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European Assessment Document for

Kits for the strengthening of concrete elements by externally bonded carbon fibre reinforced polymer strips

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 No (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 kits for the strengthening of concrete elements by externally bonded carbon fibre reinforced polymer strips (in the following referred to as kits) consist at least of the following components:

A unidirectional carbon fibre reinforced polymer (CFRP) strips,

B structural bonding agent for CFRP strips according to EN 1504-4[1].

Furthermore, the kit may contain the following components:

C repair mortar with polymer binder (polymer concrete (PC)),

D bonding agent for the repair mortar, normal concrete or shotcrete (both not part of the kit),

E cleaning agent for the CFRP strips.

The assessment methods covered by this EAD are based on the assumption that the concrete surface is repaired before strengthening by externally bonded CFRP strips if the concrete surface which is to be strengthened

- is not level and/or
- does not meet a minimum value of bonding strength and/or
- has not enough concrete cover for the inner reinforcement.

Depending on the situation on site[2] this can be done by the repair mortar (component C), by normal concrete or shotcrete (all three optional part of the kit). In addition, with some kits it is necessary to apply a bonding agent (component D) to the concrete surface before using the repair mortar (component C), normal concrete or shotcrete so that better adhesion to the concrete of the element to be strengthened is ensured.

In some kits, a cleaning agent (component E) is also provided, which is used to clean the CFRP strips immediately before the adhesive is applied.

The CFRP strips are produced by pultrusion or broadband press method. The bonding between the fibres is realised by an epoxy resin.

The structural bonding agent (component B) is an epoxy resin optional filled with quartz sand. The repair mortar (component C) is polymer concrete. The structural bonding agent for the repair mortar (component D) is the same epoxy resin as used for the repair mortar itself (component C).

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 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.

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

2 If only small areas of the concrete surface show defects, the fast-curing repair mortar (component C) is generally used. For large-scale replacement of the concrete surface to be strengthened, it is generally more economical to use normal concrete or shotcrete.

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

1.2.1 Intended use(s)

The kits are used for strengthening the tensile area of concrete elements like beams, slabs, walls and columns. They are intended to contribute to the increase of the structural capacity for static, quasi-static and high fatigue loaded concrete elements according to the design rules.

If the concrete surface to be strengthened
- is level,
- has the minimum required bond strength and
- provides sufficient concrete cover of the inner reinforcement

it is possible to glue the CFRP strips directly onto the concrete surface according to the manufacturer´s product installation instructions (MPII) (see Figure 1.2.2, layer structure1).

If these conditions are not fulfilled the repair mortar (component C), normal concrete or shotcrete (both not part of the kit) is used to improve the concrete surface before gluing the CFRP strips to the repaired concrete surface according to the MPII.

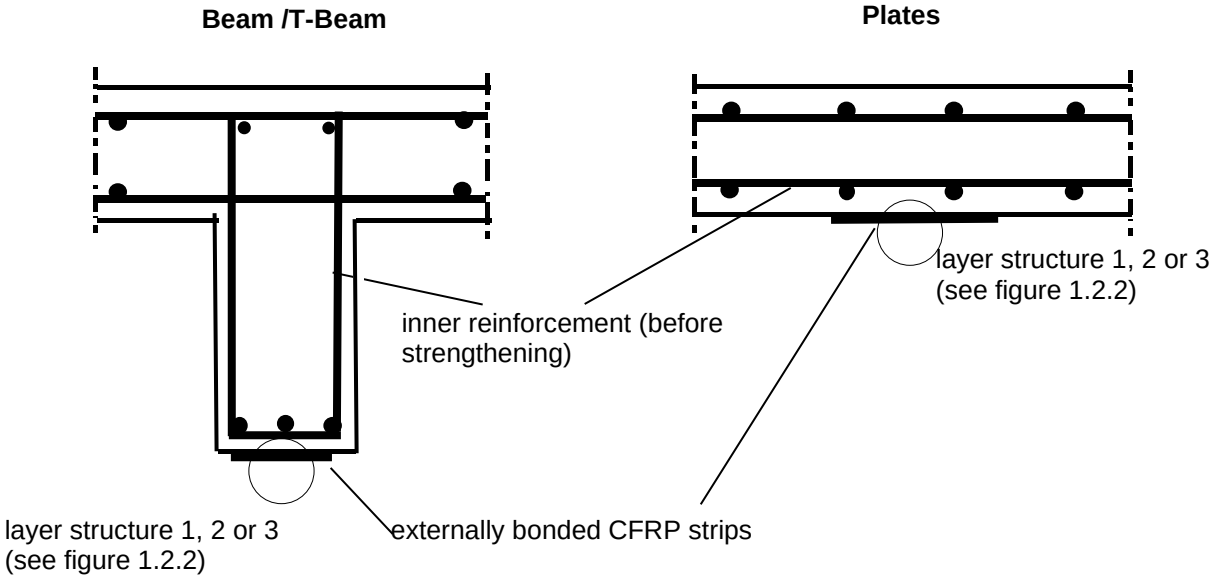

Figure 1.2.1: Principle sketches of reinforced concrete sections with subsequent strengthening by externally bonded CFRP strips

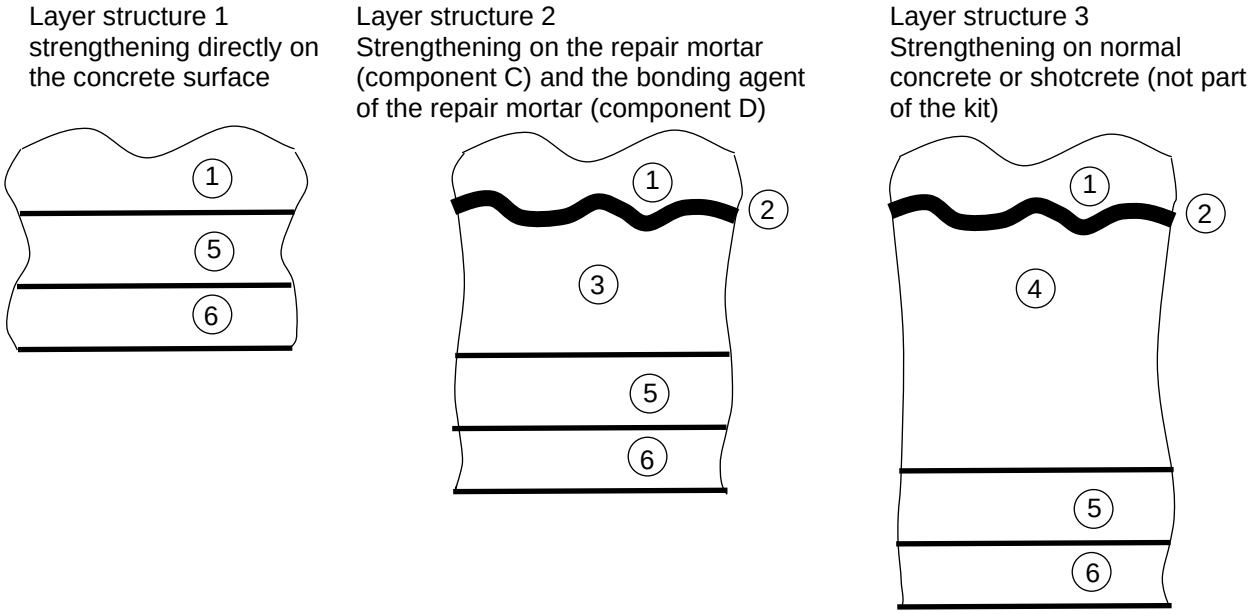

Figure 1.2.2: Principle sketches of possible layer structures with and without repair mortar as well as with normal concrete or shotcrete (both not part of the kit)

1 concrete of the element to be strengthened
2 if included in the kit layer of bonding agent (component D) for the repair mortar (component C) as well as for layers of normal concrete or shotcrete (both not part of the kit)
3 if included in the kit layer of repair mortar (component B) (minimum thickness $d_{\mathrm{M,min}}$ and maximum thickness $d_{\mathrm{M,max}}$)
4 layer of normal concrete or shotcrete (both not part of the kit)
5 layer of bonding agent (component B) (minimum thickness $d_{\mathrm{G,min}}$ and maximum thickness $d_{\mathrm{G,max}}$)
6 layer of CFRP strip

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 kits for the intended use of 25 years when installed in the works (provided that the kits are subject to appropriate installation and use (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[3].

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 Significant cross sections of one type of CFRP strips

If for one type of CFRP strips (see 1.3.3) more than one cross section exists, the significant cross sections are those with the smallest and the highest thickness, those with the smallest and highest

3 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.

width as well as those with the section of the highest ratio between circumference and cross-section area.

1.3.2 Smallest coil diameter of CFRP strips

CFRP strips are usually delivered on site in form of coils. The default value of the smallest inner coil diameter is 70 cm. The default value shall only be used if the manufacturer's product installation instructions (MPII) do not contain any other information.

1.3.3 Type of CFRP strips

A type of CFRP strips is characterised by the same production technology, the same fibres and size of fibres (see 1.3.7), the same fibre content and the same matrix material.

1.3.4 Standard environmental conditions in the assessment procedures

In the framework of this EAD standard environmental conditions are a temperature of $21 \pm 2\,°C$ and relative air humidity of (50 ± 10) %.

1.3.5 Minimum temperature of installation

The following terms are used in this document:

$T_{\mathrm{Gmin,a}}$, minimum temperature of installation of the structural bonding agent (component B),

$T_{\mathrm{Mmin,a}}$, minimum temperature of installation of the repair mortar (component C) and, if included in the kit, the bonding agent for the repair mortar (component D).

The default values for these temperatures are 8 °C. The default values shall only be used if the MPII do not contain any other information.

1.3.6 Minimum and maximum temperature for the intended use

The default values for the minimum and maximum temperature of the repair mortar (component C) and, if included in the kit, the bonding agent for the repair mortar (component D) as well as the bonding agent (component B) for the intended use is -10 °C and 40 °C. The default values shall only be used if the MPII do not contain any other information.

1.3.7 Size of fibres

During the spinning process the size is raised on the carbon fibres. It is a protective coating for the fibres of less than 100 nm of thickness and improves the bond of the fibres to the matrix materials of the CFRP strips. Mostly it consists of polymers.

1.3.8 Minimum and maximum thickness of layers of bonding agent (component B) and repair mortar (component C) and, if included in the kit, the bonding agent for the repair mortar (component D)

The default minimum and maximum thicknesses

- of the layers of bonding agent (component B) are $d_{\mathrm{G,min}}$ = 1 mm and $d_{\mathrm{G,max}}$ = 5 mm and
- of the repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) $d_{\mathrm{M,min}}$ = 5 mm and $d_{\mathrm{M,max}}$ = 30 mm.

The default values shall only be used if the MPII do not contain any other information.

1.3.9 Minimum curing time of the bonding agent (component B) and repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) at standard environmental conditions (1.3.4) and at minimum temperature of installation (see 1.3.5)

The default values for the minimum curing time of the bonding agent (component B) are t_{GTn}= 7 d at standard environmental conditions (1.3.4) and t_{GTmin} = 28 d at minimum temperature of installation (1.3.5). The default values shall only be used if the MPII do not contain any other information.

The default values for the minimum curing time of the repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) are t_{MTn} = 7 d at standard environmental conditions (1.3.4) and t_{MTmin} = 28 d at minimum temperature of installation (1.3.5). The default values shall only be used if the MPII do not contain any other information.

1.3.10 Minimum and maximum strength class of the concrete substrate

The default values for the minimum and maximum strength classes of the concrete substrate are C12/15 and C50/60. The default values shall only be used if the MPII do not contain any other information.

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 kits for the strengthening of concrete elements by externally bonded carbon fibre reinforced polymer strips 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	Glass transition temperature of the structural bonding agent (component B)	2.2.1	Level T_{Gg} [°C], t_{GTn}
2	Glass transition temperature of the repair mortar (component C)		Level T_{Mg} [°C], t_{MTn}
3	Flexural and compressive strength of the structural bonding agent (component B)	2.2.2	Level f_{Gfli}, f_{Gtflm}, f_{Gflk} [MPa] f_{Gci}, f_{Gcm}, f_{Gck} [MPa]
4	Flexural and compressive strength of the repair mortar (component C)		Level f_{Mfli}, f_{Mflm}, f_{Mflk} [MPa] f_{Mci}, f_{Mcm}, f_{Mck} [MPa]
5	Flexural and compressive strength of the structural bonding agent (component B) cured at minimum temperature of installation in dependence of curing time	2.2.3	Level f_{Gflij}, f_{Gflmj}, f_{Gflkj} [MPa] f_{Gcij}, f_{Gcmj}, f_{Gckj} [MPa]
6	Flexural and compressive strength of the repair mortar (component C) cured at minimum temperature of installation in dependence of curing time		Level f_{Mflij}, f_{Mflmj}, f_{Mflkj} [MPa] f_{Mcij}, f_{Mcmj}, f_{Mckj} [MPa]
7	Modulus of elasticity, tensile strength and strain at failure of CFRP strips (component A)	2.2.4	Level E_{Li}, E_{Lm} [MPa] f_{Li}, f_{Lm}, f_{Lk} [MPa] $\varepsilon_{\mathrm{Lui}}$, $\varepsilon_{\mathrm{Lum}}$ [mm/mm] If the manufacturer requests for: E_{fi}, E_{fm} [MPa] f_{fi}, f_{fm}, f_{fk}
8	Resistance of CFRP strips (component A) after storage in alkaline environment at maximum temperature according to the intended use (see 1.3.6)	2.2.5	Level E_{Lai} [MPa], f_{Lai} [MPa], $\varepsilon_{\mathrm{Luai}}$ [mm/mm] E_{Lam} [MPa], f_{Lam} [MPa], $\varepsilon_{\mathrm{Luam}}$ [mm/mm] R_{LEa}, $R_{\mathrm{L}f\mathrm{a}}$ and/or $R_{\mathrm{L}\varepsilon_{\mathrm{u}}\mathrm{a}}$
9	Resistance of CFRP strips (component A) in alkaline environment under long-term load at maximum temperature according to the intended use (see 1.3.6)	2.2.6	Level E_{Llti} [MPa], f_{Llti} [MPa], $\varepsilon_{\mathrm{Lulti}}$ [mm/mm] E_{Lltm} [MPa], f_{Lltm} [MPa], $\varepsilon_{\mathrm{Lultm}}$ [mm/mm] R_{LElt}, $R_{\mathrm{L}f\mathrm{lt}}$ and/or $R_{\mathrm{L}\varepsilon_{\mathrm{u}}\mathrm{lt}}$

No	Essential characteristic	Assessment method	Type of expression of product performance
10	Bond strength of specimens cured at standard environmental conditions (see 1.3.4)	2.2.7	Level and description compression strength class of the concrete substrate$f_{\mathrm{cti,surf}}$, $f_{\mathrm{ctm,surf}}$, $f_{\mathrm{ctk,surf}}$ failure mode according to EN 1542, clause 7.5
11	Bond strength after low-cycle fatigue action	2.2.8	Level and description compression strength class of the concrete substrate$f_{\mathrm{cti,surf,fat}}$, $f_{\mathrm{ctm,surf,fat}}$, $f_{\mathrm{ctk,surf,fat}}$, $R_{\mathrm{fat,m}}$ failure mode according to EN 1542, clause 7.5
12	Bond strength after long-term loading under harsh climatic conditions	2.2.9	Level and description compression strength class of the concrete substrate$f_{\mathrm{cti,surf,lt}}$ failure mode according to EN 1542, clause 7.5
13	Bond strength of specimens cured at minimum temperature of installation (see 1.3.5) depending on the curing time	2.2.10	Level and description compression strength class of the concrete substrate$f_{\mathrm{cti,surf,T_{min}}}$, $f_{\mathrm{ctm,surf,T_{min}}}$, $f_{\mathrm{ctk,surf,T_{min}}}$, $R_{\mathrm{T_{min},m}}$ failure mode according to EN 1542, clause 7.5
14	Shear resistance of the anchorage of CFRP strips externally bonded to concrete	2.2.11	Level and description $f_{\mathrm{ctim,surf}}$, $f_{\mathrm{ctik,surf}}$, f_{cm}, $f_{\mathrm{ck}}F_{\mathrm{bLi}}$, F_{bLm}, F_{bLk} [kN] failure mode according to EN 1542, clause 7.5
15	Fatigue behaviour of the anchorage of CFRP strips externally bonded to concrete	2.2.12	Level and description $f_{\mathrm{ctim,surf}}$, $f_{\mathrm{ctik,surf}}$, f_{cm}, $f_{\mathrm{ck}}$the cyclic load $\Delta F_{\mathrm{bLi}} = F^{u}_{\mathrm{bLi}} - F^{l}_{\mathrm{bLi}}$ and corresponding numbers of cycles
Basic Works Requirement 2: Safety in case of fire			
16	Reaction to fire of the applied kit	2.2.13	Class

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 characteristic in the Declaration of Performance, retesting of that component for issuing the ETA under the current EAD is not required.

The number of specimens to be tested necessary for specific assessment methods are given in respective clauses of this chapter. This information is also given as a summery in Annex A to facilitate the test planning.

2.2.1 Glass transition temperature of the structural bonding agent (component B) and the repair mortar (component C)

Purpose of the assessment
To identify the maximum temperature under which the kit functions according to its intended use (see 1.3.6) it is necessary to determine the glass transition temperature of the structural bonding agent (component B) T_{Gg} and the repair mortar (component C) T_{Mg} after curing under standard environmental conditions (see 1.3.4).

Assessment method
The basis for the tests is EN 12614. The glass transition temperature shall be determined on specimens of cured structural bonding agent (component B) and repair mortar (component C) from one batch of resin and hardener. The glass transition temperature shall only be measured during the first heating cycle; the heating speed shall be 10°C/min. The preparatory cycle of temperature according to EN 12614, clause 6.2, shall be omitted if it causes a change of the glass transition temperature.

The glass transition temperature shall be determined on at least two specimens of bonding agent (component B) which have cured at least for t_{GTn} (see 1.3.9) and on at least two specimens of repair mortar (component C) which have cured at least for t_{MTn} (see 1.3.9) under standard environmental conditions (see 1.3.4).

Expression of results
All measured glass transition temperatures of the structural bonding agent (component B) T_{Gg} together with the curing time t_{GTn} (see 1.3.9) and the repair mortar (component C) T_{Mg} together with the curing time t_{MTn} (see 1.3.9) shall be given in the ETA.

2.2.2 Flexural and compressive strength of the structural bonding agent (component B) and the repair mortar (component C)

Purpose of the assessment
These tests are intended to determine the relevant mechanical properties of the structural bonding agent (component B) and the repair mortar (component C) after curing under standard environmental conditions (see 1.3.4). This includes the flexural and compressive strength.

Assessment method
The flexural and compressive strength according to EN 196-1 (reference method) or EN 1015-11 of at least 3 specimens 160 mm x 40 mm x 40 mm (length x height x width) of cured structural bonding agent and repair mortar from one batch of resin and hardener shall be determined. The specimens shall cure at standard environmental conditions (see 1.3.4). At least 3 tests of the flexural strength according to EN 196-1, clause 9.1, or EN 1015-11, clause 8, and 6 tests of the compressive strength according to EN 196-1, clause 9.2, or EN 1015-11, clause 9, shall be carried out at standard environmental conditions (see 1.3.4).

Tests after curing of the bonding agent (component B) for t_{GTn} (see 1.3.9) and of the repair mortar (component C) for t_{MTn} (see 1.3.9) shall be carried out. In addition, based on the request of the manufacturer additional tests can be done after longer curing times.

Expression of results
From the failure loads of the bending tests with the specimens of structural bonding agent $F_{\mathrm{Gfl},i}$ and the specimens of repair mortar $F_{\mathrm{Mfl},i}$, the bending tensile strengths f_{Gfli} and f_{Mfli} shall be determined according to EN 196-1, clause 9.1, or EN 1015-11, clause 8. From these values, the mean values f_{Gflm} and f_{Mflm} as well as the 5% quantile value according to EN 1990, Table D.1 (V_{x} unknown), f_{Gflk} and f_{Mflk} shall be determined and given in the ETA.

From the failure loads of the compressive tests with the specimens of structural bonding agent $F_{\mathrm{Gc},i}$ and the specimens of repair mortar, $F_{\mathrm{Mc},i}$ the compressive strengths f_{Gci} and f_{Mci} shall be determined according to EN 196-1, clause 9.2, or EN 1015-11, clause 9. From these values, the mean value f_{Gcm} and f_{Mcm} as well as the 5% quantile value according to EN 1990, Table D.1 (V_{x} unknown), f_{Gck} and f_{Mck} shall be determined and given in the ETA.

2.2.3 Flexural and compressive strength of the structural bonding agent (component B) and the repair mortar (component C) cured at minimum temperature of installation depending on the curing time

Purpose of the assessment
These tests are intended to determine the flexural and compressive strength of the structural bonding agent (component B) and the repair mortar (component C) at minimum temperature of installation (see 1.3.5) depending on the curing time.

Assessment method
For different curing conditions regarding temperature and time the flexural and compression strength of cured specimens of bonding agent and repair mortar shall be determined according to 2.2.2. At least specimens of structural bonding agent (component B) cured at minimum temperature of installation $T_{\mathrm{Gmin,a}}$ [°C] (see 1.3.5) and specimens of repair mortar (component C) cured at minimum temperature of installation $T_{\mathrm{Mmin,a}}$ [°C] (see 1.3.5) shall be tested.

For each material, temperature and curing time at least 3 tests shall be carried out. The bending and compression test shall be carried out immediately after end of the curing time. For the bonding agent (component B) at least tests after curing for t_{GTmin} and 2 t_{GTmin} (see 1.3.9) and for the repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) at least tests after curing for t_{MTmin} and 2 t_{MTmin} (see 1.3.9) at the minimum temperature of installation $T_{\mathrm{Gmin,a}}$ and $T_{\mathrm{Mmin,a}}$ (see 1.3.5) shall be carried out.

Expression of results
From the failure loads of the bending tests "i" for the curing time "j" of structural bonding agent $F_{\mathrm{Gfl,ij}}$ and the specimens of repair mortar $F_{\mathrm{Mfl,ij}}$ the bending tensile strengths f_{Gflij} and f_{Mflj} shall be determined according to EN 196-1, clause 9.1, or EN 1015-11, clause 8 (reference method is EN 196-1). From these values, the mean value f_{Gflmj} and f_{Mflmj} as well as the 5% quantile value according to EN 1990, Table D.1 (V_x unknown), f_{Gflkj} and f_{Mflkj} shall be given in the ETA in conjunction with the used curing temperature and time.

From the failure loads of the compression tests "i" for the curing time "j" of the structural bonding agent $F_{\mathrm{Gc,ij}}$ and the specimens of repair mortar $F_{\mathrm{Mc,ij}}$ the bending compression strengths f_{Gcij} and f_{Mcij} shall be determined according to EN 196-1, clause 9.2, or EN 1015-11, clause 9. From these values, the mean value f_{Gcmj} and f_{Mcmj} as well as the 5% quantile value according to EN 1990, Table D.1 (V_x unknown), f_{Gckj} and f_{Mckj} shall be given in the ETA in conjunction with the used curing temperature and time.

2.2.4 Modulus of elasticity, tensile strength and strain at failure of CFRP strips (component A)

Purpose of the assessment
These tests are intended to determine the relevant mechanical properties of the CFRP strips (component A) according to EN 2561. This includes the modulus of elasticity, and the tensile strength, both related to the section of the CFRP strip and related to the fibre section as well as the ultimate strain of CFRP strips.

Assessment method
If the CFRP strips are supplied in coils, the samples for this test shall be taken from coils that have the smallest inner diameter (see 1.3.2). The tensile load at failure F_{Li} (called P_{R} in EN 2561, clause 7.2.7), the strains at 0,1 F_{Li} as well as at 0,5 F_{Li} and the strain at failure $\varepsilon_{\mathrm{Lui}}$ (called $(\varepsilon_{11})_{\mathrm{R}}$ in EN 2561, clause 7.2.7) of the CFRP strips shall be determined according to EN 2561, Annex A, with specimens type B. In deviation from EN 2561, Annex A, Table A.1, the thickness of the test specimens shall correspond to the thickness of the CFRP strips.

Tests shall be carried out at least on 5 specimens of the significant cross sections (see 1.3.1) of every type of CFRP strip (see 1.3.3).

Expression of results
According to EN 2561 it is only possible to measure failure loads F_{Li}, the strains $(\varepsilon_{\mathrm{Li}})_{\mathrm{A}}$ at 0,1 F_{Li} (called $(\varepsilon_{11})_{\mathrm{A}}$ in EN 2561, clauses 8.3 and 8.4), the strains $(\varepsilon_{\mathrm{Li}})_{\mathrm{B}}$ at 0,5 F_{Li} (called $(\varepsilon_{11})_{\mathrm{B}}$ in EN 2561, clauses 8.3 and 8.4) and the strains at failure $\varepsilon_{\mathrm{Lui}}$ (called $(\varepsilon_{11})_{\mathrm{R}}$ in EN 2561, clause 8.6). To determine strengths and secant moduli of elasticity from these test results there are two possibilities. For CFRP strips, it is customary to refer to the cross sections of the strips. But there might also be applications which refer to the cross sections of all fibres of the sections of CFRP strips.

Thus, the first possibility is to assess the strengths (called σ_{T11} in EN 2561, clause 8.1) as well as the moduli of elasticity related to the sections of the CFRP strips (called E_{T11} in EN 2561, clause 8.3). This is the reference method. The second possibility is to assess the strengths (called σ_f in EN 2561, clause 8.2) as well as the moduli of elasticity related to the sections of all fibres of the sections of CFRP strips (called E_f in EN 2561, clause 8.4).
To determine the strengths and moduli of elasticity related to the sections of CFRP strips the average value of the width b_{Lmi} and of the thickness t_{Lmi} of the specimens type B according to EN 2561, Annex A, shall be determined according to Annex C, C.2. The section of the specimens of the CFRP strips then shall be determined by $A_{Li} = b_{Lmi}t_{Lmi}$.
If requested by the manufacturer, the determination of strengths and moduli of elasticity related to the section of fibres the following sizes shall be determined for all tested CFRP strips[4]:

Before performing the strength test, the mass per meter length of the CFRP strip m_{Li} according to Annex C, C.1 of the test specimen to be used for the strength test shall be determined.

From another test specimen than to be used for the strength test but from the same batch

- the fibre content of mass W_{fi} according to EN 2564, clause 9.1, and
- the gross density of the fibres ρ_f shall be known from the MPII or shall be determined according to ISO 10119, method A.

The section of the fibres A_{fi} than shall be determined by $A_{fi} = \frac{m_{Li}W_{fi}}{\rho_f}$.

From the values F_{Li} the strength related to the section of the specimens of the CFRP strips shall be calculated by $f_{Li} = \frac{F_{Li}}{A_{fi,}}$ and the strength related to the fibre section by $f_{fi} = \frac{F_{Li}}{A_{fi,}}$.

From the values strains $(\varepsilon_{Li})_A$ and strains $(\varepsilon_{Li})_B$ the secant modulus of elasticity related to the section of the specimens of the CFRP strips shall be calculated by

$$E_{Li} = \frac{0{,}4F_{Li}}{(A_{Li}((\varepsilon_{Li})_B - (\varepsilon_{Li})_A))_,}$$

and the secant modulus of elasticity related to the fibre section by

$$E_{fi} = \frac{0{,}4F_{Li}}{(A_{fi}((\varepsilon_{Li})_B - (\varepsilon_{Li})_A))_,}$$

The average values of the secant modulus of elasticity E_{Lm}, of the tensile strengths f_{Lm} and of the ultimate strain ε_{Lum} and the 5% quantile value according to EN 1990, Table D.1 (V_x unknown), of tensile strengths f_{Lk} shall be given in the ETA for all types of CFRP strips (see 1.3.3).
If requested by the manufacturer E_{fm}, f_{fm} and f_{fk} also may be reported in the ETA.

2.2.5 Resistance of CFRP strips (component A) after storage in alkaline environment at maximum temperature according to the intended use

Purpose of the assessment
These tests are intended to determine the change of the mechanical properties of the CFRP strips (component A) according to 2.2.4 after long-time storage in alkaline environment at maximum temperature according to the intended use (see 1.3.6). This includes the change of the secant modulus of elasticity, tensile strength and ultimate strain of the CFRP strips[5].

Assessment method
If the CFRP strips are supplied in coils, the samples for this test shall be taken from coils that have the smallest inner diameter (see 1.3.2).

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4 The strength, secant modulus of elasticity and elongation at break of the CFRP strips depend on the composition. This is clearly characterized by the fiber content of mass according to EN 2564, the mass per meter of the CFRP strips according to Annex C, C.1 and the dimensions of the CFRP strips according to Annex C, C.2. Since CFRP strips after the strength tests are destroyed, the dimensions and the mass per meter of the specimens tested here shall be determined before the strength tests. Since the determination of the fiber content of mass also leads to the destruction of the test specimens, it shall be determined on specimens which come from the same batch as the corresponding specimens from the strength tests.

5 In comparison to 2.2.4 the secant modulus of elasticity and the tensile strength is only related to the cross section of the CFRP strips and not to the cross section of all fibres of the CFRP strips.

At least in one of the following alkaline solutions the CFRP strips shall be stored at maximum temperature at intended use (see 1.3.6) for at least 1800 h:

alkaline solution > pH 9.0,

alkaline solution > pH 11.0,

alkaline solution > pH 13.7.

The composition of the solutions is given in Annex D.

After this storage the specimens shall be washed and dried for 24 h at standard environmental conditions (see 1.3.4). Afterwards the tensile load at failure F_{Lai} (called P_{R} in EN 2561, clause 7.2.7), the strains at 0,1 F_{Lai} as well as at 0,5 F_{Lai} and the strain at failure $\varepsilon_{\mathrm{Lui}}$ (called $(\varepsilon_{11})_{\mathrm{R}}$ in EN 2561, clause 7.2.7) of the CFRP strips shall be determined according to EN 2561, Annex A, with specimens type B. In deviation from EN 2561, Annex A, Table A.1, the thickness of the test specimens shall correspond to the thickness of the CFRP strips.

Tests shall be carried out at least on 5 specimens of CFRP strips for at least one thickness per type of CFRP strips (see 1.3.3). It shall be the section with the highest ratio between circumference and cross-section area among all the sections of this type of CFRP strips (see 1.3.3).

Expression of results

According to EN 2561 it is only possible to measure failure loads F_{Lai}, the strains $(\varepsilon_{\mathrm{Li}})_{\mathrm{A}}$ at 0,1 F_{Li} (called $(\varepsilon_{11})_{\mathrm{A}}$ in EN 2561, clauses 8.3 and 8.4), the strains $(\varepsilon_{\mathrm{Li}})_{\mathrm{B}}$ at 0,5 F_{Lai} (called $(\varepsilon_{11})_{\mathrm{B}}$ in EN 2561, clauses 8.3 and 8.4) and the strains at failure $\varepsilon_{\mathrm{Lui}}$ (called $(\varepsilon_{11})_{\mathrm{R}}$ in EN 2561, clause 8.6). To determine strengths and secant moduli of elasticity from these test results there are two possibilities according to EN 2561. In contrast to 2.2.4, only the strengths related to the sections of the CFRP strips (called σ_{T11} in EN 2561, clause 8.1) as well as the moduli of elasticity related to the sections of the CFRP strips (called E_{T11} in EN 2561, clause 8.3) shall be determined.

To determine the strengths and moduli of elasticity related to the sections of CFRP strips the average value of the width b_{Lmi} and of the thickness t_{Lmi} of the specimens "i" type B according to EN 2561, Annex A, shall be determined[6]according to Annex C, C.2. The section of the specimens of the CFRP strips than shall be determined by $A_{\mathrm{Li}} = b_{\mathrm{Lmi}} t_{\mathrm{Lmi}}$.

From the values F_{Lai} the strength related to the section of the specimens of the CFRP strips shall be calculated by $f_{\mathrm{Lai}} = \frac{F_{\mathrm{Lai}}}{A_{\mathrm{fi}}}$.

From the values strains $(\varepsilon_{\mathrm{Li}})_{\mathrm{A}}$ and strains $(\varepsilon_{\mathrm{Li}})_{\mathrm{B}}$ the secant modulus of elasticity related to the section of the specimens of the CFRP strips shall be calculated by

$$E_{\mathrm{Lai}} = \frac{0{,}4F_{\mathrm{Lai}}}{(A_{\mathrm{Li}}((\varepsilon_{\mathrm{Li}})_B - (\varepsilon_{\mathrm{Li}})_A))}$$

From the single values E_{Lai}, f_{Lai} and $\varepsilon_{\mathrm{Lai}}$ the average values E_{Lam}, f_{Lam} and $\varepsilon_{\mathrm{Luam}}$ as well as the ratios R_{LEa}, R_{Lfa} and $R_{\mathrm{L\varepsilon_u a}}$ shall be determined as follows:

$R_{\mathrm{LEa}} = \frac{E_{\mathrm{Lam}}}{E_{\mathrm{Lm}}}$ $R_{\mathrm{L}f\mathrm{a}} = \frac{f_{\mathrm{Lam}}}{f_{\mathrm{Lm}}}$ $R_{\mathrm{L\varepsilon_u a}} = \frac{\varepsilon_{\mathrm{Luam}}}{\varepsilon_{\mathrm{Lum}}}$ where:

E_{Lam}, f_{Lam}, $\varepsilon_{\mathrm{Luam}}$ are the average Modulus of elasticity, tensile strength and ultimate strain after storage in alkaline solution

E_{Lm}, f_{Lm}, $\varepsilon_{\mathrm{Lum}}$ are the average Modulus of elasticity, tensile strength and ultimate strain according to 2.2.4

The values R_{LEa}, $R_{\mathrm{L}f\mathrm{a}}$ and $R_{\mathrm{L\varepsilon_u a}}$ shall be given in the ETA for all types (see 1.3.3) of CFRP strips and all applied alkaline solutions (pH 9 and/or 11 and/or 13,7) used for the tests.

6 The strength, secant modulus of elasticity of the CFRP strips are related to the section of the CFRP strips. Since CFRP strips after the strength tests are destroyed, the dimensions of the specimens tested here shall be determined before the strength tests.

2.2.6 Resistance of CFRP strips (component A) in alkaline environment under long-term load at maximum temperature at intended use

Purpose of the assessment
These tests are intended to determine the change of the mechanical properties of the CFRP strips (component A) according to 2.2.4 after long-time loading in alkaline environment at maximum temperature according to the intended use (see 1.3.6). This includes the change of the secant modulus of elasticity, of the tensile strength and of the ultimate strain of the CFRP strips[5].

Assessment method
If the CFRP strips are supplied in coils, the samples for this test shall be taken from coils that have the smallest inner diameter (see 1.3.2).

At least in one of the following alkaline solutions the CFRP strips shall be stored at maximum temperature at intended use (see 1.3.6) and stressed with 50% of the characteristic value of tensile strength according to 2.2.4 for at least 1800 h:

alkaline solution >pH 9.0,
alkaline solution >pH 11.0,
alkaline solution >pH 13.7.

The composition of the solutions is given in Annex D.
After this storage under loading the specimens shall be washed and dried for 24 h at standard environmental conditions (see 1.3.4). Afterwards the tensile load at failure F_{Llti} (called P_{R} in EN 2561, 7.2.7), the strains at 0,1 F_{Llti} as well as at 0,5 F_{Llti} and the strain at failure $\varepsilon_{\mathrm{Lui}}$ (called $(\varepsilon_{11})_{\mathrm{R}}$ in EN 2561, 7.2.7) of the CFRP strips shall be determined according to EN 2561, Annex A, with specimens type B. In deviation from EN 2561, Annex A, Table A.1, the thickness of the test specimens shall correspond to the thickness of the CFRP strips.
Tests shall be carried out at least on 5 specimens of CFRP strips for at least one thickness per type of CFRP strips (see 1.3.3). It shall be the section with the highest ratio between circumference and cross-section area among all the sections of this type of CFRP strips (see 1.3.3).

Expression of results
According to EN 2561 it is only possible to measure failure loads F_{Llti}, the strains $(\varepsilon_{\mathrm{Li}})_{\mathrm{A}}$ at 0,1 F_{Llti} (called $(\varepsilon_{11})_{\mathrm{A}}$ in EN 2561, clauses 8.3 and 8.4), the strains $(\varepsilon_{\mathrm{Li}})_{\mathrm{B}}$ at 0,5 F_{Llti} (called $(\varepsilon_{11})_{\mathrm{B}}$ in EN 2561, clauses 8.3 and 8.4) and the strains at failure $\varepsilon_{\mathrm{Lui}}$ (called $(\varepsilon_{11})_{\mathrm{R}}$ in EN 2561, clause 8.6). To determine strengths and secant moduli of elasticity from these test results there are two possibilities according to EN 2561. In contrast to 2.2.4, only the strengths related to the cross section of the CFRP strips (called σ_{T11} in EN 2561, clause 8.1) as well as the moduli of elasticity related to the sections of the CFRP strips (called E_{T11} in EN 2561, clause 8.3) and not to the cross section of all fibres of the CFRP strips shall be determined.
To determine the strengths and moduli of elasticity related to the sections of CFRP strips the average value of the width b_{Lmi} and of the thickness t_{Lmi} of the specimens "i" type B according to EN 2561, Annex A, shall be determined[6]according to Annex C, C.2. The section of the specimens of CFRP strips then shall be determined by $A_{\mathrm{Li}} = b_{\mathrm{Lmi}} t_{\mathrm{Lmi}}$.
From the values F_{Llti} the strength related to the section of the specimens of the CFRP strips shall be calculated by $f_{\mathrm{Llti}} = \frac{F_{\mathrm{Llti}}}{A_{\mathrm{fi}}}$.

From the values strains $(\varepsilon_{\mathrm{Li}})_{\mathrm{A}}$ and strains $(\varepsilon_{\mathrm{Li}})_{\mathrm{B}}$ the secant modulus of elasticity related to the section of the specimens of the CFRP strips shall be calculated by

$$E_{\mathrm{Llti}} = \frac{0{,}4F_{\mathrm{Llti}}}{(A_{\mathrm{Li}}((\varepsilon_{\mathrm{Li}})_B - (\varepsilon_{\mathrm{Li}})_A))}$$

From the single values $E_{\mathrm{Llt}i}$, $f_{\mathrm{Llt}i}$ and $\varepsilon_{\mathrm{Llt}i}$ the average values E_{Lltm}, f_{Lltm} and $\varepsilon_{\mathrm{Lultm}}$ as well as the ratios R_{LElt}, $R_{\mathrm{L}f\mathrm{lt}}$ and $R_{\mathrm{L}\varepsilon_{\mathrm{u}}\mathrm{lt}}$ shall be determined as follows:

$R_{\mathrm{LElt}} = \frac{E_{\mathrm{Lltm}}}{E_{\mathrm{Lm}}}$ $R_{\mathrm{L}f\mathrm{lt}} = \frac{f_{\mathrm{Lltm}}}{f_{\mathrm{Lm}}}$ $R_{\mathrm{L}\varepsilon_{\mathrm{u}}\mathrm{lt}} = \frac{\varepsilon_{\mathrm{Lultm}}}{\varepsilon_{\mathrm{Lum}}}$ where:

E_{Lltm}, f_{Lltm}, $\varepsilon_{\mathrm{Lultm}}$ are the average Modulus of elasticity, tensile strength and ultimate strain after storage in alkaline solution

E_{Lm}, f_{Lm}, $\varepsilon_{\mathrm{Lum}}$ are the average Modulus of elasticity, tensile strength and ultimate strain according to 2.2.4

The values R_{LElt}, $R_{\mathrm{L}f\mathrm{lt}}$ and $R_{\mathrm{L}\varepsilon_{\mathrm{u}}\mathrm{lt}}$ shall be given in the ETA for all types (see 1.3.3) of CFRP strips and all applied alkaline solutions (pH 9 and/or 11 and/or 13,7) used for the tests.

2.2.7 Bond strength of specimens cured at standard environmental conditions

Purpose of the assessment
The tests are performed to determine the bond strength of the following specimens:

- specimens with layers of concrete, repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D)), bonding agent (component B) and CFRP strips (component A),
- specimens with layers of concrete, bonding agent (component B) and CFRP strips (component A).

The bond strength shall be determined by pull-off tests according to EN 1542 after curing under standard conditions (see 1.3.4).

Assessment method
If the CFRP strips are supplied in coils, the samples for this test shall be taken from coils that have the smallest inner diameter (see 1.3.2).
The test is based on EN 1542. The differences to EN 1542 are the following:

- only steel dollies according to EN 1542, clause 4.7, are used, not dollies of aluminium,
- the bonding agent (component B) may be used also for the bonding of the steel dollies
- the thickness of the layers of bonding agent (also for the dollies) is $d_{\mathrm{G,min}}$ (see 1.3.8).

The preparation of the specimens with repair mortar shall be done as indicated in Annex E, clause E.1.

- After curing of the repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) and the bonding agent (component B) according to the MPII and safety information at standard environmental conditions (see 1.3.4) at least 5 annular grooves of 50 mm diameter shall be drilled through the multilayer specimen until a depth of 15 ± 5 mm in the reference concrete is reached (see Figure 2.2.7.2). If the width of the bonded CFRP strips is less than 50 mm, the ring grooves shall be arranged in the floor plan in such a way that a joint goes through the centre of the circle.

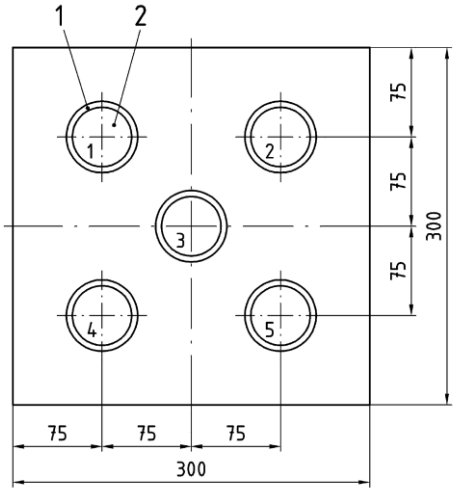


Figure 2.2.7.2: Top view on the test specimen with annular grooves showing the areas of the steel dollies
1 groove made by core drilling around the test surface
2 steel dolly with diameter of 50 mm

The preparation of the specimens without repair mortar shall be done as indicated in Annex E, clause E.2.

- After curing of the bonding agent (component B) according to the MPII and safety information at standard environmental conditions (see 1.3.4) at least 5 annular grooves of 50 mm diameter shall be drilled through the multilayer specimen until a depth of 15 ± 5 mm in the reference concrete is reached (see Figure 2.2.7.2). If the width of the bonded CFRP strips is less than 50 mm, the ring

grooves shall be arranged in the floor plan in such a way that a joint goes through the centre of the circle.

The further treatment is the same for the test specimens with and without repair mortar:

- On each annular groove a dolly according to EN 1542, clause 7.2, shall be glued on the circular surfaces with the structural bonding agent (component B). The–minimum thickness of the layer $d_{\mathrm{G,min}}$**Error! Bookmark not defined.** (see 1.3.8) of bonding agent shall be used.
- The structural bonding agent (component B) of the dollies shall cure according to the MPII and safety information at standard environmental conditions (see 1.3.4) before testing.
- Afterwards the bond strength $f_{\mathrm{cti,surf}}$ shall be determined on each annular groove of the specimens with and without repair mortar according to EN 1542, clause 7.4, at standard environmental conditions (see 1.3.4).

The bond strength shall be determined on at least 5 annular grooves with and without repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) for every type of CFRP strip.

Expression of results

The bond strengths $f_{\mathrm{cti,surf}}$ and the failure modes according to EN 1542, clause 7.5, for all specimens shall be determined for further comparison with the results according to 2.2.8 to 2.2.10. From the values $f_{\mathrm{cti,surf}}$ the average value of the bond strength $f_{\mathrm{ctm,surf}}$ and the 5% quantile value according to EN 1990, Table D.1 (V_x unknown), $f_{\mathrm{ctk,surf}}$ of tensile strength shall be determined. The values $f_{\mathrm{cti,surf}}$, $f_{\mathrm{ctm,surf}}$, $f_{\mathrm{ctk,surf}}$, the curing time of the repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) as well as of the bonding agent (component B) and the failure modes shall be reported in the ETA.

2.2.8 Bond strength after low-cycle fatigue action

Purpose of the assessment

The tests are performed to determine the bond strength of the following specimens:

- specimens with layers of concrete, repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D), bonding agent (component B) and CFRP strips (component A),
- specimens with layers of concrete, bonding agent (component B) and CFRP strips (component A).

The bond strength shall be determined by pull-off test according to EN 1542 after curing under standard conditions (see 1.3.4) and low-cycle fatigue action.

Assessment method

If the CFRP strips are supplied in coils, the samples for this test shall be taken from coils that have the smallest inner diameter (see 1.3.2).

The test is based on EN 1542. The differences to EN 1542 are the following:

- only steel dollies according to EN 1542, clause 4.7, are used, not dollies of aluminium,
- the bonding agent (component B) may be used also for the bonding of the steel dollies,
- the thickness of the layers of bonding agent (also for the dollies) is $d_{\mathrm{G,min}}$ (see 1.3.8),
- the test specimens are circular cylinders which are drilled from specimens according to EN 1542, Figure 1 (or Figure 2.2.8.2 of this EAD)[7],
- on both circular surfaces of these cylinders are glued dollies according to EN 1542, clause 7.2.

The preparation of the specimens with repair mortar shall be done as indicated in Annex E, clause E.1.

- After curing of the repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) and the bonding agent (component B) according to the MPII and safety information at standard environmental conditions (see 1.3.4) at least 5 cylinders of 50 mm diameter shall be drilled through the entire multilayer specimen (see Figure 2.2.8.2). If the width of

7 There are not only drilled grooves with a depth of 15 mm, but core holes through the different layers and the entire thickness of the reference concrete of 100 mm (see Figure 2.2.8.1) so that 5 individual cylinders are created. The cylinders shall only be tested if dollies are glued on both circular surfaces.

the bonded CFRP strips is less than 50 mm, the ring grooves shall be arranged in the floor plan in such a way that a joint goes through the centre of the circle.

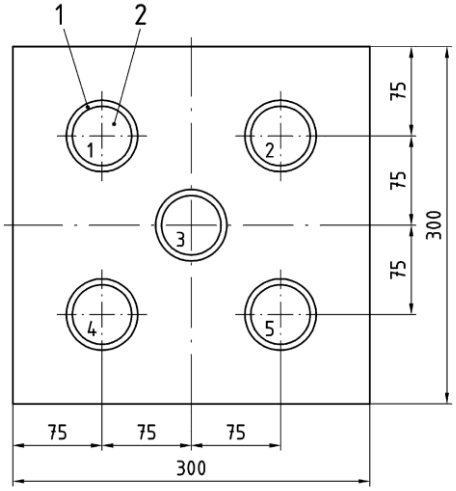


Figure 2.2.8.2: Top view on the test specimen after drilling the concrete cylinders out of the concrete plate according to EN 1542
1 groove made by core drilling around the test surface
2 steel dolly with diameter of 50 mm

The preparation of the specimens without repair mortar shall be done as indicated in Annex E, clause E.2.

- After curing of the bonding agent (component B) according to the MPII and safety information at standard environmental conditions (see 1.3.4) at least 5 cylinders of 50 mm diameter shall be drilled through the entire multilayer specimen (see Figure 2.2.8.2). If the width of the bonded CFRP strips is less than 50 mm, the ring grooves shall be arranged in the floor plan in such a way that a joint goes through the centre of the circle.

The further treatment is the same for the test specimens with and without repair mortar:

- On each cylinder two dollies according to EN 1542, clause 7.2, shall be glued on the circular surfaces with the structural bonding agent (component B). The minimum thickness $d_{\mathrm{G,min}}$**Error! Bookmark not defined.** (see 1.3.8) of the layers of structural bonding agent (component B) shall be used.
- The structural bonding agent (component B) of the dollies shall cure according to the MPII and safety information at standard environmental conditions (see 1.3.4) before testing.
- Afterwards on each of the cylinders the cyclic load shall be applied over the dollies to the concrete surface. The lower stress shall be $0.1 \cdot f_{\mathrm{ctm,surf}}$ and the upper stress $0.55 \cdot f_{\mathrm{ctm,surf}}$. $f_{\mathrm{ctm,surf}}$ is the average value of the bond strength determined according to clause 2.2.7. After 100000 loading cycles with a frequency not higher than 5 Hz the bond strength $f_{\mathrm{cti,surf,lfat}}$ shall be determined on each cylinder according to EN ISO 4624, method A, at standard environmental conditions (see 1.3.4).

The bond strength shall be determined at least on 5 cylinders with and without repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) for every type of CFRP strip (see 1.3.3).

Expression of results

The bond strengths $f_{\mathrm{cti,surf,fat}}$ and the failure modes according to EN 1542, clause 7.5 for all specimens shall be determined. From the values $f_{\mathrm{cti,surf,fat}}$ the average value of the bond strength $f_{\mathrm{ctm,surf,fat}}$ and the 5% quantile value according to EN 1990, Table D.1 (V_x unknown), $f_{\mathrm{ctk,surf,fat}}$ of tensile strength shall be determined.

The ratio $R_{\mathrm{fat,m}}$ shall be determined as follows:

$$R_{\mathrm{fat,m}} = \frac{f_{\mathrm{ctm,surf,fat}}}{f_{\mathrm{ctm,surf}}}.$$

$f_{\mathrm{ctm,surf}}$ shall be determined according to 2.2.7. The values $f_{\mathrm{cti,surf,fat}}$, $f_{\mathrm{ctm,surf,fat}}$, $f_{\mathrm{ctk,surf,lfat}}$, $R_{\mathrm{fat,m}}$, the curing time of the repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) as well as of the bonding agent (component B) and the failure modes shall be reported in the ETA.

2.2.9 Bond strength after long-term loading under harsh climatic conditions

Purpose of the assessment
The tests are performed to determine the bond strength of the following specimens:

- specimens with layers of concrete, repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D), bonding agent (component B) and CFRP strips (component A),
- specimens with layers of concrete, bonding agent (component B) and CFRP strips (component A).

The bond strength shall be determined by pull-off tests according to EN 1542 after curing under standard conditions (see 1.3.4) and loading under harsh climatic conditions for half a year. Two harsh climatic conditions are possible:

Climate 1	maximum temperature at intended use and relative air humidity of ≥95% for the whole half year (reference method),
Climate 2	heat rain cycles with 1 h irrigation without heating and 1 h drying at maximum temperature according to the intended use for the whole half year (approximately 2200 cycles).

Assessment method
If the CFRP strips are supplied in coils, the samples for this test shall be taken from coils that have the smallest inner diameter (see 1.3.2).
The test is based on EN 1542. The differences to EN 1542 are the following:

- only steel dollies according to EN 1542, clause 4.7, are used, not dollies of aluminium,
- the bonding agent (component B) may be used also for the bonding of the steel dollies,
- the thickness of the layers of bonding agent (also for the dollies) is $d_{\mathrm{G,min}}$ (see 1.3.8),
- the test specimens are circular cylinders which are drilled from specimens according to EN 1542, Figure 1 (or Figure 2.2.9.2 of this EAD)[8],
- on both circular surfaces of these cylinder dollies are glued according to EN 1542, clause 7.2.

The preparation of the specimens with repair mortar shall be done as indicated in Annex E, clause E.1, with a small difference.

- After curing of the repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) and the bonding agent (component B) according to the MPII and safety information at standard environmental conditions (see 1.3.4) at least 5 cylinders of 80 mm diameter shall be drilled through the entire multilayer specimen (see Figure 2.8). If the width of the

8 There are not only drilled grooves with a depth of 15 mm, but core holes through the different layers and the entire thickness of the reference concrete of 100 mm (see Figure 2.2.9.1) so that 5 individual cylinders are created. The cylinders may only be tested if dollies are glued on both circular surfaces.

bonded CFRP strips is less than 80 mm, the ring grooves shall be arranged in the floor plan in such a way that a joint goes through the centre of the circle.

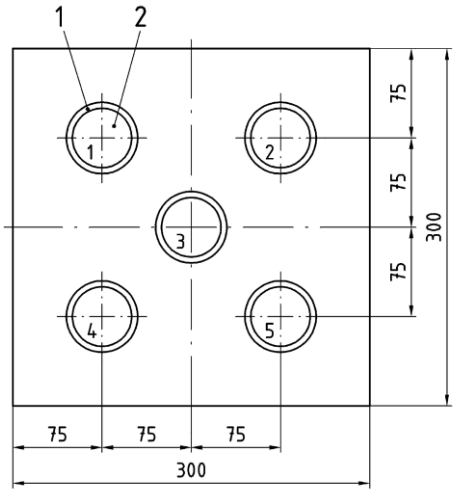


Figure 2.2.9.2: Top view on the test specimen after drilling the concrete cylinders out of the concrete plate according to EN 1542
1 groove made by core drilling around the test surface
2 steel dolly with diameter of 80 mm

The preparation of the specimens without repair mortar shall be done as indicated in Annex E, clause E.2.

- After curing of the bonding agent (component B) according to the MPII and safety information at standard environmental conditions (see 1.3.4) at least 5 cylinders of at least 80 mm diameter shall be drilled through the entire multilayer specimen (see Figure 2.2.9.2). If the width of the bonded CFRP strips is less than 80 mm, the ring grooves shall be arranged in the floor plan in such a way that a joint goes through the centre of the circle.

The further treatment is the same for the test specimens with and without repair mortar:

- On each cylinder two dollies of 80 mm diameter shall be glued on the circular surfaces with the structural bonding agent (component B) according to EN 1542, clause 7.2. The minimum thickness $d_{\mathrm{G,min}}$ (see 1.3.8) of the layers of structural bonding agent (component B) shall be used.
- The structural bonding agent (component B) of the dollies shall cure according to the MPII and safety information at standard environmental conditions (see 1.3.4).
- Afterwards on each of the cylinders the stress of at least 0,2 $f_{\mathrm{ctm,surf}}$ shall be applied for half a year perpendicular to the concrete surface at maximum temperature at intended use (see 1.3.5) under climate 1 or 2. $f_{\mathrm{ctm,surf}}$ is the average value of the bond strength determined according to 2.2.7. After long-term loading the bond strength $f_{\mathrm{cti,surf,lt}}$ shall be determined on each of these cylinders according to EN ISO 4624, method A, at standard environmental conditions (see 1.3.4).

At least 5 cylinders with and without repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) shall be tested for every long-term load level with every type of CFRP strip (see 1.3.3).

Expression of results

For all specimens without failure within the half year of testing time the residual pull-off strength $f_{\mathrm{cti,surf,lt}}$ and failure mode according to EN 1542, clause 7.5, shall be determined and reported in the ETA. For all specimens were failure occurred before the end of the half year the time to failure and the failure mode according to EN 1542, clause 7.5, shall be reported in ETA. Furthermore, the curing time of the repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) as well as of the bonding agent (component B) and the used climate shall be reported in the ETA.

2.2.10 Bond strength of specimens cured at minimum temperature of installation depending on the curing time

Purpose of the assessment
The tests are performed to determine the bond strength of the following specimens:

- specimens with layers of concrete, repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D), bonding agent (component B) and CFRP strips (component A),
- specimens with layers of concrete, bonding agent (component B) and CFRP strips (component A).

The bond strength shall be determined by pull-off tests according to EN 1542 after curing at $T_{\mathrm{Mmin,a}}$ or $T_{\mathrm{Gmin,a}}$ depending on the curing time.

Assessment method
If the CFRP strips are supplied in coils, the samples for this test shall be taken from coils that have the smallest inner diameter (see 1.3.2).
The test is based on EN 1542. The differences to EN 1542 are the following:

- Only steel dollies according to EN 1542, clause 4.7, are used, not dollies of aluminium,
- the thickness of the layers of bonding agent (also for the dollies) is $d_{\mathrm{G,min}}$ (see 1.3.8).

The preparation of the specimens with repair mortar shall be done as indicated in Annex E, clause E.1

- After curing of the repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) and the bonding agent (component B) according to the MPII at $T_{\mathrm{Gmin,a}}$ and T_{Mmina} at least 5 annular grooves of 50 mm diameter shall be drilled through the multilayer specimen until a depth of 15 ± 5 mm in the reference concrete is reached (see Figure 2.2.10.2). If the width of the bonded CFRP strips is less than 50 mm, the ring grooves shall be arranged in the floor plan in such a way that a joint goes through the centre of the circle.

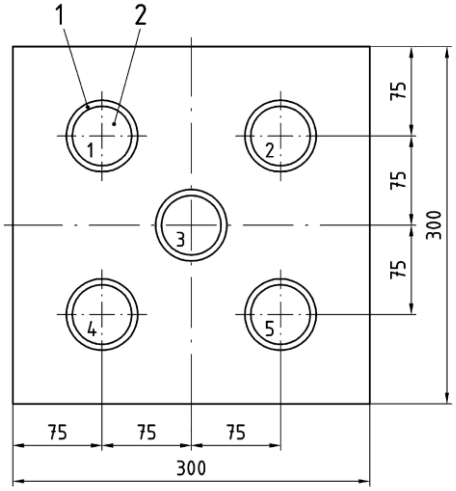


Figure 2.2.10.2: Top view on the test specimen with annular grooves showing the areas of the steel dollies
1 groove made by core drilling around the test surface
2 steel dolly with diameter of 50 mm

The preparation of the specimens without repair mortar shall be done as indicated in Annex E, clause E.2.

- After curing of the bonding agent (component B) according to the MPII at $T_{\mathrm{Gmin,a}}$ at least 5 annular grooves of 50 mm diameter shall be drilled through the entire multilayer specimen until a depth of 15 ± 5 mm in the reference concrete is reached (see Figure 2.2.10.2). If the width of the bonded CFRP strips is less than 50 mm, the ring grooves shall be arranged in the floor plan in such a way that a joint goes through the centre of the circle.

The further treatment is the same for the test specimens with and without repair mortar:

- On each annular groove a dolly according to EN 1542, clause 7.2, shall be glued on the circular surfaces. This shall not be done with the structural bonding agent (component B) but with another

bonding agent, which achieves the necessary bond strength after a few minutes of curing to exclude any failure of the bonding layers of the steel dollies during testing.

- Afterwards on each annular groove the bond strength $f_{\mathrm{cti,surf,T_{min}}}$ shall be determined according to EN 1542, clause 7.4 at standard environmental conditions (see 1.3.4).

At least 5 annular grooves with and without repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) shall be tested for every type of CFRP strip (see 1.3.3).

Expression of results

The bond strengths $f_{\mathrm{cti,surf,T_{min}}}$ shall be measured and failure modes according to EN 1542, clause 7.5 shall be reported. From the values $f_{\mathrm{cti,surf,T_{min}}}$ the average value of the bond strength $f_{\mathrm{ctm,surf,T_{min}}}$ and the 5% quantile value according to EN 1990, Table D.1 (V_x unknown), $f_{\mathrm{ctk,surf,T_{min}}}$ of tensile strength shall be determined.

The ratio $R_{T_{\mathrm{min}},\mathrm{m}}$ shall be determined as follows:

$$R_{T_{\mathrm{min}},\mathrm{m}} = \frac{f_{\mathrm{ctm,surf,T_{min}}}}{f_{\mathrm{ctm,surf}}}.$$

The value $f_{\mathrm{ctm,surf}}$ shall be determined according to 2.2.7. The values $f_{\mathrm{cti,surf,T_{min}}}$, $f_{\mathrm{ctm,surf,T_{min}}}$, $f_{\mathrm{ctk,surf,T_{min}}}$, $R_{\mathrm{T_{min},m}}$, the curing time of the repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) as well as of the bonding agent (component B) and the failure modes shall be reported in the ETA.

2.2.11 Shear resistance of the anchorage of CFRP strips externally bonded to concrete

Purpose of the assessment
The tests are performed to determine the shear resistance F_{bLk} and the shear force – slip relation of the anchorage for relevant configurations of CFRP strips externally bonded to the concrete.

Assessment method
If the CFRP strips are supplied in coils, the samples for this test shall be taken from coils that have the smallest inner diameter (see 1.3.2).
Test specimen:
The double-sided bond specimen consists of a concrete block divided horizontally by a crack plate in two parts (see figure 2.2.11.1). The length of the part above the crack plate shall be more than 50 cm and the length of the part below the crack plate shall be more than 100 cm (see right sketch in Figure 2.2.11.1). The width of the concrete block b shall be at least 2 cm higher than the width of the CFRP strips b_{bL} The thickness *d* of the concrete block shall be more than 150 mm.

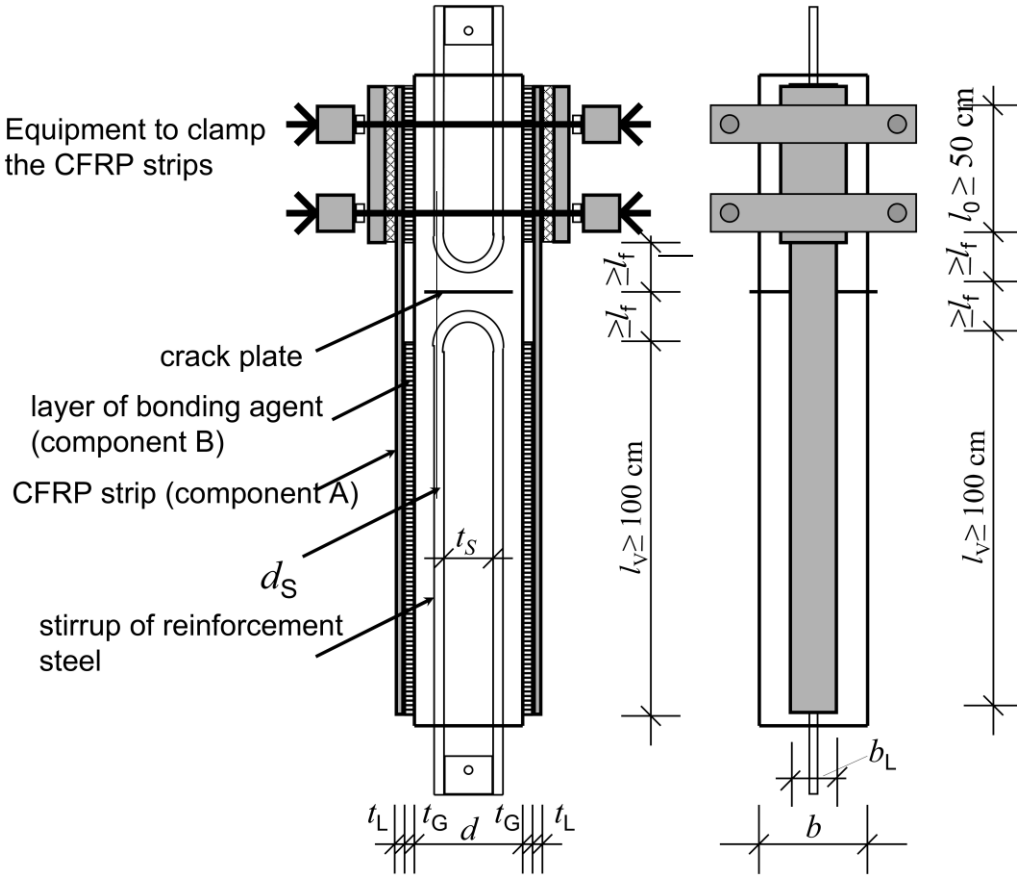


Figure 2.2.11.1 Tension-tension double-–sided bond specimen to determine the bonding behaviour of bonded CFRP strips

On two parallel sides of the concrete block (preferably the sides which were in vertical position during concreting of the specimen) two CFRP strips are bonded on the surface with the minimum thickness $d_{\mathrm{G,min}}$[6] (see 1.3.8) of the layer of structural bonding agent (component B). The thickness d_{bL} of the CFRP strips (component A) shall be the maximum thickness of the CFRP strips of the kit. On the upper short part of the concrete block, additionally to the bonding, the CFRP strips shall be clamped by special equipment to the surfaces of the concrete block. On the lower long part of the concrete block the CFRP strips shall only be fixed by the structural bonding agent. After applying CFRP strips the structural bonding agent shall cure at least for t_{GTn} at standard environmental conditions (see 1.3.4).
Loading shall be carried out deformation controlled through the two stirrups of concrete reinforcement steel. The concrete cover of the stirrups shall be at least 10 mm. Above and below the crack plate a non-bonded area of the CFRP strips of at least l_{f} =10 cm shall be provided (see figure 2.2.11.1).

The failure loads depend on the following parameters:

- bond length l_v of the CFRP strips to the concrete,
- the geometry (thickness t_L and width b_L [6]of the CFRP strips,
- the modulus of elasticity of the CFRP strips,
- compressive strength class of the concrete,
- pull-off bond strength at the surface of the concrete.

At least specimens for the minimum bond length l_v, the maximum thickness t_L and width b_L of the CFRP strips, the minimum and maximum modulus of elasticity of the CFRP strips and the minimum and maximum strength class of the concrete substrate (see 1.3.10) shall be tested. For each parameter set at least 3 tests shall be carried out.

Examination:

The tests shall be carried out deformation controlled with a constant piston rate of 1 mm/min (± 10%).
At least the relative displacement between concrete surface and CFRP strip at the beginning of the bond area and the strains of the CFRP strip in the un-bonded and bonded area shall be measured as a function of loading. The strains of the CFRP strip in the bonded area shall be measured with a chain of strain gauges. One strain gauge shall be applied in the bond-less area. In the bonded area at least 3 strain gauges (tensometers) shall be applied with a distance of 30 mm starting at a distance of 30 mm from the beginning of the bonded area. The force – strain curves in all strain gauges shall be plotted.

The compressive strength of the concrete for all tested concrete compression classes shall be determined as follows:

At the same time as the concrete blocks are concreted 6 concrete cylinders according to EN 12390-1, clause 4.3, with d = 150 mm shall be concreted and stored under the same conditions as the concrete blocks. After at least 28 days and before applying CFRP strips to the concrete blocks the cylinder compressive strength of these 6 concrete cylinders shall be determined according to EN 12390-3. From these 6 values f_{ci}, the average value f_{cm} and the characteristic value f_{ck} shall be calculated.

Performing the shear tests usually the bond of one of the two CFRP strips fails first. The test shall be interrupted if one of the two CFRP strips has separated from the concrete within the first 30 mm of bond length. This is the case when at the first strain gauge in the bonded area strain values are measured which have the same level as in the bond-less area.

After fixing the separated CFRP strip by a suitable contact pressure, the test shall be continued until separating of the second CFRP strip occurs. This is again the case when at the first strain gauge in the bonded area of the second CFRP strip strain values are measured which have the same level as in the bond less area.

The measured strains, relative displacements and forces shall be recorded at least at a frequency of 5 Hz.

After determination of the anchorage failure loads the concrete pull-off strength $f_{ctij,surf}$ tested according to EN 1542 at three places "j" of each concrete specimen "i" shall be determined. From the values $f_{ctij,surf}$ the values $f_{ctim,surf}$ and $f_{ctik,surf}$ for each concrete specimen "i" shall be determined.

Expression of results

For each tested configuration of specimens, the following values shall be determined and reported in the ETA:

- the single values of the anchorage failure loads F_{bLi} together with the pull-off strength $f_{ctim,surf}$ and $f_{ctik,surf}$, the measured shear force – slip diagrams, shear force – strain diagrams as well as the failure modes according to EN 1542, clause 7.5,
- the average value F_{bLm} together with the average compressive strength of the concrete f_{cm}, and
- the 5% quantile value according to EN 1990, Table D.1 (V_x unknown), F_{bLk} together with the characteristic compressive strength of the concrete f_{ck}.

2.2.12 Fatigue behaviour of the anchorage of CFRP strips externally bonded to concrete

Purpose of the assessment

The tests shall be performed to determine the input parameters of a SN curve for the shear resistance of the anchorage of CFRP strips externally bonded to concrete for relevant configurations. The default value for the maximum number of load cycles is 2 million.

Assessment method
The assessment method is identical to 2.2.11. The only difference is that a cyclic load $\Delta F_{\mathrm{bLi}} = F_{\mathrm{bLi}}^{u} - F_{\mathrm{bLi}}^{l}$is applied to the specimen, where F_{bLi}^{u} is the upper load and F_{bLi}^{l} the lower load. The transfer of pressure loads via the CFRP strips is excluded.

At least specimens for the minimum bond length l_v, the maximum thickness t_{L} and width b_{L} of CFRP strips, the minimum or maximum modulus of elasticity of the CFRP strips and the minimum, intermediate and maximum strength class of the concrete substrate (see 1.3.10) shall be tested. For all these configurations of specimens the cyclic load levels according to Table 2.2.12.1 shall be tested.

Table 2.2.12.1 Minimum number of tests for every specimen configuration

Load level	Strength class of the concrete substrate		
	Minimum	Intermediate	Maximum
A	x	x	x
B	x		
C	x	x	
D	x		x

The load levels are characterised by the average value of the anchorage failure load F_{blm} determined for the same configuration of specimen under 2.2.11:
Load level A: $F_{\mathrm{bli}}^{\mathrm{l}} = 0{,}15\ F_{\mathrm{blm}}$ to $F_{\mathrm{bli}}^{\mathrm{u}} = 0{,}45\ F_{\mathrm{blm}}$
Load level B: $F_{\mathrm{bli}}^{\mathrm{l}} = 0{,}30\ F_{\mathrm{blm}}$ to $F_{\mathrm{bli}}^{\mathrm{u}} = 0{,}55\ F_{\mathrm{blm}}$
Load level C: $F_{\mathrm{bli}}^{\mathrm{l}} = 0{,}45\ F_{\mathrm{blm}}$ to $F_{\mathrm{bli}}^{\mathrm{u}} = 0{,}64\ F_{\mathrm{blm}}$
Load level D: $F_{\mathrm{bli}}^{\mathrm{l}} = 0{,}60\ F_{\mathrm{blm}}$ to $F_{\mathrm{bli}}^{\mathrm{u}} = 0{,}74\ F_{\mathrm{blm}}$
After reaching 2 million load cycles or a separated length of 30 mm a higher upper load level shall be chosen:

Load level A: $F_{\mathrm{bli}}^{\mathrm{l}} = 0{,}15\ F_{\mathrm{blm}}$ to $F_{\mathrm{bli}}^{\mathrm{u}} = 0{,}49\ F_{\mathrm{blm}}$

Load level B: $F_{\mathrm{bli}}^{\mathrm{l}} = 0{,}30\ F_{\mathrm{blm}}$ to $F_{\mathrm{bli}}^{\mathrm{u}} = 0{,}58\ F_{\mathrm{blm}}$

Load level C: $F_{\mathrm{bli}}^{\mathrm{l}} = 0{,}45\ F_{\mathrm{blm}}$ to $F_{\mathrm{bli}}^{\mathrm{u}} = 0{,}67\ F_{\mathrm{blm}}$

Load level D: $F_{\mathrm{bli}}^{\mathrm{l}} = 0{,}60\ F_{\mathrm{blm}}$ to $F_{\mathrm{bli}}^{\mathrm{u}} = 0{,}76\ F_{\mathrm{blm}}$

In agreement with the manufacturer, other load levels may be chosen in addition.

Examination:
The load cycle frequency shall be not higher than 5 Hz.
The strains of the CFRP strip in the un-bonded and bonded area should be measured as a function of loading. The strains of the CFRP strip in the bonded area shall be measured with a chain of strain gauges. One strain gauge shall be applied in the bond-less area. In the bonded area at least 3 strain gauges shall be applied with a distance of 30 mm starting at a distance of 30 mm from the beginning of the bonded area. The force – strain curves at least of the strain gauges in the bond-less area as well as of the two first strain gauges in the bonded area (from the beginning of the bonded area on the loaded side of the CFRP strip) shall be plotted.

The compressive strength of the concrete for all tested concrete compression classes shall be determined as follows:

At the same time as the concrete blocks are concreted 6 concrete cylinders according to EN 12390-1, clause 4.3, with d = 150 mm shall be concreted and stored under the same conditions as the concrete blocks. After at least 28 days and before applying CFRP strips to the concrete blocks the cylinder compressive strength of these 6 concrete cylinders shall be determined according to EN 12390-3. From these 6 values f_{ci}, the average value f_{cm} and the characteristic value f_{ck} shall be calculated.

After cyclic testing the concrete pull-off strength tested according to EN 1542 at three places of each concrete specimen shall be determined.

The mechanical properties according to 2.2.4 of the used CFRP strips shall be determined.[9]

Performing the fatigue tests usually the bond of one of the two CFRP strips fails first. The fatigue test shall be interrupted if one of the two CFRP strips has separated from the concrete within the first 30 mm of bond length. This is the case when at the first strain the gauge in the bonded area has the same value as in the bond less area.

After fixing the separated CFRP strip by a suitable contact pressure, cyclic loading shall be continued until separating of the second CFRP strip occurs. This is again the case when at the first strain gauge in the bonded area of the second CFRP strip strain values are measured which have the same level as in the bond less area.

The measured strains and forces shall be recorded at least every 60 min for 10 s at a frequency of 100 Hz. Shortly before the expected separating of the CFRP strip, the measurement shall be continued continuously until the interruption or termination of the test.

After determination the fatigue test the concrete pull-off strength $f_{\mathrm{ctij,surf}}$ tested according to EN 1542 at three places "j" of each concrete specimen "i" shall be determined. From the values $f_{\mathrm{ctij,surf}}$ the values $f_{\mathrm{ctim,surf}}$ and $f_{\mathrm{ctik,surf}}$ for each concrete specimen "i" shall be determined.

Expression of results

For each tested cyclic load $\Delta F_{\mathrm{bLi}} = F_{\mathrm{bLi}}^{u} - F_{\mathrm{bLi}}^{l}$ the corresponding number of cycles until separating of the CFRP strips, the pull-off strength $f_{\mathrm{ctim,surf}}$ and $f_{\mathrm{ctik,surf}}$ and the concrete compressive strength f_{cm} and f_{ck} of the concrete substrate for all tests shall be given in the ETA.

2.2.13 Reaction to fire

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

The mounting and fixing conditions of Annex B shall be considered.

The reaction to fire class obtained for the kit shall be stated in the ETA together with those conditions (see parameters addressed in Annex B) for which the classification is valid.

[9] If CFRP strips from the same batch as used for 2.2.3 are used the re-determination of the properties of the CFRP strips is not necessary.

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[10].

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 (CFRP strips, structural bonding agent, repair mortar)	Supplier data check	Control plan	-	each delivery
2	Visual inspection for defects of the CFRP strips	Visual check	Control plan	-	constantly
3	Gel time of the resin of the CFRP strips	EN ISO 8987	Control plan	-	each batch of the raw material
4	Fibre content of the CFRP strips	3.4.1	Control plan	-	in case of doubt about the information in the supplier data
5	Mass per m of the CFRP strips	3.4.2	Control plan	-	in case of doubt about the information in the supplier data
6	Dimensions of the CFRP strips	3.4.3	Control plan	3	each 150 m
7	E-Modulus, strength and failure elongation	2.2.4	Control plan	3	each 150 m
8	Glass transition temperature of CFRP strips	EN 12614	Control plan	2	each 1000 m
9	Pot life of bonding agent at 21 ± 2°C	EN ISO 9514	Control plan	1	each batch
10	Flexural and compressive strength of the structural bonding agent (component B)	2.2.2, according to the method as chosen for the assessment	Control plan	3	each batch of structural bonding agent
11	Reaction to fire	2.2.13	Control plan	At least one depending on test method	1/year

10 Official Journal of the European Communities/Union L 240/4 of 14 July 1997.

3.3 Tasks of the notified body

The cornerstones of the actions to be undertaken by the notified body of the product in the procedure of assessment and verification of constancy of performance 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	Verifying that the production process, the staff and equipment are suitable to ensure the production of consistent products. - Presence of suitable test equipment - Presence of trained personnel - Presence of an appropriate quality assurance system and necessary stipulations	Verification of the complete FPC as described in the control plan agreed between the TAB and the manufacturer	As defined in the control plan	-	1/year
Continuous surveillance, assessment and evaluation of factory production control					
2	Verifying if the FPC is in accordance with the control plan - Inspection of factory, of the production of the product and of the facilities for factory production control - Evaluation of the documents concerning the factory production control - Issuing a report of surveillance	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 process and to the product as indicated in Table 3.2.1	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					
3	All subjects/type of control 1 to 10 according to Table 3.2.1	see Table 3.2.1	Control plan	see Table 3.2.1	2/year
4	Reaction to fire	2.2.13	Control plan	At least one depending on test method	1/year

3.4 Special methods of control and testing used for the assessment and verification of constancy of performance

3.4.1 Fibre content of the CFRP strips

The fibre content shall be determined according to EN 2564, method A. Tests shall be carried out at least on 6 specimens for the significant cross sections (see 1.3.1) of all types of CFRP strips.

The determined fibre content shall be consistent with the fibre content of the specimens used in the assessment tests.

3.4.2 Mass per meter of the CFRP strips

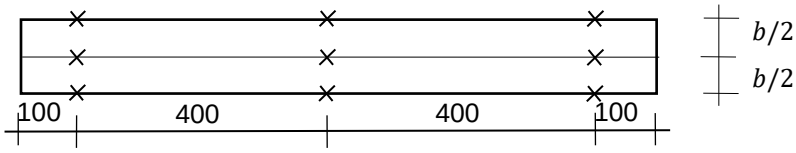
Mass of 1 m long pieces of CFRP strips m_{Li} shall be determined. Tests shall be carried out at least on 6 specimens for the significant cross sections (see 1.3.1) of all types of CFRP strips (see 1.3.3).

The average value m_{Lm} of the determined mass of 1 m long pieces m_{Li} shall be consistent with the mass of the specimens used in the assessment tests.

3.4.3 Dimensions of the CFRP strips

Thickness and width of 1 m long pieces of CFRP strips shall be measured. The used micrometer shall fulfil the accuracy of EN 2561, section 5.1.

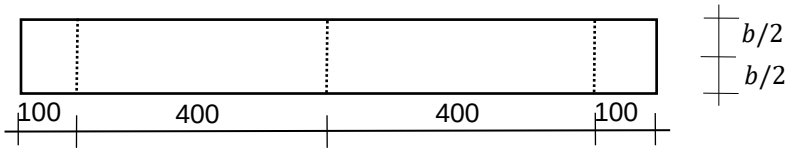
The thickness shall be measured on at least 9 points (see Figure 3.4.3.1) and the width at least on 3 places per specimen (see Figure 3.4.3.2). Tests shall be carried out at least on 6 specimens for the significant cross sections (see 1.3.1) of all types of CFRP strips (see 1.3.3).



x measuring point

dimensions in mm

Figure 3.4.3.1: Measure points for the thickness of CFRP strips



measuring line

dimensions in mm

Figure 3.4.3.2: Measure lines for the width of CFRP strips

The average value b_{Lm} and t_{Lm} of the determined widths b_{Li} and thicknesses t_{Li} shall be consistent with the dimensions used in the assessment tests.

4 REFERENCE DOCUMENTS

EN 196-1:2016	Methods of testing cement – Part 1: Determination of strength
EN 1015-11:2019	Methods of test for mortar for masonry – Part 11: Determination of flexural and compressive strength of hardened mortar
EN 1504-4:2004	Products and systems for the protection and repair of concrete structures – Definitions, requirements, quality control and evaluation of conformity – Part 4: Structural bonding
EN 1542:1999	Products and systems for the protection and repair of concrete structures - Test methods - Measurement of bond strength by pull-off
EN 1990:2002+A1:2005+A1:2005/AC:2010	Eurocode: Basis of structural design
EN 2561:1995	Aerospace series – Carbon fibre reinforced plastics – Unidirectional laminates - Tensile test parallel to the fibre direction
EN 2564:2018	Aerospace series – Carbon fibre laminates – Determination of the fibre, resin and void contents
EN 12390-1:2021	Testing hardened concrete – Part 1: Shape, dimensions and other requirements for specimens and moulds
EN 12390-3:2019	Testing hardened concrete – Part 3: Compressive strength of test specimens
EN 12614:2004	Products and systems for the protection and repair of concrete structures - Test methods - Determination of glass transition temperatures of polymers
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 ISO 4624:2023	Paints and varnishes – Pull-off test for adhesion (ISO 4624:2016)
EN ISO 8987:2005	Plastics - Phenolic resins - Determination of reactivity on a B-transformation test plate (ISO 8987:2005)
EN ISO 9514:2019	Paints and varnishes - Determination of the pot life of multicomponent coating systems - Preparation and conditioning of samples and guidelines for testing (ISO 9514:2019)
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)
ISO 10119:2020	Carbon fibre — Determination of density

ANNEX A – SUMMARY OF ASSESSMENT TESTS FOR THE KIT

	Essential characteristic	Test procedure	CONDITIONING	Minimum number of specimens
Properties of the components	**Repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D)**			
	Glass transition temperature	2.2.1	Specimens cured for t_{MTn} (see 1.3.9) at standard environmental conditions (see 1.3.4)	2
	Flexural strength	2.2.2		3
	Compressive strength	2.2.2		6
	Flexural strength	2.2.3	Specimens cured for t_{MTmin} and 2 t_{MTmin} (see 1.3.9) at minimum temperature of installation $T_{\mathrm{Mmin,a}}$ (see 1.3.5)	3 for every curing time
	Compressive strength	2.2.3		6 for every curing time
	Bonding agent (component B)			
	Glass transition temperature	2.2.1	Specimens cured for t_{GTn} (see 1.3.9) at standard environment conditions (see 1.3.4)	2
	Flexural strength	2.2.2		3
	Compressive strength	2.2.2		6
	Flexural strength	2.2.3	Specimens cured for t_{GTmin} and 2 t_{GTmin} (see 1.3.9) at minimum temperature of installation $T_{\mathrm{Gmin,a}}$ (see 1.3.5)	3 for every curing time
	Compressive strength	2.2.3		6 for every curing time
	CFRP strips (component A)			
	Modulus of elasticity	2.2.4	at standard environmental conditions (see 1.3.4)	5 per significant cross sections (see 1.3.1) of every type of CFRP strip (see 1.3.3)
	Tensile strength	2.2.4		
	Ultimate strain	2.2.4		
	Modulus of elasticity	2.2.5	1800h storage in alkaline solution pH 9.0 and/or pH 11.0 and/or pH 13.7 unloaded	5 with sections of the highest ratio between circumference and cross-section area of every type of CFRP strip (see 1.3.3)
	Tensile strength	2.2.5		
	Ultimate strain	2.2.5		
	Modulus of elasticity	2.2.6	1800h storage in alkaline solution pH 9.0 and/or pH 11.0 and/or pH 13.7 loaded with 50% of the characteristic value of the tensile strength	5 with sections of the highest ratio between circumference and cross-section area of every type of CFRP strip (see 1.3.3)
	Tensile strength	2.2.6		
	Ultimate strain	2.2.6		
Bond to the concrete	Bond strength of a multilayer specimen consisting of: - repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) - bonding agent (component B) - CFRP strips (component A) (see Figure 2.2.7.1 b) to the concrete.	2.2.7	Preparation of specimens according to 2.2.7 at standard environmental conditions (see 1.3.4)	5 for every type of CFRP strip (see 1.3.3)
	Bond strength of a multilayer specimen consisting of: - bonding agent (component B) - CFRP strips (component A) (see Figure 2.2.7.3 b) to the concrete.		Preparation of specimens according to 2.2.7 at standard environmental conditions (see 1.3.4)	5 for every type of CFRP strip (see 1.3.3)
	Bond strength of a multilayer specimen consisting of: - repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) - bonding agent (component B) - CFRP strips (component A) (see Figure 2.2.8.1 b) to the concrete after low-cycle fatigue action	2.2.8	Preparation of specimens according to 2.2.8 at standard environmental conditions (see 1.3.4) Before testing of bond strength 100000 load cycles	5 for every type of CFRP strip (see 1.3.3)
	Bond strength of a multilayer specimen consisting of: - bonding agent (component B) - CFRP strips (component A)		Preparation of specimens according to 2.2.8 at standard environmental conditions (see 1.3.4) Before testing of bond strength 100000 load cycles	5 for every type of CFRP strip (see 1.3.3)

	Essential characteristic	Test procedure	CONDITIONING	Minimum number of specimens
Properties of the components	**Repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D)**			
	Glass transition temperature	2.2.1	Specimens cured for t_{MTn} (see 1.3.9) at standard environmental conditions (see 1.3.4)	2
	Flexural strength	2.2.2		3
	Compressive strength	2.2.2		6
	Flexural strength	2.2.3	Specimens cured for t_{MTmin} and 2 t_{MTmin} (see 1.3.9) at minimum temperature of installation $T_{\mathrm{Mmin,a}}$ (see 1.3.5)	3 for every curing time
	Compressive strength	2.2.3		6 for every curing time
	Bonding agent (component B)			
	Glass transition temperature	2.2.1	Specimens cured for t_{GTn} (see 1.3.9) at standard environment conditions (see 1.3.4)	2
	Flexural strength	2.2.2		3
	Compressive strength	2.2.2		6
	Flexural strength	2.2.3	Specimens cured for t_{GTmin} and 2 t_{GTmin} (see 1.3.9) at minimum temperature of installation $T_{\mathrm{Gmin,a}}$ (see 1.3.5)	3 for every curing time
	Compressive strength	2.2.3		6 for every curing time
	CFRP strips (component A)			
	Modulus of elasticity	2.2.4	at standard environmental conditions (see 1.3.4)	5 per significant cross sections (see 1.3.1) of every type of CFRP strip (see 1.3.3)
	Tensile strength	2.2.4		
	Ultimate strain	2.2.4		
	Modulus of elasticity	2.2.5	1800h storage in alkaline solution pH 9.0 and/or pH 11.0 and/or pH 13.7 unloaded	5 with sections of the highest ratio between circumference and cross-section area of every type of CFRP strip (see 1.3.3)
	Tensile strength	2.2.5		
	Ultimate strain	2.2.5		
	Modulus of elasticity	2.2.6	1800h storage in alkaline solution pH 9.0 and/or pH 11.0 and/or pH 13.7 loaded with 50% of the characteristic value of the tensile strength	5 with sections of the highest ratio between circumference and cross-section area of every type of CFRP strip (see 1.3.3)
	Tensile strength	2.2.6		
	Ultimate strain	2.2.6		
	(see Figure 2.2.8.3 b) to the concrete after low-cycle fatigue action			
	Bond strength of a multilayer specimen consisting of: - repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) - bonding agent (component B) - CFRP strips (component A) (see Figure 2.2.9.1 b) to the concrete under harsh climatic conditions	2.2.9	Preparation of specimens according to 2.2.9at standard environmental conditions (see 1.3.4) Before testing of bond strength loading with a constant load for half a year at climate 1 or 2	5 for every tested long-term load level and every type of CFRP strip (see 1.3.3)
	Bond strength of a multilayer specimen consisting of: - bonding agent (component B) - CFRP strips (component A) (see Figure 2.2.9.3 b) to the concrete under harsh climatic conditions		Preparation of specimens according to 2.2.9 at standard environmental conditions (see 1.3.4) Before testing of bond strength loading with a constant load for half a year at climate 1 or 2	5 for every tested long-term load level and every type of CFRP strip (see 1.3.3)
	Bond strength of a multilayer specimen consisting of: - repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) - bonding agent (component B) - CFRP strips (component A) (see Figure 2.2.10.1 b) to the concrete cured at minimum temperature of installation depending on the curing time	2.2.10	Preparation of specimens according to 2.2.10 at T_{Gmina} and T_{Mmina} (see 1.3.5)	5 for every type of CFRP strip (see 1.3.3)

	Essential characteristic	Test procedure	CONDITIONING	Minimum number of specimens
Properties of the components	**Repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D)**			
	Glass transition temperature	2.2.1	Specimens cured for t_{MTn} (see 1.3.9) at standard environmental conditions (see 1.3.4)	2
	Flexural strength	2.2.2		3
	Compressive strength	2.2.2		6
	Flexural strength	2.2.3	Specimens cured for t_{MTmin} and 2 t_{MTmin} (see 1.3.9) at minimum temperature of installation $T_{\mathrm{Mmin,a}}$ (see 1.3.5)	3 for every curing time
	Compressive strength	2.2.3		6 for every curing time
	Bonding agent (component B)			
	Glass transition temperature	2.2.1	Specimens cured for t_{GTn} (see 1.3.9) at standard environment conditions (see 1.3.4)	2
	Flexural strength	2.2.2		3
	Compressive strength	2.2.2		6
	Flexural strength	2.2.3	Specimens cured for t_{GTmin} and 2 t_{GTmin} (see 1.3.9) at minimum temperature of installation $T_{\mathrm{Gmin,a}}$ (see 1.3.5)	3 for every curing time
	Compressive strength	2.2.3		6 for every curing time
	CFRP strips (component A)			
	Modulus of elasticity	2.2.4	at standard environmental conditions (see 1.3.4)	5 per significant cross sections (see 1.3.1) of every type of CFRP strip (see 1.3.3)
	Tensile strength	2.2.4		
	Ultimate strain	2.2.4		
	Modulus of elasticity	2.2.5	1800h storage in alkaline solution pH 9.0 and/or pH 11.0 and/or pH 13.7 unloaded	5 with sections of the highest ratio between circumference and cross-section area of every type of CFRP strip (see 1.3.3)
	Tensile strength	2.2.5		
	Ultimate strain	2.2.5		
	Modulus of elasticity	2.2.6	1800h storage in alkaline solution pH 9.0 and/or pH 11.0 and/or pH 13.7 loaded with 50% of the characteristic value of the tensile strength	5 with sections of the highest ratio between circumference and cross-section area of every type of CFRP strip (see 1.3.3)
	Tensile strength	2.2.6		
	Ultimate strain	2.2.6		
	Bond strength of a multilayer specimen consisting of: - bonding agent (component B) - CFRP strips (component A) (see Figure 2.2.10.3 b) to the concrete cured at minimum temperature of installation depending on the curing time		Preparation of specimens according to 2.2.10 at $T_{\mathrm{Gmin,a}}$ (see 1.3.5)	5 for every type of CFRP strip (see 1.3.3)
	Shear resistance of the anchorage of the CFRP strips	2.2.11	Preparation of specimens according to 2.2.11 at standard environmental conditions (see 1.3.4)	For each of the following configuration of the specimen at least 3 tests shall be carried out: the minimum bond length l_v, the maximum thickness t_{L} and width b_{L} of the CFRP strips, the minimum and maximum modulus of elasticity of the CFRP strips and the minimum and maximum strength class of the concrete substrate (see 1.3.10)
	Fatigue behaviour of the anchorage of CFRP strips externally bonded to concrete	2.2.12	Preparation of specimens according to 2.2.12 at standard environmental conditions (see 1.3.4) Afterwards loading with cyclic loads until failure	For each of the following configuration of the specimen at least the load level tests according to Table 2.2.12.1 shall be carried out: the minimum bond length l_v, the maximum thickness t_{L} and width b_{L} of the CFRP strips, the minimum or maximum modulus of elasticity of the CFRP strips and

	Essential characteristic	Test procedure	CONDITIONING	Minimum number of specimens
Properties of the components	**Repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D)**			
	Glass transition temperature	2.2.1	Specimens cured for t_{MTn} (see 1.3.9) at standard environmental conditions (see 1.3.4)	2
	Flexural strength	2.2.2		3
	Compressive strength	2.2.2		6
	Flexural strength	2.2.3	Specimens cured for t_{MTmin} and 2 t_{MTmin} (see 1.3.9) at minimum temperature of installation $T_{\mathrm{Mmin,a}}$ (see 1.3.5)	3 for every curing time
	Compressive strength	2.2.3		6 for every curing time
	Bonding agent (component B)			
	Glass transition temperature	2.2.1	Specimens cured for t_{GTn} (see 1.3.9) at standard environment conditions (see 1.3.4)	2
	Flexural strength	2.2.2		3
	Compressive strength	2.2.2		6
	Flexural strength	2.2.3	Specimens cured for t_{GTmin} and 2 t_{GTmin} (see 1.3.9) at minimum temperature of installation $T_{\mathrm{Gmin,a}}$ (see 1.3.5)	3 for every curing time
	Compressive strength	2.2.3		6 for every curing time
	CFRP strips (component A)			
	Modulus of elasticity	2.2.4	at standard environmental conditions (see 1.3.4)	5 per significant cross sections (see 1.3.1) of every type of CFRP strip (see 1.3.3)
	Tensile strength	2.2.4		
	Ultimate strain	2.2.4		
	Modulus of elasticity	2.2.5	1800h storage in alkaline solution pH 9.0 and/or pH 11.0 and/or pH 13.7 unloaded	5 with sections of the highest ratio between circumference and cross-section area of every type of CFRP strip (see 1.3.3)
	Tensile strength	2.2.5		
	Ultimate strain	2.2.5		
	Modulus of elasticity	2.2.6	1800h storage in alkaline solution pH 9.0 and/or pH 11.0 and/or pH 13.7 loaded with 50% of the characteristic value of the tensile strength	5 with sections of the highest ratio between circumference and cross-section area of every type of CFRP strip (see 1.3.3)
	Tensile strength	2.2.6		
	Ultimate strain	2.2.6		
				the minimum, intermediate and maximum strength class of the concrete substrate (see 1.3.10)
	Reaction to fire of the kit	2.2.13	Preparation of the specimens according to the provisions of the corresponding test standards	According to the provisions of the corresponding test standards

ANNEX B – MOUNTING AND FIXING PROCEDURES FOR REACTION TO FIRE TESTS

B.1 General

Relevant configurations of the kit shall be tested shall be tested for the assessment of reaction to fire. The following parameters shall be considered for the preparation of the test specimens:

- type / composition of the components B to D (structural bonding agent, repair mortar, bonding agent for the repair mortar), as defined by a combination of certain raw materials and a certain type of production process,
- thickness and corresponding applied quantity per unit area of the components B to D,
- type of the CFRP strips (see 1.3.3) and
- thickness of the CFRP strips.

B.2 Tests according to EN 13823 (SBI)

The corner specimen consists of two wings, designated the short and long wings. The kit shall be tested applied on a representative substrate in accordance with EN 13238 and shall be configured as follows:

- layer of bonding agent (component D) with its maximum thickness and corresponding applied quantity per unit area if it is part of the kit,
- layer of repair mortar (component C) with the maximum thickness $d_{\mathrm{M,max}}$ (see 1.3.8) and corresponding applied quantity per unit area,
- layer of structural bonding agent (component B) with the maximum thickness $d_{\mathrm{G,max}}$ (see 1.3.8) and corresponding applied quantity per unit area,
- the CFRP strip (see 1.3.3) with maximum thickness of every type of CFRP strips bonded with component B to component C/D and the substrate.

B.3 Tests according to EN ISO 11925-2

The kit shall be tested applied on a representative substrate in accordance with EN 13238. The specimen shall be configured as follows:

- layer of bonding agent (component D) with its maximum thickness and corresponding applied quantity per unit area, if it is part of the kit,
- layer of repair mortar (component C) with the maximum thickness $d_{\mathrm{M,max}}$ (see 1.3.8) and corresponding applied quantity per unit area,
- layer of structural bonding agent (component B) with the maximum thickness,
- the CFRP strip (see 1.3.3) with maximum thickness of every type of CFRP strips bonded with component B to component C/D and the substrate.

Tests shall be conducted with surface and edge exposure. Depending on the thickness of the entire configuration of the kit, additional tests shall be conducted with edge exposure on every layer of specimens turned 90 degrees on their vertical axis according to clause 7.3.3.2.3 of the test standard.

B.4 Application of test results

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

- the tested assembly of the kit only with
- the same bonding agent (component D) with the same or lower thickness and corresponding applied quantity per unit area than tested,
- the same repair mortar (component C) with the same or lower thickness and corresponding applied quantity per unit area than tested,
- the same structural bonding agent (component B) with the same or lower thickness and corresponding applied quantity per unit area and
- the tested type of CFRP strips only with the same or lower thickness of the strips than tested.

The results of the tests may also be applied to other types of CFRP strips differing only in the type of carbon fibres but neither in the fibre content nor in the type of matrix material (resin), if orientation tests have been carried out with each type of carbon fibres in the CFRP strips as part of the specimens. For this purpose, at least one SBI test according to EN 13823 and at least two tests each with surface and edge exposure according to EN ISO 11925-2 shall be performed, which shall not provide more critical test results than those tests used for the final classification.

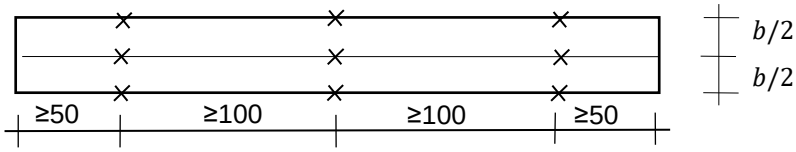
ANNEX C – TEST-PROCEDURES FOR THE DETERMINATION OF CHARACTERISTICS OF CFRP STRIPS

C.1 Mass per meter of the CFRP strips

If the manufacturer also requests the determination of tensile strength and the modulus of elasticity in relation to the cross section of the fibres in 2.2.4, the mass of all tested CFRP strips M_{Li} shall be determined before the determination of tensile strength. The mass per meter of the specimens is obtained by dividing its mass by its length $m_{\mathrm{Li}} = M_{\mathrm{Li}}/l_{\mathrm{Li}}$.

C.2 Dimensions of the sections of the CFRP strips

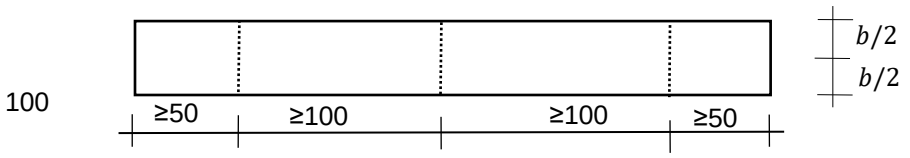
Before testing the tensile strength and the modulus of elasticity in 2.2.4 to 2.2.6 the thickness and width of the specimens of CFRP strips shall be measured. The used micrometer shall fulfil the accuracy of EN 2561, section 5.1. The thickness shall be measured on at least 9 points (see figure C.2.1) and the width at least on 3 places per specimen (see figure C.2.2).



x measuring point

dimensions in mm

Figure C.2.1 Measuring points for the thickness of CFRP strips



measuring line

dimensions in mm

Figure C.2.2: Measure lines for the width of CFRP strips

ANNEX D – COMPOSITION OF THE SOLUTIONS FOR ASSESSMENT PROCEDURES 2.2.5 AND 2.2.6

Solution No.	Element	Concentration [g/l]	Molar mass [g/mol]	Molar concentration [mol/l]	pH
1	NaOH	0,000558	40	0,00001394	9,62
	KOH	0,001489	56,11	0,00002654	
	$Ca(OH)_2$	0,000060	74,1	0,00000081	
2	NaOH	0,019521	40	0,00048802	11,15
	KOH	0,052123	56,11	0,00092895	
	$Ca(OH)_2$	0,002104	74,1	0,00002839	
3	NaOH	16,007000	40	0,40017500	13,80
	KOH	42,741000	56,11	0,76173588	
	$Ca(OH)_2$	1,725000	74,1	0,02327935	

ANNEX E – PREPARATION OF SPECIMENS IN SECTION 2.2.7 TO 2.2.10

E.1 Preparation of the specimens with repair mortar

On at least one specimen according to EN 1542, clause 4.12, with the maximum strength class of the concrete substrate (see 1.3.10) a layer of repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) with the maximum thickness $d_{\mathrm{M,max}}$[11] (see 1.3.8) shall be installed according to the MPII (see Figure E.1.1 a).
The preparation of the surface according to EN 1542, clause 5, shall be done for the use in vertical position.
On the repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) a layer of CFRP strips bonded by a layer of bonding agent (component B) with the minimum thickness $d_{\mathrm{G,min}}$[12] (see 1.3.8) shall be installed according to the MPII (see Figure E.1.1 b). If different widths are provided in the kit within one type of CFRP strips (see 1.3.3), the width used for this assessment procedure shall be specified as follows:

- If the kit for this type of CFRP strips includes strips width of 50 mm (80 mm)[13], this strip width shall be used.
- If the kit for this type of CFRP strips includes strips width greater than 50 mm (80 mm)[13], the strip width greater than 50 mm (80 mm) [13] shall be used, which has the smallest distance to the width of 50 mm (80 mm) [13].
- If the kit for this type of CFRP strips includes only strips width less than 50 mm (80 mm) [13], the greatest strip width shall be used.
- In the latter case, several strips shall be glued next to each other on the concrete surface according to Figure E.1.1 until the width of 50 mm (80 mm) [13] is reached or exceeded.

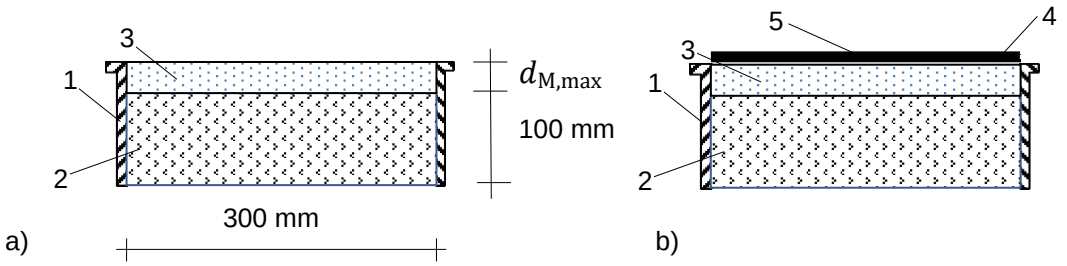


Figure E.1.1: Cross section through the test specimen with repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D)
1 attached formwork
2 reference body of concrete according to EN 1542
3 layer of repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D) with maximum thickness $d_{\mathrm{M,max}}$
4 layer of bonding agent (component B) with minimum thickness $d_{\mathrm{G,min}}$
5 CFRP strip (component A) externally bonded to the repair mortar (components C) and, if included in the kit, the bonding agent for the repair mortar (component D)

Steps of producing the test specimen:
first step a) specimen with repair mortar (component C) and, if included in the kit, the bonding agent for the repair mortar (component D),
second step b) the bonding agent (component B) and externally bonded CFRP strips (component A) are added to the specimen produced according to step a).[14]

11 At least one test series with the maximum layer thickness of repair mortar is necessary.
12 At least one test series with the minimum layer thickness of bonding agent is necessary.
13 The strip width of 50 mm applies to sections 2.2.7, 2.2.8 and 2.2.10. The strip width of 80 mm for section 2.2.9.
14 This step follows subsequently the previous step a) after a time given for save application and hardening, which will be provided and set by the manufacturer's product installation instructions (MPII).

E.2 Preparation of the specimens without repair mortar

The preparation of the surface according to EN 1542, clause 5, shall be done for the use in vertical position. On at least one specimen according to EN 1542, clause 4.12 (see Figure E.2.1.a), with the maximum strength class of the concrete substrate (see 1.3.10) a layer of CFRP strips (component A) bonded by a layer of bonding agent (component B) with the minimum thickness $d_{\mathrm{G,min}}$ **Error! Bookmark not defined.** (see 1.3.8) shall be installed according to the MPII (see Figure E.2.1.b).

If different widths are provided in the kit within one type of CFRP strips (see 1.3.3), the width used for this assessment procedure shall be specified as follows:

- If the kit for this type of CFRP strips includes strips width of 50 mm (80 mm) [13], this strip width shall be used.
- If the kit for this type of CFRP strips includes strips width greater than 50 mm (80 mm) [13], the strip width greater than 50 mm (80 mm) [13] shall be used, which has the smallest distance to the width of 50 mm (80 mm) [13].
- If the kit for this type of CFRP strips includes only strips width less than 50 mm (80 mm) [13], the greatest strip width shall be used.
- In the latter case, several strips shall be glued next to each other on the concrete surface according to Figure E.2.1 until the width of 50 mm (80 mm) [13] is reached or exceeded.

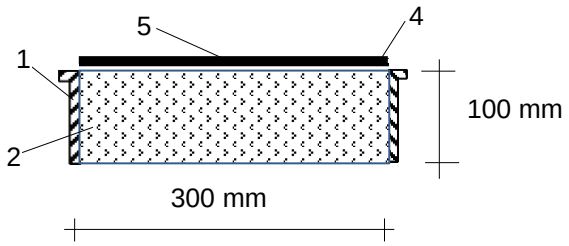


Figure E.2.1: Cross section through the test specimen without repair mortar

1 attached formwork
2 reference body of concrete according to EN 1542
4 layer of bonding agent (component B) with minimum thickness d_{in} (see 1.3.8)
5 CFRP strip (component A) externally bonded to the concrete