Preparation of a Resistance Formula for Net-Tension Failure of Single and Multi-rowed Bolted Connections of Fibre-Polymer Composite

J. Toby Mottram, Emeritus Professor

Fibre-Polymer Composites in Construction (FPCC)

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1

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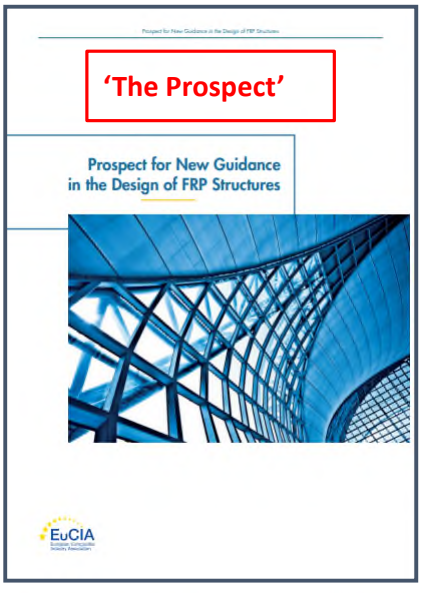
STAGE 1: Ascione, L., Caron, J-F., Godonou, P., van IJselmuijden, K., Knippers, J., Mottram, T., Oppe, M., Gantriis Sorensen, M., Taby J. and Tromp, L., *Prospect for New Guidance in the Design of FRP*, JRC Science and Policy Report, Policy Framework Existing Regulations and Standards, JRC99714, EUR 27666 EN, European Union, Luxembourg. 2016 & 2017.

https://tinyurl.com/yycmwzs4 (1 September 2022)
(*free download*)



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2

2

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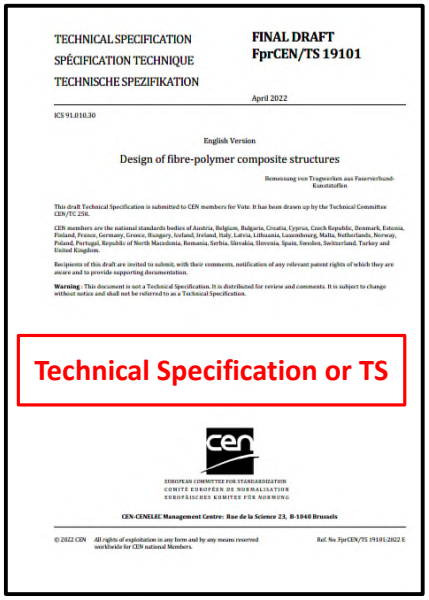
STAGE 2: **FprCEN/TS 19101** ***Design of Fibre-Polymer Composite Structures***

Transforming STAGE 1 Prospect to be with:

- ❑ Basic of design (γ_Ms, η_cs and $\phi(t)$s);
- ❑ ULS of sandwich panels;
- ❑ Creep rupture;
- ❑ Fatigue;
- ❑ Detailing;
- ❑ Adhesive joints and connections;
- ❑ Structural fire design.



TECHNICAL SPECIFICATION
SPÉCIFICATION TECHNIQUE
TECHNISCHE SPEZIFIKATION

FINAL DRAFT
FprCEN/TS 19101

April 2022

ICS 91.010.30

English Version

Design of fibre-polymer composite structures

Bemessung von Tragwerken aus Faserverbund-Kunststoffen

This draft Technical Specification is submitted to CEN members for Vote. It has been drawn up by the Technical Committee CEN/TC 250.

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Technical Specification or TS

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STAGE 2: **FprCEN/TS 19101** ***Design of Fibre-Polymer Composite Structures***

CEN Technical Specification (TS) has:

- adopted CEN's policy guidelines and procedures;
- taken into account and resolving comments from National Standard Bodies (NSBs) not incorporated in STAGE 1;
- revised paragraphs, clauses and subclauses that been identified to require improvements.

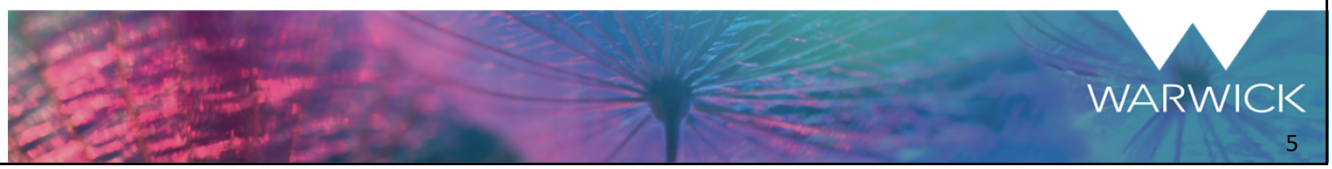
To accompany our TS there is:

- a **Background Document** of '1000' pages with a commentary to the important paragraphs, figures and tables;
- 16 **Worked Examples** covered over '300' pages
- A **National Annex** for National Determined Parameter and other national information.

Taster to Eurocode Project

1. Scope
2. Normative reference
3. Terms, definition and symbols
4. Basic 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

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



5

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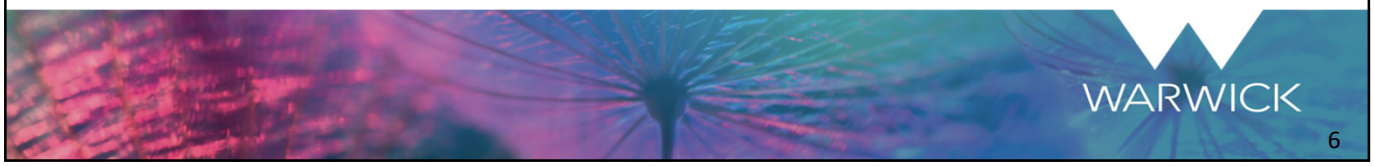
Luigi Ascione, J. R. Correia, T. Keller, J. Knippers, J. T. Mottram, C. Paulotto and J. Sena-Cruz, '*Design of fibre-polymer composite structures - European Technical Specification: Overview and scope*,' **in Proceedings of 20th European Conference on Composite Materials (ECCM 20), 2022**, Paper 61551.

João R. Correia, J. Pacheco, J. D. Sorensen, T. Keller, J. T. Mottram, J. Sena-Cruz, '*Design of fibre-polymer composite structures – European Technical Specification: Basis of Design*,' *ibid*, Paper 61625.

José Sena-Cruz, M. Garrido Mário, J. R. Correia, J. Pedro, T. Keller, J. T. Mottram, '*Design of fibre-polymer composite structures – European Technical Specification: Temperature and moisture effects*,' *ibid*, Paper 61619.

J. Toby Mottram, L. Tromp, M. Pavlovic, J. R. Correia, T. Keller and J. Sena-Cruz, '*Design of fibre- polymer composite structures – European Technical Specification: Combined stresses*,' *ibid*, Paper 61618.

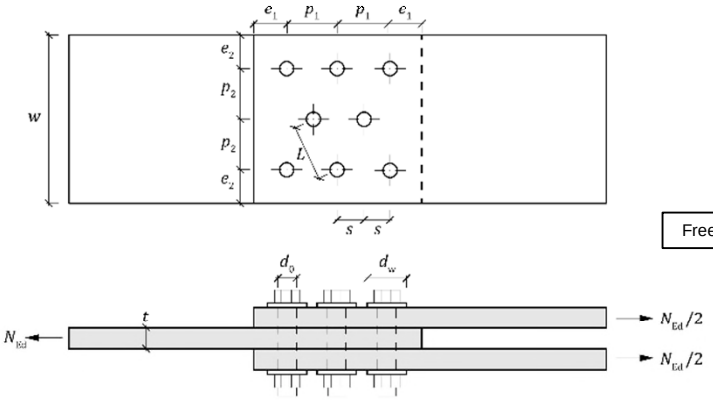
Thomas Keller, J. R. Correia, J. T. Mottram, and J. Sena-Cruz, '*Design of fibre-polymer composite structures – European Technical Specification: Fatigue and detailing*,' *ibid*, Paper 61617.

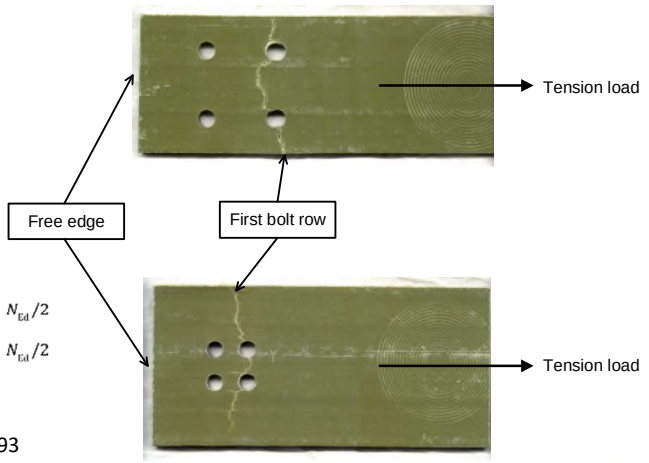


6

Net-Tension Failure of Bolted Connections

Steel bolts (same diameter) no more than four rows and four columns of bolting, can be staggered





Steel or stainless steel washers of uniform diameter $d_w > 2d$
(where d is the nominal bolt diameter) and conforming to ISO 7093

Net-Tension Failure of Bolted Connections

Table 11.1. Minimum requirements for bolted connection geometries (reproduced from TS)

Nominal bolt diameter (d) (recommended range)	$d \geq t_{min}$ ($t_{min} \leq d \leq 1.5\ t_{min}$)
Nominal bolt hole clearance	$d_0 - d \geq 1$ mm
Distances between holes without staggered bolts	$p_1 \geq 4d$; $p_2 \geq 4d$
Distances between holes with staggered bolts	$p_1 \geq 4d$; $p_2 \geq 2d$; $L \geq 2{,}8d$
Distances from edges single row multi-rows	side $e_2 \geq 2d$ end $e_1 \geq 2{,}5d$ or ≥ 30mm end $e_1 \geq 2d$

Net-Tension Failure of Bolted Connections

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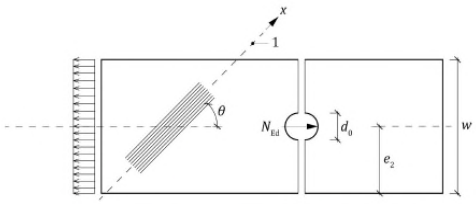
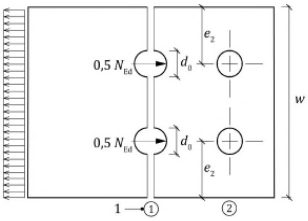


Key

1 principal direction of laminate or direction of pultrusion

Figure 12.2 — Net-tension failure mode illustrated with a single bolt, $n_{b,1} = 1$



Key

1 row No. (*i*)

Figure 12.3 — Net-tension failure mode illustrated with a 2 × 2 multi-bolted connection, $n_{b,1} = 2$

Net-Tension Failure of Bolted Connections

12.2.3.1 Net-tension failure

IMPORTANT – Test results

(1) When the net-tension force is oriented at an angle $0° \le \theta \le \pm 5°$ to the x direction of pultruded profiles or pultruded flat laminates of constant thickness (see Figures 12.2 and 12.3), its design value, N_{Ed}, for net-tension failure should satisfy the condition in Formula (12.3):

where

$N_{x,nt,Rd}$ is the design value of the net-tension resistance in the x direction, given by Formula (12.4),

Net area tension strength of composite

$$N_{x,nt,Rd} = \frac{1}{k_{tc}} \cdot \left(w - n_{b,1} \cdot d_0\right) \cdot t \cdot f_{x,t,d} \qquad (12.4)$$

In 'The Prospect' k_{tc} = 3,75

FprCEN/TS 19101:2022

Net-Tension Failure of Bolted Connections

where

w	is the width of the component ($w \geq 4d$, from Table 11.1), see also 12.2.3.1(5);
$n_{b,1}$	is the number of bolts across the first bolt row (Row 1) where the net-tension failure mode occurs (see Figures 12.2 and 12.3);
d_0	is the nominal bolt hole diameter;
t	is the laminate thickness;
k_{tc}	is a stress concentration factor that should be taken from Table 12.2 for specific bolted connection configurations that satisfy the geometry requirements in Table 11.1; for other bolted connection configurations, k_{tc} should be taken equal to 3,0;
$f_{x,t,d}$	is the design value of the tensile strength of the pultruded laminate in the x direction, given by Formula (12.5),

In 'The Prospectus' k_{tc} = 3,75

$$f_{x,t,d} = \frac{\eta_c}{\gamma_m \cdot \gamma_{Rd}} \cdot f_{x,t,k} \qquad (12.5)$$

Net-Tension Failure of Bolted Connections

e.g, Moisture η_{cm} = 0,85 (Exposure Class II) and temperature η_{ct} = 0,9

$$f_{x,t,d} = \frac{\eta_c}{\gamma_m \cdot \gamma_{Rd}} \cdot f_{x,t,k} \qquad (12.5)$$

e.g., γ_m = 1,15 (V_x = 0.1) and γ_{Rd} = 1,50 (calibrated using test results with ISO 2394 Annex C, Section C.6 & prEN 1990, Annex D)

where

γ_m	is defined in 4.4.5 (to be selected for $f_{x,t,k}$);
γ_{Rd}	is defined in 4.4.6 (Table 4.5, Net-tension failure);
η_c	is defined in 4.4.7 (to be selected for $f_{x,t,k}$);
$f_{x,t,k}$	is the characteristic value of the tensile strength of the pultruded laminate material in the x direction.

EN ISO 527 (all parts), Plastics – Determination of tensile properties

Net-Tension Failure of Bolted Connections

Table 12.2 — Values of stress concentration factor k_{tc} for specified bolted connection configurations when N_{Ed} is oriented with an angle $0^o \leq \theta \leq \pm 5^o$ to the major principal axis (x direction) of pultruded laminates with glass fibres

Bolted connection configuration	k_{tc}
Single	2,0
1 × 2 (single row)	2,5
2 × 1 (single column)	2,5
1 × 3	2,5
3 × 1	2,5
2 × 2	2,0
3 × 3	1,5
1 × 1 (staggered)	2,0
2 × 2 (staggered)	2,0

<< 3,75

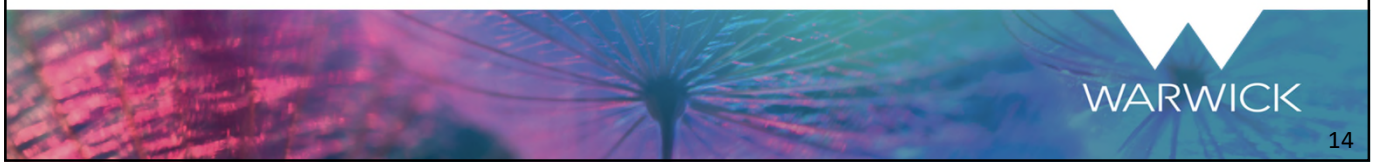
<< 3,75

13

Net-Tension Failure of Bolted Connections

Bolt configuration	Rosner [6] or Hassan [7]	Lutz [5][1] or Wang [8] or Turvey [9]	Prabhakaran Razzaq & Devara [10]	Matharu [11]	k_{tc} in Formula (12.4)
(1)	(2)	(3)	(4)	(5)	(6)
Single	1,0-1,6	1,5-1,6; 1,5			2,0
1x2 (single row)	0,9-2,0	1,3-2,3; 1,6-2,2		1,5-1,8	2,5
2x1 (single column)	1,0-1,9	1,3-2,2	1,7	1,7	2,5
1x3	1,1-2,0				2,5
3x1	1,4-2,4				2,5
2x2	1,0-1,6	1,3-1,9; 1,4-2,1	1,8	1,2-1,3	2,0
3x3		1,2-1,4			1,5
1x1 (staggered)				1,9	2,0
2x2 (staggered)			2,1; 1,8; 2,1		2,0

Based on Mean and NOT characteristic values



14

Concluding Remarks

1. What a milestone has been achieved with the publication (SOON) of the Eurocode CEN Technical Specification (**CEN/TS 19101** – passed the Formal Vote step) and its accompanying Background Document and Worked Examples.
2. All National Standard Bodies (NSBs) requirements were met when transforming '*The Prospect*' into the TS.
3. A pragmatic design procedure based on a semi-empirical formula has been prepared that determines the resistance of bolted-connections of fibre-polymer composites.
4. For efficient designs the constant 'stress concentration' factor of 3,75 in '*The Prospect*' has been replaced with values of 1,5, 2,0 or 2,5 and 3,0 for different connection configurations; thereby making detailing more efficient and cheaper.

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15

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Hit me with your Questions?

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16