



BSI Standards Publication

Design of fibre-polymer composite structures

National foreword

This Published Document is the UK implementation of CEN/TS 19101:2022.

The UK participation in its preparation was entrusted to Technical Committee B/525, Building and civil engineering structures.

A list of organizations represented on this committee can be obtained on request to its committee manager.

The UK committee draws users' attention to National Annex NA, which provides further guidance to assist users in the application of this document.

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English Version

Design of fibre-polymer composite structures

Calcul des structures en matériaux composites

Bemessung von Tragwerken aus Faserverbund-
Kunststoffen

This Technical Specification (CEN/TS) was approved by CEN on 22 August 2022 for provisional application.

The period of validity of this CEN/TS is limited initially to three years. After two years the members of CEN will be requested to submit their comments, particularly on the question whether the CEN/TS can be converted into a European Standard.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

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European foreword

This document (CEN/TS 19101:2022) has been prepared by Technical Committee CEN/TC 250 “Structural Eurocodes”, the secretariat of which is held by BSI. CEN/TC 250 is responsible for all Structural Eurocodes and has been assigned responsibility for structural and geotechnical design matters by CEN.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under Mandate M/515 issued to CEN by the European Commission and the European Free Trade Association.

This document has been drafted to be used in conjunction with relevant execution, material, product and test standards, and to identify requirements for execution, materials, products and testing that are relied upon by this document.

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to announce this Technical Specification: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Türkiye and the United Kingdom.

0 Introduction

0.1 Introduction to CEN/TS 19101

This document for the design of fibre-polymer composite structures, which was prepared in line with the Eurocodes, is intended for use by designers, clients, manufacturers, constructors, relevant authorities (in exercising their duties in accordance with national or international regulations), educators, software developers, and committees drafting standards for related product, testing and execution standards.

NOTE 1 Some aspects of design are most appropriately specified by relevant authorities or, where not specified, can be agreed on a project-specific basis between relevant parties such as designers and clients. The Eurocodes identify such aspects making explicit reference to relevant authorities and relevant parties.

NOTE 2 Fibre-polymer composites are also commonly referred to as fibre-reinforced polymers (FRP) or as composites.

0.2 Verbal forms used in this Technical Specification

The verb “shall” expresses a requirement strictly to be followed and from which no deviation is permitted in order to comply with the Eurocodes.

The verb “should” expresses a highly recommended choice or course of action. Subject to national regulation and/or any relevant contractual provisions, alternative approaches could be used/adopted where technically justified.

The verb “may” expresses a course of action permissible within the limits of the Eurocodes.

The verb “can” expresses possibility and capability; it is used for statements of fact and clarification of concepts.

0.3 National Annex to CEN/TS 19101

This Technical Specification gives values within notes indicating where national choices can be made. Therefore, a national document implementing CEN/TS 19101 can have a National Annex containing all Nationally Determined Parameters to be used for the assessment of buildings and civil engineering works in the relevant country.

When not given in the National Annex, the national choice will be the default choice specified in the relevant Technical Specification.

The national choice can be specified by a relevant authority.

When no choice is given in the Technical Specification, in the National Annex, or by a relevant authority, the national choice can be agreed for a specific project by appropriate parties.

National choice is allowed in CEN/TS 19101 through the following clauses:

4.3.1.2(4), NOTE 2	4.4.6(1), NOTE	4.4.6(2), NOTE	4.4.6(3), NOTE
4.4.7.1(2), NOTE	4.4.7.1(3), NOTE	8.5(2), NOTE 4	10.3(1), NOTE 1
12.4.5.1(1), NOTE 1	D4.5(1), NOTE		

National choice is allowed in CEN/TS 19101 on the application of the following informative annexes:

Annex A	Annex B	Annex E
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The National Annex can contain, directly or by reference, non-contradictory complementary information for ease of implementation, provided it does not alter any provisions of the Eurocodes.

1 Scope

1.1 Scope of CEN/TS 19101

(1) This document applies to the design of buildings, bridges and other civil engineering structures in fibre-polymer composite materials, including permanent and temporary structures. It complies with the principles and requirements for the safety, serviceability and durability of structures, the basis of their design and verification that are given in EN 1990.

NOTE In this document, fibre-polymer composite materials are referred to as composite materials or as composites.

(2) This document is only concerned with the requirements for resistance, serviceability, durability and fire resistance of composite structures.

NOTE 1 Specific requirements concerning seismic design are not considered.

NOTE 2 Other requirements, e.g. concerning thermal or acoustic insulation, are not considered.

(3) This document gives a general basis for the design of composite structures composed of (i) composite members, or (ii) combinations of composite members and members of other materials (hybrid-composite structures), and (iii) the joints between these members.

(4) This document applies to composite structures in which the values of material temperature in members, joints and components in service conditions are (i) higher than $-40\text{ }^{\circ}\text{C}$ and (ii) lower than $T_g - 20\text{ }^{\circ}\text{C}$, where T_g is the glass transition temperature of composite, core and adhesive materials, defined according to 5.1(1).

NOTE 1 Composite structures have a temperature-dependent behaviour. The temperature-dependence of the properties of composite, core and adhesive materials is considered through a conversion factor for temperature, η_c , as defined in 4.4.7.2, which depends on the T_g and the maximum material temperature in service conditions (T_s).

NOTE 2 5.1(1) defines requirements for the T_g of composite, core and adhesive materials as a function of the T_s .

(5) This document applies to:

(i) composite members, i.e. profiles and sandwich panels, and

(ii) bolted, bonded and hybrid joints and their connections.

NOTE 1 Profiles and sandwich panels can be applied in structural systems such as beams, columns, frames, trusses, slabs, plates and shells.

NOTE 2 Sandwich panels include homogenous core and web-core panels. In web-core panels, the cells between webs can be filled (e.g. with foam) or remain empty (e.g. panels from pultruded profiles).

NOTE 3 This document does not apply to sandwich panels made of metallic face sheets.

NOTE 4 Built-up members can result from the assembly of two or more profiles, through bolting and/or adhesive bonding.

NOTE 5 The main manufacturing processes of composite members include pultrusion, filament winding, hand layup, resin transfer moulding (RTM), resin infusion moulding (RIM), vacuum-assisted resin transfer moulding (VARTM).

NOTE 6 This document does not apply to composite cables or special types of civil engineering works (e.g. pressure vessels, tanks or chemical storage containers).

(6) This document applies to:

(i) the composite components of composite members, i.e. composite plies, composite laminates, sandwich cores and plates or profiles, and

(ii) the components of joints or their connections, i.e. connection plates or profiles (e.g. cleats), bolts, and adhesive layers.

NOTE 1 Composite components are composed of composite materials (i.e. fibres and matrix resins) and core materials. Components of joints and their connections are also composed of composite, steel or adhesive materials.

NOTE 2 The fibre architecture of composite components can comprise a single type of fibres or a hybrid of two or more types of fibres.

NOTE 3 This document does not apply to composite components used for internal reinforcement of concrete structures (composite rebars) or strengthening of existing structures (composite rebars, strips or sheets).

(7) This document applies to composite materials, comprising:

(i) glass, carbon, basalt or aramid fibres, and

(ii) a matrix based on unsaturated polyester, vinylester, epoxy or phenolic thermoset resins.

NOTE This document does not apply to composite materials comprising a matrix based on thermoplastic resins.

(8) This document applies to the core materials (i) polymeric foams, and (ii) balsa wood.

NOTE 1 The core of sandwich panels can be reinforced by composite webs and inserts.

NOTE 2 This document does not apply to honeycomb cores.

(9) This document applies to thermoset adhesives, including epoxy, polyurethane, and acrylic resins.

NOTE This document does not apply to thermoplastic adhesives.

(10) This document applies to other types of fibres, thermoset resins, homogeneous cores and thermoset adhesives than those specified in 1.1(6)-(9), provided that their mechanical and physical properties are obtained from appropriate testing according to Clause 5, and that they are in line with the other relevant clauses of this document.

1.2 Assumptions

(1) The assumptions of EN 1990 apply to this document.

(2) This document is intended to be used in conjunction with EN 1990, EN 1991 (all parts), EN 1997 (all parts), EN 1998 (all parts), ENs, EADs and ETAs for construction products relevant to composite structures.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE See the Bibliography for a list of other documents cited that are not normative references, including those referenced as recommendations (i.e. in 'should' clauses), permissions ('may' clauses), possibilities ('can' clauses), and in notes.

EN 1990:—¹, *Basis of structural and geotechnical design*

EN 1991 (all parts), *Eurocode 1: Actions on structures*

EN 1991-1-2:—², *Eurocode 1: Actions on structures — Part 1-2: General actions — Actions on structures exposed to fire*

EN 1993-1-4, *Eurocode 3: Design of steel structures — Part 1-4: General rules — Supplementary rules for stainless steels*

EN 1993-1-8:—³, *Eurocode 3: Design of steel structures — Part 1-8: Design of joints*

EN 1997 (all parts), *Eurocode 7: Geotechnical design*

EN 1998 (all parts), *Eurocode 8: Design of structures for earthquake resistance*

EN 13706-1, *Reinforced plastics composites — Specifications for pultruded profiles — Part 1: Designation*

EN 13706-2:2002, *Reinforced plastics composites — Specifications for pultruded profiles — Part 2: Methods of test and general requirements*

EN 13706-3, *Reinforced plastics composites — Specifications for pultruded profiles — Part 3: Specific requirements*

EN 16245 (all parts), *Fibre-reinforced plastic composites — Declaration of raw material characteristics*

ISO 6721-11, *Plastics — Determination of dynamic mechanical properties — Part 11: Glass transition temperature*

¹ Under preparation. Stage at the time of publication: prEN 1990:2021.

² Under preparation. Stage at the time of publication: prEN 1991-1-2:2021.

³ Under preparation. Stage at the time of publication: prEN 1993-1-8:2021.

3 Terms, definitions, symbols and abbreviations

For the purposes of this document, the terms and definitions given in EN 1990 and the following terms, definitions, symbols and abbreviations apply.

3.1 Terms and definitions

3.1.1 Terms relating to constituent materials

3.1.1.1

accelerator

substance used in small proportions that accelerates the chemical reaction between the polymer resin system and the curing agent

3.1.1.2

additive

specialist chemical substance that is added to the polymer resin to impart specific matrix properties, such as removal from processing mould, flame retardancy and UV protection; known also as modifier

3.1.1.3

bi-directional ply

ply with all the continuous fibres aligned in two orientations

3.1.1.4

chopped strand mat

CSM

non-woven mat with short strands cut (approximately 50 mm long) from continuous fibre (or filament) strands and fairly evenly distributed and randomly oriented in a swirled pattern within the plane of the mat; the mat is held together by a binder

3.1.1.5

composite material

material composed of layers of rovings, fabrics, and mats, embedded in a polymer matrix

3.1.1.6

continuous fibre mat

CFM

non-woven mat with yarns or strands (of continuous fibres) fairly evenly distributed and randomly oriented in a swirled pattern within the plane of the mat; the mat is held together by a binder

3.1.1.7

core

central part of a sandwich panel to which top and bottom composite face sheets are attached

3.1.1.8

fibre

general term for a material in a filamentary form

3.1.1.9**filler**

relatively inert substance added to the polymer resin to alter its physical, mechanical, thermal, electrical or other properties (e.g. shrinkage or flammability), or to lower cost

3.1.1.10**gel coat**

thin layer of unreinforced quick-setting resin, sometimes containing a colorant, applied on the outer surface of a composite component to improve the surface properties

3.1.1.11**mat ply**

ply comprising randomly oriented chopped or swirled continuous fibres loosely held together with a binder

3.1.1.12**non-woven fabric**

textile structure produced by bonding or interlocking of continuous fibres, or both, accomplished by mechanical, chemical, thermal or solvent means, and combinations thereof

3.1.1.13**ply**

single layer (or lamina) in a laminate with a number of individual layers of fibres

3.1.1.14**resin**

solid, semisolid or pseudosolid organic material that has an indefinite and often high relative molecular mass, exhibits a tendency to flow when subjected to stress, and usually has a softening or melting range

3.1.1.15**roving**

collection of parallel strands (assembled roving) or parallel continuous filaments (direct roving) assembled without intentional twist

3.1.1.16**sizing**

coating applied to fibres during their manufacture to improve handling and fibre-matrix adhesion/compatibility, protect from water absorption and abrasion, lubricate the fibres and reduce static electricity

3.1.1.17**surface veil**

very thin mat, usually 0,18 mm to 0,51 mm thick, of highly filamentized non-reinforcing fibres

Note 1 to entry: Usually present in pultruded composite materials to enhance the quality of the surface finish, to block out the fibre pattern of the underlying fibre layers and to add ultraviolet protection and a moisture diffusion barrier.

3.1.1.18

tape

prepreg of finite width consisting of resin impregnated unidirectional fibres

3.1.1.19

thermoset

class of polymers that, when cured using heat, chemical, or other means, changes into a substantially infusible and insoluble material, through the formation of cross-links (primary bonds) between the molecular chains

3.1.1.20

tow

large number of filaments collected into a loose strand or assemblage substantially without twist; commonly used in referring to carbon fibres; typically designated by a number followed by K, meaning multiplication by 1 000 (e.g. a 12K tow has 12 000 filaments)

3.1.1.21

unidirectional ply

ply with all the continuous fibres aligned in a single orientation

3.1.1.22

woven fabric

generic architecture consisting of interlaced yarns or fibres, usually a planar structure; the warp direction of the woven fabric is taken to be the longitudinal direction, which is the direction of the principal load action

3.1.1.23

woven roving

woven fabric formed by the weaving of rovings

3.1.2 Terms relating to manufacturing

3.1.2.1

cure

process of hardening of a thermosetting polymer resin (by cross-linking of the molecular structure); may be accomplished by addition of curing agents, with or without catalyst, and with or without heat energy

3.1.2.2

cure temperature

temperature profile to which the composite material or adhesive is subjected to during the curing process

3.1.2.3

fibre content

quantity of fibres in the composite material; usually expressed as the percentage of volume or weight fraction in the composite material

3.1.2.4

filament winding

automated composite manufacturing process in which continuous filaments (or tapes) are covered with resin and wound onto a rotating mandrel in a predetermined pattern design under controlled tension

3.1.2.5**gel time**

period of time from a pre-determined starting point to the onset of gelation time (gel point) as defined by a specific test method

3.1.2.6**hand layup**

composite manufacturing process in which a polymer resin and the fibre layers are applied manually either to an open mould or to a working surface in a number of successive layers

3.1.2.7**layup**

fabrication process involving the stacking of successive plies (also referred to as laminae or layers)

3.1.2.8**post-cure**

additional elevated temperature cure of the matrix usually without pressure

Note 1 to entry: For certain resins, complete cure is attained only by exposure of the polymer matrix to higher temperatures.

3.1.2.9**pultrusion**

automated, continuous closed mould manufacturing process for thin-walled open and closed composite shapes (or profiles or sections), having constant cross-sectional area in the direction of pultrusion

3.1.2.10**resin infusion moulding****RIM**

composite manufacturing process in which a catalysed polymer resin is infused into a closed mould already containing the preform for the component, with application of vacuum

3.1.2.11**resin transfer moulding****RTM**

composite manufacturing process in which a catalysed polymer resin is injected into a closed mould already containing the preform for the component

3.1.2.12**vacuum-assisted resin transfer moulding****VARTM**

composite manufacturing process in which a catalysed polymer resin is introduced into a closed mould already containing the preform for the component, with simultaneous application of vacuum to assist in resin flow

3.1.3 Terms relating to composite components and members

3.1.3.1

balanced laminate

laminate in which the individual layers (or plies) are stacked so that there is a balance maintained of $+\theta$ oriented layers and $-\theta$ oriented layers at the same height from the laminate's mid-plane

3.1.3.2

component

constituent of a composite member (e.g. ply, laminate, core) or a connection between composite members (e.g. cleat, bolt, adhesive)

3.1.3.3

hybrid-composite structure

structure composed of a combination of composite members and members of other materials (e.g. steel, concrete)

3.1.3.4

hybrid laminate

laminate with a fibre architecture made from two or more different fibre types (e.g. glass and carbon)

3.1.3.5

interface

surface between two materials (e.g. where there is contact between fibre, sizing and matrix)

3.1.3.6

interphase

region of nanometre thickness where the sizing and matrix combine and the matrix has different physical and chemical properties from the bulk matrix

3.1.3.7

laminate

relatively thin flat or curved composite component of members (such as profiles and sandwich panels) or structural systems (such as plates and shells), with two dimensions considerably larger than the third (thickness) direction, formed from curing and consolidating one or more plies of one or more composite materials

3.1.3.8

member

physically distinguishable part of a structure (e.g. profile, sandwich panel, cable), possibly made up of components (e.g. plies, laminates, cores)

Note 1 to entry: Members are connected by joints or connections, which are composed of further components (connection plates, bolts, adhesive layers), to form structural systems (e.g. beams, columns, trusses, slabs, plates, shells).

3.1.3.9**profile**

prismatic composite member manufactured by pultrusion or other composite manufacturing processes used in structural systems, such as beams, columns, frames and trusses

Note 1 to entry: For pultruded profiles, rovings are aligned along the member axis and fibres with other orientations can also be (and often are) used.

3.1.3.10**sandwich panel**

two-dimensional composite member used in structural systems such as slabs, plates and shells comprising, in its simplest form, a relatively thick and lightweight core bonded to two relatively thin, parallel and high strength composite face sheets

3.1.3.11**sublaminates**

thinner representative laminate of a full-thickness laminate, in terms of constituent materials, fibre architecture and processing method

3.1.3.12**symmetric laminate**

laminate in which each lamina (or ply) type, angles and composition is exactly mirrored about the mid-plane of the composite material

3.1.3.13**web-core sandwich panel**

sandwich panel comprising composite webs, with or without core infills between the webs

3.1.4 Terms relating to design**3.1.4.1****conversion factor**

factor accounting for changes of material properties due to effects of environmental conditions (e.g. moisture, temperature) and effects of ageing (long-term effects of exposure to environmental conditions)

3.1.4.2**conversion factor for moisture**

factor accounting for changes of material properties due to moisture absorption over time (including ageing effects resulting from long-term exposure)

3.1.4.3**conversion factor for temperature**

factor accounting for changes of material properties due to material temperatures deviating from 20 °C in service conditions (excluding effects of long-term exposure)

3.1.4.4**creep**

time-dependent deformation resulting from sustained stress

3.1.4.5

creep coefficient

coefficient accounting for the creep effects on the deformations of composite structures, by reducing the initial mean values of the relevant elastic moduli of materials

3.1.4.6

creep rupture

failure (by rupture) of a composite material at a sustained stress level that can be considerably lower than the corresponding short-term strength

3.1.4.7

fail-safe structural member or joint

member or joint in which local failure of the member or joint does not result in failure of the structure or critical parts thereof

3.1.4.8

fibre-dominated property of composite material

property of composite material mainly governed by the fibres; at elevated temperature, such property has low sensitivity to polymer matrix softening; fibre-dominated properties include tensile strength and modulus and compressive modulus in direction(s) with high ratio of fibres

3.1.4.9

flexible core

core of a sandwich panel with relatively low ratio between the flexural stiffness of the core and the flexural stiffness of the face sheets

3.1.4.10

glass transition temperature

representative temperature of the glass transition process experienced by a composite material, a polymeric core material or an adhesive at elevated temperature, in which the material changes from a glassy state to a rubbery state; taken as the onset value of the storage modulus decay obtained from dynamic mechanical analysis

3.1.4.11

linear viscoelasticity

mechanical behaviour of materials in which (i) the stress is proportional to the strain at a given time (creep compliance is independent of the stress level) and (ii) the linear (Boltzmann) superposition principle holds

3.1.4.12

matrix-dominated property of composite material

property of composite material governed by the polymer matrix; at elevated temperature, such property has high sensitivity to polymer matrix softening; matrix-dominated properties include compressive strength, interlaminar shear strength, in-plane shear strength and modulus, and tensile strength and modulus and compressive modulus in direction(s) with low ratio of fibres

3.1.4.13

non-fail-safe structural member or joint

member or joint in which local failure of the member or joint could lead to failure of the structure or critical parts thereof

3.1.4.14**pseudo-ductility**

ability of a composite component or member to sustain irreversible inelastic deformation without significant loss of resistance, during progressive composite material failure and associated dissipation of inelastic energy

3.1.4.15**relaxation**

time-dependent decrease in stress in a solid under given constraint conditions

3.1.4.16**rigid core**

core of a sandwich panel with relatively high ratio between the flexural stiffness of the core and the flexural stiffness of the face sheet

3.1.4.17**service temperature**

temperature range (minimum and maximum temperatures) to which composite structures are exposed to throughout their design service life

3.1.4.18**thick face sheet**

face sheet of a sandwich panel with relatively low ratio of the distance between the centroid axes of the face sheets to the face sheet thickness

3.1.4.19**thin face sheet**

face sheet of a sandwich panel with relatively high ratio of the distance between the centroid axes of the face sheets to the face sheet thickness

3.1.5 Terms relating to failure modes**3.1.5.1****crippling**

failure of a composite component (e.g. a web of a profile) under transverse loads, in a phenomenon that may involve crushing, buckling or a combination thereof

3.1.5.2**delamination**

separation of the layers of material in a laminate, which can occur locally or cover a significant area of the laminate, at any time in the cure or subsequent design service life of the laminate

Note 1 to entry: This failure mode can arise from a wide variety of causes, being linked to a relatively low out-of-plane (through thickness) tensile strength.

3.1.5.3**dimpling**

buckling of the face sheet of a sandwich panel into or out of the individual cells of a discontinuous core (e.g. honeycomb) due to localized compressive or shear stresses

Note 1 to entry: This is also referred to as intracell buckling.

3.1.5.4

indentation

crushing of the core material of a sandwich panel caused by a transverse (out-of-plane) concentrated load

3.1.5.5

punching

shear failure of the core of a sandwich panel caused by a transverse (out-of-plane) concentrated load

3.1.5.6

shear crimping

core-dominated buckling of a sandwich panel under in-plane compression governed by the transverse shear stiffness of the core

3.1.5.7

wrinkling

short wave buckling of the face sheet or web of a sandwich panel due to in-plane compression, which may occur either towards the core or outwards, depending on the stiffness of the core in compression

3.1.6 Terms relating to joints and connections

3.1.6.1

joint

composition of several connections (e.g. double-lap joint)

3.1.6.2

connection

single location at which two members or laminates are connected (e.g. single-lap connection)

3.1.6.3

hybrid connection or joint

connection or joint where the members are interconnected by a combination of bolting and adhesive bonding

3.1.6.4

lap-shear connection

connection made by overlapping two (thin-walled) components and forming a load carrying connection between them

3.1.6.5

cleat

angle profile (made of composite or other material, e.g. steel or stainless steel) used to join composite members

EXAMPLE Double angle web cleats used to join an I-beam and an H-column, with one leg-side having a bolted connection to the web of the beam and the other leg-side having a bolted connection to the outstand flanges of the column).

3.1.6.6

adherend

component or member in an adhesively bonded connection or joint

3.1.6.7**adhesive**

substance (polymer or non-polymer-based, in liquid, film or paste form) capable of holding materials together by surface attachment

3.1.6.8**adhesive failure**

failure of an adhesively bonded connection such that the separation occurs at the adhesive-adherend interface

3.1.6.9**cohesive failure**

failure of an adhesively bonded connection such that the separation is within the adhesive or within the adherend

3.1.6.10**fibre-tear failure**

failure of an adhesively bonded connection occurring exclusively within the composite matrix, characterized by the appearance of reinforcing fibres on both ruptured surfaces (a specific type of cohesive failure)

3.1.6.11**fillet**

portion of an adhesive which fills the corner or angle formed where two adherends are joined

3.1.6.12**tapering**

gradual reduction of the thickness of the adherends along the overlap of an adhesively bonded connection to reduce stress concentrations

3.1.7 Terms relating to defects**3.1.7.1****blistering**

surface bump that grows because a pocket of gas or liquid develops within the composite material

3.1.7.2**chalking**

surface defect resulting from the breakdown of the polymer matrix of the composite material or of the protective gel coat for a release of a powdery, chalk-like appearance or deposit, as a consequence of poor application, UV or weather degradation

3.1.7.3**crazing**

network of fine cracks at or under the surface of the matrix material in the finished composite component

3.1.7.4**fibre blooming**

progressive exposure of the topmost fibre layers of the composite material due to UV-induced degradation of the polymer resin system

3.1.7.5

flaking

detachment of surface material resulting from a chemical degradation mechanism at the level of the topmost layer (for example, chemical reactions induced by UV radiation)

3.1.7.6

hydrolysis

chemical degradation mechanism resulting from a chemical reaction in which water molecules break down the chemical bonds of a particular substance

Note 1 to entry: This reaction occurs in polymeric materials in the presence of water or moisture (particularly at higher temperatures). The susceptibility of each material to hydrolysis depends on the presence and position of water-sensitive groups in the polymer backbone, as well as on morphology aspects.

3.1.7.7

pitting

chemical degradation mechanism resulting from the attack of the surface of fibres of composite materials induced by exposure to chemical solutions

Note 1 to entry: The susceptibility of each material to pitting depends on the composition of its fibre architecture, and also on the nature of the chemical, temperature and duration of exposure.

3.1.7.8

plasticization

physical degradation mechanism of composite materials or polymeric adhesives caused by the absorption of small molecules (low molecular weight) into the macromolecular chains of polymers

Note 1 to entry: Water molecules, in particular, act as plasticizing agent for polymeric materials and can modify their thermal and mechanical properties.

3.1.7.9

saponification

chemical degradation mechanism of polymers resulting from the alkaline hydrolyses of ester groups

Note 1 to entry: In an alkali environment, the ester link of unsaturated polyesters can undergo hydrolysis; the susceptibility of each material depends on its chemical structure and its crosslinking geometry.

3.1.7.10

swelling

volumetric changes due to absorption of moisture, independent of thermal expansion

3.2 Symbols and abbreviations

3.2.1 Symbols

Latin upper case letters

A	gross area of a cross-section
A_{eff}	area over which the concentrated load is uniformly distributed
A_{m}	area defined by the middle line of a closed cross-section
A_{net}	net area of a cross-section
A_{ns}	net area of a laminate subjected to shear
A_{nt}	net area of a laminate subjected to tension
A_{v}	shear area of a cross-section
D	flexural stiffness per unit width of a symmetric sandwich section of constant thickness with homogeneous core
D_{c}	flexural stiffness per unit width of the core of a sandwich section (about its own neutral axis)
D_{f}	flexural stiffness per unit width of each face sheet of a sandwich section (about its own neutral axis)
D_{k}	characteristic value of the flexural stiffness per unit width of a sandwich beam
D_0	flexural stiffness per unit width of the face sheets of sandwich sections (about the neutral axis of the sandwich section)
D_{11}	longitudinal flexural stiffness
D_{12}	coupling flexural stiffness
D_{22}	transverse flexural stiffness
D_{66}	shear flexural stiffness
D^*	flexural stiffness per unit width of a symmetrical web-core sandwich section of constant thickness with homogeneous core infill
E	elastic modulus

E_c	elastic modulus of the core or core infill (web-core sandwich) of sandwich sections; compressive modulus of adhesive
E_c^*	elastic modulus of the equivalent homogeneous core of web-core sandwich sections
E_d	design value of effect of actions
$E_d(\gamma_{Ff} \cdot Q_{fat})$	design value of an action effect in a structural member or joint (an internal force and/or moment), caused by the fatigue action model
$E_{d,fi}$	design value of effect of actions for the fire situation (including effects of thermal expansions and deformations)
$E_{d,min}$	minimum design value of an action effect in a member or joint (obtained from the permanent and fatigue loads)
$E_{d,max}$	maximum design value of an action effect in a member or joint (obtained from the permanent and fatigue loads)
E_f	constant elastic modulus of each face sheet of sandwich sections
$E_{f,1}$	elastic modulus in the longitudinal direction of fibres
$E_{f,2}$	elastic modulus in the transverse direction of fibres
$(E_{i,c,k})_f$	characteristic value of the compressive modulus in the i direction of the face sheet
$(E_{i,c,k})_w$	characteristic value of the compressive modulus in the i direction of the web
$(E_{\perp,k})_c$	characteristic value of the elastic modulus of the core in the direction perpendicular to the plane of the web in web-core sandwiches (based on the value of the tensile or compressive modulus, whichever is lower)
E_r	elastic modulus of resins
E_t	tensile modulus of adhesives
E_w	elastic modulus of the web
E_x	in-plane elastic modulus in x direction of balanced symmetrical bi-directional laminates
$E_{x,c}$	in-plane compressive modulus in x direction of composite pultruded profiles, composite laminates/plies or core materials

$E_{x,c,k}$	characteristic value of the in-plane compressive modulus in the x direction
$E_{x,t}$	in-plane tensile modulus in x direction of composite pultruded profiles, composite laminates/plies or core materials
E_x^{full}	effective full section flexural modulus of composite profiles
E_y	in-plane elastic modulus in y direction of balanced symmetrical bi-directional laminates
$E_{y,c}$	in-plane compressive modulus in y direction of composite or core materials
$E_{y,c,k}$	characteristic value of the in-plane compressive modulus in the y direction
$(E_{y,c,k})_w$	characteristic value of the in-plane compressive modulus in the transverse (y) direction of the web
$E_{y,t}$	in-plane tensile modulus in y direction of composite materials or core materials
$E_{z,c}$	out-of-plane compressive modulus of core materials
$(E_{z,k})_c$	characteristic value of the out-of-plane elastic modulus of the core
$E_{z,t}$	out-of-plane tensile modulus of core materials
E_1	in-plane elastic modulus in the 1 direction of UD plies
E_1^{UD}	longitudinal elastic modulus of a fictitious UD ply
E_2	in-plane elastic modulus in the 2 direction of UD plies
E_2^{UD}	transverse elastic modulus of a fictitious UD ply
$F_{\text{cr,sw}}$	elastic critical in-plane flexural buckling load for global (sway) buckling mode
F_{Ed}	design value of actions used in assessment of E_d
$F_1, F_2, F_{12}, F_6, F_{11}, F_{22}, F_{66}$	strength coefficients of Tsai-Wu failure criterion to predict failure of orthotropic plies
G	shear modulus of the core of sandwich sections, adhesive materials, or mat plies

G_c	shear modulus of the homogeneous core or core infill (web-core sandwich) of sandwich sections
G_f	shear modulus of fibres
$(G_{iz,k})_c$	characteristic value of the out-of-plane shear modulus (iz plane) of the core
$G_{I,Ed}$	design value of the strain energy release rate for crack initiation in Mode I
$G_{II,Ed}$	design value of the strain energy release rate for crack initiation in Mode II
$G_{Ic,Rd}$	design value of the critical strain energy release rate for crack initiation in Mode I
$G_{IIc,Rd}$	design value of the critical strain energy release rate for crack initiation in Mode II
$(G_{\perp,k})_c$	characteristic value of the shear modulus of the core in the plane perpendicular to the web that includes the i direction
$(G_k)_c$	characteristic value of the out-of-plane shear modulus of the core
$G_{k,ic}$	characteristic values of the critical strain energy release rate for crack initiation
G_r	shear modulus of resins
G_{xy}	in-plane shear modulus of composite laminates/plies, or balanced symmetrical bi-directional laminates
$G_{xy,k}$	characteristic value of the in-plane shear modulus (xy plane)
G_{xy}^{full}	effective full section shear modulus of composite profiles
G_{xy}	in-plane shear modulus (xy plane) of core materials
G_{xz}	out-of-plane shear modulus (xz plane) of core materials
G_{yx}	in-plane shear modulus (xy plane) of core materials
G_{yz}	out-of-plane shear modulus (yz plane) of core materials
G_{zx}	out-of-plane shear modulus (xz plane) of core materials
G_{zy}	out-of-plane shear modulus (yz plane) of core materials

G_{12}	in-plane shear modulus of UD plies
I_t	torsional constant of a profile cross-section
I_w	warping constant of a profile cross-section
I_z	minor-axis second moment of area of a profile cross-section
H_{Ed}	total design horizontal load, including equivalent forces, transmitted from the floor (storey shear) of a frame
H_i	horizontal forces applying to the supporting system (associated to sway imperfections)
K	slip modulus
L	span (Clause 9), or distances between holes (Clause 11), or unbraced profile length (Annex C)
M	bending moment
$M_{cr,Rd}$	design value of the bending moment resistance to local buckling of a profile
M_{Ed}	design value of the bending moment about a principal axis at each cross-section of a profile
M_f	mass volume fraction (or content) of a composite material
$M_{LT,Rd}$	design value of the bending moment resistance to lateral-torsional buckling of a profile
M_{Rd}	design value of the bending moment resistance about a principal axis of a profile
M_{Rd1}	design value of the bending moment resistance of a cross-section to material failure (about a principal axis)
M_{Rd2}	design value of the bending moment resistance to global buckling of a profile (about a principal axis) or local buckling of the cross-section (including the interaction thereof)
N	axial force (in general), or number of cycles of the fatigue action (Clause 10)
$N_{bs,Rd}$	design value of the block-shear resistance for a multi-bolted connection, with laminate of constant thickness
$N_{c,Ed}$	design value of the compressive force at each cross-section of a profile

$N_{c,Rd}$	design value of the compressive resistance in the longitudinal (x) direction of a profile
$N_{c,Rd1}$	design value of the compressive resistance to crushing of a cross-section
$N_{c,Rd2}$	design value of the compressive resistance to global buckling of a profile or local buckling of a cross-section (including the interaction thereof)
$N_{cr,Rd}$	design value of the compressive resistance to local buckling of a profile
$N_{E,Rd}$	design value of the flexural buckling resistance of a profile (with or without considering the effects of shear deformation)
N_{Ed}	design value of the axial force for the connection force
$N_{Ed,i}$	design value of the connection force transferred at the i^{th} -bolt row's section
$N_{FT,Rd}$	design value of the compressive resistance to flexural-torsional buckling of a profile
$N_{i,Ed}$	design value of the axial force applied to a sandwich panel
$(N_{i,Ed})_f$	design value of the axial force per unit width in the face sheets, in the i direction
$N_{po,Rd}$	design value of the pull-out resistance per bolt
$N_{T,Rd}$	design value of the compressive resistance to torsional buckling of a profile
$N_{t,Ed}$	design value of the tensile force at each cross-section of a profile
$N_{t,Rd}$	design value of the tensile resistance of a cross-section in the longitudinal (x) direction
$N_{ty,Ed}$	design value of the tensile force or prying action for tying force failure
$N_{ty,Rd}$	design value of the tying force resistance of a web cleated beam-to-column joint of two leg-angles having constant thickness outstands
$N_{x,nt,Rd}$	design value of the net-tension resistance in the x direction
$N_{y,nt,Rd}$	design value of the net-tension resistance in the y direction
$N_{z,Ed}$	design value of the out-of-plane (z direction) tensile force transferred at the bolt

$N_{z,Rd}$	design value of the bolt tension resistance (12.2.4.2), or design value for the resistance for the out-of-plane tension force (12.2.4.3)
$N_{1,Ed}$	contribution of N_{Ed} at the first row of bolts ($i = 1$)
$N_{2,Ed}$	contribution of N_{Ed} at the second row of bolts ($i = 2$)
$P_{c,d}$	design value of the buckling load per unit width (of a sandwich panel)
$P_{cb,d}$	design value of the buckling load component corresponding to pure bending (Euler buckling load)
$P_{cs,d}$	design value of the buckling load component corresponding to transverse shear forces
P_{Ed}	design value of the transverse concentrated load; design value of the applied transverse concentrated load or support reaction borne by the web
$P_{i,c,d}$	design value of the buckling load in the i direction (of a sandwich panel)
Q_{fat}	constant amplitude fatigue action
R	radius of a profile with circular section (Clause 8), or ratio between minimum or maximum design value of an action effect in a member or member-joint (Clause 10), or coefficient to identify which section wall of a profile subjected to compression or bending first triggers local buckling (Annex C)
$R\{\dots\}$	output of the resistance model
$R_{ac,k}$	characteristic value of the adhesive connection resistance
$R_{ac,Rd}$	design value of the adhesive connection resistance
R_d	design value of resistance
$R_{f,k}$	characteristic value of the fatigue resistance of a member or member-joint (at constant amplitude)
$R_{d,t,fi}$	design resistance in the fire situation
S	shear stiffness per unit width of a symmetric sandwich section with homogeneous core and thin face sheets
T	maximum tightening torque

T_{Ed}	design value of the torsional moment at each cross-section of a profile
$T_{Ed}^{(SV)}$	design value of the uniform torsional moment of a cross-section associated to the Saint-Venant's torsion
$T_{Ed}^{(W)}$	design value of the non-uniform torsional moment of a cross-section for constrained warping
T_g	glass transition temperature of composite, core or adhesive materials
T_{Rd}	design value of the torsional resistance of a cross-section
T_s	maximum material temperature of composite, core or adhesive materials in service conditions
V	shear force
$V_{b,i,Ed}$	design value of the connection force per bolt at the i^{th} -row of bolts
$V_{br,Rd}$	design value of the pin-bearing resistance per bolt
$V_{br,i,Ed}$	design value of the bearing force transferred per bolt at the i^{th} -bolt row for pin-bearing failure
V_{Ed}	design value of shear force (in general), or total design vertical load, transmitted from the floor (storey thrust) of a frame (Clause 7)
$(V_{Ed})_w$	design value of the shear force in the web component (of a sandwich panel)
V_f	fibre volume fraction (or content) of a ply or composite material
$V_{i,Ed}$	design value of the acting transverse shear force per unit width in the examined i direction
$(V_{i,Ed})_c$	design value of the shear force in the core component of web-core sandwiches with core infill
V_{Rd}	design value of the shear resistance of a cross-section
V_{Rd1}	design value of the shear resistance to material failure of a cross-section
V_{Rd2}	design value of the shear resistance to local buckling of a cross-section
$V_{so,i,Ed}$	design value of bearing force transferred by a column line of bolts for shear-out failure

$V_{so,1,Ed}$	design value of the bearing force transferred by a bolt at the first row of bolts for shear-out failure
$V_{so,2,Ed}$	design value of the bearing force transferred by a column line of two bolts for shear-out failure
$V_{so,i,Rd}$	design value of the shear-out resistance per line of bolts, $V_{so,3,Rd}$ or $V_{so,4,Rd}$, in a laminate of constant thickness
$V_{so,1,Rd}$	design value of the shear-out failure resistance
$V_{so,2,Rd}$	design value of the shear-out resistance per line of bolts
V_x	coefficient of variation of a material or product property
$V_{x,br,Rd}$	design value of the pin-bearing resistance per bolt in the x direction
$V_{x,exp}$	coefficient of variation of the tested sample
$V_{y,br,Rd}$	design value of the pin-bearing resistance per bolt in the y direction
$V_{wc,Ed}$	design value of the shear force acting over the area of a laminate at the fillet radius junction between two legs of leg-angles of composite material
$V_{wc,Rd}$	design value of the shear resistance at the fillet radius junction between two legs of leg-angles of composite material
W	elastic flexural modulus of a cross-section
W_{net}	elastic flexural modulus of a net cross-section
W_y	major-axis elastic modulus of a cross-section
$X_{d,fi}$	design value of mechanical (strength and stiffness) material properties for the fire situation
X_k	characteristic value of material properties (strength or stiffness, generally f_k or E_k)
$X_{k,i}$	characteristic value of a material or product property i
$X_{k,\theta}$	characteristic value of a property at temperature θ
X_n	nominal value of a material property

$X_m(0)$	initial mean value of elastic or shear modulus X (at time $t=0$)
$X_m(t)$	mean value of elastic or shear modulus X at time t to take into account creep effects

Latin lower case letters

a_d	design value of geometrical parameters
b	web spacing of a web-core sandwich section (Clause 7 and 8.4), or width of the flange of a profile section (8.3)
b_c	core infill width between webs of a web-core sandwich section
b_f	flange width of a profile section
b_i	width of the section wall i of a profile section
b_w	web width of a profile section
c_E	empirical constant (for flexural buckling)
c_{LT}	empirical constant (for lateral-torsional buckling)
$c_{p,\theta}$	design value of the ratio between the effective specific heat as a function of temperature θ and the corresponding value at 20 °C
$c_{r,i}$	bolt row load distribution coefficient for the i^{th} -bolt row
c_1	equivalent uniform moment coefficient that depends on the shape of the bending moment diagram
c_2	coefficient associated with load level and dependent on the shape of the bending moment diagram and out-of-plane restraint conditions
d	distance between the centroid axes of the face sheets of a sandwich section (Clauses 7 and 8), or nominal bolt diameter (Clauses 11 and 12)
d_i	diameter of i^{th} hole
d_w	diameter of the washer
d_0	nominal bolt hole diameter (Clauses 11 and 12), or

	distance from the centroid to the shear centre of cross-section (Annex C)
d_1	hole clearance (inner diameter) of washer
d_2	outside diameter of washer
e	lever arm distance from the centre of the nearest line of bolt holes to the centre of the beam's web
$e_{0,d}$	initial bow imperfection
e_1	end edge distance from the first row of bolts
f_c	compressive strength of adhesive materials
f_{cy}	compressive stress at yield of adhesive materials
$f_{E,cr,k}$	characteristic value of the critical flexural buckling stress (without considering the effects of shear deformation)
$f_{FT,cr,k}$	characteristic value of the critical flexural-torsional buckling stress of a profile
$f_{i,b,cr,d}$	design value of the critical buckling bending stress in the i direction of a laminate
$f_{i,b,cr,k}$	characteristic value of the critical buckling bending stress in the i direction of a laminate
$f_{i,b,d}$	design value of the in-plane bending strength in the i direction of a laminate
$f_{i,c,d}$	design value of the compressive strength in the i direction of a laminate
$(f_{i,c,d})_c$	design value of the in-plane compressive strength in the i direction of the core
$(f_{i,c,d})_f$	design value of the in-plane compressive strength in the i direction of the face sheet
$f_{i,c,k}$	characteristic value of the compressive strength in the i direction of a laminate
$(f_{i,c,k})_c$	characteristic value of the in-plane compressive strength in the i direction of the core
$(f_{i,c,k})_f$	characteristic value of the in-plane compressive strength in the i direction of the face sheet
$f_{i,cr,d}$	design value of the critical buckling compressive stress in the i direction of a laminate

$(f_{i,cr,d})_f$	design value of the critical buckling compressive stress in the i direction of the face sheet
$f_{i,cr,k}$	characteristic value of the critical buckling compressive stress in the i direction of a laminate
$(f_{i,cr,k})_f$	characteristic value of the critical buckling compressive stress in the i direction of the face sheet
$f_{i,f,d}$	design value of the flexural strength in the i direction of a laminate
$f_{i,f,k}$	characteristic value of the flexural strength in the i direction of a laminate
$f_{i,t,d}$	design value of the tensile strength in the i direction of a laminate
$(f_{i,t,d})_c$	design value of the in-plane tensile strength in the i direction of the core
$(f_{i,t,d})_f$	design value of the in-plane tensile strength in the i direction of the face sheet
$f_{i,t,k}$	characteristic value of the tensile strength in the i direction of a laminate
$(f_{i,t,k})_c$	characteristic value of the in-plane tensile strength in the i direction of the core
$(f_{i,t,k})_f$	characteristic value of the in-plane tensile strength in the i direction of the face sheet
$(f_{i,v,d})_c$	design value of the shear strength in the i direction of the core
$(f_{i,v,k})_c$	characteristic value of the shear strength in the i direction of the core
$(f_{i,wr,d})_f$	design value of the wrinkling stress in the i direction of the face sheet
$(f_{i,wr,k})_f$	characteristic value of the wrinkling stress in the i direction of the face sheet
$f_{iz,ILS,d}$	design value of the interlaminar shear strength (iz plane) of a laminate
$(f_{iz,v,k})_c$	characteristic value of the out-of-plane shear strength (iz plane) of the core, perpendicular to the face sheets
$f_{LT,cr,k}$	characteristic value of the critical lateral-torsional buckling stress of a profile
f_t	tensile strength of adhesive materials

$f_{T,cr,k}$	characteristic value of the critical torsional buckling stress of a profile
f_{ty}	tensile stress at yield of adhesive materials
$(f_{v,d})_c$	design value of the out-of-plane shear strength of the core
f_{v_x}	factor that accounts for statistical uncertainty
$f_{x,b,cr,k}$	characteristic value of the critical stress associated to local buckling of a profile in bending
$(f_{x,b,cr,k})_f$	characteristic value of the critical stress of a compressed flange (of a profile in bending) for a uniform stress distribution over the flange width
$(f_{x,b,cr,k})_f^{SS}$	characteristic value of the critical stress of a compressed flange (of a profile in bending) for a uniform stress distribution over the flange width, corresponding to a simply supported (SS) boundary condition along the web-flange junction
$(f_{x,b,cr,d})_w$	design value of the in-plane critical buckling bending stress in the longitudinal (x) direction of the web
$(f_{x,b,cr,k})_w$	characteristic value of the in-plane critical buckling bending stress in the longitudinal (x) direction of the web
$(f_{x,b,cr,k})_w^{SS}$	characteristic value of the in-plane critical buckling bending stress in the longitudinal (x) direction of the web (of a profile in bending) for a linear stress distribution along the web height, corresponding to a simply supported (SS) boundary condition along the web-flange junction
$f_{x,br,d}$	design value of the pin-bearing strength in the x direction of a laminate
$f_{x,br,k}$	characteristic value of the pin-bearing strength in the x direction of a laminate
$f_{x,c}$	in-plane compressive strength in x direction of composite laminates, core materials, or balanced symmetrical bi-directional laminates
$(f_{x,c,d})_w$	design value of the compressive strength in the longitudinal (x) direction of the web
$f_{x,c,k}$	characteristic value of the compressive strength in the longitudinal (x) direction
$(f_{x,c,k})_w$	characteristic value of the compressive strength in the longitudinal (x) direction of the web
$f_{x,cr,k}$	characteristic value of the critical stress associated to local buckling of a profile in compression

$(f_{x,cr,k})_f$	characteristic value of the critical stress of a compressed flange for a uniform stress distribution over the flange width
$(f_{x,cr,k})_f^{SS}$	characteristic value of the critical stress of a compressed flange for a uniform stress distribution over the flange width, corresponding to a simply supported (SS) boundary condition along the web-flange junction
$(f_{x,cr,k})_w$	characteristic value of the critical stress of a compressed web for a uniform stress distribution over the web width
$(f_{x,cr,k})_w^{SS}$	characteristic value of the critical stress of a compressed web for a uniform stress distribution over the web width, corresponding to a simply supported (SS) boundary condition along the web-flange junction
$f_{x,f}$	flexural strength in x direction of a laminate
$f_{x,t}$	in-plane tensile strength in x direction of composite laminates, core materials, or balanced symmetrical bi-directional laminates
$f_{x,t,d}$	design value of the tensile strength in the x direction of a laminate
$(f_{x,t,d})_w$	design value of the tensile strength in the longitudinal (x) direction of the web
$f_{x,t,k}$	characteristic value of the tensile strength in the x direction of a laminate
$(f_{x,t,k})_w$	characteristic value of the tensile strength in the longitudinal (x) direction of the web
$(f_{x,wr,d})_w$	design value of the wrinkling stress in the longitudinal (x) direction of the web
$(f_{x,wr,k})_w$	characteristic value of the wrinkling stress in the longitudinal (x) direction of the web
$f_{xy,cr,d}$	design value of the critical buckling shear stress of a laminate
$(f_{xy,cr,d})_w$	design value of the critical buckling shear stress of the web
$f_{xy,cr,k}$	characteristic value of the critical buckling shear stress of a laminate
$(f_{xy,cr,k})_w$	characteristic value of the critical buckling shear stress of the web
$f_{xy,v}$	in-plane shear strength of laminates, or balanced symmetrical bi-directional laminates
$f_{xy,v,d}$	design value of the in-plane shear strength of a laminate

$(f_{xy,v,d})_w$	design value of the in-plane shear strength of the web
$f_{xy,v,k}$	characteristic value of the in-plane shear strength of a laminate
$(f_{xy,v,k})_w$	characteristic value of the in-plane shear strength of the web
$f_{xz,ILS}$	interlaminar shear strength (xz plane) of laminates, or of balanced symmetrical bi-directional laminates
$f_{xz,ILS,k}$	characteristic value of the interlaminar shear strength (xz plane) of a laminate
$f_{xz,v}$	out-of-plane shear strength (xz plane) of core materials, perpendicular to face sheets
$f_{xz,v,d}$	design value of the out-of-plane shear strength (xz plane) of a laminate
$f_{xz,v,k}$	characteristic value of the out-of-plane shear strength (xz plane) of a laminate
$(f_{xz,v,k})_c$	characteristic value of the out-of-plane shear strength (zx plane) of the core, perpendicular to the face sheets
$f_{y,br,d}$	design value of the pin-bearing strength in the y direction of a laminate
$f_{y,br,k}$	characteristic value of the pin-bearing strength in the y direction of a laminate
$f_{y,c}$	in-plane compressive strength in y direction of laminates, core materials, or balanced symmetrical bi-directional laminates
$(f_{y,c,d})_w$	design value of the compressive strength in the transverse (y) direction of the web
$(f_{y,c,k})_w$	characteristic value of the compressive strength in the transverse (y) direction of the web
$(f_{y,cr,d})_w$	design value of the critical buckling compressive stress in the transverse (y) direction of the web
$(f_{y,cr,k})_w$	characteristic value of the critical buckling compressive stress in the transverse (y) direction of the web
$f_{y,f}$	flexural strength in y direction of a laminate
$f_{y,f,d}$	design value of the flexural strength in the y direction of a laminate
$f_{y,f,k}$	characteristic value of the flexural strength in the y direction of a laminate

$f_{y,t}$	in-plane tensile strength in y direction of laminates, core materials, or balanced symmetrical bi-directional laminates
$f_{y,t,d}$	design value of the tensile strength in the y direction of a laminate
$f_{y,t,k}$	characteristic value of the tensile strength in the y direction of a laminate
$(f_{y,wr,d})_w$	design value of the wrinkling stress in the transverse (y) direction of the web
$(f_{y,wr,k})_w$	characteristic value of the wrinkling stress in the transverse (y) direction of the web
$f_{yz,ILS}$	interlaminar shear strength (yz plane) of a laminate
$f_{yz,ILS,k}$	characteristic value of the interlaminar shear strength (yz plane) of a laminate
$f_{yz,v}$	out-of-plane shear strength (yz plane) of core materials, perpendicular to face sheets
$(f_{yz,v,k})_c$	characteristic value of the out-of-plane shear strength (yz plane) of core materials, perpendicular to the face sheets
$(f_{wr,v,d})_w$	design value of the shear wrinkling stress of the web
$(f_{wr,v,k})_w$	characteristic value of the shear wrinkling stress of the web
$f_{z,c}$	out-of-plane compressive strength of core materials
$(f_{z,c,d})_c$	design value of the out-of-plane compressive strength of core materials
$f_{z,c,lim}$	limiting out-of-plane compressive strength of a laminate
$(f_{z,c,k})_c$	characteristic value of the out-of-plane compressive strength of core materials
$(f_{zi,v,k})_c$	characteristic value of the out-of-plane shear strength (zi plane) of the core, parallel to the face sheets
$f_{z,t}$	out-of-plane tensile strength of a laminate or core materials
$f_{z,t,d}$	design value of the out-of-plane tensile strength of a laminate
$(f_{z,t,d})_c$	design value of the out-of-plane tensile strength of core materials

$f_{z,t,k}$	characteristic value of the out-of-plane tensile strength of a laminate
$(f_{z,t,k})_c$	characteristic value of the out-of-plane tensile strength of core materials
$f_{zx,v}$	out-of-plane shear strength (xz plane) of core materials, parallel to face sheets
$(f_{zx,v,k})_c$	characteristic value of the out-of-plane shear strength (xz plane) of core materials, parallel to the face sheets
$f_{zy,v}$	out-of-plane shear strength (yz plane) of core materials, parallel to face sheets
$(f_{zy,v,k})_c$	characteristic value of the out-of-plane shear strength (yz plane) of core materials, parallel to the face sheets
$f_{1,c}$	longitudinal compressive strength of UD plies, balanced bi-directional plies, or mat plies
$f_{1,t}$	longitudinal tensile strength of UD plies, balanced bi-directional plies, or mat plies
$f_{12,v}$	in-plane shear strength of UD plies, balanced bi-directional plies, or mat plies
$f_{13,v}$	intralaminar shear strength of UD plies, balanced bi-directional plies, or mat plies
$f_{2,c}$	transverse compressive strength of UD plies, balanced bi-directional plies, or mat plies
$f_{2,t}$	transverse tensile strength of UD plies, balanced bi-directional plies, or mat plies
$f_{23,v}$	intralaminar shear strength of UD plies, balanced bi-directional plies, or mat plies
h	height of a structure (Clause 7), or height of the web of a profile section (Clause 8), or depth of the leg-angle (Clause 12)
h_w	web depth (equal to the distance between the face sheets' centroids)
h_r	depth of the shear plane at the fillet radius of the leg-angle (Clause 12)
i	radius of gyration about the relevant axis of a profile cross-section
i_0	polar radius of gyration about the shear centre of a profile cross-section
l_{eff}	effective width for the verifications of transverse compression in the web (of sandwich panels)

l_0	buckling length
k	effective length parameter to take into account the restraining effects of end supports to flexural buckling of a profile about the relevant axis of bending
k_{cc}	reduction factor accounting for the bearing compressive stress concentration in front of the bolt from having a clearance hole with limit on dimension
$k_{c,creep}$	strength reduction factor for compressive creep rupture for continuous unidirectional fibres
k_{sw}	second-order sway effects due to vertical loads
k_{tc}	stress concentration factor for specific bolted connection configurations (net tension failure)
$k_{t,creep}$	strength reduction factor for tensile creep rupture for continuous unidirectional fibres
k_w	warping end restraint parameter for torsional buckling of a profile cross-section
k_z	effective length parameter allowing for the effect of minor-axis rotation at supports
$\tilde{k}$	rotational spring
k_θ	temperature-dependent reduction factor ($X_{k,\theta} / X_k$) for a strength or stiffness property
m	number of columns in a row of a frame (Clause 7), or exponent that depends on the actual connection configuration (12.4.5.4)
n	number of test results (4.4.5), or exponent that depend on the actual connection configuration (12.4.5.4)
$n_{b,i}$	number of bolts at the i^{th} bolt row
$n_{b,1}$	number of bolts at the first row of bolts ($i = 1$)
$n_{b,2}$	number of bolts at the second row of bolts ($i = 2$)
n_w	d_2 -to- d_1 ratio
p_1	spacing between centres of bolts in a line in the load transfer direction
p_2	spacing measured perpendicular to the load transfer direction between adjacent lines of bolts

r_i	radius of curvature of the face sheet, with regard to its centroid, in the iz plane (positive for concave, negative for convex)
s	staggered pitch, the spacing of the centres of two consecutive holes in the chain measured parallel to the member axis
s_n	width obtained by a dispersion of the load or support reaction at 45° through a z depth
s_s	width along the web on which the load is applied or the support reaction acts
t	laminate thickness (in general), or time (Clauses 4, 8.5, 9, Annex A, Annex D)
t_a	thickness of the adhesive layer
t_c	thickness of the core of a sandwich section
t_f	constant thickness of each face sheet of a sandwich section (Clause 7 and 8.4), or flange thickness of a profile section (8.3 and Annex C)
t_i	thickness of the ply i of a laminate (Annex B), or thickness of the section wall i of a profile section (Annex C)
t_{l-a}	thickness of a leg-angle cleat
t_k	thickness of the wall k where a hole is located
$t_{\max}$	thickness of the thickest wall of a cross-section
$t_{\min}$	thickness of the thinnest wall of a cross-section (Clause 8), or total minimum thickness from the pair of web cleats subjected to $V_{wc,Ed}$ (Clause 12)
t_w	web thickness of a sandwich or a profile section
u	control perimeter
w	width of the component
w_1	initial part of the deflection under permanent loads of the relevant combination of actions
w_2	long-term part of the deflection under permanent loads including quasi-permanent loads
w_3	instantaneous deflection due to variable actions excluding the quasi-permanent loads

w_c	precamber in the unloaded structural member (if applied)
$w_{\max}$	remaining total deflection taking into account the precamber
w_{tot}	total deflection as the sum of w_1 , w_2 , w_3
w_{G_k}	initial part of the deflection under permanent loads
$w_{Q_{k,1}}$	instantaneous deflection due to the leading variable action
$w_{Q_{k,j}}$	instantaneous deflection due to accompanying variable actions
z_g	distance between the point of load application and the shear centre of a profile

Greek upper case letters

Φ_E	auxiliary coefficient for flexural buckling of a profile
Φ_{LT}	auxiliary coefficient for lateral-torsional buckling of a profile

Greek lower case letters

α	coefficient of linear thermal expansion of sandwich core materials
$\alpha_{cr,sw}$	factor by which the design load would have to be increased to cause elastic instability of a structure in a global in-plane (sway) mode
$\alpha_{f,1}$	coefficient of linear thermal expansion in 1 direction of fibres
$\alpha_{f,2}$	coefficient of linear thermal expansion in 2 direction of fibres
α_h	reduction factor for length or height of a frame
$\alpha_{i,j}$	coefficient of linear thermal expansion of the j^{th} ply along the assigned direction i (x or y)
α_m	reduction factor for the number of columns in a row of a frame
α_q	coefficient of linear thermal expansion of mat plies with randomly oriented fibres
α_r	coefficient of linear thermal expansion of resins

α_x, α_y	coefficient of linear thermal expansion in x and y direction of laminates
α_1, α_2	coefficient of linear thermal expansion in the longitudinal and transverse direction of UD plies, balanced bi-directional plies, or mat plies
$\alpha_1^{\text{UD}}, \alpha_2^{\text{UD}}$	coefficient of linear thermal expansion of a fictitious UD ply with the same fibre volume fraction as the mat ply
β_1	coefficient of moisture expansion in the longitudinal direction for swelling of plies
β_2, β_3	coefficients of moisture expansion in the transverse direction for swelling of plies
γ_{ff}	partial factor for the fatigue action
γ_{M}	single partial material factor accounting for the uncertainty in a resistance model
$\gamma_{\text{M,ac}}$	partial factor for the adhesive connection resistance
$\gamma_{\text{M,creep}}$	partial factor for creep rupture
γ_{Mf}	partial factor for the fatigue resistance
$\gamma_{\text{M,fi}}$	partial factor for the relevant mechanical material property for the fire situation
γ_{m}	partial factor for a material or product property
$\gamma_{\text{m},i}$	partial factor for a material or product property accounting for unfavourable deviation of the properties of a material or product i from their characteristic values, and geometrical deviations (if these are not modelled explicitly)
γ_{Rd}	partial factor associated with the uncertainty in a resistance model
$\varepsilon_{\text{f},1}$	tensile strain at failure in longitudinal direction of fibres
$\varepsilon_{\text{t,k}}^{\text{crack}}$	characteristic value of the tensile strain causing matrix cracking
$\varepsilon_{\text{t,d}}^{\text{crack}}$	design value of the tensile strain causing matrix cracking
$\varepsilon_{\text{t,SLS}}$	tensile strain due to the frequent combination of actions
ε_{r}	maximum tensile elongation of a thermoset resin type
η_{c}	conversion factor

$\eta_{c,i}$	conversion factor, accounting for effects of temperature and moisture, effects of ageing of materials, including the uncertainty of those effects
η_{cm}	conversion factor for moisture effects
η_{ct}	conversion factor for temperature effects
η_{fi}	reduction factor applied to E_d in order to obtain $E_{fi,d}$
θ	temperature
λ	thermal conductivity
$\lambda_{f,1}$	thermal conductivity in longitudinal direction of fibres
λ_E	profile slenderness for interaction between local and flexural buckling
λ_{LT}	profile slenderness for interaction between local and lateral-torsional buckling
λ_r	thermal conductivity of resins
λ_θ	design value of the ratio between the effective thermal conductivity as a function of temperature θ and the corresponding value at 20 °C
λ_1	thermal conductivity in 1 direction of UD plies, or balanced bi-directional plies
λ_2	thermal conductivity in 2 direction of UD plies, or balanced bi-directional plies
ν	Poisson's ratio of mat plies
ν_f	Poisson's ratio of fibres
ν_r	Poisson's ratio of resins
ν_{xy}	in-plane major Poisson's ratio of laminates, or balanced symmetrical bi-directional laminates
$\nu_{xy,k}$	characteristic value of the in-plane major Poisson's ratio of laminates, or balanced symmetrical bi-directional laminates
ν_{yx}	in-plane minor Poisson's ratio of laminates, or balanced symmetrical bi-directional laminates
$\nu_{yx,k}$	characteristic value of the minor Poisson's ratio of laminates, or balanced symmetrical bi-directional laminates

ν_{12}	Poisson's ratio of UD plies
ρ	density
ρ_f	density of fibres
ρ_r	density of resins
ρ_θ	design value of the ratio between density as a function of temperature θ and the corresponding value at 20 °C
$\sigma_{c,creep,Ed}$	design value of the maximum sustained compressive stress caused by the quasi-permanent combinations of actions
$\sigma_{c,creep,Rd}$	design value of the compressive stress limit for creep rupture
$\sigma_{f,1}$	tensile strength in longitudinal direction of fibres
$\sigma_{i,b,Ed}$	design value of the in-plane bending stress in the i direction at each section of a laminate
$\sigma_{i,c,Ed}$	design value of the in-plane axial compressive stress in the i direction at each section of a laminate
$\sigma_{i,ob,Ed}$	design value of the out-plane bending stress in the i direction at each section of a laminate
$(\sigma_{i,Ed})_c$	design value of the normal stress in the core
$(\sigma_{i,Ed})_f$	design value of the in-plane stress (tensile or compressive) in the face sheets in the i direction
$(\sigma_{i,M,Ed})_c$	design value of the bending stress in the core in the i direction
$(\sigma_{i,M,Ed})_f$	design value of the bending stress in the face sheets in the i direction
$(\sigma_{i,N,Ed})_c$	design value of the axial stress in the core in the i direction
$(\sigma_{i,N,Ed})_f$	design value of the axial stress in the face sheets in the i direction
$\sigma_{i,t,Ed}$	design value of the in-plane axial tensile stress in the i direction at each section of a laminate
$\sigma_{r,c}, \sigma_{r,t}$	compressive and tensile strength of resins

$\sigma_{t,creep,Ed}$	design value of the maximum sustained tensile stress caused by the quasi-permanent combinations of actions
$\sigma_{t,creep,Rd}$	design value of the tensile stress limit for creep rupture
$(\sigma_{x,M,Ed})_w$	design value of the in-plane bending stress in the web
$(\sigma_{y,c,Ed})_w$	design value of the compressive stress in the web, resulting from transverse concentrated loads
$(\sigma_{z,Ed})_c$	design value of the out-of-plane stress in the core
$\sigma_{z,t,Ed}$	design value of the out-of-plane tensile stress
σ_{11}, σ_{22}	longitudinal and transverse stress in a ply resulting from the effect of the actions
τ_{Ed}	design value of the shear stress due to torsion
$(\tau_{Ed})_c$	design value of the out-of-plane shear stress in the core
$(\tau_{Ed})_w$	design value of the out-of-plane shear stress in the web
$\tau_{Ed}^{(SV)}$	design value of the shear stress due to uniform torsional moment
$\tau_{Ed}^{(w)}$	design value of the shear stress due to non-uniform torsional moment
$(\tau_{i,Ed})_c$	design value of the shear stress in the core
$\tau_{iz,Ed}$	design value of the interlaminar shear stresses in the iz plane of a laminate
τ_{max}	maximum average shear stress of adhesive materials
τ_r	shear strength of resins
$\tau_{xy,Ed}$	design value of the in-plane shear stress at each section of a laminate
τ_{12}	shear stress in a ply resulting from the effect of the actions
ϕ	initial sway imperfection
$\phi(t)$	creep coefficient at time t

ϕ_0	basic value for initial sway imperfection (equal to 1/200)
χ_E	reduction factor to take into account the interaction between local and flexural buckling of a profile
$\chi_{E,\text{shear}}$	reduction factor to take into account the influence of shear deformation
$\chi_{i,b}$	buckling reduction factor for bending in the i direction to take into account imperfections of a laminate
$\chi_{i,c}$	buckling reduction factor for compression in the i direction to take into account imperfections of a laminate
χ_{LT}	reduction factor to take into account the interaction between local and lateral-torsional buckling of a profile
χ_v	buckling reduction factor for in-plane shear to take into account imperfections of a laminate
$\psi_{1,1}, \psi_{2,1}, \psi_{2,i}$	combination factors applied to variable actions

3.2.2 Abbreviations

CFM	continuous fibre mat
CLT	classical lamination theory
CSM	chopped strand mat
CZM	cohesive zone modelling
DCB	double cantilever beam
DMA	dynamic mechanical analysis
DSC	differential scanning calorimetry
EAD	european assessment document
ENF	end-notched flexure
ETA	european technical approval
FEM	finite element modelling
FRP	fibre-reinforced polymer

HM	high modulus
HS	high strength
ILSS	interlaminar shear strength
PET	polyethylene terephthalate
PQM	production quality management
PUR	polyurethane
PVC	polyvinyl chloride
RIM	resin infusion moulding
RTM	resin transfer moulding
SLS	serviceability limit states
TG	thermogravimetry
TMA	thermomechanical analysis
TTSP	time-temperature superposition principle
UD	unidirectional
ULS	ultimate limit states
UV	ultraviolet
VARTM	vacuum-assisted resin transfer moulding
VCCT	virtual crack closure technique

3.3 Symbols for member axes

(1) Figure 3.1 shows the convention for the local axes (1, 2 and 3) of a unidirectional ply:

- The axes 1 and 2 are for the in-plane directions of the ply, respectively in the direction of the fibres and in the direction transverse to the fibres;
- The axis 3 is for the out-of-plane direction of the ply.

NOTE A unidirectional ply contains all reinforcing fibres aligned in one direction.

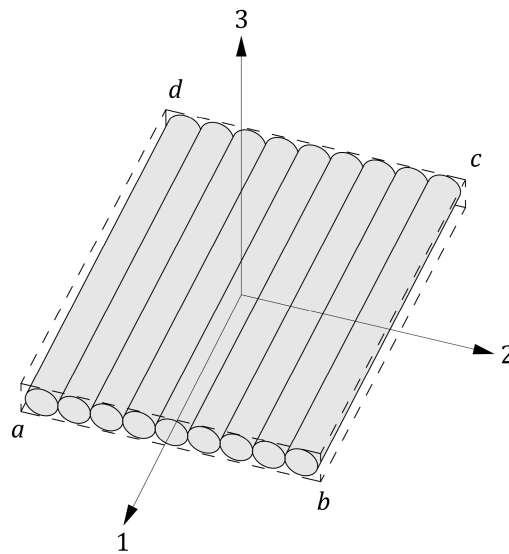


Figure 3.1 — Reference axes (local) for a unidirectional ply

(2) Figure 3.2 shows the convention for the global axes (x , y and z) of a laminate, consisting of several plies, each of them with a certain orientation:

- The axes x and y are for the in-plane directions of the laminate, respectively in the longitudinal and transverse directions;
- The axis z is for the out-of-plane direction of the laminate;
- The angle θ defining the orientation of each ply with respect to the laminate is measured counter-clockwise from the local axis 1 of the ply to the global axis x of the laminate.

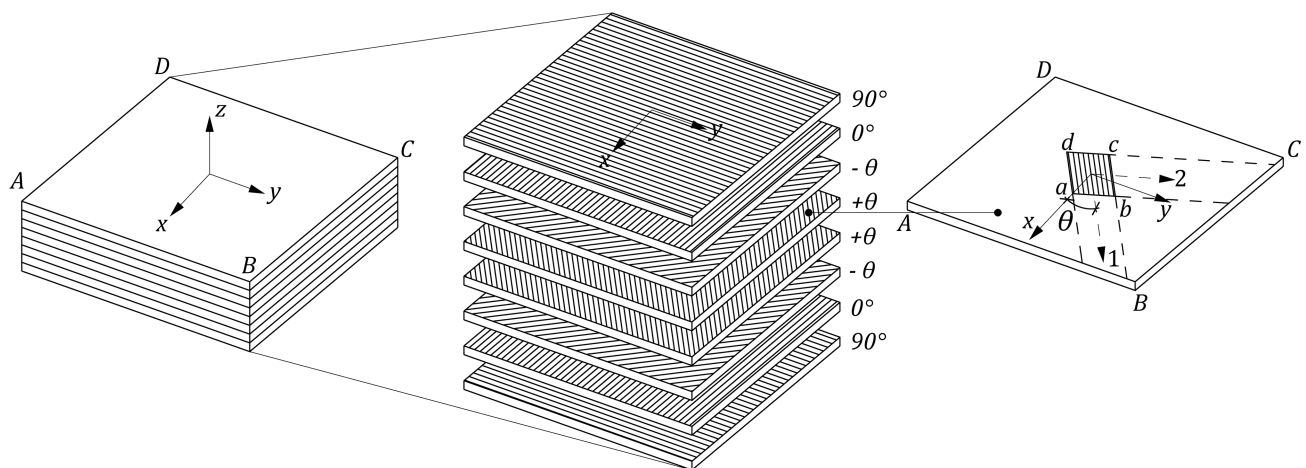


Figure 3.2 — Reference axes (global) for a laminate with several plies with different fibre orientations, with reference to a ply (abcd, Figure 3.1)

(3) Figure 3.3 shows the convention for the global axes (x , y and z) of a profile, consisting of several laminates:

- The axis x is along the member longitudinal axis;
- The axes y and z are for the cross-section axes.

NOTE 1 In general, y and z are for the cross-section axes, respectively parallel and perpendicular to the flanges.

NOTE 2 For angle sections, y and z are for the cross-section axes parallel and perpendicular to the smaller leg (or orthogonal leg for angle sections with equal legs).

NOTE 3 In I-section profiles, the principal material directions of orthotropy of the flanges are aligned with the xyz coordinate system in Figure 3.3; on the other hand, in the web, x and y denote the in-plane longitudinal and transverse directions, and z the out-of-plane direction of the web laminate.

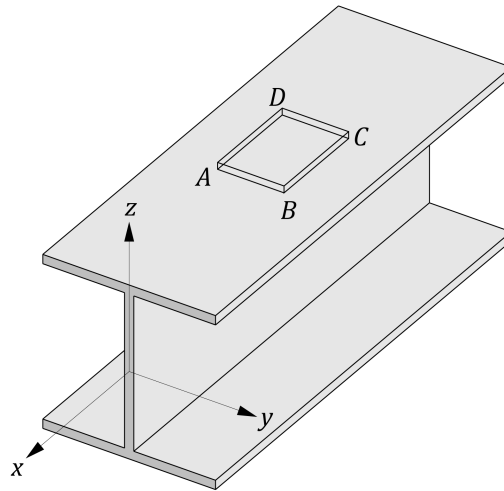


Figure 3.3 — Reference axes (global) for a profile, with reference to a laminate (ABCD, Figure 3.2)

(4) Figure 3.4 shows the convention for the global axes (x , y and z) of homogeneous-core and web-core sandwich panels:

- The axes x and y are for the midplane of the core, respectively in the longitudinal and transverse directions;
- The axis z is the out-of-plane direction.

NOTE 1 The principal material directions of orthotropy of the face sheet laminates and the core are aligned with the xyz coordinate system in Figure 3.4.

NOTE 2 In webs of web-core sandwiches, x and y denote the in-plane longitudinal and transverse directions, and z the out-of-plane direction of the web laminate.