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TECHNICAL REPORT

Design of bonded fasteners in concrete under fire conditions

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1 INTRODUCTION

This Technical Report contains a fire design method for bonded fasteners in concrete having a European Technical Assessment (ETA) in accordance with EAD 330499-02-0601 [1] and later version of EAD without technical changes of fire assessment (applies throughout document).

2 SCOPE

2.1 General

This Technical Report provides a fire design method for bonded fasteners comprised of bonding material and an embedded metal part placed in pre-drilled holes perpendicular to the surface (maximum deviation 5°) in concrete and anchored therein primarily by means of bond. Bonded fasteners are often used to connect structural elements and non-structural elements to structural components.

The embedded metal part may be a threaded rod, deformed reinforcing bar, internal threaded sleeve or other shape made of carbon steel or stainless steel.

The design rules in this Technical Report are only valid for bonded fasteners with a European Technical Assessment (ETA) in accordance with EAD 330499-02-0601 [1], which can be used in cracked concrete.

This Technical Report covers fire design for bonded fasteners in normal weight concrete with a strength of at least C20/25 and at most C50/60. The determination of the fire resistance is according to the conditions given in EN 1363-1 [2] using the “standard temperature/time curve”.

In general, the duration of fire resistance of anchorages depends mainly on the configuration of the structure itself (base material, anchorage including the fixture). It is not possible to classify a bonded fastener for its fire resistance. The design concept includes the behaviour of the bonded fastener in concrete and the parts outside the concrete. The thermal influence of thin steel fixtures is considered negligible. In the calculations given in Annex A the fixture was neglected.

Bonded fasteners installed in reinforced concrete shall be designed for the required fire resistance duration of the base material.

Local spalling of concrete is possible under fire conditions. To avoid any influence of the spalling on the anchorage, the concrete member must be designed according to EN 1992-1-2 [3]. The members shall be protected from direct moisture until the fire event (i.e., e.g., fixing of sprinklers is covered), and the moisture content of the concrete has to be representative of dry internal conditions.

This Technical Report is intended for safety related applications in which the failure of bonded fasteners under fire conditions may result in collapse or partial collapse of the structure, cause risk to human life or lead to significant economic loss. In this context it also covers non-structural elements.

This Technical Report covers bonded fasteners for one-sided exposure to fire conditions only. The design method complements EN 1992-4 [4], Annex D.

Bonded fasteners under fire conditions shall have a European Technical Assessment for use in cracked concrete. They shall also be assessed for fire conditions in accordance with EAD 330499-02-0601 [1]. In general, cracked concrete is assumed for fasteners under fire conditions.

This Technical Report covers bonded fasteners with the following dimensions:

- Minimum thread size of 6 mm (M6),
- Minimum embedment depth $h_{ef,min}$ larger than or equal to 40 mm and larger than or equal to $4 \cdot d$,
- Maximum embedment depth $h_{ef,max}$ smaller than or equal to $20 \cdot d$.

Note 1: The stated limit for the maximum embedment depth of $20 \cdot d$ is in accordance with EAD 330499-02-0601 [1] and EN 1992-4 [4].

The fire resistance is classified according to EN 13501-2 [5] using the standard temperature/time curve (post flash-over fire, which is identical to the ISO 834-1 [6] standard curve).

In general, the design under fire conditions is carried out according to the design method for ambient temperature given in EN 1992-4 [4]. However, partial factors and characteristic resistances under fire conditions are used instead of the corresponding values under ambient temperature.

3 SYMBOLS AND ABBREVIATIONS

3.1 Indices

cr	=	cracked
fi	=	fire
k	=	characteristic value
max	=	maximum
min	=	minimum
p	=	pull-out
R	=	resistance
Rk	=	characteristic resistance
s	=	steel
t	=	test

3.2 Symbols

A_s	=	relevant stressed cross section of the metal part of the fastener
$c_{cr,N_p,fi}$	=	characteristic edge distance for ensuring the transmission of the characteristic resistance of a single bonded fastener under tension load in case of combined concrete and pull-out failure under fire conditions
d	=	diameter of the embedded part
e_N	=	eccentricity of resultant tension force of tensioned fasteners in respect to the centre of gravity of the tensioned fasteners, see EN 1992 [4], Figure 6.3
h_{ef}	=	effective embedment depth, see EN 1992-4 [4], Figure 3.3
$k_{fi,p}(\theta)$	=	reduction factor for bond resistance under fire conditions
$k_{fi,p}\big(\theta(x)\big)$	=	temperature reduction factor for considered segment length Δx determined using mean temperature along considered segment length Δx
$M^0_{Rk,s,fi(t)}$	=	characteristic shear resistance in case of shear load with lever arm at a given time t of exposure to fire conditions
$N^0_{Rk,p}$	=	characteristic resistance of a single bonded fastener not influenced by adjacent bonded fasteners or edges of the concrete member in case of combined pull-out and concrete failure under tension load

$N^0_{Rk,p,fi(t)}$	=	Characteristic tension resistance of a single bonded fastener not influenced by adjacent bonded fasteners or edges of the concrete member in case of combined pull-out and concrete failure under fire conditions at a given time t of exposure to fire conditions
$N_{Rk,s,fi(t)}$	=	characteristic tension resistance in case of steel failure at a given time t of exposure to fire conditions
$s_{cr,N_p,fi}$	=	characteristic spacing to ensure the transmission of the characteristic resistance of a single bonded fastener under fire conditions
$V_{Rk,s,fi(t)}$	=	characteristic shear resistance in case of steel failure at a given time t of exposure to fire conditions
$\alpha_{sus,fire}$	=	ratio between the value of sustained actions (comprising permanent actions and permanent component of variable actions) and the value of total actions all considered at ULS under fire conditions
Δx	=	segment length considered in the Resistance Integration Method for calculation of the fire resistance to combined pull-out and concrete failure
θ	=	temperature in the tests for bond strength under fire conditions (tests according to EAD 330499-02-0601 [1], Table A.1, line F2)
θ_{max}	=	maximum temperature in the tests for bond strength under fire conditions, beyond which the bond resistance of the mortar is considered zero.
$\sigma_{Rk,s,fi(t)}$	=	characteristic tension strength of a fastener in case of steel failure a given time t of exposure to fire conditions
$\tau_{Rk,cr}$	=	characteristic bond resistance for cracked concrete at normal ambient temperature for concrete strength class C20/25 to be taken from the ETA of the product
$\tau_{Rk,fi}(\theta)$	=	characteristic bond resistance for cracked concrete under fire conditions for a given temperature (θ)
$\tau_{Rk,fi,min}$	=	minimum bond strength under fire conditions determined according to Equation (7.1) using the reduction factor $k_{fi,p}(\max\theta)$ for the maximum temperature $\max\theta$, along the embedment depth
$\tau_{Rk,ucr}$	=	characteristic bond resistance for uncracked concrete at normal ambient temperature for concrete strength class C20/25 to be taken from the ETA of the product
ψ_{ce,N_p}	=	factor taking into account the group effect when different tension loads are acting on the individual fasteners of a group in case of concrete cone failure at normal ambient temperature
$\psi_{ce,N_p,fi}$	=	factor taking into account the group effect when different tension loads are acting on the individual fasteners of a group in case of concrete cone failure under fire conditions
ψ_{g,N_p}	=	factor taking into account group effect for closely spaced bonded fasteners at normal ambient temperature
ψ_{g,N_p}	=	factor taking into account group effect for closely spaced bonded fasteners under fire conditions
$\psi_{re,N}$	=	shell spalling factor

ψ_{s,N_p}	=	factor taking into account the disturbance of the distribution of stresses in the concrete due to the proximity of an edge in the concrete member in case of combined pull-out and concrete failure of bonded fasteners at normal ambient temperature
$\psi_{s,N_p,fi}$	=	factor taking into account the disturbance of the distribution of stresses in the concrete due to the proximity of an edge in the concrete member in case of combined pull-out and concrete failure of bonded fasteners under fire conditions
$\psi_{sus,fire}$	=	factor that takes account of the influence of sustained load on the bond strength under fire conditions, see 7.2.3
$\psi^0_{sus,fire}$	=	product dependent factor that takes account of the influence of sustained load on the bond strength before a fire event, to be taken from the ETA of the product

4 BASIS OF DESIGN

EN 1992-4 [4], Section 4 applies. However, partial factors are addressed in Section 5.

5 PARTIAL FACTORS

EN 1992-4 [4], D.2 applies.

6 ACTIONS

EN 1992-4 [4], D.3 applies.

7 RESISTANCE

7.1 General

The characteristic resistances for steel failure and combined pull-out and concrete failure under fire conditions are given in the relevant European Technical Assessment (ETA). If the characteristic resistance under fire conditions for steel failure under tension or shear loading is not available in the ETA, the conservative values given in 7.2.1 or 7.3.1, respectively, may be used.

7.2 Tension load

7.2.1 Steel failure

<u>Stress criterion</u>

Testing and assessment are given in EAD 330499-02-0601 [1], Table A.1, line F1. If these tests are omitted, the characteristic tension strength $\sigma_{Rk,s,fi}$ of a fastener in case of steel failure under fire conditions given in EN 1992-4 [4], Tables D.1 and D.2 for the covered steel materials is valid for the unprotected steel part of the fastener outside the concrete and may be used in the design. These values are conservative against values assessed according to EAD 330499-02-0601 [1].

The characteristic resistance $N_{Rk,s,fi}$ is obtained from EN 1992-4 [4], Equation (D.1).

7.2.2 Concrete cone failure

EN 1992-4 [4], D4.2.2 applies.

7.2.3 Combined pull-out and concrete failure

The assessment according to EAD 330499-02-0601 [1] provides characteristic bond strengths τ_{Rk} for concrete strength classes C20/25 to C50/60 and reduction factors under fire conditions $k_{fi,p}(\theta)$ depending on the temperature θ, which are given in the corresponding ETA of the bonded fastener system. From these values, the characteristic bond resistance under fire conditions can be determined using Equation (7.1).

$$\tau_{Rk,p,fi}(\theta) = k_{fi,p}(\theta) \cdot \tau_{Rk,cr} \qquad (7.1)$$

Where

$k_{fi,p}(20°C) = 1{,}0$. Therefore, $\tau_{Rk,fi}(20°C) = \tau_{Rk,cr}$

$k_{fi,p}(21°C \leq \theta \leq \theta_{max})$ is taken from the ETA of the product

$k_{fi,p}(\theta > \theta_{max}) = 0$

$\tau_{Rk,cr}$ = characteristic bond resistance for cracked concrete at normal ambient temperature for concrete strength class C20/25 to be taken from the ETA of the product

Note 2: Eq. (7.1) may be used with Eq. (7.2) *(Simplified Method) or Eq. (7.5) (Resistance Integration Method) in this document. The first case is expected to lead to conservative (lower) fire resistance values.*

Temperature distribution

The determination of the characteristic resistance to combined pull-out and concrete of bonded fasteners requires the knowledge of the thermal distribution along the bond at a given time during the fire. Thermal fields shall be determined using the thermal and physical properties for concrete (EN 1992-1-2 [3]) and steel (EN 1993-1-2 [7]).

Simplified Method

In the simplified method the highest temperature of the temperature profile along the embedment depth of the bonded fastener is used for determination of the resistance to combined pull-out and concrete under fire conditions as given by Eq. (7.2), replacing EN 1992-4 [4], Eq. (7.14).

$$N^0_{Rk,p,fi} = \psi_{sus,fire} \cdot \tau_{Rk,p,fi,min} \cdot \pi \cdot d \cdot h_{ef} \qquad (7.2)$$

Where

$$\psi_{sus,fire} = 1 \text{ for } \alpha_{sus,fire} \leq \psi^0_{sus,fire} \qquad (7.3)$$

$$\psi_{sus,fire} = \psi^0_{sus,fire} + 1 - \alpha_{sus,fire} \text{ for } \alpha_{sus,fire} > \psi^0_{sus,fire} \qquad (7.4)$$

The factor $\psi_{sus,fire}$ is included in Equations (7.2) and (7.5) to account for situations where the anchor is subjected to sustained load effect for a long period of time and a fire may occur afterwards. The sustained load effect may be evaluated according to EN 1992-4 and $\psi_{sus,fire}$ may be taken = 1,0 if proper justification is provided as detailed in Equations (7.3) and (7.4). If no value is given in the ETA of the product, a value of $\psi^0_{sus,fire} = \psi^0_{sus}$ according to EN 1992-4 [4], 7.2.1.6(2) shall be used.

As simplification and to keep the static and fire load cases separate, the actions considered for accidental design situations (fire conditions) shall be used. For the purposes of the determination of the ratio $\alpha_{sus,fire}$, the design actions to be considered shall be determined by the designer of the fastening according to EN 1990 [8], 6.4.3.3. Additional guidance may be given in national documents.

Conservatively, if the ratio between the value of sustained actions (comprising permanent actions and permanent component of variable actions) and the value of total actions all considered at ULS under fire conditions $\alpha_{sus,fire}$ is lower than 0,40, $\psi_{sus,fire}$ may be assumed equal to 1,0.

Resistance Integration Method

The resistance to combined pull-out and concrete of bonded fasteners under fire conditions can be determined using the Resistance Integration Method [9]. For the determination of the temperature profile along the embedment depth of the bonded fastener, the method requires the following entry data:

- Fire temperature-time relationship
- Exchange coefficients to determine the thermal boundary conditions (i.e., applied heat fluxes on the fire exposed and unexposed surfaces)
- Conductive properties of concrete
- Geometry of the structure

The standard temperature/time curve (see EN 13501-2 [5], ISO 834-1 [6]) is used to describe the gas temperature during exposure to fire conditions.

The emissivity and convection factor shall be taken from EN 1992-1-2 [3] for concrete, and EN 1993-1-2 [7] for steel. They shall be used to determine the radiative and convective heat fluxes applied to the fire exposed and unexposed surfaces.

The thermal and physical properties (specific heat $c_p(\theta)$, density $\rho(\theta)$ and thermal conductivity $\lambda(\theta)$) for concrete (EN 1992-1-2 [3]) and steel (EN 1993-1-2 [7]) shall be used. Concrete type and moisture content may influence the thermal distribution. Conservative thermal distribution can be obtained by considering the peak of the specific heat associated to a concrete moisture content of 1,5% (EN 1992-1-2 [3], 3.3.2).

The geometry of the structure influences the thermal distribution by the area and position of the fire exposed surfaces of concrete, in addition to the position of the fastener in the concrete element. The existence of a fixture on the extended metal part of the fastener yields lower temperatures along the bond. Therefore, the consideration of the fastener geometry (diameter × embedment depth) without the fixture (as unprotected) results in conservative (i.e., higher) temperature profiles.

The characteristic resistance to combined pull-out and concrete is calculated by integrating the bond resistances $\tau_{Rk,fi}(\theta(x))$ along the surface of the bonded fastener. The integration is carried out numerically and consists in adding the bond resistances on short segments of the fastener, each presenting a different temperature.

$$N_{Rk,p,fi}^{0} = \pi \cdot d \cdot \psi_{sus,fire} \cdot \int_{0}^{h_{ef}} \tau_{Rk,p,fi}\big(\theta(x)\big) \cdot dx \approx \pi \cdot d \cdot \psi_{sus,fire} \cdot \sum_{0}^{h_{ef}} k_{fi,p}\big(\theta(x)\big) \cdot \tau_{Rk,cr} \cdot \Delta x \qquad (7.5)$$

Where Eq. (7.3), Eq. (7.4) apply.

Further explication regarding $\psi_{sus,fire}$ can be found in the simplified method above.

For representativity, the segment length Δx shall be smaller than $2 \cdot d$ and is generally taken around 10 mm [10]. The temperature of each segment is considered as the mean temperature along the segment to represent the bond resistance along the segment.

Note 3: The Resistance Integration Method has been validated for bonded fasteners and post-installed rebar connections in uncracked concrete [9]-[16]. However, the method may also be applied to cracked concrete, which is the relevant concrete condition in this TR (see also EN 1992-4 [4], Annex D).

Note 4: The Resistance Integration Method does not take into account the displacement compatibility. The method assumes that at failure, all segments present the highest bond *resistance (that can be reached at a certain temperature), regardless of the slip profile. However, in case of combined pull-out and concrete failure of the bonded fastener under fire conditions, the differential displacements between the segment of the fastener are considered negligible. This hypothesis appears sufficiently representative through experimental and theoretical support to predict bond failure at high temperatures [13].*

Note 5: The temperature distribution along the fastener may be calculated neglecting the bond layer around the embedded metal part of the fastener as long as the thickness of the bond around the fastener does not exceed $0{,}25d$ [14]. This hypothesis results in negligible differences in temperature profiles. For cases where the thickness of the bond exceeds $0{,}25d$, the thermal and physical properties of the bond should be provided by the manufacturer to be taken into account in the calculation of the thermal distribution. Consequently, the thermal influence of the bond is reflected on the outcome of the Resistance Integration Method.

In order to facilitate the applicability of the Resistance Integration Method, temperature profiles are provided for common configurations of fastener diameter × embedment depth for bonded fasteners directly exposed to fire conditions in Annex A of this Technical Report.

<u>Determination of characteristic bond resistance of a bonded fastener</u>

The characteristic resistance of a fastener, a group of fasteners and the tensioned fasteners of a group of fasteners in case of combined pull-out and concrete failure under fire conditions $N_{Rk,p,fi}$ shall be obtained as given in EN 1992-4 [4], Eq. (7.13), by replacing $N^0_{Rk,p}$ by $N^0_{Rk,p,fi}$ as determined in equation (7.2) or (7.5) (see also Note 2) and the following stipulations concerning specific parameters:

Determine $\tau_{Rk,p,ucr,fi}$ as follows:

$$\tau_{Rk,p,ucr,fi} = \tau_{Rk,p,ucr} \cdot \frac{N^0_{Rk,p,fi}}{N^0_{Rk,p}} \tag{7.6}$$

Replace τ_{Rk} by $\tau_{Rk,ucr,fi}$ in EN 1992-4 [4], Eq. (7.15) and (7.16), leading to:

$$s_{cr,N_p,fi} = 7{,}3d\left(\psi_{sus,fire} \cdot \tau_{Rk,p,ucr,fi}\right)^{0{,}5} \leq 4h_{ef} \tag{7.7}$$

$$c_{cr,N_p,fi} = \frac{s_{cr,N_p,fi}}{2} \tag{7.8}$$

Note 6: Equations (7.7) and (7.8) in this TR serve as entry data for the determination of the ψ factors under fire conditions as given below.

Replace ψ_{g,N_p} by $\psi_{g,N_p,fi} = 1{,}0$ in EN 1992-4 [4], Equations (7.13) and (7.17).

Replace ψ_{s,N_p} by $\psi_{s,N_p,fi}$ and c_{cr,N_p} by $c_{cr,N_p,fi}$ in EN 1992-4 [4], Eq. (7.20).

Where

$$\psi_{s,N_p,fi} = 0{,}7 + 0{,}3\left(\frac{c}{c_{cr,N_p,fi}}\right) \leq 1{,}0 \tag{7.9}$$

Determine the factor $\psi_{re,N}$ where EN 1992-4 [4], 7.2.1.6(6) applies.

Replace ψ_{ec,N_p} by $\psi_{ec,N_p,fi}$ and s_{cr,N_p} by $s_{cr,N_p,fi}$ in EN 1992-4 [4], Eq. (7.21).

Where

$$\psi_{ec,N_p,fi} = \frac{1}{1 + 2(e_N/s_{cr,N_p,fi})} \leq 1{,}0 \tag{7.10}$$

7.2.4 Concrete splitting failure

EN 1992-4 [4], D.4.2.4 applies.

7.3 Shear load

7.3.1 Steel failure

<u>Stress criterion</u>

If testing and assessment given in EAD 330499-02-0601 [1], Table A.1, line F3 was conducted, the characteristic resistance to shear load under fire conditions shall be taken from the ETA.

If the characteristic shear resistance in case of steel failure under fire conditions $V_{Rk,s,fi}$ is not given in the ETA, the characteristic tension strength $\sigma_{Rk,s,fi}$ of a fastener in case of steel failure under fire conditions given in EN 1992-4 [4], Tables D.1 and D.2 for the covered steel materials are valid for the unprotected steel part of the fastener outside the concrete and may be used in the design. These values are conservative against values assessed according to EAD 330499-02-0601 [1].

Determine $V_{Rk,s,fi}$ where EN 1992-4 [4], Equation (D.6) applies.

Determine $M^0_{Rk,s,fi}$ where EN 1992-4 [4], Equation (D.7) applies.

7.3.2 Concrete pry-out failure

EN 1992-4 [4], D.4.3.2 applies. In addition, replace $N_{Rk,p}$ by $N_{Rk,p,fi}$ where EN 1992-4 [4], 7.2.2.4(3) applies.

7.3.3 Concrete edge failure

EN 1992-4 [4], D.4.3.3 applies.

7.4 Combined tension and shear load

The verifications according to EN 1992-4 [4], 7.2.3 for post-installed fasteners may be used. However, the design actions and design resistances used in these verifications shall correspond to fire conditions.

8 REFERENCES

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ANNEX A TEMPERATURE PROFILES OF COMMON FASTENER GEOMETRIES

A.1 Temperature profiles for bonded fasteners

The temperature profiles provided in the following tables are calculated based on the hypotheses in this Technical Report.

The bonded fastener is considered unprotected and directly exposed to fire conditions on the extended metal part of the fastener and fire exposed concrete surface surrounding the fastener. The existence of a fixture on the extended metal part of the fastener was not taken into account in the calculation of the temperature profiles. This results in conservative (higher) temperature profiles than the case where a fixture is considered.

The thermal and physical properties (specific heat $c_p(\theta)$, density $\rho(\theta)$ and thermal conductivity $\lambda(\theta)$) for concrete (EN 1992-1-2, Section 3.3 [3]) and carbon steel (EN 1993-1-2, Section 3.4 for c-steel and Section C.3 for stainless steel (informative) [7]) shall be used.

Note 7: The value of thermal conductivity $\lambda(\theta)$ for concrete may be set by the National Annex of EN 1992-1-2 [3] within the range of the lower and upper limit.

Note 8: According to EN 1992-1-2, Annex A (informative) [3], temperature profiles can be determined with moisture content 1,5%.

The emissivity shall be taken from EN 1992-1-2, Section 2.2 [3] for concrete, and EN 1993-1-2, Section 2.2 [7] for steel (i.e., equal to 0,7 unless otherwise stated by the National Annex of these standards). The convection factor shall be taken from EN 1991-1-2 [17], Section 3.1 (5) and Section 3.2.1 for the exposed surface [14]. They shall be used to determine the radiative and convective heat fluxes (i.e., thermal boundary conditions) applied to the fire exposed and unexposed surfaces.

Tables A.1 and A.2 give the temperature profiles for common configurations of fastener diameter and embedment depth (e.g., MX × h_{ef}) for fire exposure times of 30, 60, 90 and 120 min. These temperature profiles can be used as a basis for validating the calculation method of temperature profiles of other bonded fastener configurations.

Temperature profiles given in Tables A.1 and A.2 are presented as a third-degree polynomial relationship between the temperature of the fastener T and the position along the embedment depth of the fastener (x). The principle is shown by equation (8.1):

$$T(x) = a \cdot x^3 + b \cdot x^2 + c \cdot x + d \qquad (8.1)$$

Nominal diameter	**Embedment depth h_{ef}**	**Fire exposure time t**	a	b	c	d
[mm]	**[mm]**	**[min]**				
8	60	30	0.000076	0.0939	-13.371	621.87
		60	0.000257	0.0716	-13.136	783.67
		90	0.000341	0.0585	-12.625	876.57
		120	0.000527	0.0348	-11.680	940.27
	90	30	-0.000317	0.1194	-14.185	620.13
		60	-0.000147	0.0920	-14.082	774.05
		90	-0.000084	0.0801	-13.800	866.92
		120	-0.000018	0.0680	-13.297	930.99
	120	30	-0.000379	0.1247	-14.336	619.96
		60	-0.000232	0.0994	-14.364	774.11
		90	-0.000166	0.0847	-14.026	864.45
		120	-0.000133	0.0760	-13.683	928.61
10	60	30	0.000099	0.0794	-11.957	613.52
		60	0.000239	0.0626	-11.826	777.30
		90	0.000299	0.0528	-11.429	871.92
		120	0.000485	0.0297	-10.524	936.37
	90	30	-0.000218	0.0977	-12.750	608.45
		60	-0.000104	0.0791	-12.871	763.74
		90	-0.000054	0.0702	-12.697	858.29
		120	0.000001	0.0603	-12.284	922.10
	120	30	-0.000296	0.1050	-13.011	609.24
		60	-0.000176	0.0842	-13.145	762.57
		90	-0.000135	0.0744	-13.000	852.83
		120	-0.000107	0.0675	-12.762	917.70
12	70	30	-0.000012	0.0740	-11.189	602.55
		60	0.000089	0.0608	-11.255	766.21
		90	0.000123	0.0544	-11.035	861.19
		120	0.000234	0.0389	-10.406	926.99
	90	30	-0.000155	0.0827	-11.641	600.15
		60	-0.000073	0.0697	-11.888	757.29
		90	-0.000037	0.0630	-11.773	851.12
		120	0.000010	0.0544	-11.421	916.49
	110	30	-0.000225	0.0892	-11.902	599.93
		60	-0.000126	0.0723	-12.108	753.64
		90	-0.000099	0.0662	-12.094	846.38
		120	-0.000068	0.0596	-11.858	911.27
	130	30	-0.000239	0.0902	-11.937	599.03
		60	-0.000152	0.0747	-12.245	753.16

		90	-0.000119	0.0668	-12.187	843.40
		120	-0.000099	0.0616	-12.045	908.76
Nominal diameter	**Embedment depth h_{ef}**	**Fire exposure time t**	a	b	c	d
[mm]	**[mm]**	**[min]**				
16	80	30	-0.000065	0.0637	-9.871	588.26
		60	-0.000002	0.0554	-10.097	752.53
		90	0.000018	0.0513	-10.024	851.18
		120	0.000080	0.0414	-9.599	917.29
	110	30	-0.000150	0.0694	-10.276	582.73
		60	-0.000093	0.0599	-10.681	740.90
		90	-0.000071	0.0555	-10.718	835.41
		120	-0.000048	0.0507	-10.564	902.80
	140	30	-0.000170	0.0710	-10.389	583.49
		60	-0.000114	0.0606	-10.838	738.86
		90	-0.000095	0.0559	-10.919	829.84
		120	-0.000081	0.0523	-10.870	895.82
20	90	30	-0.000053	0.0344	-5.670	559.26
		60	-0.000052	0.0320	-5.550	753.13
		90	-0.000038	0.0293	-5.425	869.34
		120	0.000063	0.0122	-4.598	938.54
	120	30	-0.000064	0.0334	-5.943	532.47
		60	-0.000052	0.0312	-6.127	732.57
		90	-0.000054	0.0308	-6.109	845.93
		120	-0.000029	0.0252	-5.747	922.90
	150	30	-0.000054	0.0306	-6.056	534.68
		60	-0.000043	0.0281	-6.251	717.96
		90	-0.000041	0.0276	-6.303	831.61
		120	-0.000033	0.0251	-6.100	905.36
24	90	30	-0.000070	0.0337	-5.213	529.21
		60	-0.000071	0.0326	-5.256	739.89
		90	-0.000070	0.0324	-5.270	862.54
		120	0.000050	0.0124	-4.348	936.79
	120	30	-0.000059	0.0308	-5.525	518.85
		60	-0.000050	0.0289	-5.665	720.40
		90	-0.000057	0.0299	-5.731	839.88
		120	-0.000033	0.0245	-5.404	919.68
	150	30	-0.000052	0.0285	-5.544	502.28
		60	-0.000045	0.0276	-5.954	705.72
		90	-0.000047	0.0276	-6.035	824.75
		120	-0.000040	0.0255	-5.877	903.96

Table A.1: Examples of temperature profiles along the embedment depth of common bonded fastener configurations (for c-steel inserts)

Nominal diameter	**Embedment depth** h_{ef}	**Fire exposure time** t	a	b	c	d
[mm]	**[mm]**	**[min]**				
8	60	30	0.000966	0.0285	-14.390	673.16
		60	0.001297	-0.0363	-11.813	813.65
		90	0.001327	-0.0536	-10.410	892.46
		120	0.001291	-0.0591	-9.458	947.60
	90	30	-0.000311	0.1395	-16.991	683.87
		60	0.000272	0.0400	-13.654	818.96
		90	0.000360	0.0128	-12.165	895.10
		120	0.000419	-0.0031	-11.119	947.89
	120	30	-0.000519	0.1644	-17.751	687.81
		60	-0.000144	0.0928	-15.402	829.42
		90	0.000034	0.0523	-13.460	902.61
		120	0.000096	0.0334	-12.294	954.08
10	60	30	0.001015	0.0075	-12.889	663.91
		60	0.001260	-0.0432	-10.625	806.40
		90	0.001242	-0.0539	-9.382	886.68
		120	0.001183	-0.0559	-8.532	942.86
	90	30	-0.000119	0.1045	-15.212	673.03
		60	0.000339	0.0214	-12.297	809.26
		90	0.000412	-0.0014	-10.979	886.08
		120	0.000450	-0.0136	-10.064	939.57
	120	30	-0.000399	0.1389	-16.303	679.17
		60	-0.000048	0.0699	-13.917	818.88
		90	0.000096	0.0353	-12.190	892.66
		120	0.000139	0.0202	-11.182	944.83
12	70	30	0.000596	0.0242	-12.393	657.74
		60	0.000823	-0.0253	-10.289	799.67
		90	0.000842	-0.0380	-9.143	879.55
		120	0.000817	-0.0417	-8.365	935.54
	90	30	0.000009	0.0791	-13.806	663.72
		60	0.000368	0.0097	-11.259	801.49
		90	0.000432	-0.0098	-10.061	879.07
		120	0.000456	-0.0192	-9.243	933.27
	110	30	-0.000252	0.1106	-14.791	669.29
		60	0.000115	0.0392	-12.207	806.59
		90	0.000206	0.0136	-10.816	882.23
		120	0.000235	0.0023	-9.973	935.50
	130	30	-0.000327	0.1213	-15.185	671.75
		60	-0.000054	0.0640	-13.158	813.12
		90	0.000070	0.0331	-11.563	887.22
		120	0.000114	0.0183	-10.578	939.18

Nominal diameter	Embedment depth h_{ef}	Fire exposure time t	a	b	c	d
[mm]	[mm]	[min]				
16	80	30	0.000362	0.0263	-11.196	646.20
		60	0.000551	-0.0164	-9.333	789.78
		90	0.000551	-0.0273	-8.231	870.60
		120	0.000558	-0.0309	-7.638	927.04
	110	30	-0.000104	0.0777	-12.744	654.06
		60	0.000178	0.0189	-10.488	793.23
		90	0.000230	0.0012	-9.393	870.79
		120	0.000255	-0.0077	-8.658	924.94
	140	30	-0.000229	0.0961	-13.448	658.78
		60	-0.000022	0.0489	-11.677	801.55
		90	0.000070	0.0240	-10.313	876.67
		120	0.000104	0.0119	-9.455	929.14
20	90	30	0.000215	0.0294	-10.395	636.19
		60	0.000380	-0.0094	-8.678	781.80
		90	0.000402	-0.0195	-7.752	863.32
		120	0.000396	-0.0230	-7.130	920.24
	120	30	-0.000087	0.0662	-11.623	643.11
		60	0.000133	0.0171	-9.640	785.05
		90	0.000177	0.0014	-8.639	863.33
		120	0.000197	-0.0062	-7.976	917.98
	150	30	-0.000176	0.0804	-12.212	647.35
		60	-0.000011	0.0402	-10.640	792.55
		90	0.000060	0.0194	-9.432	869.70
		120	0.000088	0.0090	-8.658	921.68
24	90	30	0.000240	0.0193	-9.418	625.44
		60	0.000365	-0.0121	-7.869	775.78
		90	0.000371	-0.0193	-7.009	859.56
		120	0.000359	-0.0215	-6.424	917.78
	120	30	-0.000035	0.0522	-10.535	631.30
		60	0.000146	0.0095	-8.731	776.75
		90	0.000182	-0.0033	-7.836	856.66
		120	0.000194	-0.0091	-7.238	912.42
	150	30	-0.000132	0.0677	-11.187	636.00
		60	0.000020	0.0295	-9.604	782.89
		90	0.000076	0.0119	-8.524	860.40
		120	0.000095	0.0039	-7.868	914.49

Table A.2: Examples of temperature profiles along the embedment depth of common bonded fastener configurations (for stainless steel inserts)