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European Assessment Document for

Kits for the strengthening of concrete elements by externally-bonded and near-surface-mounted carbon fibre-reinforced polymer strips

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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 (EB, see Figure 1.2.1.1) or near- surface- mounted (NSM, see Figure 1.2.1.2) carbon fibre reinforced polymer strips (in the following referred to as “kit(s)”) consist at least of the following components:

A unidirectional carbon fibre reinforced polymer (CFRP) strip,

B structural bonding agent for CFRP strips in accordance with 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.

This EAD covers only CFRP strips which are prefabricated to the width and thickness required in the manufacturing plant. Strips cut on site to the width needed for the intended use are not covered by this EAD.

The assessment methods covered by this EAD are based on the assumption that the concrete surface is repaired, where necessary, before strengthening by externally bonded (EB) or near surface mounted (NSM) CFRP strips. The concrete surface to be strengthened requires repair or preparation if at least one of the below conditions is fulfilled:

- It is not even;
- It does not meet a minimum value of bonding strength required for the kit;
- There is 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), or by normal concrete or shotcrete (both not 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 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).

The product is not fully covered by EAD 160086-00-0301. Compared to the previous version of the EAD, assessment procedures for the near surface mounted reinforced polymer strips (NSM, see Figure 1.2.1.2) have been added with two new essential characteristics and related assessment methods. By adding these new assessment procedures 2.2.13 and 2.2.14 to BWR 1, the assessment procedure for BWR 2, numbered 2.2.13 in EAD 160086-00-0301, has been given the section number 2.2.15

1 All undated references to standards 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.

These products are not covered by EAD 340351-00-0104 or EAD 340352-00-0104 because

- they are not intended to be used for seismic retrofitting of structures and for seismic prevention,
- they are, however, intended to be used for the resistance to long-term loads in bond with concrete,
- they are intended to be used not only for externally bonded but also near surface mounted CFRP strips.

Additionally, the reinforcements used for strengthening are not fabrics as in EAD 340352-00-0104, but CFRP strips.

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

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

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

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

1.2.1 Intended use(s)

The 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 even,
- 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 (EB) or in milled slots perpendicular to the concrete surface (NSM) according to the manufacturer´s product installation instructions (MPII) (see Figure 1.2.1.3 for EB or 1.2.1.4 for NSM, layer structure 1).

If these conditions are not fulfilled the repair mortar (component C), normal concrete or shotcrete is used to improve the concrete surface before gluing the CFRP strips to the repaired concrete surface according to the MPII (see Figure 1.2.1.3 for EB and 1.2.1.4 for NSM, layer structure 2 or 3).

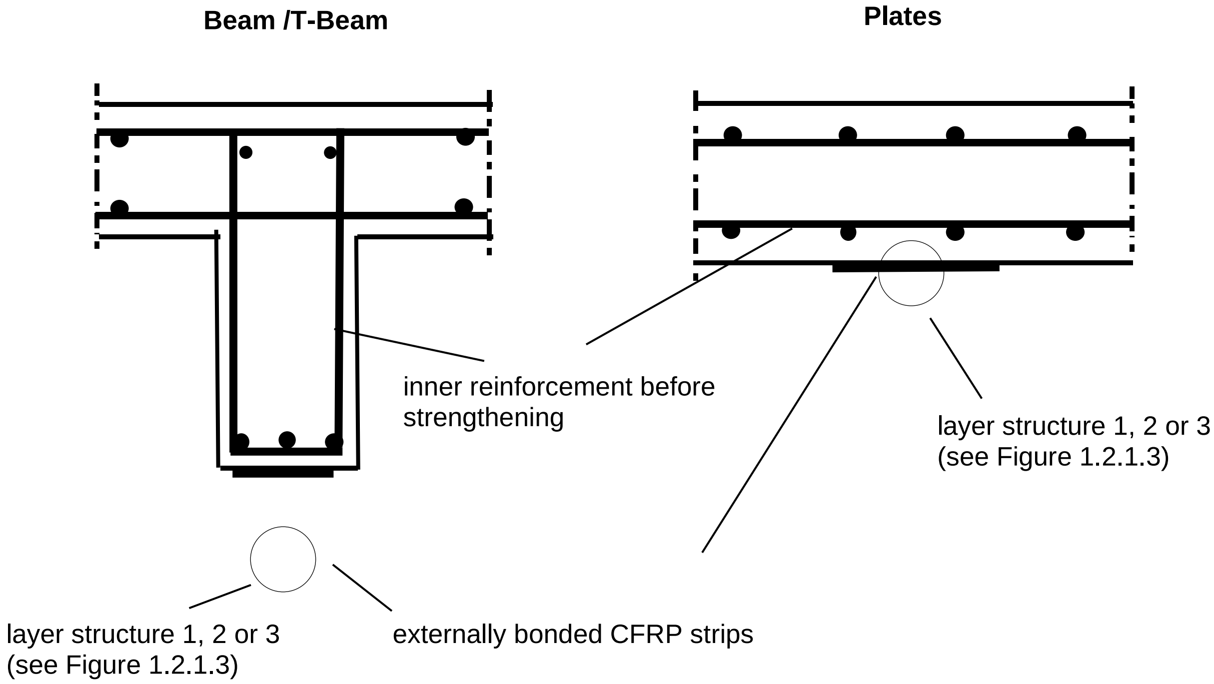

Figure 1.2.1.1: Principle sketches of reinforced concrete sections with subsequent strengthening by externally bonded (EB) CFRP strips

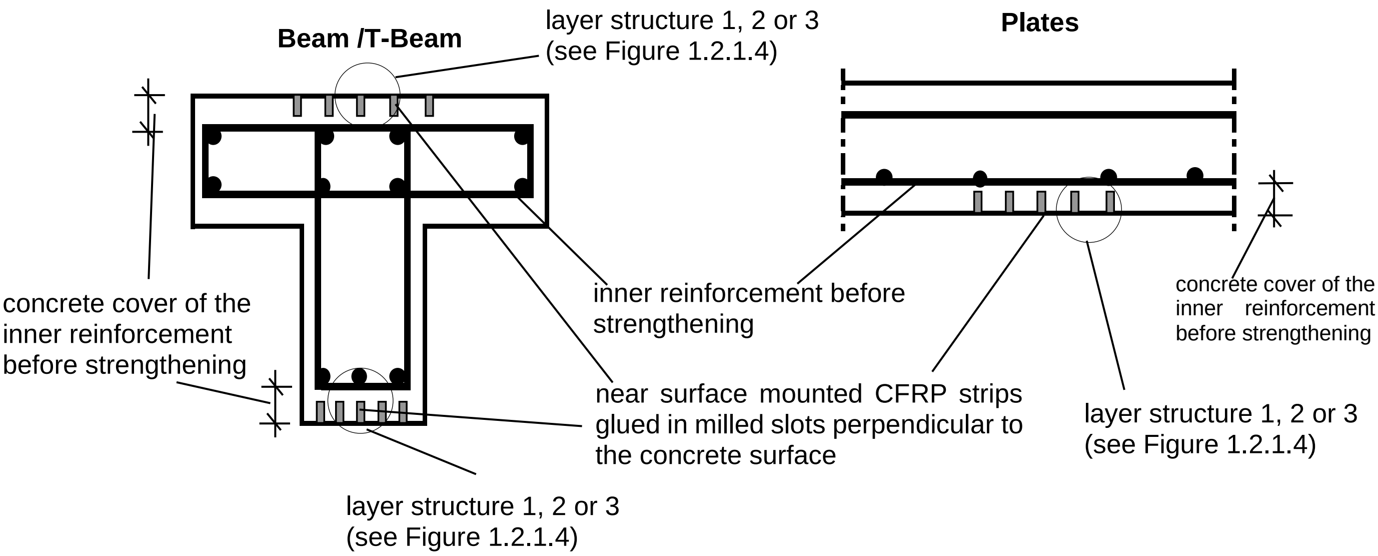

Figure 1.2.1.2: Principle sketches of reinforced concrete sections with subsequent strengthening by near surface mounted (NSM) CFRP strips, strips are placed upright within the slots

Layer structure 1
strengthening directly on the concrete surface

Layer structure 2
Strengthening on the repair mortar (component C) and the bonding agent of the repair mortar (component D)

Layer structure 3
Strengthening on normal concrete or shotcrete (not part of the kit)

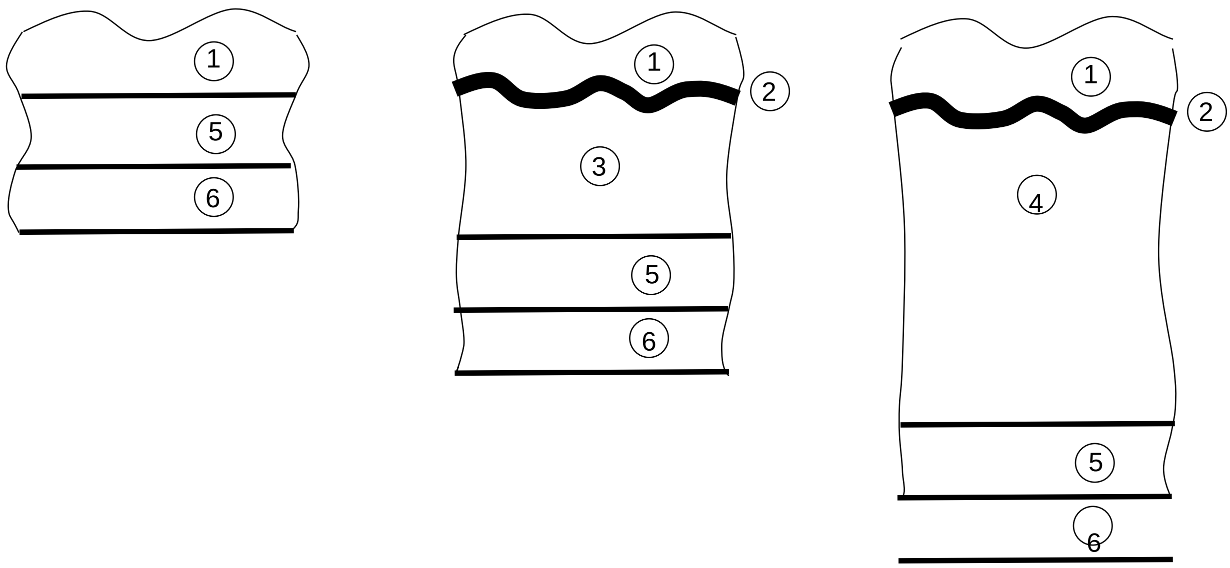

Figure 1.2.1.3: Principle sketches of possible layer structures with and without repair mortar as well as with normal concrete or shotcrete for externally bonded CFRP strips.

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

3 if included in the kit layer of repair mortar (component C) (minimum thickness $d_{\mathrm{M,min}}$ and maximum thickness $d_{\mathrm{M,max}}$)

4 layer of normal concrete or shotcrete

5 layer of structural bonding agent (component B) (minimum thickness $d_{\mathrm{G,min}}$ and maximum thickness $d_{\mathrm{G,max}}$)

6 layer of CFRP strip

Layer structure 1	**Layer structure 2**	**Layer structure 3**
strengthening directly on the concrete surface	Strengthening on the repair mortar (component C) and the bonding agent of the repair mortar (component D)	Strengthening on normal concrete or shotcrete (not part of the kit)

Longitudinal section

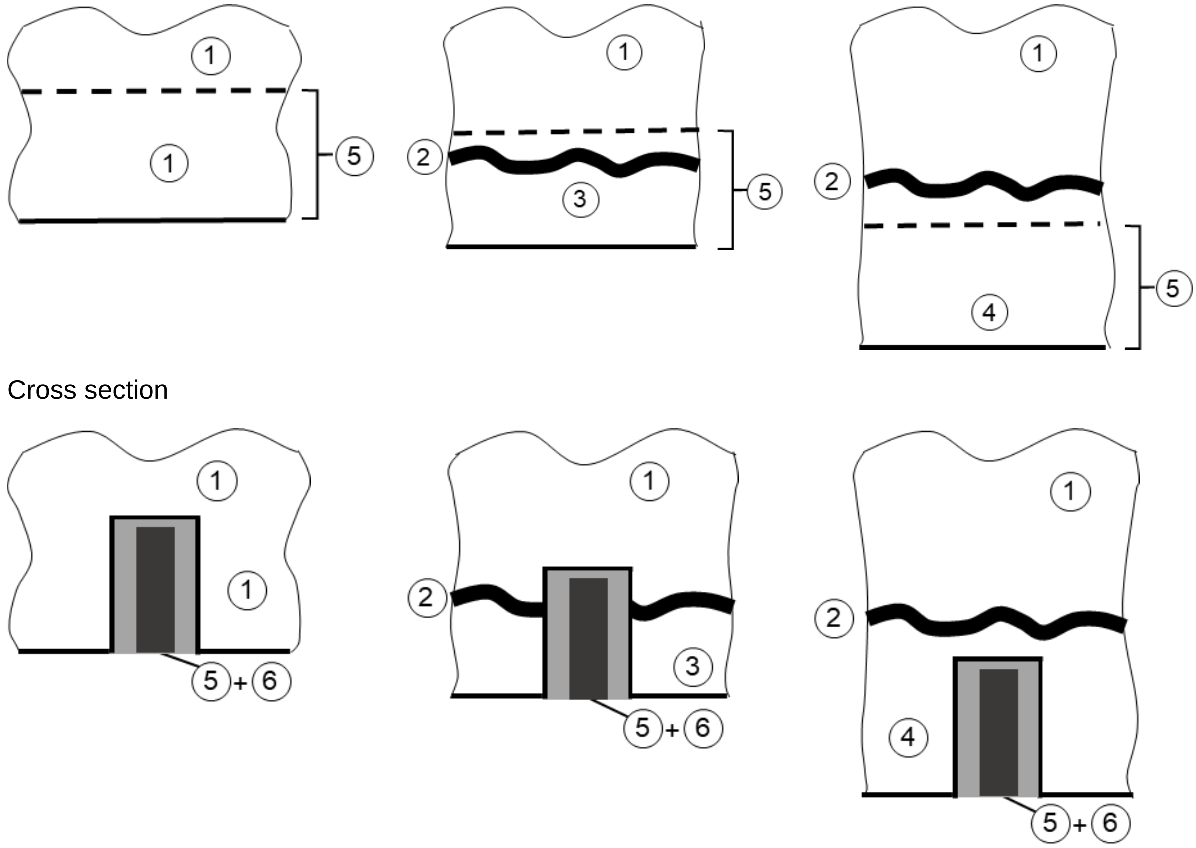

Figure 1.2.1.4: Principle sketches of possible layer structures with and without repair mortar as well as with normal concrete or shotcrete for near surface mounted CFRP strips.

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

3 if included in the kit, layer of repair mortar (component C) (minimum thickness $d_{\mathrm{M,min}}$ and maximum thickness $d_{\mathrm{M,max}}$)

4 layer of normal concrete or shotcrete

5 CFRP strip glued in milled slots (components A) perpendicular to the concrete surface (NSM)

6 structural bonding agent (component B) that coats the 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 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 epoxy resin.

1.3.4 Standard environmental conditions in the assessment procedures

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

1.3.5 Minimum temperature of installation

The following terms are used in this document:

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

$T_{\mathrm{Mmin,I}}$, 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 structural 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.

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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.

1.3.7 Coating (size) of fibres

During the spinning process the coating 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 structural 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 structural bonding agent (component B) are $d_{\mathrm{G,min}}$ = 1 mm and $d_{\mathrm{G,max}}$ = 5 mm and

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

The default values for the minimum curing time of the structural bonding agent (component B) are t_{GTn}= 7 d at standard environmental conditions (see 1.3.4) and t_{GTmin} = 28 d at minimum temperature of installation (see 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 (component 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 (see 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.

1.3.11 Symbols and units

Letters

upper case		
A	[mm²]	area
E	[MPa]	young's modulus / modulus of elasticity
F	[kN]	force / load
ΔF	[kN]	force / load difference
R	[-]	ratio
T	[°C]	temperature

lower case		
d	[mm]	thickness
f	[MPa]	strength
t	[s]	time
b	[mm]	width
l	[mm]	length

greek		
ε	[MPa]	strain

indices

upper case, subscript	
G	structural bonding agent (component B)
I	installation
L	CFRP strips (component A)
M	repair mortar (component C)
T	temperature
C	concrete

lower case, subscript	
a	alkaline environment at maximum temperature of intended use
b	bond / anchorage
b(NSM)	Bond / anchorage for Near Surface Mount application
c	compression
t	pull-off, perpendicular to the concrete surface
f	related to the fibre section
fat	low-cycle fatigue
fl	flexural
g	glass transition
i	single value,
j	single value
k	characteristic value
lt	after long-term loading
m	mean value
n	standard environmental conditions
max	maximum
min	minimum
surf	perpendicular to surface
t	tension
u	failure
v	unbonded

lower case, superscript	
u	upper load
l	lower load

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 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} [s]
2	Glass transition temperature of the repair mortar (component C)		Level T_{Mg} [°C], t_{MTn} [s]
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 depending on the 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 depending on the 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} [MPa]
8	Resistance of CFRP strips (component A) after storage in alkaline environment at maximum temperature for 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 $R_{\mathrm{L}\varepsilon_{\mathrm{u}}\mathrm{a}}$

No	Essential characteristic	Assessment method	Type of expression of product performance
9	Resistance of CFRP strips (component A) in alkaline environment under long-term load at maximum temperature for 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 $R_{\mathrm{L}\varepsilon_{\mathrm{u}}\mathrm{lt}}$
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 $f_{\mathrm{Cti,surf}}$, $f_{\mathrm{Ctm,surf}}$, $f_{\mathrm{Ctk,surf}}$ [MPa]
11	Bond strength after low-cycle fatigue action for robustness	2.2.8	Level and description compression strength class of the concrete substrate $f_{\mathrm{Cti,surf,fat}}$, $f_{\mathrm{Ctm,surf,fat}}$, $f_{\mathrm{Ctk,surf,fat}}$, [MPa], $R_{\mathrm{fat,m}}$
12	Bond strength after long-term loading under harsh climatic conditions	2.2.9	Level and description compression strength class of the concrete substrate $f_{\mathrm{Cti,surf,lt}}$ [MPa]
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 $f_{\mathrm{Cti,surf,T_{min}}}$, $f_{\mathrm{Ctm,surf,T_{min}}}$, $f_{\mathrm{Ctk,surf,T_{min}}}$, [MPa] $R_{\mathrm{T_{min},m}}$
Further essential characteristics only of kits with externally bonded (EB) CFRP strips			
14	Shear resistance of the bond anchorage of CFRP strips externally bonded to concrete	2.2.11	Level and description $f_{\mathrm{Ctim,surf}}$, $f_{\mathrm{Ctik,surf}}$, f_{Ccm}, f_{Cck} [MPa] F_{bLi}, F_{bLm}, F_{bLk} [kN]
15	Fatigue behaviour of the bond anchorage of CFRP strips externally bonded to concrete	2.2.12	Level and description $f_{\mathrm{Ctim,surf}}$, $f_{\mathrm{Ctik,surf}}$, f_{Ccm}, f_{Cck} [MPa] the cyclic load $\Delta F_{\mathrm{bLi}} = F_{\mathrm{bLi}}^{u} - F_{\mathrm{bLi}}^{l}$ [kN] and corresponding numbers of cycles
Further essential characteristics only of kits with near surface mounted (NSM) CFRP strips			
16	Ultimate anchorage load of near surface mounted CFRP strips	2.2.13	Level and description $F_{\mathrm{b(NSM)Li}}$, $F_{\mathrm{b(NSM)Lm}}$, $F_{\mathrm{b(NSM)Lk}}$ [kN]
17	Long-term ultimate anchorage load (creep rupture of near surface mounted CFRP strips at maximum temperature for the intended use and relative air humidity of ≥ 75 %)	2.2.14	Level and description observed times until failure t_j [s] in dependence of load level $F_{\mathrm{b(NSM)l,lt,j}}$ [kN]
Basic Works Requirement 2: Safety in case of fire			
18	Reaction to fire of the applied kit	2.2.15	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 in accordance with 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 the structural 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 in accordance with 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 in accordance with EN 196-1, clause 9.1, or EN 1015-11, clause 8, and 6 tests of the compressive strength in accordance with 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 structural 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 in accordance with 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 in accordance with 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 in accordance with 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 in accordance with 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 the structural bonding agent and repair mortar shall be determined in accordance with 2.2.2. At least specimens of structural bonding agent (component B) cured at minimum temperature of installation $T_{\mathrm{Gmin,I}}$ [°C] (see 1.3.5) and specimens of repair mortar (component C) cured at minimum temperature of installation $T_{\mathrm{Mmin,I}}$ [°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 structural 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 (component 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 $T_{\mathrm{Gmin,I}}$ and $T_{\mathrm{Mmin,I}}$ (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 in accordance with 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 in accordance with 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 in accordance with 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 in accordance with 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) in accordance with 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 specimens 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 in accordance with 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. The test specimens are to be cut out of the CFRP strips of the batches to be tested. The length of the CFRP strips at least shall be 250 mm and the free length at least 130 mm.

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

In accordance with 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 average thickness d_{Lmi} of the specimens type B in accordance with EN 2561, Annex A, shall be determined in accordance with Annex C, clause C.2 of this EAD. The section of the specimens of the CFRP strips then shall be determined by $A_{\mathrm{Li}} = b_{\mathrm{Lmi}} d_{\mathrm{Lmi}}$.

Before performing the strength test, the mass per meter length of the CFRP strip m_{Li} in accordance with Annex C, clause C.1 and the dimensions of the CFRP strips in accordance with Annex C, clause C.2 of the test specimen to be used for the strength test shall be determined.

If requested by the manufacturer, the determination of strengths and moduli of elasticity related to the section of fibres shall be determined for all tested CFRP strips by using the following sizes:

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

- the fibre content of mass W_{fi} in accordance with EN 2564, clause 9.1, and
- the gross density of the fibres ρ_{f} shall be known from the MPII or shall be determined in accordance with ISO 10119, method A.

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

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

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

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

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

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

The average values of the secant modulus of elasticity E_{Lm}, of the tensile strengths f_{Lm} and of the ultimate strain $\varepsilon_{\mathrm{Lum}}$ and the 5% quantile value in accordance with 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 for 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) in accordance with 2.2.4 after long-time storage in alkaline environment at maximum temperature for 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[4].

Assessment method

If the CFRP strips are supplied in coils, the specimens for this test shall be taken from coils that have the smallest inner diameter (see 1.3.2). The CFRP strips to be tested shall be cut from CFRP strips of the same batch as used for 2.2.4. The CFRP strips shall have the same dimensions as for the samples used for 2.2.4.

The CFRP strips shall be stored in an alkaline solution of at least pH9 (see Annex D) at maximum temperature for the intended use (see 1.3.6) for at least 1800 h.

Additionally test series are possible for following alkaline solutions (see Annex D):

alkaline solution > pH 11.0,

4 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.

alkaline solution > pH 13.7.

The composition of the solutions is given in Annex D.

After this storage the CFRP 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} shall be tested according to 2.2.4. with the same anchorage and free length as in 2.2.4.

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

In accordance with 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 in accordance with 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 td_{Lmi} of the specimens "i" type B in accordance with EN 2561, Annex A, shall be determined[5] in accordance with Annex C, clause C.2. The section of the specimens of the CFRP strips than shall be determined by $A_{\mathrm{Li}} = b_{\mathrm{Lmi}} d_{\mathrm{Lmi}}$.

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

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

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 in accordance with 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 used for the tests.

2.2.6 Resistance of CFRP strips (component A) in alkaline environment under long-term load at maximum temperature for 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) in accordance with 2.2.4 after long-time loading in alkaline environment at maximum

5 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.

temperature for 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[4].

Assessment method

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

The CFRP strips shall be stored in an alkaline solution of at least pH9 (see Annex D) at maximum temperature for the intended use (see 1.3.6) and stressed with 50% of the characteristic value of tensile strength in accordance with 2.2.4 for at least 1800 h.

Additionally test series are possible for following alkaline solutions (see Annex D):

alkaline solution > pH 11.0,

alkaline solution > pH 13.7.

The composition of the solutions is given in Annex D.

The CFRP strips shall be clamped into the test setup according to Figure 2.2.6.1. The CFRP strips to be tested shall be cut from CFRP strips of the same batch as used for 2.2.4. The length of the CFRP strips shall be higher as the specimens in accordance with 2.2.4. At least the total length of the CFRP strips tested in accordance with 2.2.4 shall be in the alkali bath. To ensure this, length allowances are recommended to compensate for changes in the level in the alkali bath.

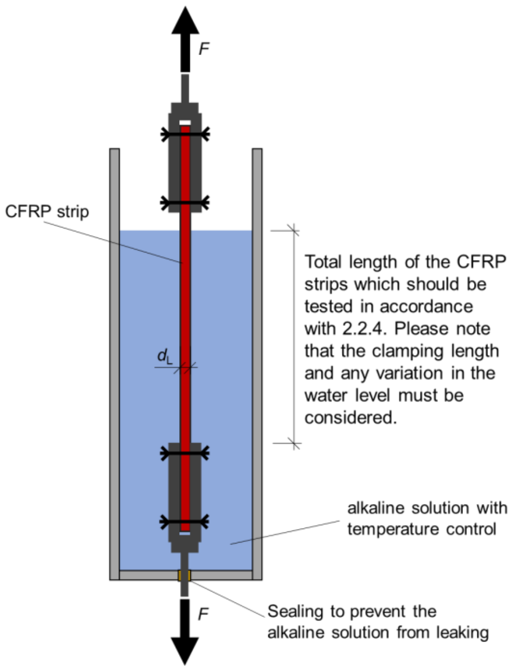

Figure 2.2.6.1: Test setup for the storage of the CFRP strips at maximum temperature for the intended use (see 1.3.6) and stressed with 50% of the characteristic value of tensile strength in accordance with 2.2.4 for at least 1800 h. The arrangement of the CFRP strips and corresponding ring grooves is given in clauses 2.2.6 to 2.2.10.

After this storage under loading, the specimens shall be washed and dried for 24 h at standard environmental conditions (see 1.3.4). From the length of the CFRP strips located in the alkali bath, specimens shall be cut out whose length corresponds to that of the specimens in accordance with 2.2.4. After the anchorages have been installed, the specimens shall also have the same free length as those in accordance with 2.2.4. Afterwards the tensile load at failure F_{Llti} shall be tested in accordance with 2.2.4.

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

In accordance with 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 in accordance with 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 d_{Lmi} of the specimens "i" type B in accordance with EN 2561, Annex A, shall be determined[5] in accordance with Annex C, clause C.2. The section of the specimens of CFRP strips then shall be determined by $A_{\mathrm{Li}} = b_{\mathrm{Lmi}} d_{\mathrm{Lmi}}$.

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

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

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 $\varepsilon_{\mathrm{L}u\mathrm{ltm}}$ 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:

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

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

$E_{\mathrm{Lm}}, f_{\mathrm{Lm}}, \varepsilon_{\mathrm{Lum}}$ are the average Modulus of elasticity, tensile strength and ultimate strain in accordance with 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 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 (component C, if included in the kit) and, the bonding agent for the repair mortar (component D, if included in the kit), structural bonding agent (component B) and CFRP strips (component A),
- specimens with layers of concrete, structural bonding agent (component B) and CFRP strips (component A).

The bond strength shall be determined by pull-off tests in accordance with EN 1542 after curing under standard environmental conditions (see 1.3.4).

If the bond strength for B to the structural element is assessed for NSM, the strips can be excluded. If testing refers to externally bonded strips, they cannot be excluded.

The load transfer varies for both systems, hence the bond for NSM can be determined with omitting the strips. On site the strips (A) are fully covered in (B) within the slots. Thus, if only NSM applications are intended, this assessment method can also be used without CFRP strips.

Assessment method

If the CFRP strips are supplied in coils, the specimens 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 in accordance with EN 1542, clause 4.7, are used, not dollies of aluminium,
- the structural bonding agent (component B) may be used also for the bonding of the steel dollies,
- the thickness of the layers of the structural bonding agent (also for the dollies) is $d_{\mathrm{G,min}}$ (see 1.3.8).

When repair mortar is included in the kit, 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 (component C) and, if included in the kit, the bonding agent for the repair mortar (component D) and the structural bonding agent (component B) according to the MPII 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 2.2.7.1). 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.

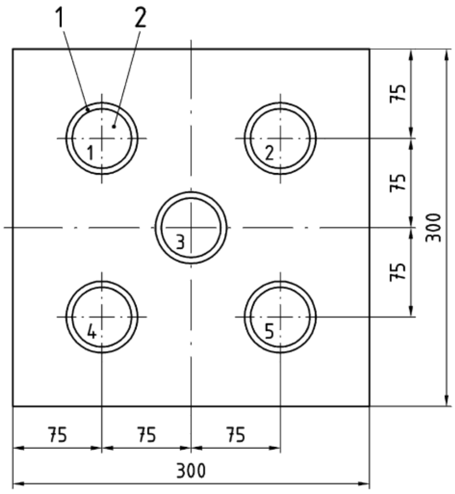

Figure 2.2.7.1: Top view on the test specimen with annular grooves showing the areas of the steel dollies

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 structural bonding agent (component B) according to the MPII 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 2.2.7.1). 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 in accordance with 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 $d_{\mathrm{G,min}}$ (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 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 in accordance with 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 (component 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 in accordance with EN 1542, clause 7.5, for all specimens shall be determined for further comparison with the results in accordance with 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 in accordance with 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 (component C) and, if included in the kit, the bonding agent for the repair mortar (component D) as well as of the structural bonding agent (component B) and the failure modes shall be reported in the ETA.

2.2.8 Bond strength after low-cycle fatigue action for robustness

Purpose of the assessment

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

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

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

If only NSM applications are intended, this assessment method can also be used without CFRP strips.

Assessment method

If the CFRP strips are supplied in coils, the specimens 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 in accordance with EN 1542, clause 4.7, are used, not dollies of aluminium,
- the structural bonding agent (component B) may be used also for the bonding of the steel dollies,
- the thickness of the layers of the structural 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 in accordance with EN 1542, Figure 1 (or Figure 2.2.8.1 of this EAD)6,

6 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.

- on both circular surfaces of these cylinders are glued dollies in accordance with EN 1542, clause 7.2.

When repair mortar is included in the kit, 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 (component C, if included in the kit) and, the bonding agent for the repair mortar (component D, if included in the kit) and the structural bonding agent (component B) according to the MPII 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 2.2.8.1). 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.

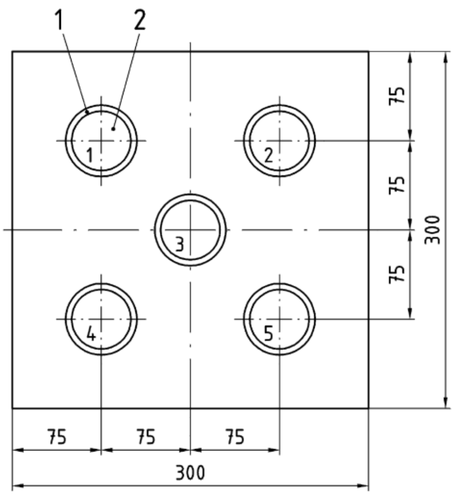

Figure 2.2.8.1: Top view on the test specimen after drilling the concrete cylinders out of the concrete plate in accordance with EN 1542

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 structural bonding agent (component B) according to the MPII 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 2.2.8.1). 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 in accordance with EN 1542, clause 7.2, shall be glued on the circular surfaces with the structural bonding agent (component B). The minimum thickness $d_{\mathrm{G,min}}$ (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 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 cylinder's 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 in accordance with 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 in accordance with 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 (component 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 in accordance with 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 in accordance with 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 in accordance with 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 (component C) and, if included in the kit, the bonding agent for the repair mortar (component D) as well as of the structural 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 (component C, if included in the kit) and the bonding agent for the repair mortar (component D, if included in the kit), structural bonding agent (component B) and CFRP strips (component A),
- specimens with layers of concrete, structural bonding agent (component B) and CFRP strips (component A).

The bond strength shall be determined by pull-off tests in accordance with EN 1542 after curing under standard environmental 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 for the 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 for the intended use for the whole half year (approximately 2200 cycles).

If only NSM applications are intended, this assessment method can also be used without CFRP strips.

Assessment method

If the CFRP strips are supplied in coils, the specimens 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 in accordance with EN 1542, clause 4.7, are used, not dollies of aluminium,
- the structural bonding agent (component B) may be used also for the bonding of the steel dollies,
- the thickness of the layers of the structural 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 in accordance with EN 1542, Figure 1 (or Figure 2.2.9.1 of this EAD)[7],
- on both circular surfaces of these cylinder dollies are glued in accordance with EN 1542, clause 7.2.

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 2.2.9.1) so that 5 individual cylinders are created. The cylinders may only be tested if dollies are glued on both circular surfaces.

When repair mortar is included in the kit, 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 (component C, if included in the kit) and the bonding agent for the repair mortar (component D, if included in the kit) and the structural bonding agent (component B) according to the MPII 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 2.2.9.1). 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.

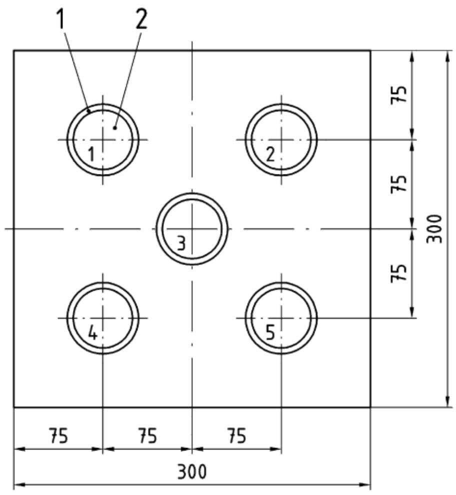

Figure 2.2.9.1: Top view on the test specimen after drilling the concrete cylinders out of the concrete plate in accordance with EN 1542

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 structural bonding agent (component B) according to the MPII 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 2.2.9.1). 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) in accordance with 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 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 for the intended use (see 1.3.6) under climate 1 or 2. $f_{\mathrm{Ctm,surf}}$ is the average value of the bond strength determined in accordance with 2.2.7. After long-term loading the bond strength $f_{\mathrm{Cti,surf,lt}}$ shall be determined on each of these cylinders in accordance with EN ISO 4624, method A, at standard environmental conditions (see 1.3.4).

At least 5 cylinders with and without repair mortar (component 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 $f_{\mathrm{Ctisurf,lt}}$ and failure mode in accordance with EN 1542, clause 7.5, shall be determined and reported in the ETA. For all specimens where failure occurred before the end of the half year the time to failure and the failure mode in accordance with EN 1542, clause 7.5, shall be reported in ETA. Furthermore, the curing time of the repair mortar (component C) and, if included in the kit, the bonding agent for the repair mortar (component D) as well as of the structural 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 (component C, if included in the kit) and, the bonding agent for the repair mortar (component D, if included in the kit) structural bonding agent (component B) and CFRP strips (component A),

specimens with layers of concrete, structural bonding agent (component B) and CFRP strips (component A).

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

If only NSM applications are intended, this assessment method can also be used without CFRP strips.

Assessment method

If the CFRP strips are supplied in coils, the specimens 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 in accordance with EN 1542, clause 4.7, are used, not dollies of aluminium,
- the thickness of the layers of structural bonding agent (also for the dollies) is $d_{\mathrm{G,min}}$ (see 1.3.8).

When repair mortar is included in the kit, 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 (component C, if included in the kit) and, the bonding agent for the repair mortar (component D, if included in the kit) and the structural 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 2.2.10.1). 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.

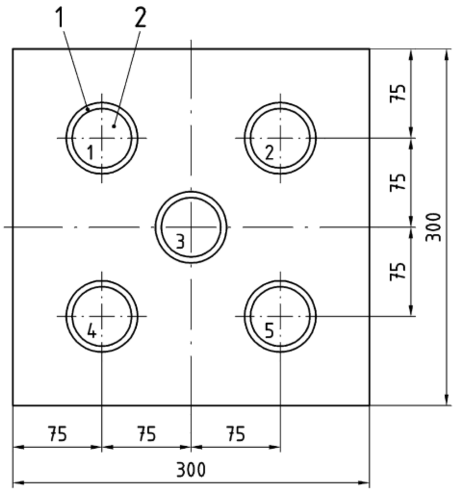

Figure 2.2.10.1: Top view on the test specimen with annular grooves showing the areas of the steel dollies

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 structural 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 2.2.10.1). 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 in accordance with 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 in accordance with EN 1542, clause 7.4 at standard environmental conditions (see 1.3.4).

At least 5 annular grooves with and without repair mortar (component 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 in accordance with 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 in accordance with 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 in accordance with 2.2.7. The values $f_{\mathrm{Cti,surf,T_{min}}}$, $f_{\mathrm{Ctm,surf,T_{min}}}$, $f_{\mathrm{Ctk,surf,T_{min}}}$, $R_{\mathrm{T_{min}},\mathrm{m}}$, the curing time of the repair mortar (component C) and, if included in the kit, the bonding agent for the repair mortar (component D) as well as of the structural bonding agent (component B) and the failure modes shall be reported in the ETA.

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

Purpose of the assessment

The tests are performed to determine the shear resistance represented by the characteristic value of the maximum force 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 specimens 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 60 cm and the length of the part below the crack plate shall be more than 110 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_L The thickness *d* of the concrete block shall be more than 150 mm. Loading shall be carried out through the two stirrups of concrete reinforcement steel. The concrete cover of the stirrups shall be at least 10 mm.

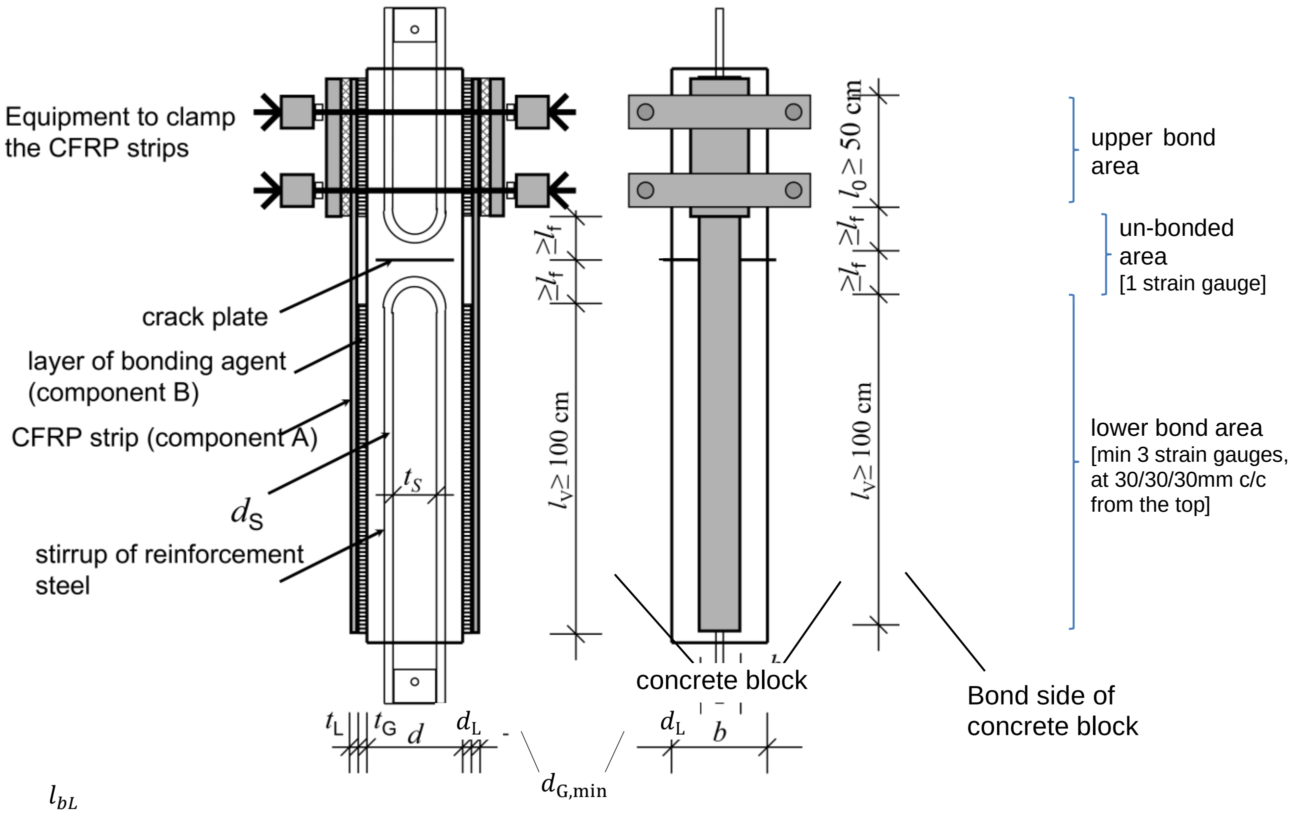

Figure 2.2.11.1: Tension-tension double-sided bond specimen to determine the bonding behaviour of bonded CFRP strips

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 $d_{G,min}$ (see 1.3.8) of the layer of structural bonding agent (component B). The CFRP strips shall come from one of the batches tested in accordance with 2.2.4. The thickness d_L 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. Above and below the crack plate unbonded areas of the CFRP strips of at least l_{f} =10 cm shall be provided (see Figure 2.2.11.1). After applying CFRP strips the structural bonding agent shall cure at least for t_{GTn} at standard environmental conditions (see 1.3.4).

The maximum shear force is the maximum tensile force applied during loading of tension-tension double-sided bond specimen. The maximum shear force F_{bL} depends on the following parameters:

- bond length l_{bL} of the CFRP strips to the concrete,
- the geometry (thickness d_{L} and width b_{L} 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.

As default specimens for the minimum bond length l_{bL}, the maximum thickness d_{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. Additionally, other parameter sets can be tested.

Examination:

The tests shall be carried out deformation controlled with a constant piston rate of 1 mm/min (± 10 %).

The relative displacement (slip) between concrete surface and CFRP strip at the upper beginning of the lower bond area and the strains of the CFRP strip in the unbonded and lower bonded area shall be measured as a function of loading.

The strains of the CFRP strip in the lower bond area shall be measured with a chain of strain gauges. One strain gauge shall be applied in the unbonded area. In the lower bond 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 upper beginning of the lower bondarea. 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 in accordance with 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 after testing the tension-tension double--sided bond specimens the cylinder compressive strength of these 6 concrete cylinders shall be determined in accordance with EN 12390-3. From these 6 values f_{Cci}, the average value f_{Ccm} and the characteristic value f_{Cck} shall be calculated.

Performing the shear tests usually the bond of one of the two CFRP strips fails first by separating from the concrete. The test shall be interrupted if one of the two CFRP strips has separated from the concrete within the first 30 mm of lower bond area. This is the case when the same strain occurs at the first strain gauge in the lower bond area as at the strain gauge in the unbonded area.

After fixing the separated CFRP strip by a suitable contact pressure, the test shall be continued until complete separation of the second CFRP strip occurs.

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

After determination of the maximum shear force F_{bLi} the failure modes in accordance with EN 1542, clause 7.5, shall be determined. Then the concrete pull-off strength $f_{\mathrm{ctij,surf}}$ tested in accordance with EN 1542 at three places "j" of the bond sides of each concrete block "i" (see figure 2.2.11.1) 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 configuration of specimens, the following values shall be determined and reported in the ETA:

- the single values of the maximum shear force F_{bLi} together with the pull-off strength $f_{\mathrm{Ctim,surf}}$ and $f_{\mathrm{Ctik,surf}}$, the measured shear force – slip diagrams, shear force – strain diagrams as well as the failure modes in accordance with EN 1542, clause 7.5,
- the average value F_{bLm} of the maximum shear forces F_{bLi} together with the average compressive strength of the concrete f_{Cm} and
- the 5% quantile value in accordance with EN 1990, Table D.1 (V_x unknown), F_{bLk} of the maximum shear forces F_{bLi} together with the characteristic compressive strength of the concrete f_{Ck}.

2.2.12 Fatigue behaviour of the bond 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 bond 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 test setup is identical to 2.2.11. The CFRP strips shall come from one of the batches tested according to 2.2.4. The only difference is that a cyclic load $\Delta F_{\mathrm{bLi}} = F^{u}_{\mathrm{bLi}} - F^{l}_{\mathrm{bLi}}$ is applied to the specimen, where F^{u}_{bLi} is the upper load and F^{l}_{bLi} the lower load. The fixing of the separated CFRP strip by a suitable contact pressure is excluded for testing to avoid obtaining unconservative results.

At least specimens for the minimum bond length l_v, the maximum thickness d_{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 in accordance with 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 maximum shear force F_{bLm} determined for the same configuration of specimen under 2.2.11:

Load level A1: $F^{\mathrm{l}}_{\mathrm{bli}} = 0{,}15\ F_{\mathrm{blm}}$ to $F^{\mathrm{u}}_{\mathrm{bLi}} = 0{,}45\ F_{\mathrm{blm}}$

Load level B1: $F^{\mathrm{l}}_{\mathrm{bli}} = 0{,}30\ F_{\mathrm{blm}}$ to $F^{\mathrm{u}}_{\mathrm{bli}} = 0{,}55\ F_{\mathrm{blm}}$

Load level C1: $F^{\mathrm{l}}_{\mathrm{bli}} = 0{,}45\ F_{\mathrm{blm}}$ to $F^{\mathrm{u}}_{\mathrm{bli}} = 0{,}64\ F_{\mathrm{blm}}$

Load level D1: $F^{\mathrm{l}}_{\mathrm{bli}} = 0{,}60\ F_{\mathrm{blm}}$ to $F^{\mathrm{u}}_{\mathrm{bli}} = 0{,}74\ F_{\mathrm{blm}}$

The corresponding number of cycles until failure of bond of the CFRP strips is determined. Failure of bond is the status when the CFRP strip has separated from the concrete within the first 30 mm of lower bond area. This is the case when the same strain occurs at the first strain gauge at the lower bond area as at the strain gauge in the unbonded area.

After reaching 2 million load cycles or with no separation of the CFRP strip by 30 mm[8] () a higher upper load level shall be chosen to test until failure:

Load level A2: $F_{\mathrm{bli}}^{\mathrm{l}} = 0{,}15\ F_{\mathrm{blm}}$ to $F_{\mathrm{bli}}^{\mathrm{u}} = 0{,}49\ F_{\mathrm{blm}}$

Load level B2: $F_{\mathrm{bli}}^{\mathrm{l}} = 0{,}30\ F_{\mathrm{blm}}$ to $F_{\mathrm{bli}}^{\mathrm{u}} = 0{,}58\ F_{\mathrm{blm}}$

Load level C2: $F_{\mathrm{bli}}^{\mathrm{l}} = 0{,}45\ F_{\mathrm{blm}}$ to $F_{\mathrm{bli}}^{\mathrm{u}} = 0{,}67\ F_{\mathrm{blm}}$

Load level D2: $F_{\mathrm{bli}}^{\mathrm{l}} = 0{,}60\ F_{\mathrm{blm}}$ 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 unbonded and lower bond area should be measured as a function of loading. The strains of the CFRP strip shall be measured with a chain of strain gauges. One strain gauge shall be applied in the unbonded area. In the lower bond 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 shear force – strain curves at least of the strain gauges in the unbonded area as well as of the two first strain gauges in the lower bond area (from the beginning of the lower bond 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 in accordance with 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 in accordance with EN 12390-3. From these 6 values f_{Cci}, the average value f_{Ccm} and the characteristic value f_{Cck} shall be calculated.

After cyclic testing the concrete pull-off strength tested in accordance with EN 1542 at three places "j" of of each concrete block "i" (see figure 2.2.11.1) shall be determined.

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 in accordance with EN 1542 at three places "j" of the bond sides of each concrete block "i" (see Figure 2.2.11.1) 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 Ultimate anchorage load of near surface mounted CFRP strips

Purpose of the assessment

The tests are performed to determine the ultimate anchorage load $F_{\mathrm{b(NSM)Lu}}$, i.e., the load which can be transferred from the strip through the bond into the concrete structure, for relevant configurations of near surface mounted CFRP strips.

Assessment method

Test specimen:

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8 This is the case when at the first strain gauge in the lower bond area strain values are measured which have the same level as in the unbonded area, see chapter 2.2.11.

The specimen consists of an unreinforced concrete block (see Figure 2.2.13.1) where after at least 28 days and before applying CFRP strips a slot is milled on one side. In this slot a CFRP strip shall be bonded with the structural bonding agent (component B) (see Figure 2.2.13.1).

The CFRP strips shall come from one of the batches tested in accordance with 2.2.4.

The cross section of this concrete block shall be 30 cm x 30 cm. After at least 28 days of hardening of the concrete blocks the slots may be cut into the concrete blocks and the CFRP strips may be glued into the slots as shown in Figure 2.2.13.1.

The length of the slot shall be equal to $l_f + l_{\mathrm{bL}}$. The width of the slot shall fulfil the following conditions: $d_L + 1\ \mathrm{mm} \le b_\mathrm{s} \le d_\mathrm{L} + 3\ \mathrm{mm}$, where d_L is the thickness of the CFRP strip and b_s the width of the slot (see Figure 2.2.13.1).

The default value of the depth t_s of the slot is $b_\mathrm{L} + 3\ \mathrm{mm}$, where b_L is the width of the CFRP strips. The default values shall be used if the MPII do not contain any other information.

After curing of the structural bonding agent according to the MPII at standard environmental conditions the anchorage test shall be carried out. The load F shall be applied at upper end of the CFRP strip. The configuration in Figure 2.2.13.1 is an example of load application to obtain a tension-compression configuration.

Loading shall be carried out deformation-controlled. At the upper part of the slot a bondless area shall be foreseen of at least l_f = 10 cm in the longitudinal direction of the concrete block (see Figure 2.2.13.1).

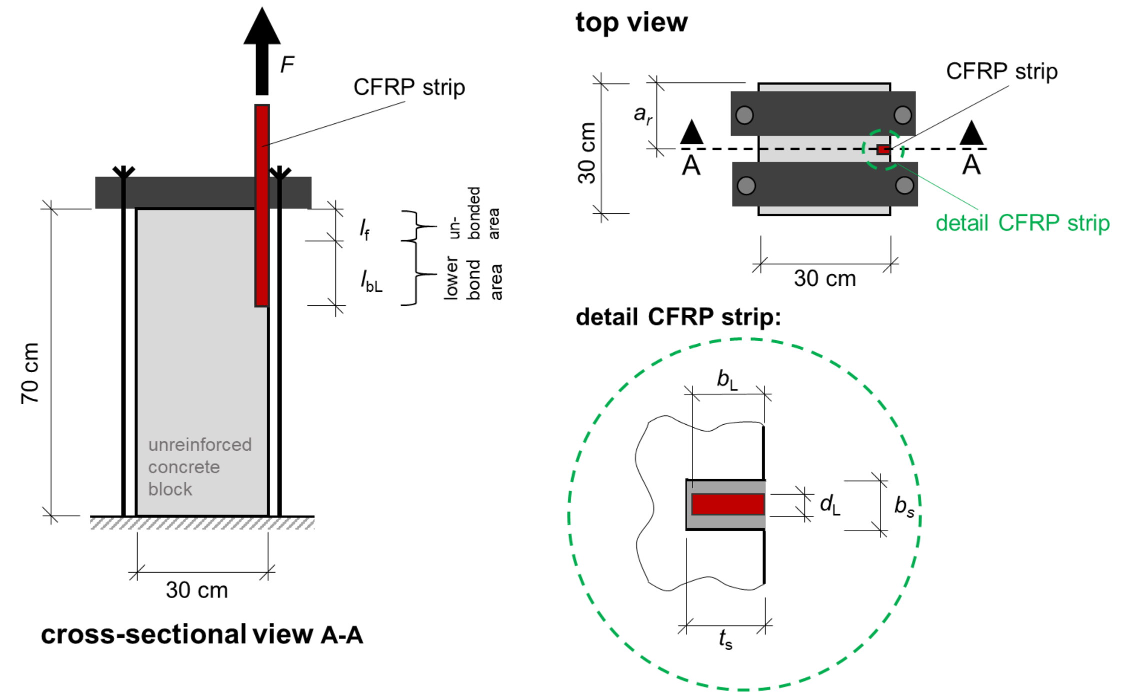


Figure 2.2.13.1: Tension-pressure shear specimen to determine the ultimate anchorage load in dependence of the bond length l_{bL}, and the edge distance a_r of the slot The dimensions of the CFRP strips (width d_L and thickness b_L) and the slot (width b_s and depth t_s) are also shown in detail.

Failure loads depend on the following parameters:

- bond length l_{bL} of the CFRP strips in the slot,
- the geometry of the CFRP strips (thickness d_{L} and width b_L) and the mechanical properties in accordance with 2.2.4,
- edge distance a_r of the slot,
- flexural and compressive strength of the structural bonding agent,
- compressive strength class of the concrete.

The default values for the bond lengths l_{bL} and the edge distances a_r are 150 mm. The default value for the concrete strength class of the specimens is C20/25. The default values shall be used unless they are explicitly excluded in the MPII. Based on the wish of the manufacturer other values can be used in addition.

For each parameter set at least 3 tests shall be carried out.

After applying CFRP strips the structural bonding agent shall cure in accordance with the MPII at standard environmental conditions (see 1.3.4).

The tests shall be carried out deformation-controlled with a constant piston rate of 1 mm/min (± 10 %). At least the relative displacement (slip) between concrete surface and CFRP strip at the beginning of the bond area and the tensile forces of CFRP strip in the unbonded area shall be measured as a function of loading.

For each parameter set at least 3 tests shall be carried out.

The compressive strength class of the concrete shall be determined as follows:

At the same time as the concrete blocks are concreted 6 concrete cylinders in accordance with EN 12390-1, clause 4.3, d = 150 mm, shall be concreted and stored under the same conditions as the concrete blocks.

Shortly before or after the anchorage test the cylinder compressive strength of these 6 concrete cylinders shall be determined in accordance with EN 12390-3. From these 6 values f_{Ci}, the average values f_{Ccm} and f_{Cck} shall be calculated.

The flexural and compressive strength of the structural bonding agent shall be determined as follows:

At the same time as the CFRP strips are bonded in the slots of concrete blocks 6 specimens of structural bonding agent in accordance with 2.2.2, shall be produced. After curing under the same conditions as the bonding of the CFRP strips in the specimens of the shear test the values f_{Gflk} and f_{Gck} for the structural bonding agent shall be determined in accordance with 2.2.2, shortly before or after the shear tests.

Expression of results

For each tested parameter set the following properties shall be reported in the ETA:

- the depth t_{s}, the width b_{s} and the edge distance a_r of the slots, in which the CFRP strips were glued,
- the concrete strength and the flexural and compressive strength of the structural bonding agent,
- the single values of the anchorage failure load $F_{\mathrm{b(NSM)Li}}$, the average value $F_{\mathrm{b(NSM)Lm}}$ and the 5% quantile value in accordance with EN 1990, Table D.1 (V_{x} unknown) $F_{\mathrm{b(NSM)Lk}}$. as well as the failure modes.

2.2.14 Long-term ultimate anchorage load (creep rupture of near surface mounted CFRP strips at maximum temperature for the intended use and relative air humidity of ≥ 75%)

Purpose of the test

The objective of the test is to determine the long-term ultimate anchorage load $F_{\mathrm{bL,lt,m,25a}}$ of the near surface mounted CFRP strips. Therefore, it is only necessary to test such parameter sets of 2.2.13 that led to failure of the structural bonding agent. If no failure of the structural bonding agent occurred in 2.2.13 at least the parameter sets of 2.2.13 with the shortest anchorage length shall be tested.

Assessment method

The test setup corresponds to that of clause 2.2.13.

In difference to 2.2.13 long-term tests shall be carried out at different constant load levels, maximum temperature of intended use and relative air humidity of ≥ 75%. The test specimens shall always be loaded until the bond between the CFRP lamellas and the concrete fails.

At least 3 load levels (see "step by step" approach further down in this paragraph) shall be tested to reach the following ranges of time to failure:

1. 60 to 500 h
2. 500 to 2000 h
3. ≥ 2000 h

For each range of time to failure at least 2 tests are necessary. At least one of the tests for the third range of time to failure shall reach 4000 h.

If the failure times are not achieved, tests have to be repeated with a changed set-up (alkaline environment) or lower loading.

If the results for the minimum number of tests required above for the ranges of time to failure are available, the expected anchoring force after 25 years $F_{\mathrm{bL,lt,m,25a}}$ can be determined according to Annex F on the safe side. Through additional tests, especially in the third range of time to failure, an improvement of the value $F_{\mathrm{bL,lt,m,25a}}$ is possible.

Execution of long-term test

Long-time loading on the test specimen shall only be carried out after curing of the structural bonding agent (component B) for the CFRP strip into the slot according to the MPII. The bondless length of l_v = 100 mm shall be considered.

If the load levels are unknown, a step-by-step approach to determine the above-mentioned ranges of time to failure shall be followed. This will likely require more than 6 tests.

For the step-by-step approach, the following procedure can be used in coordination with the manufacturer:

Before starting the first assessment of the load levels, the short-term bond force F_m in accordance with 2.2.13 shall be known.

First of all, three load levels that appear reasonable shall be agreed between the TAB and the manufacturer for the first test run:

1. Load level for expected times to failure of 60 to 500 h (e.g., $F_{\mathrm{bl,1}} = 0{,}6 * F_{\mathrm{m}}$)

2. Load level for expected times to failure of 500 to 2000 h (e.g., $F_{\mathrm{bl,2}} = 0{,}5 * F_{\mathrm{m}}$)

3. Load level for expected times to failure of ≥ 5000 h (e.g., $F_{\mathrm{bl,3}} = 0{,}4 * F_{\mathrm{m}}$).

It is not absolutely necessary, but in order to save time, the tests should be started simultaneously for all load levels on two specimens each.

If the ranges of time to failure specified above are not achieved, an improved estimate of the load levels in accordance with Annex F using the results of all tests carried out so far is possible. For this, at least 3 results for achieved times to failure shall be available.

With these improved load levels, the missing long-term tests may be carried out in order to be able to meet the above-mentioned ranges of time to failure.

This improved estimate of the load level shall be repeated with the results of all tests carried out so far until the above-mentioned ranges of time to failure have been reached for the required number of tests.

The compressive strength class of the concrete shall be determined as follows:

At the same time as the concrete blocks are concreted 6 concrete cylinders in accordance with EN 12390-1, clause 4.3, 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 in accordance with EN 12390-3. From these 6 values f_{Cci}, the average value f_{Ccm} and f_{Cck} shall be calculated. The concrete strength class shall be higher or equal to C50/60.

The flexural and compressive strength of the structural bonding agent shall be determined as follows:

At the same time as the CFRP strips are bonded in the slots of concrete blocks 6 specimens of structural bonding agent in accordance with 2.2.2, shall be produced. After curing under the same conditions as the bonding of the CFRP strips in the specimens of the shear test the values f_{Gflk} and f_{Gck} for the structural bonding agent shall be determined in accordance with 2.2.2, shortly before or after the shear tests.

Expression of results

For the tested parameter sets the following properties shall be reported in the ETA:

- bonding length l_{bL} and edge distance a_{r}
- the depth t_{s}, the width b_{s} and the edge distance a_r of the slots, in which the CFRP strips were glued,
- the concrete strength and the flexural and compressive strength of the structural bonding agent,
- the applied temperature and relative air humidity together with the observed times until failure t_j and associated long-term load levels $F_{\mathrm{bl,lt,j}}$,
- the average values $F_{\mathrm{bL,lt,m,25a}}$ (see Annex F, clause F.2)l and the ratio $R_{\mathrm{Fbl,lt,m}} = \frac{F_{\mathrm{bL,lt,m,25a}}}{F_{\mathrm{bLm}}}$.

2.2.15 Reaction to fire

Configurations of the complete kit shall be tested, using test method(s) relevant for the corresponding reaction to fire class in accordance with EN 13501-1. The kit shall be classified in accordance with 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.

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[9].

The system is 1+.

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

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

3.3 Tasks of the notified body

The cornerstones of the actions to be undertaken by the notified body in the procedure of assessment and verification of constancy of performance for the kits 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	According to Control plan	According to Control plan	When starting the production or a new line
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	According to Control plan	According to 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 in accordance with Table 3.2.1	see Table 3.2.1	According to Control plan	see Table 3.2.1	2/year
4	Reaction to fire	2.2.15	According to Control plan	At least one depen-ding 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 in accordance with 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 (see 1.3.3).

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, clause 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).

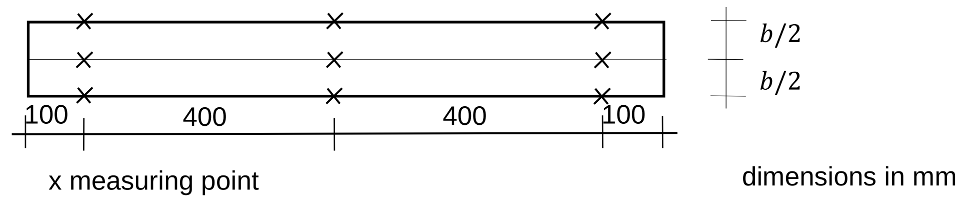


Figure 3.4.3.1: Measure points for the thickness of CFRP strips

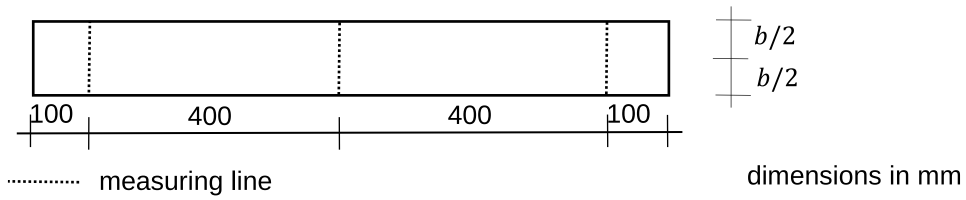


Figure 3.4.3.2: Measure lines for the width of CFRP strips

The average value b_{Lm} and d_{Lm} of the determined widths b_{Li} and thicknesses d_{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 1990:2023	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 4624:2023)
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 (component 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
	Structural 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	1800 h 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	1800 h 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 (component C) and, if included in the kit, the bonding agent for the repair mortar (component D) - structural bonding agent (component B) - CFRP strips (component A) (see Figure E.1.1 b) to the concrete.	2.2.7	Preparation of specimens in accordance with 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: - structural bonding agent (component B) - CFRP strips (component A) (see Figure E.2.1) to the concrete.		Preparation of specimens in accordance with 2.2.7 at standard environmental conditions (see 1.3.4)	5 for every type of CFRP strip (see 1.3.3)

	Essential characteristic	Test procedure	CONDITIONING	Minimum number of specimens
	Bond strength of a multilayer specimen consisting of: - repair mortar (component C) and, if included in the kit, the bonding agent for the repair mortar (component D) - structural bonding agent (component B) - CFRP strips (component A) (see Figure E.1.1 b) to the concrete after low-cycle fatigue action	2.2.8	Preparation of specimens in accordance with 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: - structural bonding agent (component B) - CFRP strips (component A) (see Figure E.2.1) to the concrete after low-cycle fatigue action		Preparation of specimens in accordance with 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: - repair mortar (component C) and, if included in the kit, the bonding agent for the repair mortar (component D) - structural bonding agent (component B) - CFRP strips (component A) (see Figure E.1.1 b) to the concrete under harsh climatic conditions	2.2.9	Preparation of specimens in accordance with 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: - structural bonding agent (component B) - CFRP strips (component A) (see Figure E.2.1) to the concrete under harsh climatic conditions		Preparation of specimens in accordance with 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 (component C) and, if included in the kit, the bonding agent for the repair mortar (component D) - structural bonding agent (component B) - CFRP strips (component A) (see Figure E.1.1 b) to the concrete cured at minimum temperature of installation depending on the curing time	2.2.10	Preparation of specimens in accordance with 2.2.10 at T_{Gmina} and T_{Mmina} (see 1.3.5)	5 for every type of CFRP strip (see 1.3.3)
	Bond strength of a multilayer specimen consisting of: - structural bonding agent (component B) - CFRP strips (component A) (see Figure E.2.1) to the concrete cured at minimum temperature of installation depending on the curing time		Preparation of specimens in accordance with 2.2.10 at $T_{\mathrm{Gmin,a}}$ (see 1.3.5)	5 for every type of CFRP strip (see 1.3.3)

	Essential characteristic	Test procedure	CONDITIONING	Minimum number of specimens
	Essential characteristics only of kits with externally bonded (EB) CFRP strips			
	Shear resistance of the anchorage of the CFRP strips	2.2.11	Preparation of specimens in accordance with 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 in accordance with 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 the minimum, intermediate and maximum strength class of the concrete substrate (see 1.3.10)
	Essential characteristics only of kits with near surface mounted (NSM) CFRP strips			
	Ultimate anchorage load	2.2.13	preparation of specimens according to the MPII at standard environment conditions (see 1.3.4)	For every concrete strength class: 3 for each parameter set of bond length l_{bl}, thickness of CFRP strip t_L, edge distance a_r, concrete strength class and flexural and compressive strength of the structural bonding agent
	Long-term ultimate anchorage strength	2.2.14	preparation of specimens according to the MPII at standard environment conditions (see 1.3.4) Afterwards loading with a constant load until failure at maximum temperature of use (see 1.3.6) and ≥ 75 % relative air humidity	At least for one concrete strength class ≥ C50/60 and 3 load levels > 2000 h: 2 for each load level for each parameter set of bond length l_{bl}, thickness of CFRP strip t_L, edge distance a_r, concrete strength class and flexural and compressive strength of the structural bonding agent
	Reaction to fire of the kit	2.2.15	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 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 in accordance with 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 in accordance with 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 in accordance with 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 used epoxy 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 in accordance with EN 13823 and at least two tests each with surface and edge exposure in accordance with 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, clause 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).

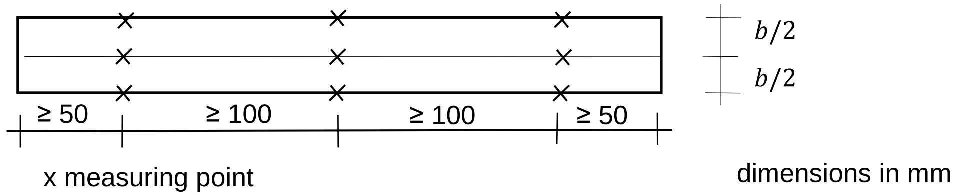


Figure C.2.1: Measuring points for the thickness of CFRP strips

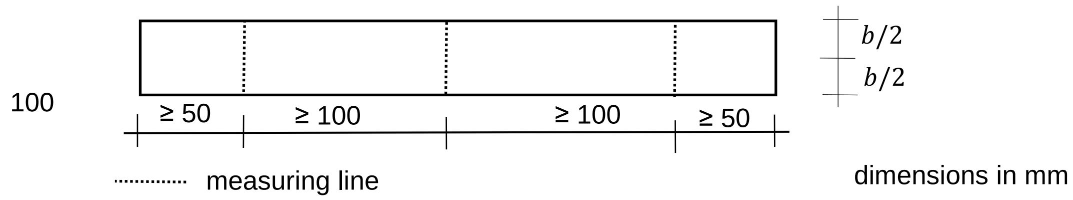


Figure C.2.2: Measure lines for the width of CFRP strips

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 2.2.7 TO 2.2.10

E.1 Preparation of the specimens with repair mortar

On at least one specimen in accordance with EN 1542, clause 4.12, with the maximum strength class of the concrete substrate (see 1.3.10) a layer of repair mortar (component C) and, if included in the kit, the bonding agent for the repair mortar (component D) with the maximum thickness $d_{\mathrm{M,max}}$[10] (see 1.3.8) shall be installed according to the MPII (see Figure E.1.1 a).

The preparation of the specimens shall be done in accordance with EN 1542, clauses 5 and 6.2, shall for the use in vertical position.

On the repair mortar (component 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 structural bonding agent (component B) with the minimum thickness $d_{\mathrm{G,min}}$[11] (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)[12], this strip width shall be used.
- If the kit for this type of CFRP strips includes strips width greater than 50 mm (80 mm)[12], the strip width greater than 50 mm (80 mm) [12] shall be used, which has the smallest distance to the width of 50 mm (80 mm) [12].
- If the kit for this type of CFRP strips includes only strips width less than 50 mm (80 mm) [12], the greatest strip width shall be used.
- In the latter case, several strips shall be glued next to each other on the concrete surface in accordance with Figure E.1.1 until the width of 50 mm (80 mm) [12] is reached or exceeded.

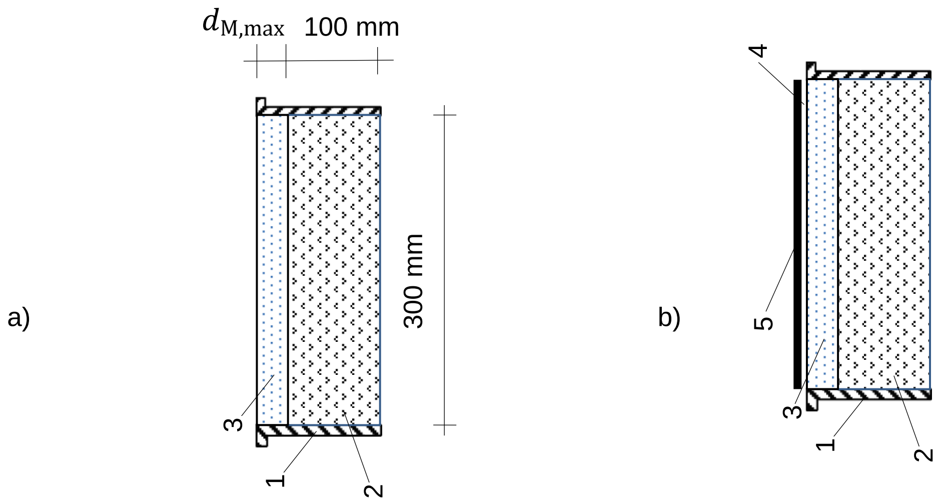


Figure E.1.1: Cross section through the test specimen with repair mortar (component C) and, if included in the kit, the bonding agent for the repair mortar (component D)

1 attached formwork

2 reference body of concrete in accordance with EN 1542

3 layer of repair mortar (component C) and, if included in the kit, the bonding agent for the repair mortar (component D) with maximum thickness $d_{\mathrm{M,max}}$

10 At least one test series with the maximum layer thickness of repair mortar is necessary.

11 At least one test series with the minimum layer thickness of bonding agent is necessary.

12 The strip width of 50 mm applies to 2.2.7, 2.2.8 and 2.2.10. The strip width of 80 mm for 2.2.9.

4 layer of structural bonding agent (component B) with minimum thickness $d_{\mathrm{G,min}}$

5 CFRP strip (component A) externally bonded to the repair mortar (component 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 structural bonding agent (component B) and externally bonded CFRP strips (component A) are added to the specimen produced according to step a).[13]

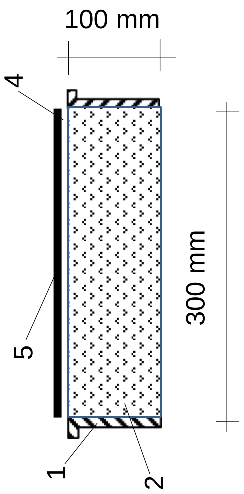
E.2 Preparation of the specimens without repair mortar

The preparation of the surface in accordance with EN 1542, clause 5, shall be done for the use in vertical position.

On at least one specimen in accordance with 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 structural bonding agent (component B) with the minimum thickness $d_{\mathrm{G,min}}$ (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) [12], this strip width shall be used.
- If the kit for this type of CFRP strips includes strips width greater than 50 mm (80 mm) [12], the strip width greater than 50 mm (80 mm) [12] shall be used, which has the smallest distance to the width of 50 mm (80 mm) [12].



- If the kit for this type of CFRP strips includes only strips width less than 50 mm (80 mm) [12], the greatest strip width shall be used.
- In the latter case, several strips shall be glued next to each other on the concrete surface in accordance with Figure E.2.1 until the width of 50 mm (80 mm) [12] is reached or exceeded.

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

13 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 MPII.

1 attached formwork

2 reference body of concrete in accordance with EN 1542

4 layer of structural bonding agent (component B) with minimum thickness d_{in} (see 1.3.8)

5 CFRP strip (component A) externally bonded to the concrete

ANNEX F – LINEAR REGRESSION ON A LOGARITHMIC SCALE FOR TIME TO FAILURE

F.1 Determination of the regression line

The general equation of a straight line is:

$$y = a + b * x \tag{F.1.1}$$

Therein mean:

y dependent variable (load levels $F_{\mathrm{bL,lt,i}}$ $[kN]$ in accordance with 2.2.14)

x independent variable ($\log(t)$ logarithm of time to failure $t[h]$ in accordance with 2.2.14)

The following statistical values are to be calculated from the results of all long-term tests carried out:

$$\bar{x} = \frac{\sum x_i}{n} \tag{F.1.2}$$

$$\bar{y} = \frac{\sum y_i}{n} \tag{F.1.3}$$

$$Q_x = \sum x_i^2 - \frac{(\sum x_i)^2}{n} \tag{F.1.4}$$

$$Q_y = \sum y_i^2 - \frac{(\sum y_i)^2}{n} \tag{F.1.5}$$

$$Q_{xy} = \sum x_i * y_i \ - \frac{(\sum x_i * \sum y_i)}{n} \tag{F.1.6}$$

$$s_R^2 = \left(Q_y - \frac{Q_{xy}^2}{Q_x * (n-2)}\right) \tag{F.1.7}$$

$$s_R = \sqrt{s_R^2} \tag{F.1.8}$$

$$r^2 = \frac{Q_{xy}^2}{Q_x * Q_y} \tag{F.1.9}$$

$$r = \sqrt{r^2} \tag{F.1.10}$$

$$b = \frac{Q_{xy}}{Q_x} \tag{F.1.11}$$

$$a = \bar{y} - b * \bar{x} \tag{F.1.12}$$

Here means:

n number of long-term tests

x_i x-values

y_i y-values

$\bar{x}$ mean of the x-values

$\bar{y}$ mean of the y-values

Q_x sum of the squared deviation of the x-values

Q_y sum of the squared deviation of the y-values

Q_{xy} sum of the squared deviation of the x- and y-values

b slope of the straight line

a Absolute term of the straight line

s_R^2 residual standard deviation

r^2 coefficient of determination

r correlation coefficient

F.2 Determination of the mean value of the long-term ultimate anchorage load for 25 years

The regression line is determined from the values of the specified load levels and the logarithmic values of the associated times to failure. Results of times to failure of less than 10 hours may not be included in the assessment.

The failure points are to be shown graphically on a simple logarithmic scale (abscissa: logarithmic division, ordinate linear division), whereby the logarithm of the time to failure forms the abscissa and the load level forms the ordinate. The entry of the measured value pairs serves as an aid for the optical verification of the position of the measured values in relation to the position of the regression line.

Equation of the regression line:

$$F_{lt,m} = a + b * \log (t) \quad \text{(F.2.1)}$$

The test results can be regarded as meaningful and suitable for the long-term bond strength if the following conditions are met:

- the coefficient b must be negative.
- the value of the coefficient of determination r^2 must be greater than 0.65,
- the value of the residual variance s_R^2 must be less than 0.065.

If one or more of these conditions are not met, a regression analysis cannot be used for extrapolation. This can be remedied by further tests in the relevant time to failure range.

If three test results are already available for a larger range of time to failure, the regression line determined using the method described above can also be used to estimate the load levels of the remaining long-term tests.

If the above conditions and the criterion for the minimum number of long-term tests in accordance with 2.2.6 are met, the extrapolation of the mean value of the bond strength for 25 years may be carried out. For this purpose, the regression line in accordance with F.1 must be determined for all tests carried out. The logarithm of the mean value of the long-term bond strength is then obtained by inserting t = 25a≈219000 h into equation (F.2.1):

$$F_{lt,m,25a} = a + b * \log (219000 \text{ h}) \quad \text{(F.2.2)}$$