p. 4-9. In Proc. Conf. Fibre-Polymer Composites in Construction (FPCC 2024), 2nd Ed., 5 September, Milton Keynes, UK.

Status and Future for the Structural Eurocode project Design of Fibre-Polymer Composite Structures

J. Toby Mottram
The University of Warwick
School of Engineering
Coventry
West Midlands, UK
CV4 7AL

ABSTRACT

Presented in this paper are the current status and future developments for the structural Eurocode project *Design of Fibre-Polymer Composite Structures*, which in 2022 had the milestone publication of the CEN Technical Specification CEN/TS 19101:2022. It is important to understand that the acronym "FRP" for “Fibre Reinforced Polymer” is no longer utilized in the TS, and this shift in terminology use has been endorsed by the European composites industry, via EuCIA. The focus of the paper is on current and future outputs from the project work by committee CEN/TC 250 WG4 and how stakeholders (e.g., practitioner and academic researcher users of the TS) can provide valuable support to future developments that will include the first version of Eurocode standard EN 19101.

INTRODUCTION

As part of a major project with CEN Technical Committee 250 (CEN/TC 250 Eurocodes) to update the 1st generation of Eurocodes the development of a new standard for fibre-polymer composite structures was initiated. CEN/TC 250’s project timetable is for the 2nd generation of Eurocodes to be mandatory from April 2028. A standard for the construction material of fibre-polymer composites was not included in the 1st generation suite of 58 parts. A new Working Group (WG4 *Fibre Reinforced Polymer Structure*) under the aegis of CEN/TC 250 was appointed in 2016 to lead a project to draft this new Eurocode, under the convenorship of Professor Luigi Ascione (The Università degli Studi di Salerno, Italy). By 2024, WG4 had 70 members for expert representatives from many European countries, and membership includes the European Composites Industry Association (EuCIA), and six experts from the UK.

There are three evolution steps to us having a Eurocodes standard, and they are [1]: (i) publication of a Technical and Scientific report [2]; (ii) publication of a Technical Specification (referred to as TS, which is for the Current Status) [3]; and (iii) after a period of trial use, conversion of the TS into a Eurocode standard, which is for Future Developments.

The first step was completed in 2016 with the publication of *Prospect for New Guidance in the Design of FRP* [2], which aimed at promoting discussions within Europe on the design of composite structures for civil engineering works.

In July 2018, by way of Mandate M/515, CEN/TC 250 and WG4 set-up a Project Team (WG4.T2) that had an aim of drafting a TS that built upon the contributions in the prospect report [2], which in 2017 had been revised to resolve many hundreds of comments from a CEN-country enquiry. For the step ii drafting project, WG4.T2 had the following six members: João Ramôa Correia (Leader, Full Professor, Universidade de Lisboa, Portugal), Thomas Keller (Full Professor, École Polytechnique Fédérale de Lausanne, Switzerland), Jan Knippers (Full Professor, University of Stuttgart, Germany), Toby Mottram (Full Professor, The University of Warwick, UK), Carlo Paulotto (Ferrovial, Spain), and José Sena-Cruz (since September 2020, Associate Professor, University of Minho, Portugal), replacing Till Vallée (until November 2019, Senior Researcher at Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Germany). Over the next four years this project team worked on preparing the TS and consulted closely with other members of WG4, and when required with other technical experts such as for fire design and the reliability analysis used to calibrate partial factors for resistance.

In November 2022, the English version of CEN/TS 19101:2022, *Design of Fibre-Polymer Composite Structures* was published [3]. This followed a comprehensive and thorough enquiry review of the TS's content articulated through the 34 National Standardization Bodies (NSBs) with CEN, and an independent Technical Review by members of CEN/TC 250. CEN/TS 19101:2022 has therefore been available for over two years for use by producers, designers, and contractors, even if conflicting national standards may continue to exist. A TS is a normative document made available by CEN and is established and approved by a CEN Technical Committee by a weighted vote of CEN Members. German and French translations have also been made available.

In this paper the term "composite" will be used as shorthand for "fibre-polymer composite".

CURRENT STATUS

The work of WG4 over 7-8 years, and more recently by WG4.T2 drafting CEN/TS 19101:2022 has ignited considerable interest for the exploitation of fibre-polymer composites in construction in Europe and beyond. One reason for the increased interest is because standardization plays a key role in supporting industrial policy in the era of globalization. The improvement of *harmonized competition in markets through the adoption of Eurocodes is well recognized, as* they stand out as a tool for accelerating the process of convergence of different national and regional regulatory approaches.

In the UK, Technical Committee B/525 *Building and Civil Engineering Structures* is responsible for establishing and coordinating policies for the planning, programming, resourcing, preparation, and maintenance of British Standards in the area of building and civil engineering structures. It provides UK input to CEN/TC 250. More of its terms of reference require it to establish and maintain an efficient structure and, for designated subject areas, to delegate responsibilities within such agreed policy as exists and as may be subsequently updated for the preparation and approval of the technical content of the relevant Eurocode standards and for providing UK input to ISO and CEN equivalent committees. Committee B/525 has 19 sub-committees including B/525/-/4, which is the UK's mirror group to WG4, and the author is the current chair. To look after the UK's interests this committee has six expert members comprising two academics and four practitioners with either design or execution experiences.

Following an action within B/525/-/4 to draft the National Annex, the UK version of the TS (PD CEN/TS 19101:2022, see Figure 1 for its front cover) was published by BSI in April 2023 [4]. This UK specific publication milestone includes a one-page National Annex on page 239; the NA is therefore not a separate document. As stated in the National Foreword "This publication is not to be regarded as a British Standard". CEN does permit TSs to be national standards if there is no conflict. Eurocode standards that are recognized as UK standards are listed in Section 1 of the *Building Regulations. Approved Document A* [5], and Approved Document A last received amendments in 2013.

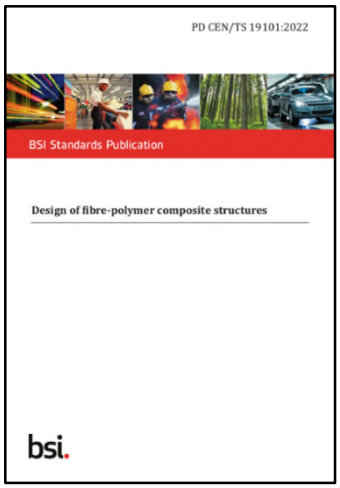

Figure 1. Front cover of PD CEN/TS 19101:2022

The scope of the TS is for the design of buildings, bridges, and other civil engineering structures, including permanent and temporary structures, made of composite materials or combinations of composite materials and conventional structural materials, in so called hybrid structures.
The TS covers composite laminates, profiles (e.g., produced by the pultrusion processing method) and sandwich panels (including web-core panels), with bolted, bonded, and hybrid bolted-bonded connections and joints. It covers composites made with the fibre types of glass, carbon, basalt, or aramid [6]. Polymer types are the thermosetting resins of polyesters, vinylesters, epoxies or phenolics for composite matrices and adhesively bonded connections. For sandwich panels the cores can be of polymeric foams or balsa wood. These constituent materials can be applied in structural members produced by composite manufacturing processes, such as pultrusion, filament winding, hand layup, resin transfer moulding, and vacuum-assisted resin transfer moulding [6]. Also, the TS applies to composite structures whose material temperature in service conditions (to be determined based on climatic temperatures, as defined in EN 1991-1-5:2003 [7]) varies between -40 ºC and the (dry) glass transition temperature of composites minus 20ºC (and there is specific guidance in the TS for how his key material property must be determined).

What the TS does not cover are composite cables, strengthening systems or reinforcing bars used in reinforced concrete structures. Composite reinforcements and strengthening systems are now covered by Annexes J and R in EN 1992-1-1:2023 [8]. The TS also does not apply to special composite structures, such as buried pipes, pressure vessels, tanks, or chemical storage containers, which are already covered by specific European standards.

The structure of CEN/TS 19101:2022 [3 or 5] is consistent with that of the 2nd generation Eurocodes, thus presenting the same sequence of main clauses. The document comprises of 12 clauses (1 to 12) and five annexes (A to E).

The Clauses are:

1. Scope
2. Normative references
3. Terms, definitions, and symbols
4. Basis of design
5. Materials
6. Durability
7. Structural analysis
8. Ultimate limit states
9. Serviceability limit states
10. Fatigue
11. Detailing
12. Connections and joints.

And the Annexes are:

A. Creep coefficients (informative)
B. Indicative values of material properties for preliminary design (informative)
C. Buckling of orthotropic laminates and profiles (normative)
D. Structural fire design (normative)
E. Bridge details (informative).

For an introductory summary to the TS, you should consult reference [9]. Furthermore, it is noteworthy to convey that during step ii several deficiencies in the prospect report [2] were resolved in the preparation of the TS. These deficiencies included the; basis of design and the definition of partial factors (for resistance modes of failure); determination of material properties to be used in design verifications; consideration of the effects of moisture and temperature by way of conversion factors; consideration of the effects of creep and fatigue by way of design procedures (and not by conversion factors); and design of adhesively bonded connections and joints.

Another aim of the WG4.T2 project, with essential support from members of WG4 and other experts, was to prepare two accompanying documents that shall permit greater accessibility to users of the TS to design and/or research and develop composite structures, and, at the same time, provide stakeholders with information to the provenance of the brand-new content in the 12 Clauses and five Annexes. These two documents represent a Commentary comprising nearly 400 background reports

[10], and a set of 16 Worked Examples to cover both isolated member and joint designs, together with full structure designs [11]. These two CRC Press publications will be available open access. To end this discussion on the current status of the Eurocode project (*Design of Fibre-Polymer Composite Structures*) it is instructive to record that several papers have been published to disseminate general and specific information related to the content of CEN/TS 19101:2022 [9, 12-15].

FUTURE DEVELOPMENTS

WG4 activities

Following a NSB vote for approval by CEN in 2023 a future project for WG4 is to draft an "Execution" standard, which we can expect to have a similar technical level of content found in, for example, the EN 1090 standards that regulate the fabrication and assembly of steel and aluminium structures (and are recognized by the Construction Products Regulation). The aim of this drafting project is to have execution guidance for composites structures, which had become a necessary future development because CEN requirements do not permit execution clauses to be part of a TS (or Eurocode). The execution standard is intended to be used alongside CEN/TS 19101:2022 (and its Eurocode version from step iii), and is expected to offer guidance on production, assembly, installation, and maintenance procedures for composite structures.

The proposed 10 clauses are:

1. Scope
2. Normative references
3. Terms and definitions
4. Specifications and documentation
5. Constituent products
6. Preparation and assembly
7. Mechanical fastening
8. Erection
9. Geometrical tolerances
10. Inspection, testing and correction.

With a project team formed from members of WG4 this project will start in earnest during 2024 with the intention that the drafting stage is complete after 24 months, and the progamme of work will include an enquiry stage, followed by a comment resolution stage, Formal Vote, etc.

Following the trial period of utilization generating feedback comments and upon the process to convert the CEN/TS 19101:2022 into a Eurocode standard (EN 19101), several technical developments are anticipated to be implemented or explored further. These future developments with WG4 can include: seismic design guidelines; further consideration of robustness (to address the potential brittle failure modes of composite structures); provisions for composite cables; specific provisions for built-up composite members; additional provisions for the ULS design of profiles (encompassing aspects such as web crippling resistance, buckling of channel sections, and resistance to combined internal forces), and, sustainability to mitigate against the adverse effects of the climate emergency.

Academic and Practitioner activities

One key reason for the step ii publication of a TS [3 or 5] is to provide our composites in construction community with the opportunity to provide WG4 with user comments so that there can be a focused project to convert the TS into a Eurocode. If you are a practitioner using the TS in design work (either for a client or on a trial basis) and wish to provide comments for future developments of the Clauses and Annexes do contact your NSB representative (in the UK this person can be the author) to request an official comments form. Professor Luigi Ascione (convenor to WG4) can provide the name of a WG4 member in your country or on behalf of WG4 accept comments if our country is without a member. WG4 will be delighted to receive comments from users of the TS designing composite structures. Structures that are executed can also provide a source of field applications for long-term monitoring and inspection that will generate technical information that will inform the longer-term future developments of the next generation of Eurocode standards for the design and execution of composite structures.

The final discussion in this paper is to summarize why the TS (with its accompanying Commentary [10] and Worked Examples [11]) is a valuable source of information for academic researchers. These three documents offer researchers consensus-generated guidance to assist them in planning and conducting targeted R&D that gives stakeholders (including code writers) reliable and relevant research results. Without the robust planning framework that these Eurocode documents naturally provide many academic research projects will deliver physical test and numerical results that are deemed 'useless' for code drafting [16]. The author was a member of the project team (2007-10) and the Fiber Composites and Polymers Standards (FCAPS) committee of the Codes and Standards Activities Division of the Structural Engineering Institute of ASCE (2011-23), whose efforts have resulted in the recent publication of a North American LFRD standard for the design of composite structures using pultruded profiles [17]. In 2009, whilst contributing to the pre-standard project the author presented a conference paper [16] on the design guidance for bolted connections with a focus on gaps in knowledge. Following a critical evaluation of the state-of-the-art up to 2009, the author established 20 R&D questions to be addressed (before seismic design was introduced by FCAPS into this LFRD standard project). It is instructive to reproduce these 20 questions next, observing that over the intervening 15 years few have been answered adequately, but not necessarily comprehensively (notably numbers 1 and 5), many have received a degree of new research effort (numbers 3, 6-9, 11, 16,17 and 19), and several are still to receive new research (namely numbers 2, 4, 10, 12-15, 18 and 20).

1. What are to be the recommended details for: connection geometries (e.g., hole clearance, end distance, side distance, bolt spacings); bolt, nut, and washer types; bolt installation torque?
2. Is it acceptable to have a joint with a single bolt?
3. What are the limitations (on strength and durability) for allowing bolt thread to bear against the fibre-polymer composite material?
4. Are there to be limits specified on maximum distances in connection geometry?
5. What is to be the standard test method that shall be specified to determine pin-bearing strength?
6. How does pin-bearing strength vary with environmental conditioning, bolt shaft flexure, position of bolt in clearance hole, orientation of 'bearing' force to the orientation of material?
7. What is the strength reduction factor when loading is for the single-lap plate-to-plate configuration and the basic resistance formulae are based on a double-lap test arrangement?
8. How do we predict strength when there are two or more rows of bolting (i.e., when the by-pass loading exists and there is a requirement to know the open-hole stress concentration factor)?
9. What is the distribution of the connection force between the bolts in multi-rows?
10. What information do we need to prepare mandatory text for staggered bolt arrangements?
11. Are the closed formed formulae for clearly defined modes of failure necessary and/or sufficient?
12. How much does the material viscoelasticity affect how the force is transferred and how the connection fails?
13. How is the strength of connections affected by a combination of in- and out-of-plane actions (as found in frame joints)?
14. Do we have adequate information to verify a strength formula for the situation where the side distance is, on one or both sides of the bolt hole, relatively large?
15. What is the strength of connections for bracing members with eccentric loading?
16. What is the moment-rotation response of 'prescriptive' web-cleated ('pinned') connections that fail by the prying action causing the composite cleats or composite columns to delaminate?
17. Is there localized bearing damage in frame joints when a composite structure is carrying serviceability loading (static and fatigue)?
18. Can the rotational and in-plane stiffnesses be characterized such that analysis can be used to check if frame deformation satisfies a serviceability limit state?
19. What is the tying force of frame joints, needed to be present to control disproportionate collapse?
20. How are columns of pultruded shapes to be connected to the ground?

Using information for the design procedures in the TS, combined with Eurocode 0 Annex D [18] and with other technical information as required, academics planning research projects (on bolted connections (in Clause 12) and for other Clauses or Annexes) can create a robust framework to carry-out quality research whose results can readily be transferred into practice. Such a targeted approach to conducting research for composites in construction will go a long way to eliminating the following reasons (and there are four others presented in [19]) for why disseminated research results can often be deemed to be 'useless' when used by code writers as a basis for preparing design rules:

- no clear definition of the domain of applicability of the work;
- no critical review of previous research relevant to that domain;
- test results that omit crucial data on properties of specimens;
- test specimens with materials having strengths different to typical design strengths.

One essential for physical test results to be deemed 'useful' to code writes as input data in reliability analyses that calibrate the partial factors for resistance (for CEN/TS 19101:2022 refer to the three background reports to sub-clause 4.4.6 in [10]), is to determine characteristic values of the material properties using the standard test methods specified in the TS. This important connection between how characteristics values are established for reliability analyses was not possible prior to the publication of the TS and this is one reason why "sound" research data to 2021 was less 'useful' than it could have been to Project Team WG4.T2 when calibrating partial factors. Because of the uncertainties surrounding the quality of test results the evaluation of the reliability analyses also required assumptions to be made to finalize values of partial factors for resistance. For a future development that could be implemented when the TS is converted into its Eurocode standard, new test results for the input data in reliability analyses can have reduced uncertainties and this might lower the current values for partial factors (there remains other factors not accounted for in reliability analyses that are for a risk of failure).

CONCLUDINGS REMARKS

The main observations from the information presented in this paper on the current status and future developments of the Eurocode project *Design of Fibre-Polymer Composite Structures* is that the work of committee CEN/TC 250 WG4 is progressing in a timely manner and has already delivered game-changing outputs. Specifically, in November 2022 the Technical Specification CEN/TS 19101:2002 was published and is available via National Standard Bodies (which in the UK is BSI). This is step ii of iii to having a Eurocode standard adopted as a national standard in accordance with CEN rules. During 2024 two important open access documents for a Commentary (1000 pages) and for a set of Worked Examples (over 300 pages) can have been published. This group of three documents (and related journal and conference papers) provides users of the TS with the necessary depth of information to design or conduct research and development projects with composite structures. Furthermore, users of the TS are encouraged to provide WG4 with feedback comments and/or new test results from targeted research that will support the work to convert the TS into the Eurocode standard EN 19101.

REFERENCES

1. CEN/TC 250 Structural Eurocodes. N 1250. *Policy Guidelines and Procedures. Version v12*. European Committee for Standardization, Brussels, (2023).
2. Ascione, L., Caron, J., Godonou, P., Van Ijselmuijden, K., Knippers, J., Mottram. T., Oppe, M., Sorensen, M., Taby J. and Tromp, L. *Prospect for New Guidance in the Design of FRP*. EUR 27666. Publications Office of the European Union, Ispra, Italy, (2016).
3. CEN/TS 19101:2022, *Design of Fibre-Polymer Composite Structures*. European Committee for Standardization, Brussels, (2022).
4. PD CEN/TS 19101:2022. *Design of Fibre-Polymer Composite Structures*, British Standard Institution, London, (2022).
5. *The Building Regulations. Approved Document A*. H M Government, London, (2004 Edition incorporating 2004, 2010 and 2013 amendments).
6. Mottram, J. T. and Henderson, J., (Eds.), *FRP Bridges – Guidance for Designers*. CIRIA C779. London, (2018).
7. EN 1991-1-5:2003. *Eurocode 1. Actions on Structures – Part 1-5: Thermal Actions*. European Committee for Standardization, Brussels, (2003).
8. EN 1992-1-1: 2023. *Eurocode 2. Design of Concrete Structures – General Rules and Rules for Buildings, Bridges and Civil Engineering Structure*s. European Committee for Standardization, Brussels, (2023).
9. Ascione, L., Correia, J. R., Keller, T., Knippers, J., Mottram, J. T., Paulotto, C. and Sena-Cruz, J., Design of Fibre-Polymer Composite Structures (CEN/TS 19101): Overview, Commentary and Worked Examples presented at the *11th International Conference on Fiber-Reinforced Polymer (FRP) Composites in Civil Engineering (CICE 2023)*, Rio de Janeiro, Brazil, July 23-26, 2023. 10.5281/zenodo.8066346

10. Correia, J. R., Ascione, L., Keller, T., Knippers, J., Mottram J. T., Pauletto, C. and Sena-Cruz, J., *Design of Fibre-Polymer Composite Structures. Commentary to CEN/TS 19101:2022*. CRC Press (in press 2024).
11. Ascione, L., Correia JR, Keller T, Knippers J, Mottram J. T., Pauletto C. and Sena-Cruz J., *Design of Fibre-Polymer Composite Structures. Worked Examples for CEN/TS 19101:2022*. CRC Press (in press 2024).
12. Correia, J. R., Pacheco, J., Sørensen, J. D., Garrido, M., Firmo, J. P., Keller, T., Sena-Cruz, J., Mottram, J. T., Ascione, L. and Tromp, L., Design of Fibre Polymer Composite Structures (CEN/TS 19101): Basis of Design and Effects of Temperature and Moisture presented at the *11th International Conference on Fiber-Reinforced Polymer (FRP) Composites in Civil Engineering (CICE 2023)*, Rio de Janeiro, Brazil, July 23-26, 2023. 10.5281/zenodo.8066317
13. Russo, S., Mottram, J. T., Talledo, D. A. and Tondi, M., Design of Fibre Polymer Composite Structures (CEN/TS 19101): ULS Analysis of a Spatial Reticular Structure presented at the *11th International Conference on Fiber-Reinforced Polymer (FRP) Composites in Civil Engineering (CICE 2023)*, Rio de Janeiro, Brazil, July 23-26, 2023. 10.5281/zenodo.8066513
14. Sena-Cruz, J., Sa, M., Correia, J.R., Mottram, J.T., Keller, T., Pérez, M.G., Ascione, L., Tromp, L. and Russo, S., 'Design of Fibre Polymer Composite Structures (CEN/TS 19101): Serviceability limit states and creep rupture,' presented at the *11th International Conference* on *Fiber-Reinforced Polymer (FRP) Composites in Civil Engineering (CICE 2023)*, Rio de Janeiro, Brazil, July 23-26, 2023. 10.5281/zenodo.8066441
15. Correia J. R., Ascione, L., Keller T., Mottram J. T., Sena-Cruz J., Paulette C., Knippers J., Pacheco, J., Sorensen, J-D., Garrido, M., Sá, M., Firmo, J. and Tromp, L., Overview and Aspects of the European Technical Specification CEN/TS 1910:2022 Design of Fibre-Polymer Composite Structures. *Journal of Composites for Construction*, June 2024 (in revision).
16. Mottram, J. T., Design Guidance for Bolted Connections in Structures of Pultruded Shapes: Gaps in Knowledge presented at the *17th International Conference on Composite Materials (ICCM17)*, Edinburgh, July 27-31, 2009.
17. ASCE/SEI 74-23. *Standard for Load and Resistance Factor design (LRFD) of Pultruded Fiber Polymer (FRP) Structures*, American Society of Civil Engineers/Structural Engineering Institute, Reston, Virginia. (2023).
18. EN 1990:2023. *Eurocode – Basis of Structural and Geotechnical Design*. European Committee for Standardization, Brussels, (2023).
19. Johnson, R. P., Bridging Gaps, Gold Medal Paper, *The Structural Engineer*, **84(23)**, 58-64 (2006).