EUROPEAN ASSESSMENT DOCUMENT

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GLASS, BASALT, ARAMID, CARBON, PBO (POLYPARAPHENYLENE BENZOBISOXAZOLE) AND STEEL ROVINGS FOR FIBRE-REINFORCED ANCHOR SPIKES

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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 (EU) No 305/2011 as a basis for the preparation and issuing of European Technical Assessments (ETA).

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1 SCOPE OF THE EAD

1.1 Description of the construction product

The glass, basalt, aramid, carbon, PBO (polyparaphenylene benzobisoxazole) and steel rovings for fibre-reinforced anchor spikes (hereinafter referred to as “rovings”) are a bundle of continuous parallel strands/yarns (tow). The fibres can be of different materials, namely E-glass, Alkali-Resistant (AR) glass, basalt, aramid, carbon, PBO, and three types of steel (brass-plated, galvanized, and stainless steel according to EN 10088-1[1]). They are embedded or fixed into concrete or masonry substrates by using a matrix (organic or inorganic) (Figure 1.1.1), which is not part of this EAD. The free ends of the anchor spike are fanned-out and fixed through the matrix in order to join the anchor to the FRP reinforcement system (fanned-out anchor spikes). Alternatively, one end can be completely embedded (embedded anchor spikes) (Figure 1.1.2).

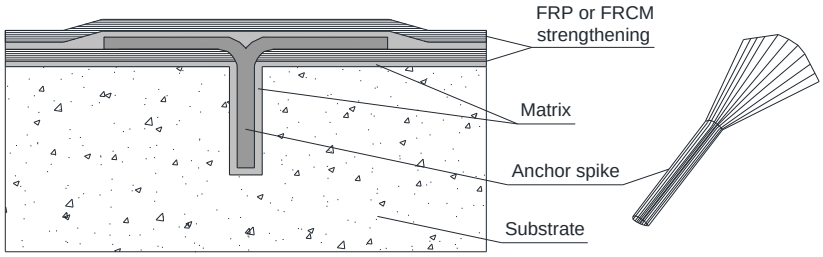

Figure 1.1.1. Fibre-based anchor spike.

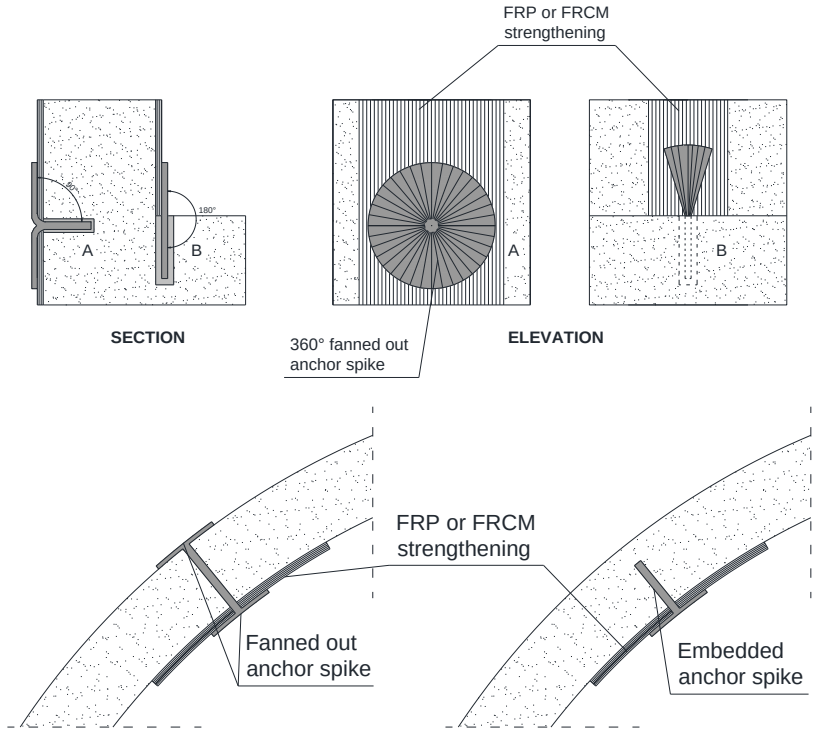

Figure 1.1.2. Examples of applications.

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

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

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

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

Relevant manufacturer's stipulations having influence on the performance of the product covered by this European Assessment Document shall be considered for the determination of the performance and detailed in the ETA.

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

1.2.1 Intended use(s)

The rovings are intended to be used in highly specialized applications to strengthen masonry and reinforced concrete structures, coupled with strengthening systems (i.e., FRP, FRCM, welded mesh, etc.). In particular, anchor spikes are used to improve the adhesion of reinforcement systems to the substrates.

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 rovings for the intended use of 50 years when installed in the works (provided that the rovings are subject to appropriate installation (see 1.1)). These provisions are based upon the current state of the art and the available knowledge and experience.

When assessing the product, the intended use as foreseen by the manufacturer shall be taken into account. The real working life may be, in normal use conditions, considerably longer without major degradation affecting the basic requirements for works[2].

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 AR-glass

Alkali Resistant (AR) glass fibres are glass fibres with added zirconium oxide (ZrO_2) (higher than 16% according to EN 15422) to help resist attack from alkalinity.

1.3.2 E-glass

E-glass, or electrical grade glass, is alumino-borosilicate glass with less than 1% wt. alkali oxides, mainly used for glass-reinforced polymers. This type of glass was originally developed for electrical insulation applications (which gives origin to the letter "E").

[2] 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.

1.3.3 Filament

Single fibre with a diameter of a few microns.

1.3.4 FRCM

Fibre Reinforced Cementitious Matrix: Composite material made of an inorganic matrix reinforced with fibres in the form of fabric or mesh.

1.3.5 FRP

Fibre Reinforced Polymer: Composite material made of a polymer matrix reinforced with fibres in the form of fabric or mesh.

1.3.6 PBO

Polyparaphenylene benzobisoxazole fibres.

1.3.7 Roving

Combination of strands to form thicker parallel bundles.

1.3.8 Strand

Fibre strand: Bundle of filaments.

Steel strand: Assembly of single steel wires of appropriate shape and dimensions arranged and twisted according to a specific arrangement (structure).

1.3.9 Tow

Bundle of twisted or untwisted continuous fibres. A tow may contain tens or hundreds of thousands of individual filaments.

1.3.10 Wire

The smallest component of a steel strand.

1.3.11 Yarn

Generic term for a bundle of twisted or untwisted continuous fibres.

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 rovings is assessed in relation to the essential characteristics.

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

No	Essential characteristic	Assessment method	Type of expression of product performance
Basic Works Requirement 1: Mechanical resistance and stability			
1	Tensile strength	2.2.1	Level σ_m [MPa]
2	Tensile modulus of elasticity	2.2.1	Level E [MPa]
3	Tensile strain	2.2.1	Level ε_m [mm/mm]
4	Deflected tensile strength *(only for steel rovings)*	2.2.1	Level D-value [%]
5	Alkali resistance in high pH solution	2.2.2	Level and description Tensile strength $\sigma_{m,alk}$ [MPa] Modulus of elasticity E_{alk} [MPa] Strain $\varepsilon_{m,alk}$ [mm/mm] Retained tensile strength $\sigma_{m,alk,ret}$ [%] Retained modulus of elasticity $E_{alk,ret}$ [%]
6	Freezing and Thawing	2.2.3	Level and description Tensile strength $\sigma_{m,FT}$ [MPa] Modulus of elasticity E_{FT} [MPa] Strain $\varepsilon_{m,FT}$ [mm/mm] Retained tensile strength $\sigma_{m,FT,ret}$ [%] Retained modulus of elasticity $E_{FT,ret}$ [%]
7	Water resistance	2.2.4	Level and description Tensile strength $\sigma_{m,w}$ [MPa] Modulus of elasticity E_w [MPa] Strain $\varepsilon_{m,w}$ [mm/mm] Retained tensile strength $\sigma_{u,w,ret}$ [%] Retained modulus of elasticity $E_{w,ret}$ [%]
8	Saltwater resistance	2.2.5	Level and description Tensile strength $\sigma_{m,sw}$ [MPa] Modulus of elasticity E_{sw} [MPa] Strain $\varepsilon_{m,sw}$ [mm/mm] Retained tensile strength $\sigma_{m,sw,ret}$ [%] Retained modulus of elasticity $E_{sw,ret}$ [%]
9	Creep behaviour	2.2.6	Level Load causing failure Deformation $\varepsilon_{u,x}$ [mm/mm] Time at which the failure occurs $n_{h,creep}$ *or* Deformation ε_x Retained mechanical properties ($\sigma_{m,creep,ret}$ [%], $E_{creep,ret}$ [%])
Basic Works Requirement 2: Safety in case of fire			
10	Reaction to fire	2.2.7	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.

2.2.1 Tensile properties

Purpose of the assessment

This test is performed to evaluate the mechanical properties under tension of the rovings.

Assessment method

The tensile properties of the rovings shall be determined in accordance with the following indications for the different types of fibres:

- *Steel*: Direct tensile test: according to the procedure indicated in Annex B.

  Deflected tensile test: according to EN ISO 15630-3, clause 12, with the following deviations:

  1. Specimens shall be prepared according to clause B3 so to have a total length appropriate to the testing device of EN ISO 15630-3, clause 12.3.2.
  2. Anchorages shall be as indicated in Annex B, clause B3.
  3. Table 6 of EN ISO 15630-3 for the mandrel dimensions shall be applied considering the first column (12,5 to 13,0 mm) for roving diameters lower than 12,5 mm and the last column (17 to 18 mm) for roving diameters higher than 18 mm.
  4. The value D_i as per Formula (6) of EN ISO 15630-3 shall be calculated considering the average tensile maximum load $\overline{F_m}$ assessed for the specific diameter according to Annex B.

- *Other fibres*: according to the procedure indicated in Annex B.

A summary of the number of specimens to be tested is reported in Annex A.

Testing shall be carried out on minimum 5 specimens for each roving diameter.

Expression of results

For the direct tensile test of all types of fibres, the arithmetic average and characteristic values of tensile strength σ_m [MPa], tensile modulus of elasticity E [MPa] and strain at maximum force ε_m [mm/mm] of the rovings, determined as indicated in Annex B, clause B5, shall be stated in the ETA.

The (5%) characteristic value will be determined as indicated in EN 1990, by using the appropriate value of k_n for unknown V_X reported in Annex D, Table D1.

For the deflected tensile test of steel rovings, the D-value [%] according to EN ISO 15630-3 clause 12.4 shall be reported in the ETA.

2.2.2 Alkali resistance in high pH solution

Purpose of the assessment

This test is performed to evaluate the influence of alkali attack on the efficiency of the rovings.

Assessment method

Specimens to be used for the assessment shall have the total length foreseen in clause B3. Conditioning is done by immerging specimens in a liquid with pH=13 for 1,000 and 3,000 hours at a temperature of 23±2°C. Conditioned specimens are then prepared for tensile test and tested in direct tension according to 2.2.1.

A summary of the number of specimens to be tested is reported in Annex A.

Expression of results

Conditioned specimens are visually examined prior to testing using 5× magnification to describe surface changes.

The arithmetic average and characteristic value of the tensile strength $\sigma_{m,alk}$ [MPa], modulus of elasticity E_{alk} [MPa], strain $\varepsilon_{m,alk}$ [mm/mm] shall be determined as indicated in Annex B, clause B5 and reported in the ETA. The characteristic value will be determined as indicated in EN 1990, by using the appropriate value of k_n for unknown V_X reported in Annex D, Table D1.

The percentage of average mechanical properties ($\sigma_{m,alk,ret}$ [%] and $E_{alk,ret}$ [%]) retained by exposed specimens with respect to the values recorded for unconditioned specimens (Section 2.2.1) and the exposure conditions shall also be reported in the ETA.

2.2.3 Freezing and Thawing

Purpose of the assessment

This test is performed to evaluate the influence of freeze-thaw cycles on the behaviour of the rovings.

Assessment method

Specimens to be used for the assessment shall have the total length foreseen in clause B3. The specimens shall be conditioned for one week in a humidity chamber [100% humidity, 38±1°C]. They shall then be subjected to twenty freeze-thaw cycles. Each cycle consists of a minimum of four hours at -18±1°C, followed by 12 hours in a humidity chamber [100% humidity, 38±1°C]. The conditioned specimens are then prepared for tensile test and tested in direct tension according to 2.2.1.

A summary of the number of specimens to be tested is reported in Annex A.

Expression of results

Conditioned specimens are visually examined prior to testing using 5× magnification to describe surface changes.

The arithmetic average and characteristic value of the tensile strength $\sigma_{m,FT}$ [MPa], modulus of elasticity E_{FT} [MPa] and strain $\varepsilon_{m,FT}$ [mm/mm] shall be determined as indicated in Annex B, clause B5 and reported in the ETA. The characteristic value will be determined as indicated in EN 1990, by using the appropriate value of k_n for unknown V_X reported in Annex D, Table D1.

The percentage of mechanical properties ($\sigma_{m,FT,ret}$ [%] and $E_{FT,ret}$ [%]) retained by exposed specimens with respect to the value recorded for unconditioned specimens (Section 2.2.1) and the exposure conditions shall also be reported in the ETA.

2.2.4 Water resistance

Purpose of the assessment

This test is performed to evaluate the influence of water on the behaviour of the rovings.

Assessment method

Specimens to be used for the assessment shall have the total length foreseen in clause B3. Conditioning is done according to Annex C for 1,000 and 3,000 hours at a temperature of 38±2°C and relative humidity

higher than 95%. Conditioned specimens are then prepared for tensile test and tested in direct tension according to 2.2.1.

A summary of the number of specimens to be tested is reported in Annex A.

Expression of results

Conditioned specimens are visually examined prior to testing using 5× magnification to describe surface changes.

The arithmetic average and characteristic value of the tensile strength $\sigma_{m,w}$ [MPa], modulus of elasticity E_w [MPa] and strain $\varepsilon_{m,w}$ [mm/mm] shall be determined as indicated in Annex B, clause B5 and reported in the ETA. The characteristic value will be determined as indicated in EN 1990, by using the appropriate value of k_n for unknown V_X reported in Annex D, Table D1.

The percentage of average mechanical properties ($\sigma_{m,w,ret}$ [%] and $E_{w,ret}$ [%]),retained by exposed specimens with respect to the value recorded for unconditioned specimens (Section 2.2.1) and the exposure conditions shall also be reported in the ETA.

2.2.5 Saltwater resistance

Purpose of the assessment

This test is performed to evaluate the influence of saltwater on the efficiency of the rovings.

Assessment method

Specimens to be used for the assessment shall have the total length foreseen in clause B3. Conditioning is done by immerging specimens in saltwater according to Annex D for 1,000 and 3,000 hours at a temperature of 23±2°C. Conditioned specimens are then prepared for tensile test and tested in direct tension according to 2.2.1.

A summary of the number of specimens to be tested is reported in Annex A.

Expression of results

Conditioned specimens are visually examined prior to testing using 5× magnification to describe surface changes.

The arithmetic average and characteristic value of the tensile strength $\sigma_{m,sw}$ [MPa], modulus of elasticity E_{sw} [MPa] and strain $\varepsilon_{m,sw}$ [mm/mm] shall be determined as indicated in Annex B, clause B5 and reported in the ETA. The characteristic value will be determined as indicated in EN 1990, by using the appropriate value of k_n for unknown V_X reported in Annex D, Table D1.

The percentage of average mechanical properties ($\sigma_{m,sw,ret}$ [%] and $E_{sw,ret}$ [%]) retained by exposed specimens with respect to the value recorded for unconditioned specimens (Section 2.2.1) and the exposure conditions shall also be reported in the ETA.

2.2.6 Creep behaviour

Purpose of the assessment

This test is performed to evaluate the creep behaviour of the rovings.

Assessment method

Minimum eight specimens shall be prepared according to the procedure of Section 2.2.1 and Annex B. The load level is determined on the basis of the 5% fractile values of the maximum loads determined in the tensile tests in accordance with Section 2.2.1 and Annex B. In particular, the 5% fractile values of the maximum load, $F_{m;5\%}$, shall be determined as indicated in EN 1990, by using the appropriate value of k_n for unknown V_X reported in Annex D, Table D1.

The test shall be carried out by gradually applying the load or weights until a constant load level of 0.70 × $F_{m;5\%}$ is reached. The load is then maintained for 100, 500, 1000 and 4000 hours (2 specimens for each examination time). The assessment is to be done on the largest roving diameter.

The tests shall be carried out at temperature of 21±2°C and 50±5% RH.

In case no failure of specimens is reached during the permanent load, the remaining tensile resistance of the test specimens is determined according to Section 2.2.1.

Expression of results

The deformation resulting from the permanent applied load shall be measured and represented as a function of time.

If failure occurs during the permanent load, the load, the time $n_{h,creep}$ and the deformation $\varepsilon_{u,x}$[3] at which the failure occurs shall be reported in the ETA.

If no failure occurs during the permanent load, the deformation ε_x[4] reached at the end of the examination period shall be recorded. The percentage of average mechanical properties ($\sigma_{m,creep,ret}$ [%], $E_{creep,ret}$ [%]), retained by specimens with respect to the average short-time tensile strength determined in Section 2.2.1 shall be reported in the ETA for each examination period.

2.2.7 Reaction to fire

The rovings shall be tested according to EN 13501-1, using the test method(s) relevant for the corresponding reaction to fire class, in order to be classified according to Commission Delegated Regulation (EU) 2016/364. The performance class obtained from the tests shall be reported in the ETA.

[3] In the symbol $\varepsilon_{u,x}$, x represents the number of hours at which the failure occurs (x= $n_{h,creep}$).

[4] In the symbol ε_x, x represents the examination time (x= 100, 500, 1000 or 4000 hours).

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: **Decision 1997/463/EC**.

The system is: **2+**

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* - Raw material	Supplier's data check	Control Plan	-	Every batch (*)
2	*Incoming material* - Raw material	Visual check	Control Plan	-	Every batch (*)
3	*Incoming material* - Mass per unit length	Measurement	Control Plan	Minimum 3 spools/ batch of fibre/steel	Every batch (*)
4	*Incoming material* - Tensile strength	Control plan	Control Plan	Minimum 2 samples	Every batch (*)
5	Preparation of the line	Spools Count	Project Data Sheet	-	Every batch (*)
6	Production Process	Measurement of running meters	Project Data Sheet	-	Every batch (*)
7	*Product Control* - Roll weight	Measurement	Project Data Sheet	All rolls	Every batch (*)
8	*Product control* - Visual Quality	Visual Check	Control Plan	All rolls	Every batch (*)
9	*Product control - Tensile strength*	2.2.1	Control Plan	Minimum 3 samples	Every month or at every change in the production process
(*) *Batch*: every quantity of material made in a single operation, or in the case of continuous production for a defined quantity (in linear meter) which shall be demonstrated by the manufacturer to have a uniform composition and shall not exceed one day's production.					

3.3 Tasks of the notified body

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

Table 3.3.1 Control plan for the notified body; cornerstones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Initial inspection of the manufacturing plant and of factory production control					
1	The notified body will ascertain that the factory production control with the staff and equipment are suitable to ensure a continuous and orderly manufacturing of the rovings.	Verification of the complete FPC as described in the control plan agreed between the TAB and the manufacturer	As defined in the control plan	As defined in the control plan	At the beginning of the contract between NB and Manufacturer
Continuous surveillance, assessment and evaluation of factory production control					
1	The notified body will ascertain that the system of factory production control and the specified manufacturing process are maintained taking account of the control plan.	Verification of the controls carried out by the manufacturer as described in the control plan agreed between the TAB and the manufacturer with reference to the raw materials, to the process and to the product as indicated in Table 3.2.1.	As defined in the control plan	As defined in the control plan	1/year

4 REFERENCE DOCUMENTS

EN 1990:2002/A1:2005/AC:2010	Eurocode - Basis of structural design
EN 10088-1:2014	Stainless steels - Part 1: List of stainless steels
EN 13501-1:2018	Fire classification of construction products and building elements. Classification using test data from reaction to fire tests
EN 15422:2008	Precast concrete products - Specification of glassfibres for reinforcement of mortars and concretes
EN ISO 6892-1:2019	Metallic materials - Tensile testing - Part 1: Method of test at room temperature
EN ISO 10618:2004	Carbon fibre - Determination of tensile properties of resin-impregnated yarn
EN ISO 15630-3:2019	Steel for the reinforcement and prestressing of concrete - Test methods - Part 3: Prestressing steel

ANNEX A SUMMARY OF TESTS

	Essential characteristic	TEST TYPE	EXPOSURE TIME	Minimum number of specimens for each diameter
Mechanical properties	Tensile strength Tensile modulus Tensile strain	Direct tension	N/A(1)	5
	Deflected tensile strength	Deflected tensile test	N/A(1)	5
	Tensile strength after long term actions (creep)	Direct tension	100, 500, 1000 and 4000 hours	2 for each examination time (on the largest diameter)
Ageing	Alkali resistance	Direct tension	1000 hours	3
			3000 hours	3
			TOTAL	**6**
	Freezing and Thawing	Direct tension	20 freeze-thaw cycles (four hours at -18±1°C followed by 12 hours 100% humidity and 38±1°C)	3
			TOTAL	**3**
	Water resistance	Direct tension	1000 hours	3
			3000 hours	3
			TOTAL	**6**
	Saltwater resistance	Direct tension	1000 hours	3
			3000 hours	3
			TOTAL	**6**
Fire behaviour	Reaction to fire	According to relevant standard	According to relevant standard	According to relevant standard

(1) N/A: Not Applicable

ANNEX B TENSILE TESTS

The tensile test on dry fibre/steel bundle specimens is carried out to define their stiffness and strength.

B1. Test summary

A bundle of filaments having a near-constant circular cross section is mounted in the grips of a mechanical testing machine and loaded in displacement while recording load and movement. The ultimate strength of the bundle can be determined from a maximum load carried before failure. The strain or elongation is monitored with displacement transducers to determine the nominal stress-strain response of the material, from which the tensile modulus of elasticity can be also derived.

B2. Tensile-testing machine

The testing machine shall have the appropriate load capacity to withstand the foreseen ultimate forces and shall be equipped with an appropriately calibrated load cell and classifiable at least in class 1 with reference to EN ISO 6892-1.

The testing machine shall be equipped with a gripping system which allows to lock the ends of the specimen by applying them a sufficient lateral pressure to prevent the slippage of the specimen. It is desirable to use grips that are rotationally self-aligning to minimize bending stresses in the coupon. Strain/elongation measurements shall be made with a displacement transducer (resolution of at least 0.01 mm).

B3. Test specimens

The test is carried out in displacement control on a specimens constituted by a bundle of filaments/steel strands.

The minimum length of the specimen L, excluding the portions required for grips, shall be at least 40 times the nominal diameter D of the specimen and not less than 300 mm.

Specimens should be equipped with anchorages in the gripping area to ensure homogeneous distribution of stresses. The anchorage shall be suited to the geometry of the test pieces and shall have the capacity to transmit only the tensile force along the longitudinal axis of the test pieces.

The anchorage can be constituted by a threaded circular metal tube, to improve the gripping capacity, into which the bundle of fibres/steel strands is inserted. Epoxy resin or mortar can be used to fill the tube and improve adhesion with the fibres/steel strands.

A minimum anchorage length L_a of 300 mm is recommended to allow failure in the fibres/steel strands.

To avoid dispersion of results, care shall be taken to prepare the specimens, to grip them and to align the specimen in the test machine. In addition, an inappropriate gripping system may cause failure of the test pieces at the ends or a partial break of filaments and, consequently, a relevant dispersion of the results.

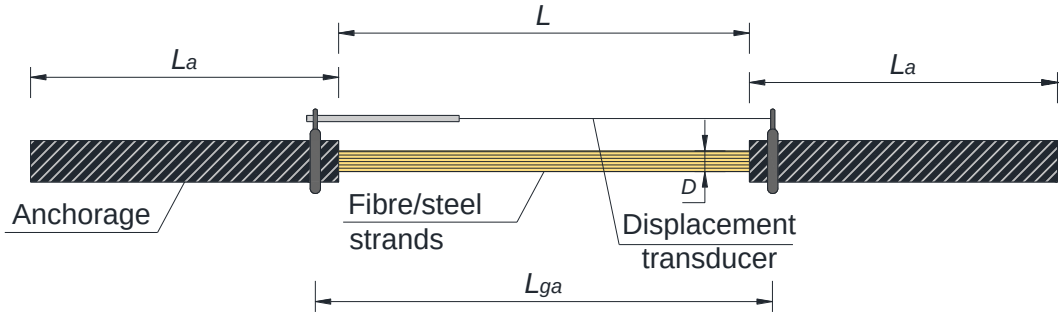

Figure B3.1: Geometry of specimens.

B4. Test procedure

The specimen shall be placed in the grips of the testing machine, paying particular attention to its alignment with the axis of the machine. During the test preparation phase, an axial force not greater than 5% of the expected failure load can be applied to the specimen in order to align the specimen.

The load shall be applied under displacement control, with a constant rate not exceeding 0.5 mm/min.

A suitable instrument for displacement measurement shall be attached to the edges of each anchorage tube (Figure B3.1).

During the test, the load value and the displacement shall be recorded continuously.

B5. Calculation

Tensile strength

For each test specimen, calculate the tensile strength of the bundle from the following equation:

$$\sigma_m = F_m / A_f \quad \text{(B5.1)}$$

σ_m is the tensile strength [MPa]

F_m is the maximum tensile force, in N

A_f is the cross sectional area of the bundle [mm^2].

The bundle cross sectional area can only be determined through the weight of a single part of it. The length of this section is evaluated based on the resolution of the instrument used to determine its weight (at least 0.01 g resolution). The area A_f can be calculated as:

$$A_f = \frac{p_{bundle}}{\rho\, l_{bundle}} 1000 \quad \text{(B5.2)}$$

where

- p_{bundle} is the bundle weight [g]
- l_{bundle} is the bundle length [mm]
- ρ is the fibre density [g/cm^3]

Tensile modulus of elasticity

On the load-displacement curve, two points, with ordinate corresponding to the 10% and 70% of the maximum load F_m, are selected.

The tensile modulus of elasticity is calculated from the following equation

$$E = \frac{\Delta F}{A_f} \frac{L}{\Delta L} 10^{-3} \quad \text{(B5.3)}$$

E is the tensile modulus of elasticity in GPa;

ΔF is the variation in the force, in N, between the two selected points;

A_f is the cross-sectional area of the bundle, in mm^2;

L is the length of the bundle, in mm;

ΔL is the variation in the length of the specimen, in mm, corresponding to the variation in the force of the two selected points.

Strain at maximum load

The strain at maximum load ε_m (dimensionless quantity [mm/mm]) is calculated from the following equation:

$$\varepsilon_m = \frac{L_{ga,m} - L_{ga,0}}{L} \quad \text{(B5.4)}$$

Where

$L_{ga,m}$ is the length of the displacement transducer at maximum load [mm]

$L_{ga,0}$ is the length of the displacement transducer at zero load [mm]

L is the length of the specimen [mm].

B6. Test Report

The following information shall be at least reported:

- Date and location of the test
- Identification of the materials tested including material specification, type and designation, manufacturer
- Size of the specimen
- Description of the specimen preparation
- Environmental conditions of the test (temperature and relative humidity)
- Number of specimens
- Specimen alignment and gripping system used
- Test speed
- Type and location of transducers used to measure deformation
- Results of the test
- Stress-strain curve and tabulated results

ANNEX C WATER CONDITIONING

C1. Summary of Test Method

Specimens are placed in an enclosed chamber containing a heated, saturated mixture of air and water vapour. The temperature of the chamber shall be maintained at 38±2 °C. At relative humidity (RH) higher than 95 %, a very small temperature difference between the specimen and the surrounding vapour causes the formation of condensation on the specimens. The exposure condition is varied by selecting the duration of the test (1,000 and 3,000 h). Any effects shall be observed and reported.

C2. Apparatus

Test Chamber - constructed of corrosion-resistant materials with supports for the test specimens.

Source of Heated Water Vapour can be created by one of the following methods:

- *Heated Water Tank*, within the test chamber, a water supply, and a water level control.

- *Water Vapour (Steam) Generator*, located outside the test chamber, a water supply, and a means of introducing the vapour to the test chamber.

Thermostatic Control, for the water heater with the sensor located adjacent to the specimen holders, or a means of controlling volume of steam.

Thermometer, with sensor located adjacent to the specimen holders.

C3. Test Specimens

Specimens are those foreseen in Section 2.2.1 (direct tensile test).

C4. Test Procedure

1. Generate the saturated water vapour with reagent water prepared by distillation, ion exchange, continuous electro-deionization, reverse osmosis, electro-dialysis, or a combination thereof.
2. Adjust the temperature of the saturated air and water vapour mixture so that the air temperature next to the test specimens is 38±2°C.
3. The temperature of the water vapour will typically be the same or higher than the air temperature next to the specimens. This is a requirement in order for this procedure to work correctly. The temperature of the water in the vapour generation is not set but water vapour temperatures that are greater than 38°C tend to make condensation more uniform over the test specimens.
4. Support flat specimens approximately 15° from the vertical with the front side facing up. Slotted non-metallic supports are suitable for flat specimens. Position 3-dimensional specimens on a support so that the primary surface is as close to end-use position as possible. Material used for supports shall be of sufficient stiffness so that they do not distort or sag during prolonged use. The minimum distance between adjacent specimens or between specimens and the walls of the chamber shall be at least 30 mm. Arrange specimens so that condensate from one specimen cannot drip on other specimens.
5. Droplets of condensation shall appear evenly on the specimen at all times if the chamber is operating properly. Short interruptions to inspect or remove specimens are permitted, but such interruptions should occur no more than once each day.
6. To control for variability within the apparatus, reposition the specimens on a regular basis so that all specimens spend equivalent amounts of time in the various areas of the apparatus (front, back, left, right, and centre).
7. Conclude the test after a specified period of time or after effects from exposure to water are observed.
8. Wipe the test specimens dry. Record any changes in colour, surface modification, etc. Evaluate specimens no less than 5 min and no more than 10 min after removal from the chamber, as the effects from water exposure can change within a short time. Remove only as many specimens as can be rated within the specified time.

9. If possible, rate the specimens again after they have been removed from the test for a recovery period long enough that moisture absorbed within the specimens dries out and the specimens reach moisture equilibrium with room air. A recovery period from 12 to 24 h is generally sufficient. The post-recovery rating allows evaluation of the permanent effects of the exposure as distinct from the transient effects.

C5. Test Report

Report at least the following information:

- Specimen identification.
- Results of the evaluation(s).
- Hours of test duration.
- Test temperature.
- Special conditions of test or any deviations in test procedure.

ANNEX D SALTWATER CONDITIONING

D1. Summary of Test Method

Specimens are placed in containers with an aqueous solution containing inorganic salts in proportions and concentrations representative of ocean water. The temperature shall be maintained at 23±2 °C. The exposure condition is varied by selecting the duration of the test (1,000 and 3,000 h). Any effects shall be observed and reported.

D2. Apparatus

Containers - of sufficient size, capacity, and inertness. These containers shall, when necessary, be capable of maintaining liquid levels of volatile solutions, that is, solvents. This can be accomplished by the use of reflux condensers.

D3. Preparation of Substitute Ocean Water

Reagent and materials

Purity of Reagents - Reagent grade chemicals shall be used in all tests.
Purity of Water - Unless otherwise indicated, references to water shall be understood to mean reagent water prepared by distillation using a still designed to produce a distillate having a conductivity of less than 1.0 µS/cm at 25°C. Ion exchange, distillation, or reverse osmosis and organic adsorption may be required prior to distillation, if the purity cannot be attained by single distillation.
Stock Solution No. 1 - Dissolve the indicated amounts of the following salts in water and dilute to a total volume of 7.0 L. Store in well stoppered glass containers.

$MgCl_2 \cdot 6H_2O$	3889.0 g (= 555.6 g/L)
$CaCl_2$ (anhydrous)	405.6 g (= 57.9 g/L)
$SrCl_2 \cdot 6H_2O$	14.8 g (= 2.1 g/L)

Stock Solution No. 2 – Dissolve the indicated amounts of the following salts in water and dilute to a total volume of 7.0 L or a convenient volume. Store in well stoppered amber glass containers.

KCl	486.2 g (= 69.5 g/L)
$NaHCO_3$	140.7 g (= 20.1 g/L)
KBr	70.4 g (= 10.0 g/L)
H_3BO_3	19.0 g (= 2.7 g/L)
NaF	2.1 g (= 0.3 g/L)

Procedure

To prepare 10.0 L of substitute ocean water, dissolve 245.34 g of sodium chloride and 40.94 g of anhydrous sodium sulfate in 8 to 9 L of water. Add 200 mL of Stock Solution No. 1 slowly with vigorous stirring and then 100 mL of Stock Solution No. 2. Dilute to 10.0 L. Adjust the pH to 8.2 with 0.1 N sodium hydroxide solution. Only a few millilitres of NaOH solution should be required.

NOTE—Prepare the solution and adjust the pH immediately prior to use.

The so prepared substitute ocean water will have the composition shown in Table D3.1.

Table D3.1- Chemical Composition of Substitute Ocean Water

Compound	Concentration, g/L
NaCl	24.53
$MgCl_2$	5.20
Na_2SO_4	4.09
$CaCl_2$	1.16
KCl	0.695
$NaHCO_3$	0.201
KBr	0.101
H_3BO_3	0.027
$SrCl_2$	0.025
NaF	0.003

D4. Test Specimens

Specimens are those foreseen in Section 2.2.1 (direct tensile test).

D5. Test Procedure

1. Prior to immersion, record a brief description of the colour and surface appearance of the specimens and the colour and the clarity of the test solution. The total number of specimens per container is not limited except by the ability of the container to hold the specimens without touching each other or the container.
2. The specimens shall always be completely immersed. Specimens shall be vertical, parallel, and spaced a minimum of 6 mm apart. There shall be a minimum 12 mm between specimen edges and the container or the liquid.
3. Discard the test solution and replace it with fresh solution as often as necessary to maintain original composition and concentration. As a minimum, solutions known to be stable need to be replaced at the end of each test period.
4. Clean the specimen and dry by blotting with a paper towel. Cold tap water is normally used for specimen cleaning..
5. Note any indication of surface attack on a specimen, any discoloration of the test solution, and the formation of any sediment.

D6. Test Report

Report at least the following information:

- Colour and surface appearance of specimens before testing.
- Test conditions; immersion medium, temperature, and the like.
- Total duration of test in hours, and examination periods, in hours.
- Appearance of specimens after immersion.
- Appearance of immersion medium (discoloration, sediment, and the like).