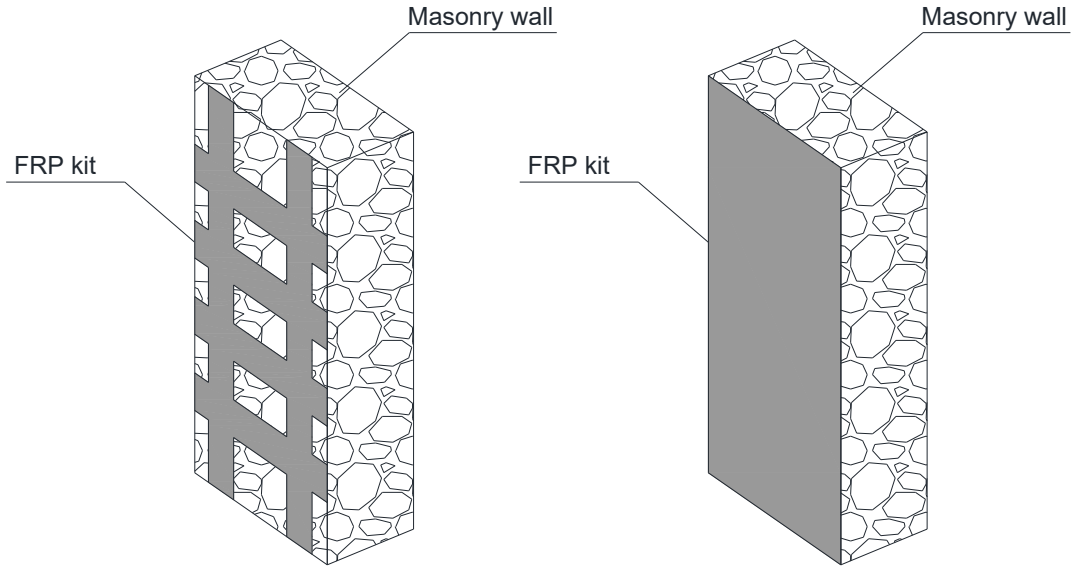


Figure 1.2.1.2: Example of strengthening schemes for masonry walls (or load-bearing concrete walls).

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 kit for the intended use of 50 years when installed in the works (provided that the FRP kit is subject to appropriate installation (see 1.1)). 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 Acronyms

DSC Differential Scanning Calorimetry

FRP Fibre Reinforced Polymer

LVDT Linear Variable Differential Transducer

RH Relative Humidity

1.3.2 Symbols

A	[mm^2]	Cross-sectional area of the FRP laminate (see clause 3.4 of EN ISO 527-1[2])
b_f	[mm]	Width of FRP laminate
d_f	[mm]	Distance between the beginning of the bonded area and the top edge of the substrate in the single-lap shear test
E_t	[GPa]	Tensile modulus (modulus of elasticity under tension) of FRP laminate (see clause 3.9 of EN ISO 527-1)
$f_{c,sub}$	[MPa]	Substrate compressive strength
f_h	[MPa]	Pull-off strength
$f_{h,ret}$	[%]	Retained pull-off strength after exposure conditions
$f_{h,sub}$	[MPa]	Substrate tensile bond strength by pull-off
f_{uk}	[MPa]	Characteristic ultimate tensile strength of steel
f_{yk}	[MPa]	Characteristic yield strength of steel
g	[mm]	Global slip
h_f	[mm]	Thickness of FRP laminate
k_n	[-]	Coefficient for the evaluation of the characteristic value (characteristic fractile factor for a sample size *n*)
l	[mm]	Specimen length/bonded length
L_f	[mm]	Total length of FRP laminate
L_T	[mm]	Tab length
L_{tot}	[mm]	Total length of each single FRP laminate in the lap tensile strength test
l_{lap}	[mm]	Lap length
m_X		Mean of the variable X
m_X^{exp}		Average value of the property X assessed for the exposed specimens
m_X^{unexp}		Average value of the property X assessed for unexposed specimens
$n_{fatigue}$	[-]	Number of cycles causing failure for fatigue

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 clause 4.

n_{seism}	[-]	Number of cycles causing failure (cyclic loading)
P	[N]	Failure load
P_{deb}	[N]	Bond capacity in single-lap shear test
P_{max}	[N]	Maximum load in single-lap shear test
t_u	[h]	Time (number of hours) at which failure occurs in the creep test
$T_{g,a}$	[°C]	Glass transition temperature of the bonding agent
$T_{g,r}$	[°C]	Glass transition temperature of the pultrusion resin
$T_{g,1}$	[°C]	Glass transition temperature of 1st conditioning cycle
$T_{g,2}$	[°C]	Glass transition temperature of 2nd conditioning cycle
V_X	[%]	Coefficient of variation
ε_b	[mm/mm]	Tensile strain (strain at break) of FRP laminate (see clause 3.7.2 of EN ISO 527-1)
σ_{lap}	[MPa]	Lap tensile strength
σ_b	[MPa]	Tensile strength (stress at break) of FRP laminate (see clause 3.6.4 of EN ISO 527-1)
τ	[MPa]	Interlaminar shear strength

1.3.3 Indices

alk	Alkali
creep	Creep behaviour
deb	Debonding
fatigue	Fatigue
FT	Freeze-Thaw
lap	Lap tensile
ret	Retained property after ageing
seism	Seismic (cyclic loading)
sub	Substrate
sw	Saltwater
w	Water

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 FRP kit 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	Tensile properties	2.2.1	Level σ_b [MPa], ε_b [mm/mm], E_t [GPa]
2	Interlaminar shear strength	2.2.2	Level and description τ [MPa] and failure mode
3	Lap tensile strength	2.2.3	Level Lap length, l_{lap} [mm] Lap tensile strength , σ_{lap} [MPa]
4	Bond strength on substrates - Pull-off test	2.2.4.1	Level Pull-off strength f_h [MPa] Residual bond strength $f_{h,w,ret}$ [%], $f_{h,sw,ret}$ [%], $f_{h,alk,ret}$ [%]
5	Bond strength on substrates - Single-lap shear test	2.2.4.2	Level Maximum load P_{max} [N], Bond capacity P_{deb} [N] Retained maximum load and bond capacity $P_{max,w,ret}$ [%], $P_{deb,w,ret}$ [%] $P_{max,sw,ret}$ [%], $P_{deb,sw,ret}$ [%] $P_{max,alk,ret}$ [%], $P_{deb,alk,ret}$ [%]
6	Tensile strength after low number of cycles (seismic behaviour)	2.2.5	Level Number of cycles causing failure n_{seism} *or* Tensile strength $\sigma_{b,seism}$ [MPa] Tensile modulus $E_{t,seism}$ [GPa] Tensile strain $\varepsilon_{b,seism}$ [mm/mm]
7	Tensile strength after high number of cycles (fatigue actions)	2.2.6	Level Number of cycles causing failure $n_{fatigue}$ *or* Tensile strength $\sigma_{b,fatigue}$ [MPa] Tensile modulus $E_{t,fatigue}$ [GPa] Tensile strain $\varepsilon_{b,fatigue}$ [mm/mm]
8	Glass transition temperature of pultrusion resin	2.2.7	Level $T_{g,r}$ [°C]
9	Glass transition temperature of bonding agent	2.2.8	Level $T_{g,a}$ [°C]
10	Creep behaviour	2.2.9	Level Deformation $\varepsilon_{b,creep}$ [mm/mm] Time at which the failure occurs t_u *or* Deformation $\varepsilon_{b,creep}$ [mm/mm]
11	Creep behaviour related to the adhesion on substrate	2.2.10	Level and description Displacement vs time (tabular) Maximum load $P_{max,creep}$ [N] after creep Bond capacity $P_{deb,creep}$ [N] after creep

No	Essential characteristic	Assessment method	Type of expression of product performance
Basic Works Requirement 2: Safety in case of fire			
12	Reaction to fire	2.2.15	Class
Aspects of durability			
13	Freezing and thawing(1)	2.2.11	Level and description Tensile strength $\sigma_{b,FT}$ [MPa] Tensile modulus $E_{t,FT}$ [GPa] Tensile strain $\varepsilon_{b,FT}$ [mm/mm] Interlaminar shear strength τ_{FT} [MPa] Retained tensile strength $\sigma_{b,FT,ret}$ [%] Retained tensile modulus $E_{t,FT,ret}$ [%] Retained interlaminar shear strength $\tau_{FT,ret}$ [%]
14	Water resistance(2)	2.2.12	Level and description Tensile strength $\sigma_{b,w}$ [MPa] Tensile modulus $E_{t,w}$ [GPa] Tensile strain $\varepsilon_{b,w}$ [mm/mm] Interlaminar shear strength τ_{w} [MPa] Lap tensile strength $\sigma_{lap,w}$ [MPa] Retained tensile strength $\sigma_{b,w,ret}$ [%] Retained tensile modulus $E_{t,w,ret}$ [%] Retained interlaminar shear strength $\tau_{w,ret}$ [%] Retained lap tensile strength $\sigma_{lap,w,ret}$ [%]
15	Saltwater resistance(2)	2.2.13	Level and description Tensile strength $\sigma_{b,sw}$ [MPa] Tensile modulus $E_{t,sw}$ [GPa] Tensile strain $\varepsilon_{b,sw}$ [mm/mm] Interlaminar shear strength τ_{sw} [MPa] Lap tensile strength $\sigma_{lap,sw}$ [MPa] Retained tensile strength $\sigma_{b,sw,ret}$ [%] Retained tensile modulus $E_{t,sw,ret}$ [%] Retained interlaminar shear strength $\tau_{sw,ret}$ [%] Retained lap tensile strength $\sigma_{lap,sw,ret}$ [%]
16	Alkali resistance(2)	2.2.14	Level and description Tensile strength $\sigma_{b,alk}$ [MPa] Tensile modulus $E_{t,alk}$ [GPa] Tensile strain $\varepsilon_{b,alk}$ [mm/mm] Interlaminar shear strength τ_{alk} [MPa] Lap tensile strength $\sigma_{lap,alk}$ [MPa] Retained tensile strength $\sigma_{b,alk,ret}$ [%] Retained tensile modulus $E_{t,alk,ret}$ [%] Retained interlaminar shear strength $\tau_{alk,ret}$ [%] Retained lap tensile strength $\sigma_{lap,alk,ret}$ [%]

(1) The durability aspect is linked to essential characteristics No. 1 and 2.
(2) The durability aspect is specifically linked to essential characteristics No. 1, 2 and 3. Water, saltwater and alkali exposures are also foreseen in clauses 2.2.4.1 and 2.2.4.2.

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.

If for any components covered by harmonised standards or European Technical Assessments the manufacturer of the component has included the performance regarding the relevant essential characteristic in the Declaration of Performance, retesting of that component for issuing the ETA under the current EAD is not required.

Where not explicitly expressed, the *mean value* refers to the arithmetic mean, i.e., the sum of the sum of random variables (observed values) divided by the number of terms in the sum.

The *characteristic value* of a property X shall be determined by using the following expression (EN 1990, clause D.7.2):

$$X_k = m_X(1 - k_n V_X) \tag{2.2.1}$$

where m_X is the mean of the variable X from n sample results, V_X is the coefficient of variation of X and k_n the characteristic fractile factor for a sample size n, reported in EN 1990, Annex D, Table D.1 for “unknown V_X”. The coefficient of variation V_X shall be calculated by using Formulae (D.2) and (D.3) of EN 1990.

A summary of the number of specimens to be tested for each essential characteristic is presented in Annex A.

If for one type of fibre more than one cross section exists, the *significant cross sections* are those with the smallest and the highest thickness h_f.

2.2.1 Tensile properties

Purpose of the assessment

Tensile tests are performed to evaluate the tensile strength (stress at break, σ_b [MPa]), the tensile modulus (modulus of elasticity under tension, E_t [GPa]) and the tensile strain (strain at break, ε_b [mm/mm]) of the FRP laminate (A).

Assessment method

The tensile properties of specimens shall be determined in accordance with EN ISO 527-4. The test specimen is type 3. For calculation of stress, strain and tensile modulus, EN ISO 527-1 clauses 10.1, 10.2.1 (determined with an extensometer) and 10.3.2 (chord slope), respectively, shall be used.

Unlike EN ISO 527-1 clause 10.3.2 and due to expected level of measured values, E_t shall be expressed in GPa.

Tests shall be conducted parallel to the axial direction (x-x, see Figure 1.1.1).

Unlike the minimum number of specimens foreseen by EN ISO 527-1 clause 7.1, to have a greater precision on the mean value and reliable results on the characteristic values (EN 1990 clause D.5), a minimum number of 15 specimens (five specimens for three different batches) to be subjected to uniaxial tensile test shall be prepared for each FRP laminate configuration (i.e., laminate produced with a different coupling of fibres and epoxy resin, or different percentage in volume or weight of the two components or different production process).

Tests shall be performed under standard conditions of temperature and relative humidity (23±2°C, 50±5% RH). For laminates with a width lower than 25 mm, the nominal width of the product shall be used.

The load shall be applied under displacement control, with a constant rate in the range of 0,5-2,0 mm/min.

Expression of results

The average (arithmetic mean) and characteristic value (according to equation (2.2.1)) of the tensile strength (stress at break) σ_b [MPa], tensile modulus E_t [GPa] and tensile strain (strain at break) ε_b [mm/mm] shall be determined and stated in the ETA.

2.2.2 Interlaminar shear strength

Purpose of the assessment

This test method allows to determine the apparent interlaminar shear strength τ [MPa] of FRP laminates by the short-beam method.

Assessment method

Interlaminar shear strength tests on FRP laminates (A) shall follow the general procedures of EN ISO 14130. A minimum number of twenty specimens are required to be tested under standard conditions of temperature and relative humidity (23±2°C, 50±5% RH).

Expression of results

The average (arithmetic mean) and characteristic value (according to equation (2.2.1)) of the interlaminar shear strength τ [MPa] shall be determined and stated in the ETA.

If failure modes different from the interlaminar shear occur, the sentence “No interlaminar shear failure evidenced” shall be stated in the ETA.

2.2.3 Lap tensile strength

Purpose of the assessment

When applying FRP kits for strengthening of structural members, laps can be necessary for the reinforcement. To determine the relative tensile strength at the laminate lap splice, lap tensile strength σ_{lap} [MPa] shall be assessed.

Assessment method

The general test procedures as described in EN ISO 527-4 shall be used on tensile tests of FRP laminates. Two laminates (A) shall be overlapped and bonded through the bi-component epoxy adhesive (B2) such that the lap length is positioned at mid-length of the test specimen. The tested lap length l_{lap}, indicated by the manufacturer in the Manufacturer Product Installation Instructions (MPII), shall not be shorter than the tab length L_T defined in EN ISO 527-4 and in any case, the total length L_{tot} of each single FRP laminate shall be such that the remaining portion of laminate, excluding the tab and the lap lengths, is at least 100 mm.

$$L_{tot} - L_T - l_{lap} > 100 \text{ mm} \qquad (2.2.3.1)$$

Lap strength shall be determined by applying to the adherends a tensile force which is parallel to the bond area and to the major axis of the specimen. The test specimen shall be therefore positioned symmetrically in the grips, so that the applied force will be in the plane of the adhesive bond (a shim may be used in the grips to facilitate this condition).

Note: To avoid dispersion of results, care shall be taken to prepare the specimens, to grip them and to align the specimen in the test machine. The grips and attachments shall be so constructed that they will move into alignment with the test specimens as soon as the load is applied, so that the long axis of the test specimen will coincide with the direction of the applied force through the centre line of the grip assembly to reduce bending moments. Non-alignment of specimens causes a non-homogeneous distribution of stresses. In addition, an inappropriate gripping system may cause failure of the test pieces at the ends and, consequently, a relevant dispersion of the results.

Ten specimens shall be tested under standard conditions of temperature and relative humidity (23±2°C, 50±5% RH).

Expression of results

The tested lap length l_{lap} [mm] shall be stated in the ETA.

The lap tensile strength σ_{lap} [MPa] for each single test shall be determined as:

$$\sigma_{lap} = P/A \quad (2.2.3.2)$$

Where P [N] is the load at failure and A [mm^2] is the cross-sectional area of the FRP laminate (see clause 3.4 of EN ISO 527-1).

The average (arithmetic mean) and characteristic value (according to equation (2.2.1)) of the lap tensile strength σ_{lap} [MPa] shall be determined and reported in the ETA.

2.2.4 Bond strength on substrates

Definition of materials for the reference substrates

- *Concrete*

  Concrete type MC (0,40) shall be prepared with the grit-blasted surface in accordance with EN 1766 (surface preparation according to clause 7 of EN 1766). With reference to EN 1766 Table 1, the choice of one or the other diameter/cement combination does not influence the test results. The 28-day mean concrete compressive strength $f_{c,sub}$ [MPa] shall be measured in accordance with EN 12390-3 as specified by EN 1766 and reported in the ETA. The average tensile bond strength of reference concrete $f_{h,sub}$ [MPa], determined by pull-off in accordance with EN 1542, shall also be determined as foreseen by EN 1766 and reported in the ETA.

- *Masonry (clay, tuff, mortar)*

  Masonry bricks shall be compliant with EN 771-1 (clay) and EN 771-6 (natural stones).

  In particular, clay bricks shall have an average compressive strength $f_{c,sub}$ [MPa] in the range 15-25 MPa. The average effective resistance shall be evaluated through at least six compression tests on cubic/cylindrical specimens of brick, of approximately 50 mm size/diameter (tolerances in accordance with EN 771-1, table 1), made of the brick thickness. The general procedure of EN 772-1 shall be followed.

  Natural stone bricks (tuff) shall have an average compressive strength $f_{c,sub}$ [MPa] in the range 4-12 MPa. The average effective resistance shall be evaluated through at least six compression tests on cubic specimens (EN 772-1), of approximately 150 mm size (tolerances in accordance with EN 771-6, table 1).

  The average tensile bond strength of the bricks $f_{h,sub}$ [MPa], determined by pull-off in accordance with EN 1542, shall also be determined and reported in the ETA.

  For the preparation of masonry wall specimens (see clause 2.2.4.2), a mortar with class not exceeding M5 in accordance with EN 998-2, table 1, shall be used.

- *Timber*

  Timber shall be compliant with class C30 in accordance with EN 338. Moisture content shall be less than 18% and shall be evaluated in accordance with EN 13183-1. The selected pieces shall be as free as possible from growth defects such as knots, splits, and checks.

  The average tensile bond strength of reference timber $f_{h,sub}$ [MPa], determined by pull-off in accordance with EN 1542, shall also be determined and reported in the ETA.

- *Steel*

  Mild steel shall be used for the bond strength tests.

2.2.4.1 Pull-off test

Purpose of the assessment

The test allows to determine the adhesive strength of FRP laminate bonded on different substrates. It determines the bond strength to the substrate or the tensile strength of either the overlay or substrate, whichever is weaker.

Assessment method

For tensile bond testing, the FRP laminate (A) shall be bonded through the bonding agent (B), i.e., epoxy primer (when present) (B1) and epoxy adhesive (B2), to the substrate according to the manufacturer's instructions. Specimens shall then be exposed to water, saltwater and alkali conditions for 1000 and 3000 hours in accordance with the procedures of 2.2.12, 2.2.13 and 2.2.14. Additional specimens shall be kept under standard conditions of temperature and relative humidity (23±2°C, 50±5% RH) as control specimens (unexposed specimens), in order to have 5 acceptable number of tests (see clause 7.6 of EN 1542 for validity of test results).

Specimens in ambient conditions (unexposed specimens) and after exposure to water, saltwater and alkali environments (1000 and 3000 hours) shall be tested following the general procedures of EN 1542 with the following deviations to take into account the different substrates:

- Concrete: prisms with 300 mm x 300 mm x 100 mm sizes (in accordance with EN 1542) and concrete type MC (0,40) (in accordance with EN 1766).

- Masonry: test shall be conducted on solid bricks. Dollies shall be bonded on the larger surface of the brick or natural stone leaving a distance from the axis of the dolly to the brick edges at least equal to the size of the dollies.

- Timber: test shall be conducted on prisms with minimum thickness of 45 mm. Dollies shall be bonded on the larger surface of the prism leaving a distance from the axis of the dolly to the prism edges at least equal to the size of the dollies.

- Steel: dollies shall be applied on solid steel plates with thickness at least equal to the thickness of the dolly (in accordance with EN 1542). Alternatively, the test shall be performed on the upper flange of an I-beam of similar geometry and with the dolly positioned immediately above the beam web.

At least 5 five bond tests shall be carried out for ambient (unexposed specimens) and for each exposure condition (water, saltwater and alkali) and time (1000 and 3000 h), in order to obtain (see Annex A):

- 5 test results on unexposed specimens;
- 30 test results on exposed specimens (5 x (water, saltwater, alkali) x (1000 h, 3000 h).

When a circular cut is not feasible, it shall be allowed to cut the substrate in a hexagonal geometry to circumscribe the disk used for testing. If the substrate is cut in a hexagonal geometry and failure occurs in the substrate, the area of hexagon shall be used for the bond area for determining the pull-off strength.

Expression of results

The failure mode shall be recorded for each individual test result in accordance with the indications of EN 1542.

The average (arithmetic mean) pull-off strength f_h [MPa] shall be stated in the ETA, together with the relative coefficient of variation V_X. The coefficient of variation V_X shall be calculated by using Formulae (D.2) and (D.3) of EN 1990. The compressive strength of the substrates $f_{c,sub}$ [MPa], calculated as indicated in clause "*Definition of materials for the reference substrates*", and the average tensile bond strength of the substrates $f_{h,sub}$ [MPa] in accordance with EN 1542, shall be stated in the ETA for concrete, masonry and timber. For

steel, the grade of steel in accordance with EN 10027-1 (with corresponding yield strength value f_{yk} [MPa] and ultimate strength value f_{uk} [MPa]) shall be stated in the ETA.

The percentage of mean tensile bond strength retained by exposed specimens with respect to control specimens (residual bond strength $f_{h,w,ret}$ [%], $f_{h,sw,ret}$ [%], and $f_{h,alk,ret}$ [%]) and the exposure conditions (duration) shall also be stated in the ETA.

The generic retained property X_{ret} [%] shall be determined by using the following expression:

$$X_{ret} = \frac{m_X^{exp}}{m_X^{unexp}} \cdot 100 \qquad (2.2.4.1.1)$$

where m_X^{exp} represents the average value of the property X assessed for the exposed specimens and m_X^{unexp} represents the average value of the property X assessed for the control specimens (unexposed specimens).

2.2.4.2 Single-lap shear test

Purpose of the assessment

The test allows to determine the shear bond strength of FRP kits adhesively applied to a flat substrate.

Assessment method

A minimum of thirty-five FRP specimens shall be prepared. The FRP laminate (A) shall be bonded through the bonding agent (B), i.e., epoxy primer (when present) (B1) and epoxy adhesive (B2), to the substrate according to the manufacturer's instructions. Thirty specimens shall then be exposed to water, saltwater and alkali conditions for 1000 and 3000 hours in accordance with the procedures of 2.2.12, 2.2.13 and 2.2.14. Five specimens shall be kept under standard conditions of temperature and relative humidity (23±2°C, 50±5% RH) as control specimens. The test shall follow the general procedure presented in Annex B.

Expression of results

The average (arithmetic mean) and characteristic value (according to equation (2.2.1)) of the peak load P_{max} [N] and the bond capacity P_{deb} [N] shall be stated in the ETA, together with the compressive strength of the substrates $f_{c,sub}$ [MPa], calculated as indicated in clause "*Definition of materials for the reference substrates*", and the average tensile bond strength of the substrates $f_{h,sub}$ [MPa] in accordance with EN 1542 (for concrete, masonry and timber), and the grade of steel in accordance with EN 10027-1 (with corresponding yield strength value f_{yk} [MPa] and ultimate strength value f_{uk} [MPa]).

The percentage of maximum load and bond capacity retained by exposed specimens with respect to control specimens ($P_{max,w,ret}$ [%], $P_{deb,w,ret}$ [%], $P_{max,sw,ret}$ [%], $P_{deb,sw,ret}$ [%], $P_{max,alk,ret}$ [%] and $P_{deb,alk,ret}$ [%]) and the exposure conditions (duration) shall also be stated in the ETA. These percentages shall be calculated on the basis of average results for the set of tested specimens according to equation (2.2.4.1.1).

2.2.5 Tensile strength after low number of cycles (seismic behaviour)

Purpose of the assessment

This test is performed to determine the laminate (A) behaviour under cyclic loading (seismic behaviour).

Assessment method

Five specimens shall be prepared in accordance with the procedure of clause 2.2.1.

Fifteen pulsating cycles at 1 Hz shall be applied on the specimens. The cyclic pulsating loads consist of a lower stress level equal to 5% of the respective characteristic short time tensile strength σ_b [MPa] (clause 2.2.1) and an upper stress level equal to 90% of the respective characteristic short time tensile strength σ_b [MPa]. If no failure occurs during the cycles, the specimens shall be tested in direct tension in accordance

with clause 2.2.1. Test shall be performed under standard conditions of temperature and relative humidity (23±2°C, 50±5% RH).

Expression of results

The minimum number of pulsating cycles n_{seism} causing failure shall be stated in the ETA or, if no failure occurs during the reference number of cycles (15), the average (arithmetic mean) and characteristic value (according to equation (2.2.1)) of the tensile strength (stress at break) $\sigma_{b,seism}$ [MPa], tensile modulus $E_{t,seism}$ [GPa] and tensile strain (strain at break) $\varepsilon_{b,seism}$ [mm/mm] shall be determined and stated in the ETA.

2.2.6 Tensile strength after high number of cycles (fatigue actions)

Purpose of the assessment

This test is performed to determine the laminate (A) behaviour under fatigue loading.

Assessment method

Five specimens shall be prepared in accordance with the procedure of clause 2.2.1 (tensile test specimens). Cyclic tests shall be performed in accordance with EAD 340352-00-0104 clause 2.2.6.

Test specimens reaching the limit number of cycles (2×10^6) without failure shall be tested in direct tension in accordance with 2.2.1. Test shall be performed under standard conditions of temperature and relative humidity (23±2°C, 50±5% RH).

Expression of results

The minimum number of cycles $n_{fatigue}$ causing failure shall be stated in the ETA or, if no failure occurs during the limit number of cycles (2×10^6), the average (arithmetic mean) and characteristic value (according to equation (2.2.1)) of the tensile strength (stress at break) $\sigma_{b,fatigue}$ [MPa], tensile modulus $E_{t,fatigue}$ [GPa] and tensile strain (strain at break) $\varepsilon_{b,fatigue}$ [mm/mm] shall be determined and stated in the ETA.

2.2.7 Glass transition temperature of pultrusion resin

Purpose of the assessment

This test is performed to determine the glass transition temperature of the pultrusion resin $T_{g,r}$ [°C], which can be considered as representative of the whole laminate behaviour.

Assessment method

Glass transition temperature of the pultrusion resin $T_{g,r}$ [°C] shall be evaluated on three specimens in accordance with EN ISO 11357-2, by using the DSC (Differential Scanning Calorimetry) method and by applying the “equal-areas method” (EN ISO 11357-2, clause 10.1.2). The specimen under test shall be in solid state.

The test shall be performed on specimens - in the form of flakes or fragments - taken from the laminate 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 (FRP) material.

Expression of results

The value $T_{g,r}$ [°C] shall be stated in the ETA and it represents the minimum among the values measured on the three specimens.

2.2.8 Glass transition temperature of bonding agent

Purpose of the assessment

This test is performed to determine the glass transition temperature of the bonding agent $T_{g,a}$ [°C] (all the components foreseen by clause 1.1, separately).

Assessment method

Glass transition temperature of the bonding agent shall be evaluated on three specimens in accordance with EN ISO 11357-2, by using the DSC (Differential Scanning Calorimetry) method. The specimen under test shall be in solid state. Glass transition temperature shall be determined on each component constituting the bonding agent (B) separately (epoxy primer (B1) and epoxy putty (B2) as indicated in clause 1.1).

The preparation of the specimens and the subsequent tests shall be carried out according to the following procedure:

1. a specimen shall be made by pouring the resin - within 5 minutes from mixing the reagents - in a cylindrical container with a diameter of 80 ± 20 mm up to a height of 8 ± 2 mm;

2. the specimen thus obtained, still inside the container, shall be subjected to a first conditioning cycle, lasting 48 hours in standard atmospheric conditions (23±2 °C and 50±5% RH);

3. a small cylindrical specimen of suitable dimensions shall be taken from the container by mechanical removal near the centre of the free surface, that is not in contact with the walls of the container;

4. on the small specimen thus obtained, a first heating cycle shall be carried out by using a heating rate of 10 °C/min. The glass transition temperature shall be determined by applying the “equal-areas method” in accordance with EN ISO 11357-2, clause 10.1.2. The so obtained value shall be referred to as $T_{g,1}$ (T_g of the 1st conditioning cycle);

5. the cylindrical specimen of point 2. shall then be subjected to a second conditioning cycle - lasting 24 hours - at a temperature of 45 ± 2 °C;

6. after the second conditioning cycle, a small specimen shall be extracted and the DSC is carried out again, by using a heating rate of 10 °C/min. A second value of the glass transition temperature shall therefore be determined by applying the “equal-areas method” in accordance with EN ISO 11357-2, clause 10.1.2. The so obtained value shall be referred to as $T_{g,2}$ (T_g of the 2nd conditioning cycle).

The above procedure shall be repeated on at least three different specimens. All values shall be recorded.

Expression of results

The value $T_{g,a}$ [°C] shall be stated in the ETA and is the minimum among the values of $T_{g,1}$ (1st conditioning cycle) measured on the three specimens for each component separately.

2.2.9 Creep behaviour

Purpose of the assessment

This test is performed to determine the laminate and bonding agent behaviour under sustained loading.

Assessment method

Creep test shall be performed on 5 specimens of laminate (A) and bonding agent (B) (separately) in accordance with the indications given in clause 2.2.8 of EAD 340352-00-0104.

Specimens shall be with sizes of 64 mm x 12 mm x laminate (or bonding agent in solid state) thickness h_f.

Tests shall be conducted under standard conditions of temperature and relative humidity (23±2°C, 50±5% RH) and at the maximum service temperature recommended by the manufacturer. If no temperature is

given, a value of ($T_{g,a}$−20°C) shall be considered, where $T_{g,a}$ is the glass transition temperature of the bonding agent in accordance with 2.2.8.

Expression of results

The deformation resulting from the permanent applied load shall be measured and represented as a function of time, with the following approximate time schedule:

- before applying the load;
- immediately after applying the load;
- after 1, 6, 12 and 30 min;
- after 1, 2, 5, 20, 50, 100, 200, 500, 700 and 1000 h;
- after the 1000 h, measurements shall be done every seven days (approximately 168 hours) until the test is completed at 3000 h (reference value).

If, for a specific specimen, failure occurs before the end of the 3000 hours, the time t_u (number of hours) and the last recorded deformation $\varepsilon_{b,creep}$ [mm/mm] at which failure occurs shall be stated in the ETA.

If no failure occurs during the permanent load, the average and relative standard deviation of the deformation $\varepsilon_{b,creep}$ [mm/mm] reached at the end of the examination period shall be recorded and stated in the ETA.

2.2.10 Creep behaviour related to the adhesion on substrates

Purpose of the assessment

This test is performed to determine the shear bond strength of the FRP laminate bonded to the substrate under sustained loading.

Assessment method

Five specimens shall be prepared for each substrate in accordance with the procedure of clause 2.2.4.2. Creep test shall then be performed in accordance with the indications given in clause 2.2.13 of EAD 340210-00-0104, and considering the test setup of Annex B.

Unlike referred to in Clause 2.2.13 of EAD 340210-00-0104, tests shall be conducted under standard conditions of temperature and relative humidity (23±2°C, 50±5% RH) and at the maximum service temperature recommended by the manufacturer (with 50±5% RH). If no temperature is given, a value of ($T_{g,a}$−20°C) shall be considered, where $T_{g,a}$ is the glass transition temperature of the bonding agent in accordance with 2.2.8.

Expression of results

The displacement of each FRP laminate relative to the substrate shall be measured and recorded:

- before applying the tensile load;
- immediately after applying the tensile load;
- start of the creep curve;
- after one day, two days and every seven days until the test is completed at six months (reference value).

The average (arithmetic mean) and characteristic value (according to equation (2.2.1)) of the maximum load $P_{max,creep}$ [N] and the bond capacity $P_{deb,creep}$ [N] shall be stated in the ETA, together with the test conditions (temperature and RH).

2.2.11 Freezing and thawing

Purpose of the assessment

This test is performed to evaluate the influence of freeze-thaw cycles on the behaviour of the FRP laminates (A).

Assessment method

Freezing and thawing cycles shall be conducted in accordance with the indications given in clause 2.2.6 of EAD 340210-00-0104 on both tension FRP laminate specimens (5 specimens made as indicated in clause 2.2.1) and interlaminar shear FRP specimens (5 specimens made as indicated in clause 2.2.2). After completion of the freeze-thaw cycles, exposed specimens shall be visually examined using 5× magnification to describe surface changes, such as erosion, cracking, crazing, checking, and chalking. Results of examinations shall be recorded. The specimens are left at standard conditions (23±2°C, 50±5% RH) for at least 24 h, at the end of which they shall be tested in direct tension in accordance with 2.2.1 and for interlaminar shear strength in accordance with the test described in 2.2.2.

Expression of results

Results of examinations obtained after freeze-thaw cycles shall be given in the ETA as description.

The average (arithmetic mean) and characteristic value (according to equation (2.2.1)) of the tensile strength (stress at break) $\sigma_{b,FT}$ [MPa], tensile modulus $E_{t,FT}$ [GPa], and tensile strain (strain at break) $\varepsilon_{b,FT}$ [mm/mm] and interlaminar shear strength τ_{FT} [MPa] shall be determined and stated in the ETA.

The percentage of average tensile properties ($\sigma_{b,FT,ret}$ [%], $E_{t,FT,ret}$ [%]) and interlaminar shear strength $\tau_{FT,ret}$ [%] retained by exposed specimens with respect to the value recorded for unexposed specimens (clauses 2.2.1 and 2.2.2) and the exposure conditions shall also be stated in the ETA. These percentages shall be calculated on the basis of average results for the set of tested specimens according to equation (2.2.4.1.1).

2.2.12 Water resistance

Purpose of the assessment

This test is performed to evaluate the influence of water on the behaviour of the FRP laminate (A).

Assessment method

Exposure to water shall be conducted in accordance with the indications given in Annex B of EAD 340352-00-0104. Tension FRP laminate specimens (10 specimens made as indicated in clause 2.2.1), interlaminar shear FRP specimens (10 specimens made as indicated in clause 2.2.2) and lap tensile specimens (10 specimens made as indicated in clause 2.2.3) shall be prepared and exposed to water for the reference time (5 specimens for each typology at 1000 h and 5 for each typology at 3000 h). Exposed specimens shall be then visually examined prior to testing using 5× magnification to describe surface changes, such as erosion, cracking, crazing, checking, and chalking. Results of examinations shall be recorded. The specimens are then left at standard conditions (23±2°C, 50±5% RH) for at least 24 h, at the end of which they shall be tested in direct tension in accordance with 2.2.1, for interlaminar shear strength in accordance with the procedure described in 2.2.2 and for lap tensile shear strength in accordance with 2.2.3.

Expression of results

Results of examinations after water exposure shall be given in the ETA as description.

The average (arithmetic mean) and characteristic value (according to equation (2.2.1)) of the tensile strength (stress at break) $\sigma_{b,w}$ [MPa], tensile modulus $E_{t,w}$ [GPa], tensile strain (strain at break) $\varepsilon_{b,w}$ [mm/mm], interlaminar shear strength τ_w [MPa] and lap tensile strength $\sigma_{lap,w}$ [MPa] shall be determined.

The percentage of average tensile properties ($\sigma_{b,w,ret}$ [%], $E_{t,w,ret}$ [%]), interlaminar shear strength $\tau_{w,ret}$ [%] and lap tensile shear strength $\sigma_{lap,w,ret}$ [%] retained by exposed specimens with respect to the value recorded for unexposed specimens (clauses 2.2.1, 2.2.2 and 2.2.3) and the exposure conditions (time) shall also be

stated in the ETA. These percentages shall be calculated on the basis of average results for the set of tested specimens according to equation (2.2.4.1.1).

2.2.13 Saltwater resistance

Purpose of the assessment

This test is performed to evaluate the influence of saltwater on the efficiency of the FRP laminate (A).

Assessment method

Exposure to saltwater shall be conducted in accordance with the indications given in Annex C of EAD 340352-00-0104. Tension FRP laminate specimens (10 specimens made as specified in clause 2.2.1), interlaminar shear FRP specimens (10 specimens made as specified in clause 2.2.2) and lap tensile specimens (10 specimens made as specified in clause 2.2.3) shall be prepared and exposed to saltwater for the reference time (5 specimens for each typology at 1000 h and 5 for each typology at 3000 h). Exposed specimens shall be visually examined prior to testing using 5× magnification to describe surface changes, such as erosion, cracking, crazing, checking, and chalking. Results of examinations shall be recorded. The specimens are then left at standard conditions (23±2°C, 50±5% RH) for at least 24 h, at the end of which they shall be tested in direct tension in accordance with 2.2.1, for interlaminar shear strength in accordance with the procedure described in 2.2.2 and for lap tensile strength in accordance with 2.2.3.

Expression of results

Results of examinations after saltwater exposure shall be given in the ETA as description.

The average (arithmetic mean) and characteristic value (according to equation (2.2.1)) of the tensile strength (stress at break) $\sigma_{b,sw}$ [MPa], tensile modulus $E_{t,sw}$ [GPa], tensile strain (strain at break) $\varepsilon_{b,sw}$ [mm/mm], interlaminar shear strength τ_{sw} [MPa] and lap tensile strength $\sigma_{lap,sw}$ [MPa] shall be determined and stated in the ETA.

The percentage of average tensile properties ($\sigma_{b,sw,ret}$ [%], $E_{t,sw,ret}$ [%]), interlaminar shear strength $\tau_{sw,ret}$ [%] and lap tensile shear strength $\sigma_{lap,sw,ret}$ [%] retained by exposed specimens with respect to the value recorded for unexposed specimens (clauses 2.2.1, 2.2.2 and 2.2.3) and the exposure conditions (time) shall also be stated in the ETA. These percentages shall be calculated on the basis of average results for the set of tested specimens according to equation (2.2.4.1.1).

2.2.14 Alkali resistance

Purpose of the assessment

This test is performed to evaluate the influence of alkali attack on the efficiency of the FRP laminate (A), by immerging specimens in a liquid with pH≥9,5.

Assessment method

Exposure to alkali shall be conducted according to the clause 2.2.9 of EAD 340210-00-0104 with the following modification: the composition of the alkaline solution consists of 118,5 g of $Ca(OH)_2$, 0,9 g of NaOH and 4,2 g of KOH in 1 litre of tap water. Tension FRP laminate specimens (10 specimens made as specified in clause 2.2.1), interlaminar shear FRP specimens (10 specimens made as specified in clause 2.2.2) and lap tensile specimens (10 specimens made as specified in clause 2.2.3) shall be prepared and exposed to the alkali environment for the reference time (5 specimens for each typology at 1000 h and 5 for each typology at 3000 h). Exposed specimens shall be visually examined prior to testing using 5× magnification to describe surface changes, such as erosion, cracking, crazing, checking, and chalking. Results of examinations shall be recorded. The specimens are then left at standard conditions (23±2°C, 50±5% RH) for at least 24 hours, at the end of which they shall be tested in direct tension in accordance with 2.2.1, for interlaminar shear strength in accordance with the procedure described in 2.2.2 and for lap tensile strength in accordance with 2.2.3.

Expression of results

Results of examinations after alkali exposure shall be given in the ETA as description.

The average (arithmetic mean) and characteristic value (according to equation (2.2.1)) of the tensile strength (stress at break) $\sigma_{b,alk}$ [MPa], tensile modulus $E_{t,alk}$ [GPa], tensile strain (strain at break) $\varepsilon_{b,alk}$ [mm/mm], interlaminar shear strength τ_{alk} [MPa] and lap tensile strength $\sigma_{lap,alk}$ [MPa] shall be determined and stated in the ETA.

The percentage of average tensile properties ($\sigma_{b,alk,ret}$ [%], $E_{t,alk,ret}$ [%]), interlaminar shear strength $\tau_{alk,ret}$ [%] and lap tensile shear strength $\sigma_{lap,alk,ret}$ [%] retained by exposed specimens with respect to the values recorded for unexposed specimens (clauses 2.2.1, 2.2.2 and 2.2.3) and the exposure conditions (time) shall also be stated in the ETA. These percentages shall be calculated on the basis of average results for the set of tested specimens according to equation (2.2.4.1.1).

2.2.15 Reaction to fire

Purpose of the assessment

This test shall be performed to evaluate the reaction to fire of the FRP kit.

Assessment method

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

1. *Preparation of specimens*

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

- Type of FRP laminate (A) (material, weight per meter);
- Type of bonding agent (B1, B2) (composition, thickness, weight per unit area);
- Weight per unit area of the resin in the FRP laminate (A);
- The Q_{PCS}-value (in accordance with EN ISO 1716) of laminate constituents (fibres, resins) and bonding agent (B1, B2).

Further indications are given in the following sub-clauses.

2. *Indications for mounting and fixing*

a) *EN ISO 1182 (Non-combustibility test)*

The cylindrical specimen shall be prepared by laying down a sufficient number of layers of FRP kit components, in the sequence foreseen by the manufacturer's instruction, in order to reach the height envisaged by EN ISO 1182, clause 5.1. A special mould (made of Teflon, Plexiglas or other easily disassembling material) shall be used to prepare the cylindrical specimen.
Only the components A and B2 of the FRP kit shall be considered for the preparation of specimens.

b) *EN ISO 1716 (Heat of combustion, Q_{PCS} -value)*

The test shall be performed separately on all homogeneous materials as defined in EN ISO 1716.
The combination of components and layers thicknesses leading to the highest gross heat of combustion of the FRP kit shall be identified. An example of calculation for kits is shown in EN 16724, Annex A.

c) *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 specimen of FRP kit shall be cut to the required length (250 ±2 mm) and width (90 ±2 mm) considering the FRP laminate (A) and the layers of bonding agent (B1, B2), following the indications given in the manufacturer's product installation instructions.

The specimens shall be prepared with:

- the materials of the FRP kit with the highest Q_{PCS}-value;
- the highest weight per unit area of the resin of the FRP laminate (A);
- the highest weight per unit area of epoxy primer (B1);
- the highest thickness of epoxy adhesive (B2).

Tests shall be performed with surface and edge exposure. Depending on the thickness of the entire configuration of the FRP kit, additional tests shall be conducted with edge exposure in every layer of specimens turned 90 ° on their vertical axis in accordance with clause 7.3.3.2.3 of EN ISO 11925-2.

d) 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 laminate (A) shall be bonded on one of the substrates foreseen by the EN 13238 through the bonding agent (B1 and B2) according to the indications of the manufacturer. The specimens shall be prepared with:

- the materials of the FRP kit with the highest Q_{PCS}-value;
- the highest weight per unit area of the resin of the FRP laminate (A);
- the highest weight per unit area of epoxy primer (B1);
- the highest thickness of epoxy adhesive (B2).

3. Extended application of test results

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

- with materials with the same or lower Q_{PCS}-value than those tested;
- with same or lower weight per unit area of the resin of the FRP laminate (A);
- with same or lower weight per unit area of epoxy primer (B1);
- with same or lower thickness of epoxy adhesive (B2).

Expression of results

The reaction to fire class shall be stated in the ETA, together with those conditions for which the classification is applicable.

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 1999/469/EC, as amended by Commission Decision 2001/596/EC.

The system is 2+.

In addition, with regard to reaction to fire for products covered by this EAD the applicable European legal act is Commission Decision 1999/469/EC, as amended by Commission Decision 2001/596/EC.

The systems are:

1 for A1, A2, B, C classes (Products/materials for which a clearly identifiable stage in the production process results in an improvement of the reaction to fire classification, e.g., an addition of fire retardants or a limiting of organic material).

3 for A1, A2, B, C classes (Products/Materials for which there is not a clearly identifiable stage in the production process resulting in an improvement of the reaction to fire classification) and D, E classes.

4 for A1 to E classes (Products/materials that do not require to be tested for reaction to fire, e.g., Products/materials of Classes A1 in accordance with Commission Decision 96/603/EC) and F class.

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.

The manufacturer (regarding the components he buys from the market with DoP) shall to take into account the Declaration of Performance issued by the manufacturer of that component. No retesting is necessary.

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	Dimensions of pultruded laminate (A)	According to the Control Plan	According to the Control Plan	According to tests or control methods	Every batch (*)
2	Weight per meter of pultruded laminate (A)	According to the Control Plan	According to the Control Plan	According to tests or control methods	Every batch (*)
3	Fibre content of pultruded laminate (A)	According to the Control Plan	According to the Control Plan	3 samples	Every six months
4	Tensile properties (strength and modulus) of pultruded laminate (A)	2.2.1	According to the Control Plan	3 samples	Every six months
5	Bond/adhesion strength considering each component of bonding agent (B1, B2)	According to the Control Plan	According to the Control Plan	According to tests or control methods	Every six months
6	Glass transition temperature on each component of bonding agent separately (B1, B2)	According to the Control Plan	According to the Control Plan	According to tests or control methods	Every year
(*) Batch: every quantity of material made in a single operation, or in the case of continuous production for a defined quantity (in linear meter or square meters or tons) which shall be demonstrated by the manufacturer to have a uniform composition and shall not exceed one day's production					

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 kit 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 components of the FRP kit.	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	Once per year

The intervention of the notified body under AVCP system 1 is only necessary for reaction to fire for products/materials for which a clearly identifiable stage in the production process results in an improvement of the reaction to fire classification (e.g., an addition of fire retardants or a limiting of organic material).

In this case the cornerstones of the tasks to be undertaken by the notified body under AVCP system 1 are laid down in Table 3.3.2.

Table 3.3.2 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 carried out by the manufacturer regarding the constancy of performance related to reaction to fire					
1	Where the intervention of the Notified Body is necessary only because the conditions for the applicability of system 1 are fulfilled for reaction to fire, the notified body will consider especially the clearly identifiable stage in the production process which results in an improvement of the reaction to fire classification (e.g., an addition of fire retardants or a limiting of organic material).	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 carried out by the manufacturer regarding the constancy of performance related to reaction to fire					
2	Where the intervention of the Notified Body is necessary only because the conditions for the applicability of system 1 in the Decisions regarding reaction to fire are fulfilled, the notified body will consider especially the clearly identifiable stage in the production process which results in an improvement of the reaction to fire classification (e.g., an addition of fire retardants or a limiting of organic material).	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	Once per year

4 REFERENCE DOCUMENTS

EAD 340210-00-0104	SRP (Steel Reinforced Polymer) kit made of steel micro-wires, fiberglass mesh and epoxy adhesive
EAD 340352-00-0104	Fibre Reinforced Polymer kit made of a carbon or glass fabric and an epoxy resin
EN 338:2016	Structural timber - Strength classes
EN 771-1:2011+A1:2015	Specification for masonry units - Part 1: Clay masonry units
EN 771-6:2011+A1:2015	Specification for masonry units - Part 6: Natural stone masonry units
EN 772-1:2011+A1:2015	Methods of test for masonry units – Part 1: Determination of compressive strength
EN 998-2:2016	Specification for mortar for masonry – Part 2: Masonry mortar
EN 1542:1999	Products and systems for the protection and repair of concrete structures - Test methods - Measurement of bond strength by pull-off
EN 1766:2017	Products and systems for the protection and repair of concrete structures - Test methods - Reference concretes for testing.
EN 1990:2023	Eurocode - Basis of structural design
EN 10027-1:2016	Designation systems for steels - Part 1: Steel names
EN 12390-3:2019	Testing hardened concrete - Part 3: Compressive strength of test specimens
EN 13183-1:2002 /AC:2003	Moisture content of a piece of sawn timber – Part 1: Determination by oven dry method
EN 13238:2010	Reaction to fire tests for building products - Conditioning procedures and general rules for selection of substrates
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 16724:2015	Thermal insulation products for building applications - Instructions for mounting and fixing for determination of the reaction to fire testing of external thermal Insulation composite systems (ETICS)
EN ISO 527-1:2019	Plastics - Determination of tensile properties - Part 1: General principles
EN ISO 527-4:2023	Plastics - Determination of tensile properties - Part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites
EN ISO 1182:2020	Reaction to fire tests for products - Non-combustibility test
EN ISO 1716:2018	Reaction to fire tests for products - Determination of the gross heat of combustion (calorific value)
EN ISO 8501-1:2007	Preparation of steel substrates before application of paints and related products — Visual assessment of surface cleanliness — Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings
EN ISO 11357-2:2020	Plastics - Differential scanning calorimetry (DSC) - Part 2: Determination of glass transition temperature and step height
EN ISO 11925-2:2020	Reaction to fire tests - Ignitability of products subjected to direct impingement of flame - Part 2: Single-flame source test
EN ISO 14130:1997	Fibre-reinforced plastic composites - Determination of apparent interlaminar shear strength by short-beam method

ANNEX A SUMMARY OF TESTS

	Essential characteristic	Relevant clause in EAD	Exposure conditions and times	Minimum number of specimens
Mechanical properties	Tensile properties	2.2.1	N/A(1)	15 (five specimens per 3 batches)
	Interlaminar shear strength	2.2.2	N/A(1)	20
	Lap tensile strength	2.2.3	N/A(1)	10
Interaction with substrate	Bond strength on substrate(1) – Pull-off	2.2.4.1	Ambient (unexposed specimens)	5
			Water (1000 and 3000 hrs)	10
			Saltwater (1000 and 3000 hrs)	10
			Alkali (1000 and 3000 hrs)	10
			TOTAL	**35**
	Bond strength on substrate(1) – Single lap shear	2.2.4.2	Ambient (unexposed specimens)	5
			Water (1000 and 3000 hrs)	10
			Saltwater (1000 and 3000 hrs)	10
			Alkali (1000 and 3000 hrs)	10
		2.2.10	Creep (sustained loading)	5
			TOTAL	**40**
Ageing	Freezing and Thawing	Direct tension (2.2.11 and 2.2.1)	20 freeze-thaw cycles (4 hours at -18±1°C followed by 12 hours >90% RH and 38±2°C)	5
		Interlaminar shear (2.2.11 and 2.2.2)	20 freeze-thaw cycles (4 hours at -18±1°C followed by 12 hours >90% RH and 38±2°C)	5
			TOTAL	**10**
	Water resistance	Direct tension (2.2.12 and 2.2.1)	1000 hours	5
			3000 hours	5
		Interlaminar shear (2.2.12 and 2.2.2)	1000 hours	5
			3000 hours	5
		Lap tensile strength (2.2.12 and 2.2.3)	1000 hours	5
			3000 hours	5
			TOTAL	**30**

	Essential characteristic	Relevant clause in EAD	Exposure conditions and times	Minimum number of specimens
	Saltwater resistance	Direct tension (2.2.13 and 2.2.1)	1000 hours	5
			3000 hours	5
		Interlaminar shear (2.2.13 and 2.2.2)	1000 hours	5
			3000 hours	5
		Lap tensile strength (2.2.13 and 2.2.3)	1000 hours	5
			3000 hours	5
			TOTAL	**30**
	Alkali resistance	Direct tension (2.2.14 and 2.2.1)	1000 hours	5
			3000 hours	5
		Interlaminar shear (2.2.14 and 2.2.2)	1000 hours	5
			3000 hours	5
		Lap tensile strength (2.2.14 and 2.2.3)	1000 hours	5
			3000 hours	5
			TOTAL	**30**
Cyclic loading	Tensile strength after low number of cycles (seismic behaviour)	2.2.5	N/A(1)	**5**
	Tensile strength after high number of cycles (fatigue actions)	2.2.6	N/A(1)	**5**
Physical properties	Glass transition temperature of the pultrusion resin	2.2.7	N/A(1)	**3**
	Glass transition temperature of the bonding agent	2.2.8	N/A(1)	**3**
	Creep behaviour of laminate and bonding agent	2.2.9	N/A(1)	**5**
Fire	Reaction to fire	2.2.15	In accordance with relevant standards	In accordance with relevant standards in connection with Commission Delegated Regulation (EU) No 2016/364

Notes:
(1) N/A= Not Applicable
(2) These tests shall be repeated for each substrate foreseen by the intended use of the product.

ANNEX B SINGLE-LAP SHEAR TEST

This test method describes the apparatus and procedure for evaluating the bond properties of FRP composite systems adhesively applied to a substrate.

B.1 Summary of test method

The direct single-lap shear test shall be conducted using a push-pull configuration, where the substrate prism with square or rectangular cross-section shall be restrained while the FRP laminate is pulled until failure.

B.2 Apparatus

Tests shall be conducted using a direct single-lap shear test set-up. The prism shall be restrained against movement by two steel plates placed against the square or rectangular end cross-sections of the prism. The bottom square plate shall be gripped to the testing machine. The top plate shall be a rectangular steel element connected to the bottom one through four steel bars bolted to the two plates.

The displacement and the applied load shall be recorded continuously during the test.

Slip measurement — Linear variable differential transducers (LVDTs) shall be mounted on the substrate surface close to the top edge of the bonded region to measure the displacement of the FRP plate with respect to the substrate (an example is shown in Figure B.2.1). The LVDTs (named LVDT a and b in Figure B.2.1) react off of a thin aluminium Ω-shaped plate bonded to the FRP laminate immediately outside the bonded length.

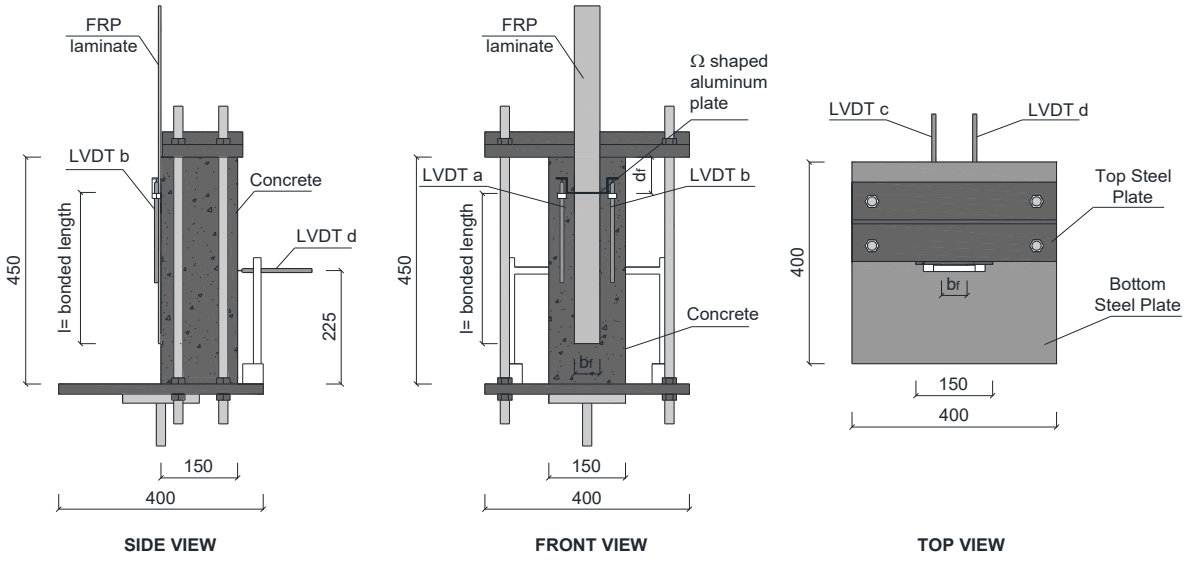


Figure B.2.1: Schematic of Suitable Apparatus for Direct Single-Lap Shear Test. Dimensions in mm.

Rotation measurement (optional) — Two optional LVDTs (named LVDT c and d in Figure B.2.1) can be used to monitor the horizontal displacement of the substrate in the direction perpendicular to the face of the FRP laminate. The LVDT c and d react off of the face of the substrate block parallel to the one to which the laminate shall be applied. The measurement point shall be approximately at half of the length of the substrate.

B.3 Test specimen

Concrete

The concrete test specimen shall conform to all requirements of EN 1766, considering an MC (0,40) concrete type. The dimensions of the concrete prism shall be 150 mm width × 150 mm depth × 450 mm length. Dimensions of the prism may be varied as long as the indicated dimensions are considered the minimum values admissible. The sides of the specimen shall be at right angles with the top and bottom. All surfaces shall be smooth and free of scars, indentations, holes, or inscribed identification marks. The prisms are reinforced on one face (neither the casting one nor the end cross-sections shall be used) with bonded FRP reinforcement. Because the formed faces of the concrete prism might have a different amount of aggregates near the surface, the position of the face used to apply the FRP laminate with respect to the casting one shall be clearly identified in the report.

Surface preparation of the specimen face that will receive the FRP system shall be according to the manufacturer's requirements of the FRP system being tested. Details of the surface preparation shall be recorded with the test data.

The distance d_f between the beginning of the bonded area and the top edge (at loaded end of the FRP laminate) of the concrete prism shall be 70±0.5 mm to avoid spalling of concrete. Bond breaking is easily accomplished using, for example, masking tape that covers the concrete surface from the top edge to the beginning of the bonded area.

Masonry

Test shall be performed on masonry made of bricks compliant with EN 771-1 (clay) or EN 771-6 (natural stone) (see clause 2.2.4 for details). Masonry shall be composed of layers of bricks so that the total length is at least 380 mm. In case of natural stone, the number of layers shall be comprised between 3 and 6. The thickness of the mortar shall be 10 mm. The width of the face where the reinforcement is applied shall be of at least 125 mm.

Surface preparation of the specimen face that will receive the FRP system shall be according to the manufacturer's requirements of the FRP system being tested. Details of the surface preparation shall be recorded with the test data.

The distance d_f between the beginning of the bonded area and the top edge (at loaded end of the FRP laminate) of the masonry element shall be 20±0.5 mm. Bond breaking is easily accomplished using, for example, masking tape that covers the masonry surface from the top edge to the beginning of the bonded area.

Timber

Timber specimens shall be 120 mm wide × 75 mm deep × 450 mm long. The selected pieces shall be as free as possible from growth defects such as knots, splits, and checks. In case of presence of annual growth rings, the FRP laminate (A) shall be applied on the side located farthest from the pith of the timber.

The surface of the timber shall be prepared as follows: (i) sanding with 120 grit sandpaper, and (ii) cleaning of the prepared surface by spraying with compressed air and then wiping with acetone. Sanding consists of sweeping the sandpaper back and forward 15 times along the longitudinal axis of the timber (i.e., direction of grain) and also at 45 degrees to the direction of grain.

The distance d_f between the beginning of the bonded area and the top edge (at loaded end of the FRP laminate) of the timber element shall be 20±0,5 mm. Bond breaking is easily accomplished using, for example, masking tape that covers the timber surface from the top edge to the beginning of the bonded area.

Steel

In order to minimize bending of the FRP test specimen, the test setup shall involve a rigid steel substrate. An example can be a steel block formed by welding two thick steel plates to two rectangular hollow sections. An example of dimensions is shown in Figure B.3.4. Another setup can be conveniently prepared to satisfy this requirement.

The test surface of the steel block shall be sandblasted and cleaned with a solvent (i.e., Acetone) or other chemical to remove any rust, residues and grease to enhance its bonding capability. The Sa 2½ (Very thorough blast cleaning) grade of blasting shall be used (EN ISO 8501-1).

FRP laminate

The FRP laminate applied to one face of the substrate specimen shall meet the following requirements as shown in Figure B.3.1 to Figure B.3.4 :

- The FRP system shall be applied according to the manufacturer's recommended procedure. The manufacturer's instructions shall be followed as to the elapsed time between FRP system application and testing.
- The width of the applied FRP laminate b_f shall be 50±0,5 mm. The FRP system shall be centred on the strengthened face of the substrate.
- The bonded length of the applied FRP laminate shall be 300±1 mm.
- The total length L_f of the FRP laminate shall be computed in accordance to Equation (B.3.1):

$$L_f = l + d_f + (300 \pm 1) \text{ mm} \qquad \text{(B.3.1)}$$

The overhang length may be reduced if the testing machine does not allow to fit long FRP strips, but shall not be less than 150 mm.

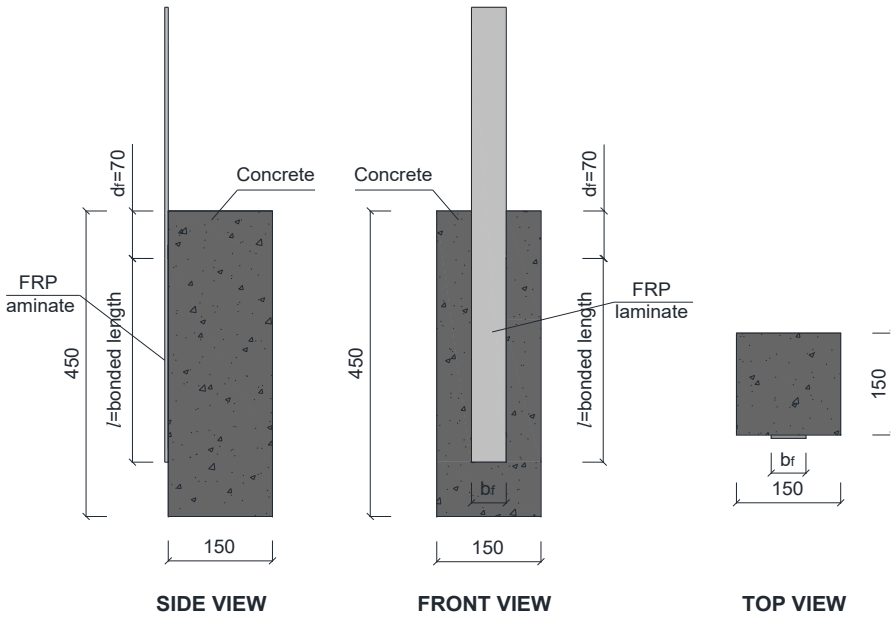


Figure B.3.1: Specimen Dimensions and Details of Bonded FRP system (FRP-to-concrete specimens). Dimensions in mm.

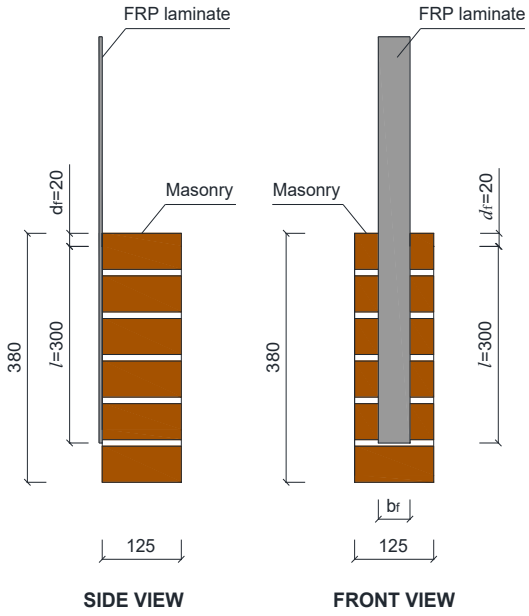


Figure B.3.2: Specimen Dimensions and Details of Bonded FRP system (FRP-to-masonry specimens). Dimensions in mm.

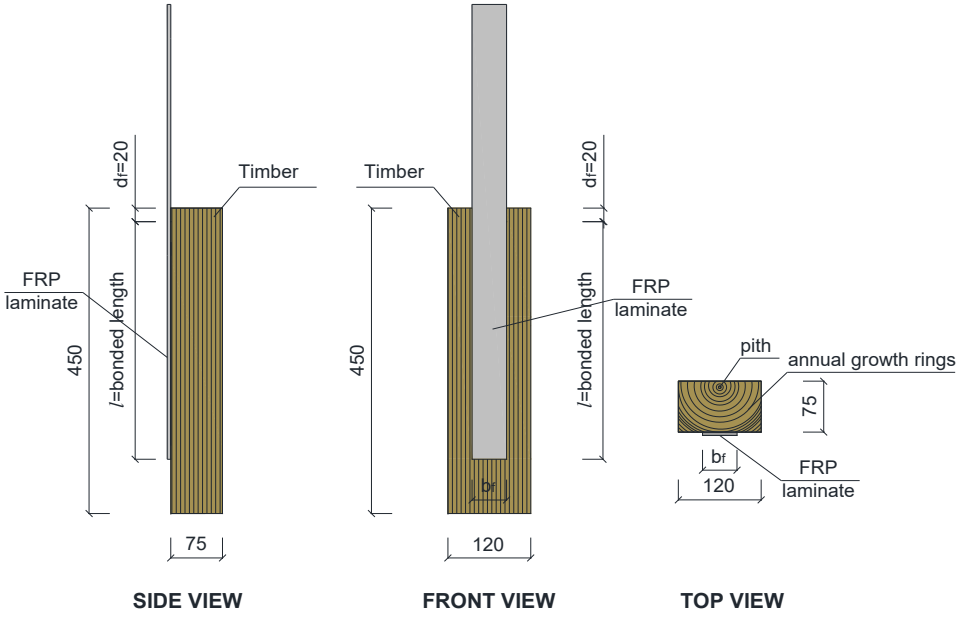


Figure B.3.3: Specimen Dimensions and Details of Bonded FRP system (FRP-to-timber specimens). Dimensions in mm.

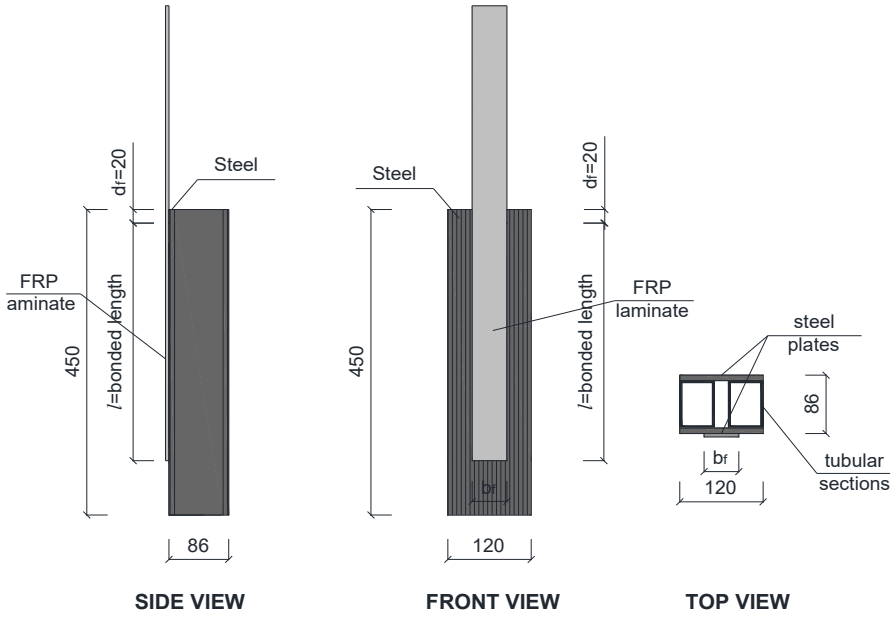


Figure B.3.4: Specimen Dimensions and Details of Bonded FRP system (FRP-to-steel specimens). Dimensions in mm.

B.4 Test procedure

1. The specimen shall be centred in order to have the FRP laminate perfectly aligned with the clamping wedge.

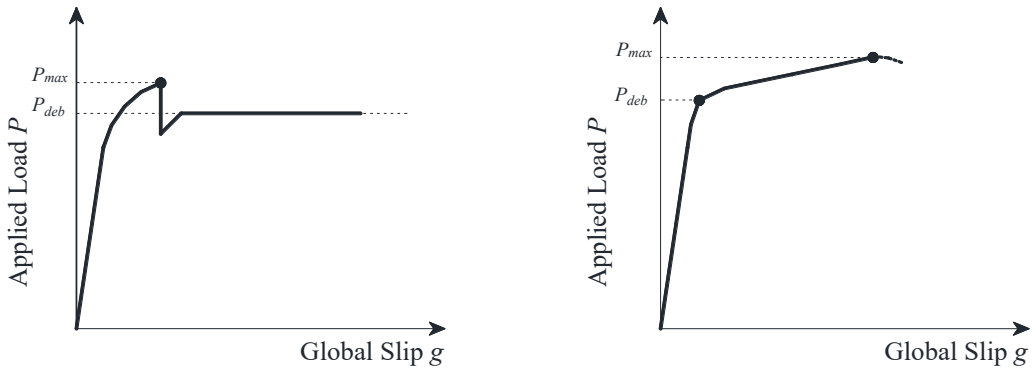
2. An initial pre-compression shall be applied to the support by tightening the bolts of the four steel bars used to connect the top and bottom plates. The total pre-compression force applied to the four steel bars shall be measured using a torque wrench. The total pre-compression shall be not greater than one fourth of the maximum applied load expected. In addition, the total force applied to the four steel bars divided by the cross-sectional area of the prism shall provide a stress that is lower or equal to one tenth of the compressive strength of substrate.

3. The loaded end of the laminate shall be clamped within the wedges of the testing machine. The position of the head of the machine shall be slowly adjusted so that no force is applied to the composite prior to testing when the FRP laminate is firmly clamped.

4. The FRP laminate shall be pulled in displacement control, increasing the displacement of the machine stroke continuously and without shock. The displacement shall be increased at a constant rate equal to 0,3 mm/min.

5. The test shall be performed in stroke until the FRP laminate completely detaches from the substrate.

6. The expected load response in terms of applied load versus global slip, g measured by LVDT a and b of Figure B.2.1, may vary as a function of the different substrates and allows to determine the maximum load P_{max} and the bond capacity P_{deb}. Some examples are shown in Figure B.4.1.



(a) (b)

Figure B.4.1: Examples of load-displacement curve.

B.5 Parameters to be recorded

At least the following information shall be recorded to the maximum extent applicable:

Test parameters

- Date of test, test temperature and relative humidity.
- Length of FRP laminate to the nearest 1 mm for each specimen.
- Width of FRP laminate to the nearest 1 mm for each specimen.
- Distance between the beginning of the bonded area and edge of substrate to the nearest 1 mm for each specimen.

Test results shall be provided for each test and average and statistics for specimen population

- Maximum applied force P_{max} in N for each specimen.
- Maximum measured displacement in mm for each specimen.
- Global slip measurement corresponding to the maximum applied force — the average measurement obtained from LVDTs a and b, named global slip, g, shall be calculated for each specimen.
- Out of plane displacement corresponding to the maximum applied force measurement — If LVDTs c and d are used, the obtained values shall be recorded for each specimen.
- The load-global slip response shall be recorded.
- Failure mode for each specimen.
- Bond capacity P_{deb} and coefficient of variation.
- Corrections made to data including test values omitted from calculated average and basis for omitting test values (such as failure mode). Note any other deviations from the procedure.