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STAINLESS STEEL IN FIRE

WP4

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Contents

1 Introduction

The present report summarises the activities of CSM in the frame of the RFCS Project "Stainless Steel in Fire" with the scope of reporting to the European Commission the works carried out for WP4 during the entire project, from 01.07.2004 to 31.12.2007.

2 General objectives

The aim of WP4 is to get knowledge about the mechanical properties of stainless steel grades dedicated to construction under fire risk. The final goal of this WP is to define parameters for constitutive modelling of the grades tested on the basis of the analytical equation indicated in Eurocode 3 Part 1-2.

3 Work undertaken

In order to achieve this goal, even if the original scope was to analyse only one stainless steel grade, due to the interest of Outokumpu an extra grade has been analysed too. So, transient state tests have been performed on two austenitic grades: a Mn low Ni grade steel (STR 18) delivered by Thyssen Krupp AST, and an EN 1.4541 delivered by Outokumpu Stainless Oy. Both the grades have been delivered at CSM site in the form of 1.5 mm thick sheets in the annealed condition.

Transient state tests have the scope of simulating real conditions of a structure under fire action where the load is constant and the temperature increases with a certain rate depending on the specific situation: the specimen is positioned in the furnace under a constant load (expressed in percentage of $R_{0.2p}$) and the temperature increases linearly from the room one up to 1000°C, with a rate of about 10°C/min (see Figure 1).

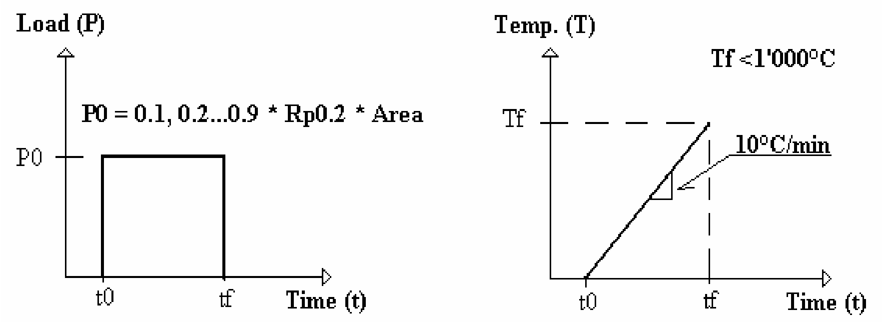


Figure 1 –Transient state test procedure.

The casting chemical composition for STR 18 is shown in Table 1, while Outokumpu grade is classified in the product standard EN 10088.

Table 1 - Casting chemical composition of STR 18 grade produced by Thyssen Krupp AST.

Element	C	Si	Mn	P	S	N	Cr	Cu	Mo	Nb	Ni	Ti
STR 18	0,04	0,23	11,05	0,026	0,002	0,27	17,85	1,87	0,13	0,01	3,95	0,01

The sheets have been machined to obtain specimens in longitudinal direction. Figure 2 shows the sketch of specimen for transient state tests. Specimens to perform standard tensile tests at room temperature (RT), instead, have been machined both in longitudinal and in transversal direction.

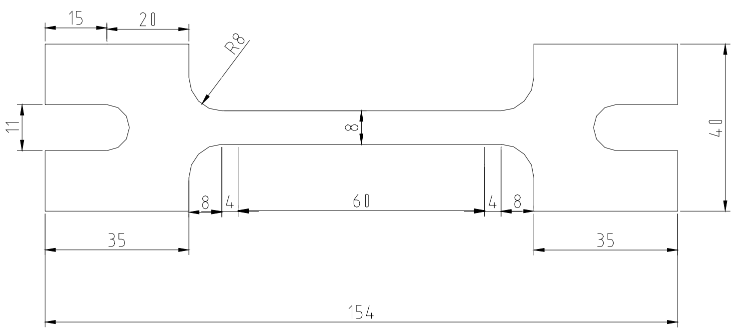


Figure 2 – Transient state tests specimen.

The total number of specimens and all the testing procedures have been scheduled on the basis of a previous research project partially funded by the ECSC ([1]), which results are now included in the Eurocode 3 Part 1-2.
Table 2 summarises performed experimental tests on both of grades.

Table 2 – Performed testing programme.

Material	Direction[1)]	Temperature curve	Load type	Load level (% of $R_{0.2p}$)	Number of performed tests	Deliverables
STR 18	L	RT[2)]	Tensile	-	3	Stress vs. Strain curves
	T	RT	Tensile	-	3	
	L	linear (10°C/min) up to failure or 1000°C	Axial and Constant	1%	1	Strain vs. Temperature curves
				10%	2	
				20%	1	
				30%	1	
				40%	2	
				50%	1	
				60%	1	
				70%	2	
				80%	1	
				90%	1	
EN 1.4541	L	RT	Tensile	-	3	Stress vs. Strain curves
	T	RT	Tensile	-	3	
	L	linear (10°C/min) up to failure or 1000°C	Axial and Constant	1%	1	Strain vs. Temperature curves
				20%	1	
				30%	2	
				50%	1	
				60%	1	
				70%	1	
				80%	1	

Notes
1) direction of the specimen with respect to the rolling direction: L = longitudinal; T = transversal
2) RT = Room Temperature

4 Material properties

Standard tensile tests have been performed to evaluate stress level to be applied during transient state tests. The experimental results are summarised in Table 3.

Table 3 - Tensile tests results at room temperature.

Material	Direction	$R_{0.2p}$ [MPa]	R_m [MPa]	A(%)	Z(%)
STR 18	L	392	759	71	55
	L	382	752	73	56
	L	382	748	73	56
Mean value		*385*	*753*	*72*	*56*
STR 18	T	385	744	67	51
	T	384	743	66	51
	T	386	739	66	51
Mean value		*385*	*742*	*66*	*51*
EN 1.4541	L	236	658	79	57
	L	248	668	79	55
	L	244	656	78	55
Mean value		*243*	*661*	*79*	*56*
EN 1.4541	T	265	663	80	59
	T	258	657	81	56
	T	261	657	83	61
Mean value		*261*	*659*	*81*	*59*

By building stress vs. strain curves for anisothermal tests at different temperatures, the curves seem to be translated along the x-axis, revealing the presence of parasite strains induced by the testing machine adjustments (see for example Figure 3, concerning EN 1.4541 steel grade). These strains can be estimated by performing a transient state test for each grade at a very low stress level (1% of $R_{0.2p}$), as show in Figure 4.

Figure 5 and Figure 6 show anisothermal strain vs. temperature curves with estimated parasite strains already subtracted, but the stress-strain curves do not yet correctly match the axes origin.

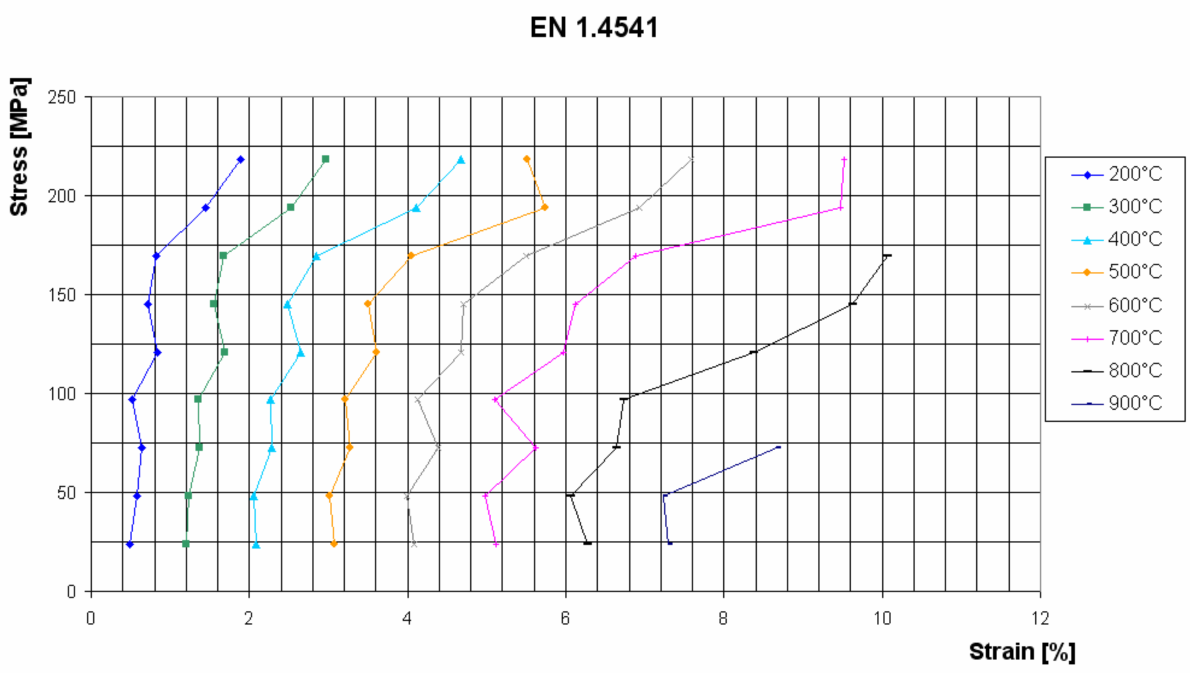


Figure 3 – EN 1.4541 steel stress-strain curves including parasite strains.

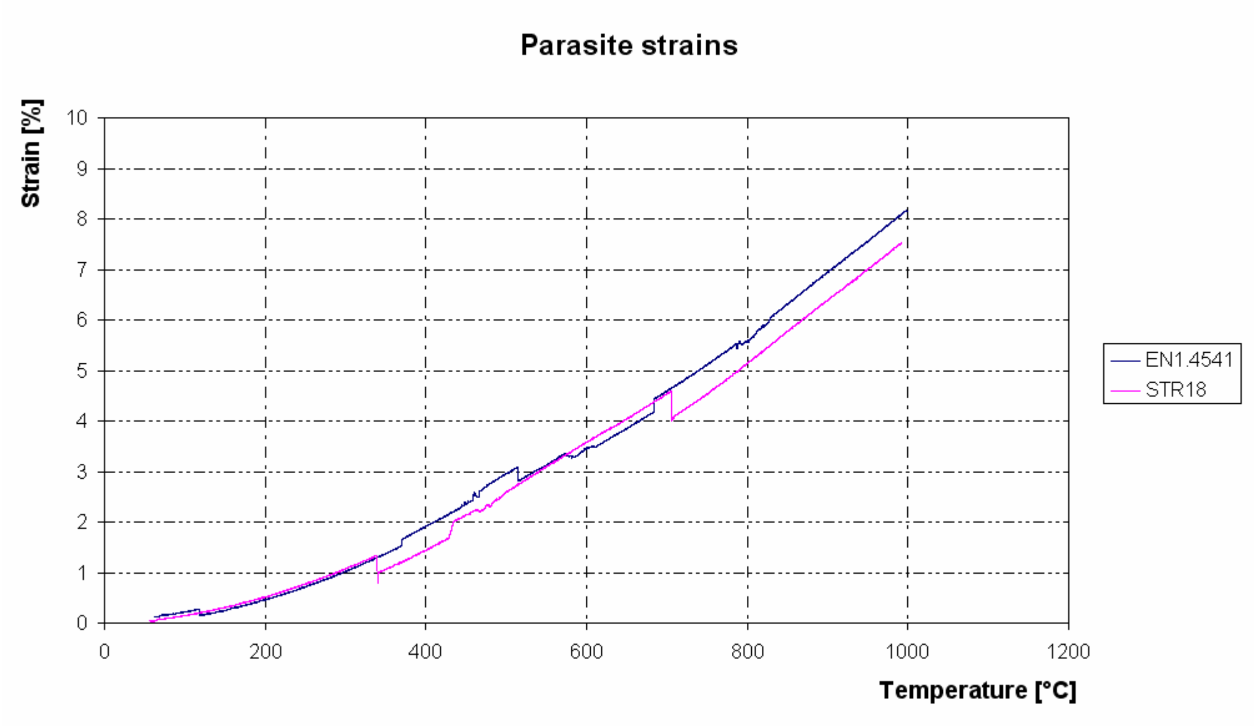


Figure 4 – Parasite strains for STR 18 and EN 1.4541 grades evaluated by low load transient state tests.

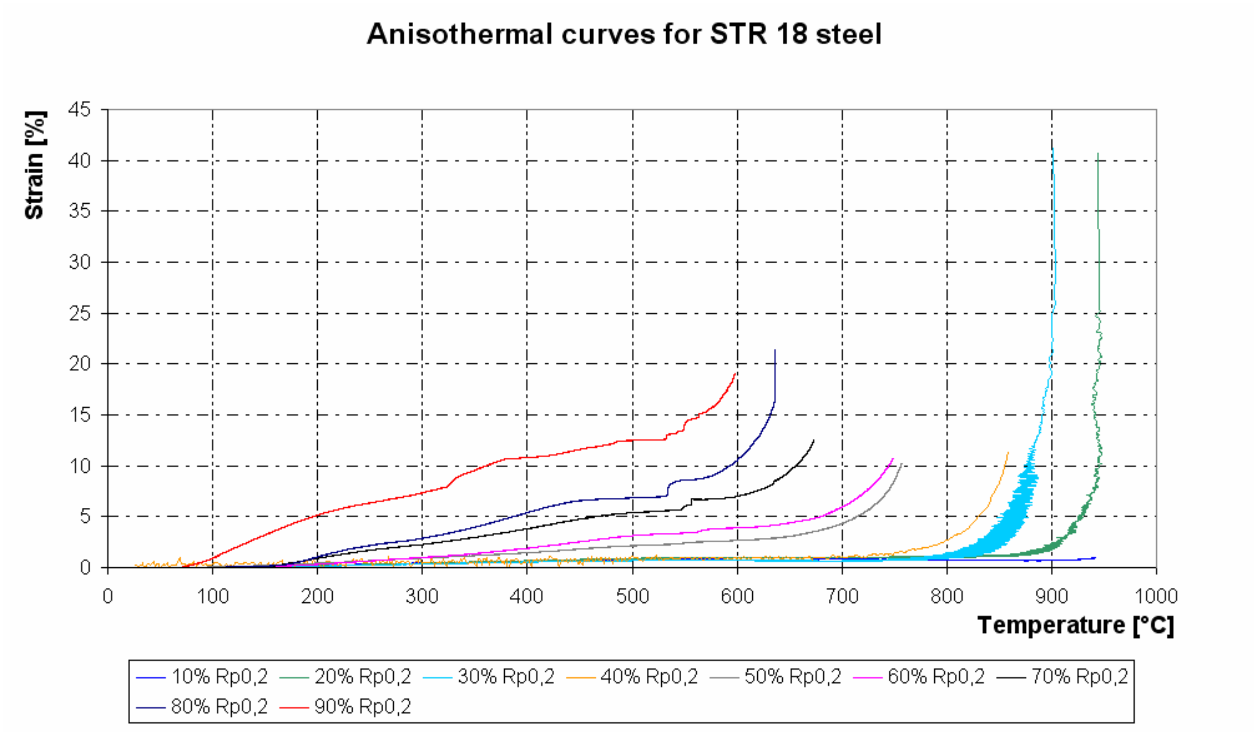


Figure 5 – Transient state tests on STR 18 grade. Parasite strains already been subtracted.

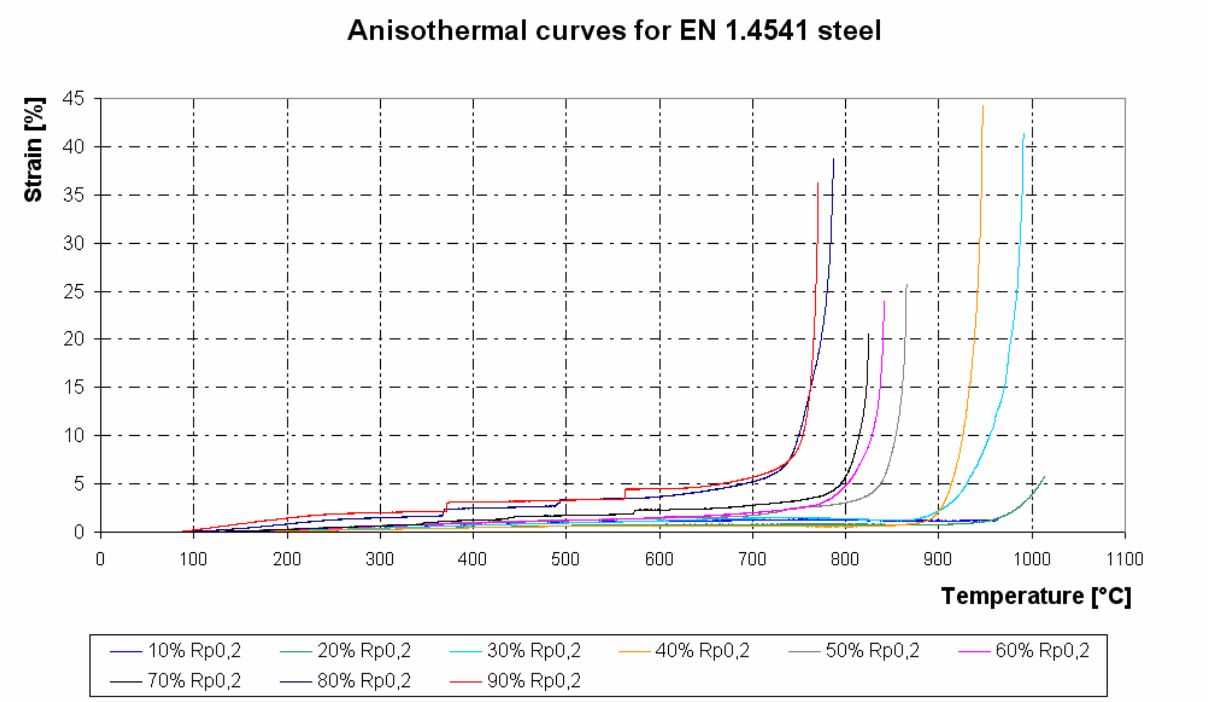


Figure 6 – Transient state tests on EN 1.4541 grade. Parasite strains already been subtracted.

On top of that, further difficulties have been found in high temperature Young modulus determination, since all values obtained were well under the ones in Eurocode 3-1-2; this is probably due to the time necessary for the test, which allows a material relaxation and consequently introduces creep phenomena. So, a further increase in parasite strains estimation has been necessary to better match axes origin and to increase Young modulus.

However, the abovementioned difficulties encountered in the elaboration of experimental data related with the definition of "parasite strains" and evaluation of elastic modulus suggest the need of develop a well defined procedure for transient state tests execution and for the subsequent elaboration of experimental data with the scope of retention parameters evaluation.

The performances of selected grades in fire situation come from the maximum temperature reached before the failure occurs; to perform an evaluation of these properties, the experimental curves reported in Figure 5 and Figure 6 have been compared with those obtained in the previous ECSC Project "Development of the use of stainless steel in construction" [1]; an example of this comparison is shown in Figure 7, referring to a stress level of 50% of $R_{0.2p}$. The curves relative to all stress levels are reported in the ANNEX A.

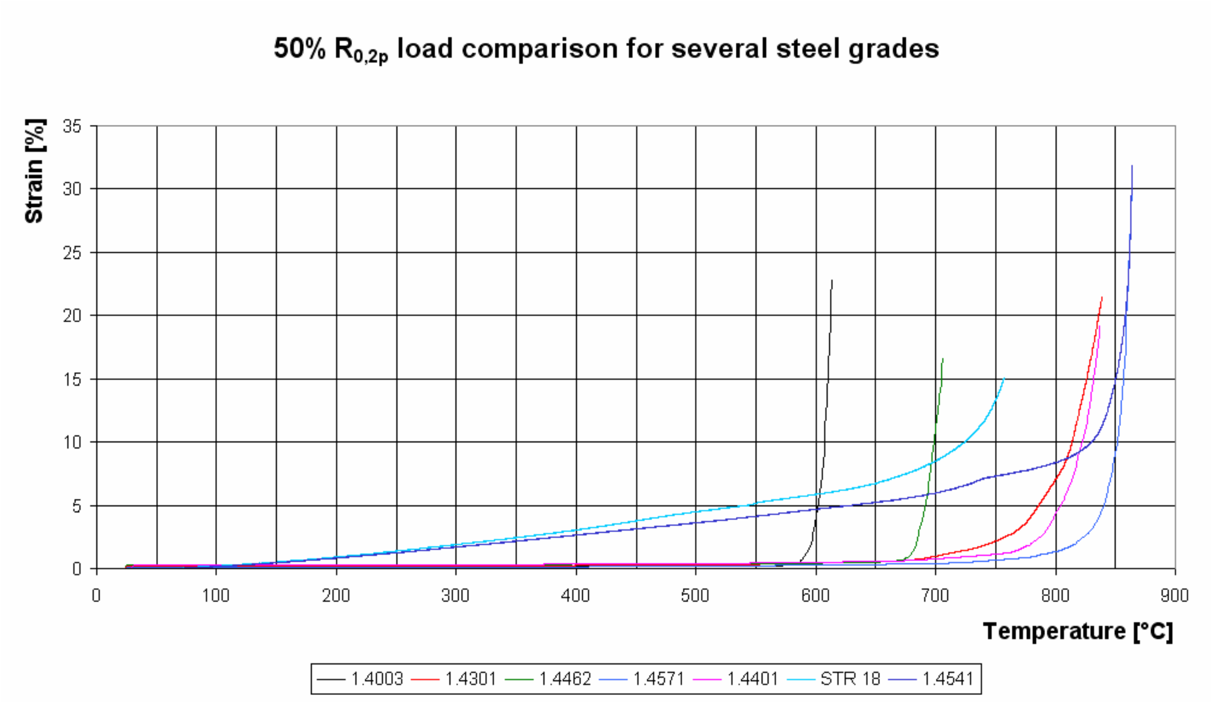


Figure 7 – Comparison among experimental curves obtained on both selected stainless steel grades and those reported in Eurocode 3 Part 1-2. Stress level is 50% of $R_{0.2p}$.

The data collected by experiments are useful to evaluate σ–ε curves at a chosen temperature by extracting the corresponding elongation value in each Elongation vs. Temperature curve at a certain stress level (i.e. % of $R_{0.2p}$).

Those experimental σ–ε curves can be fitted by a numerical model, so to obtain the material constitutive law representing the general stainless steel behaviour at elevated temperatures.

Equations reported in Eurocode 3 Part 1-2 (Figure 8 and Table 4), describing stainless steel material behaviour at elevated temperatures, have been found to fit well the experimental data provided that the retention parameters were evaluated on them basis.

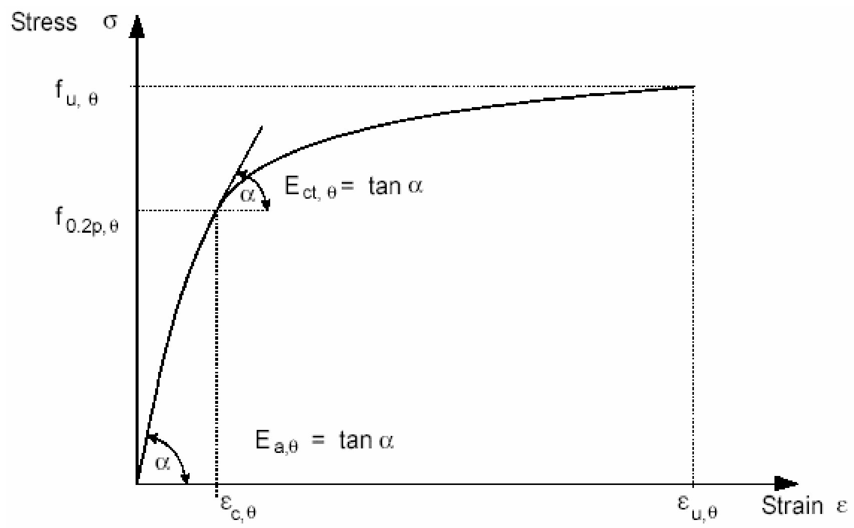


Figure 8 - Eurocode 3 Part 1-2: a sketch showing parameters governing stainless steel material behaviour at elevated temperatures.

Table 4 – Eurocode 3 Part 1-2: equations describing stainless steel material behaviour at elevated temperatures.

Strain range	Stress σ	Tangent modulus E_t
$\varepsilon \le \varepsilon_{c,\theta}$	$\dfrac{E \cdot \varepsilon}{1 + a \cdot \varepsilon^{b}}$	$\dfrac{E(1 + a \cdot \varepsilon^{b} - a \cdot b \cdot \varepsilon^{b})}{(1 + a \cdot \varepsilon^{b})^{2}}$
$\varepsilon_{c,\theta} < \varepsilon \le \varepsilon_{u,\theta}$	$f_{0.2p,\theta} - e + (d/c)\sqrt{c^2 - (\varepsilon_{u,\theta} - \varepsilon)^2}$	$\dfrac{d + (\varepsilon_{u,\theta} - \varepsilon)}{c\sqrt{c^2 - (\varepsilon_{u,\theta} - \varepsilon)^2}}$
Parameters	$\varepsilon_{c,\theta} = f_{0.2p,\theta}/E_{a,\theta} + 0.002$	
Functions	$a = \dfrac{E_{a,\theta}\,\varepsilon_{c,\theta} - f_{0.2p,\theta}}{f_{0.2p,\theta}\,\varepsilon_{c,\theta}^{\,b}}$ $c^2 = (\varepsilon_{u,\theta} - \varepsilon_{c,\theta})\left(\varepsilon_{u,\theta} - \varepsilon_{c,\theta} + \dfrac{e}{E_{ct,\theta}}\right)$ $e = \dfrac{(f_{u,\theta} - f_{0.2p,\theta})^2}{(\varepsilon_{u,\theta} - \varepsilon_{c,\theta})E_{ct,\theta} - 2(f_{u,\theta} - f_{0.2p,\theta})}$	$b = \dfrac{(1 - \varepsilon_{c,\theta}\,E_{ct,\theta}/f_{0.2p,\theta})\,E_{a,\theta}\,\varepsilon_{c,\theta}}{(E_{a,\theta}\,\varepsilon_{c,\theta}/f_{0.2p,\theta} - 1)\,f_{0.2p,\theta}}$ $d^2 = e\,(\varepsilon_{u,\theta} - \varepsilon_{c,\theta})\,E_{ct,\theta} + e^2$

The procedure used to evaluate the retention parameters is detailed below:

- $f_{u,\vartheta}$ (and consequently the retention parameter $k_{u,\vartheta}$) and $\varepsilon_{u,\vartheta}$, are taken from isothermal tensile tests (steady state tests).

- $f_{0.2p,\vartheta}$ and $E_{a,\vartheta}$ (and consequently the retention parameters $k_{0.2p,\vartheta}$ and $k_{E,\vartheta}$) are evaluated from σ–ε curves obtained from anisothermal tensile tests (transient state tests), while

  $$\varepsilon_{c,\vartheta} = \frac{f_{0.2p,\vartheta}}{E_{a,\vartheta}}$$

- The parameter $k_{2\%,\theta}$ is calculated as

  $$k_{2\%,\theta} = \frac{f_{2\%,\theta} - f_{0.2p,\theta}}{f_{u,\theta} - f_{0.2p,\theta}}$$

  where $f_{2\%,\vartheta}$ is graphically determined by numerical model of material experimental curves; $k_{2\%,\theta}$ is a parameter needed for the calculation of yield strength to be used with simple calculation method, but it has no influence in the definition of material model.

- $k_{Ect,\vartheta} = E_{ct,\vartheta} / E_a$

  $E_{ct,\vartheta}$ is adjusted to fit material model with respect to experimental data.

- Before of calculating necessary parameters from experimental results, parasite stains are subtracted from the latter ones. As abovementioned, they are measured performing a test with a very low stress level.

In Figure 9 and Figure 10, experimental σ–ε curves and material models are compared.

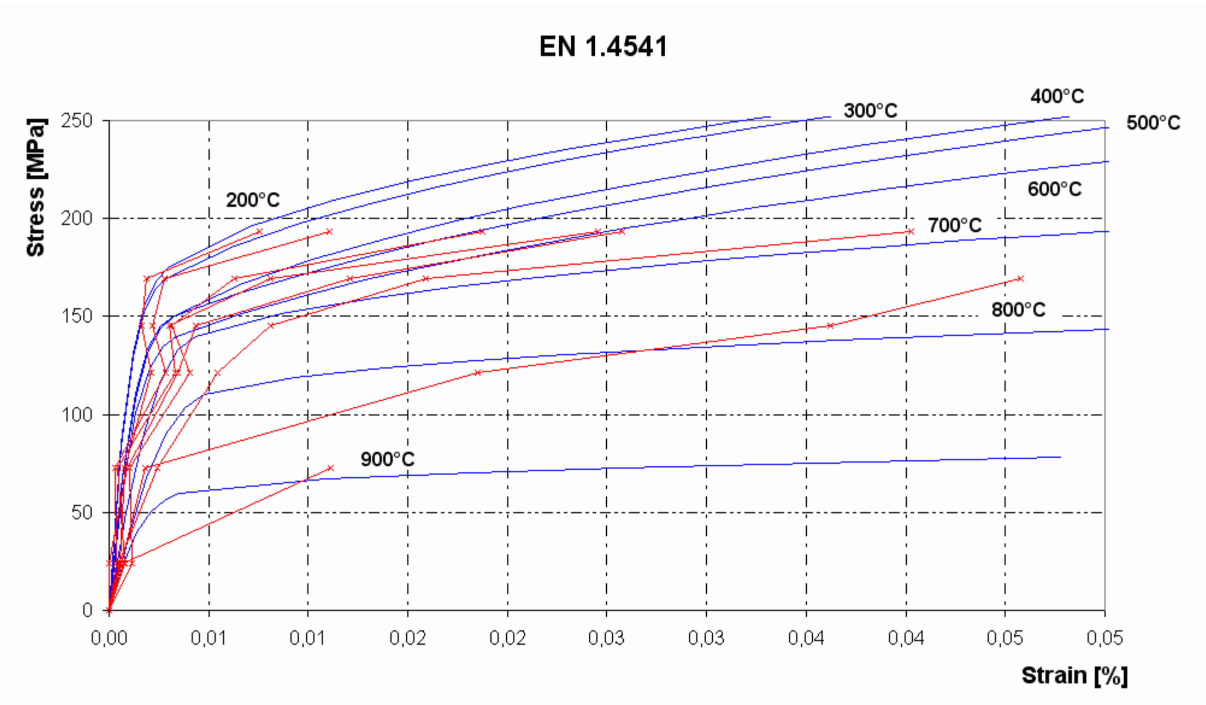


Figure 9 – Material model developed for EN 1.4541.

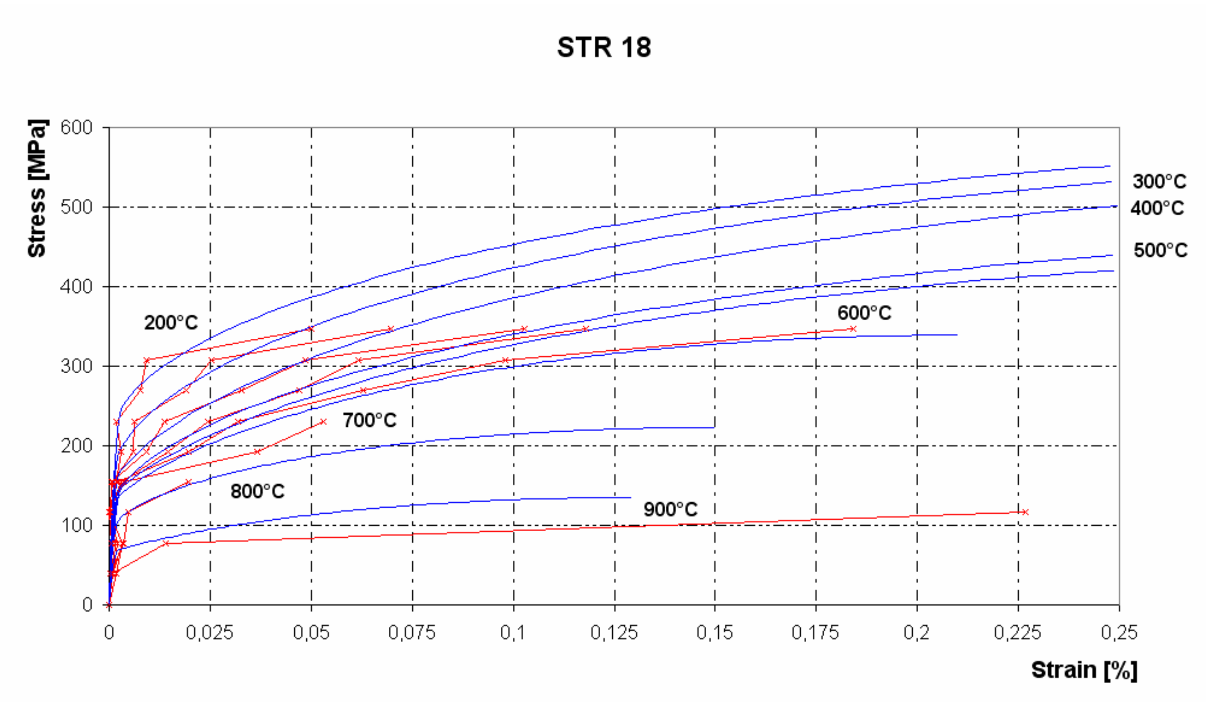


Figure 10 - Material model developed for STR 18.

Material retention factors for the two grades tested are reported in Table 5.

Table 5 – Material reduction factors for the tested materials.

Steel Temperature ϑ_a	Reduction factor (relative to E_a) for the slope of the linear elastic range $k_{E,\vartheta} = E_{a,\vartheta} / E_a$	Reduction factor (relative to f_y) for proof strength $k_{0.2p,\vartheta} = f_{0.2p,\vartheta} / f_y$	Reduction factor (relative to f_u) for tensile strength $k_{u,\vartheta} = f_{u,\vartheta} / f_u$	Factor for determination of the yield strength $f_{y,\theta}$ $k_{2\%,\vartheta}$
Grade 1.4541				
20	1	1	1	0.14
200	0.92	0.63	0.73	0.21
300	0.88	0.61	0.70	0.22
400	0.60	0.54	0.70	0.21
500	0.60	0.54	0.68	0.19
600	0.50	0.50	0.62	0.19
700	0.30	0.50	0.48	0.19
800	0.20	0.40	0.34	0.21
900	0.20	0.22	0.20	0.18

Steel Temperature ϑ_a	Reduction factor (relative to E_a) for the slope of the linear elastic range $k_{E,\vartheta} = E_{a,\vartheta} / E_a$	Reduction factor (relative to f_y) for proof strength $k_{0.2p,\vartheta} = f_{0.2p,\vartheta} / f_y$	Reduction factor (relative to f_u) for tensile strength $k_{u,\vartheta} = f_{u,\vartheta} / f_u$	Factor for determination of the yield strength $f_{y,\theta}$ $k_{2\%,\vartheta}$
STR 18				
20	1	1	1	0.18
200	0.92	0.65	0.77	0.22
300	0.88	0.52	0.74	0.22
400	0.84	0.44	0.72	0.19
500	0.80	0.39	0.63	0.19
600	0.50	0.39	0.58	0.18
700	0.71	0.36	0.45	0.21
800	0.63	0.29	0.30	0.36
900	0.45	0.18	0.18	0.32

- conts.-

-contd.-

Steel Temperature ϑ_a	Reduction factor (relative to E_a) for the slope of the linear elastic range $k_{Ect,\vartheta} = E_{ct,\vartheta} / E_a$	Ultimate strain $\varepsilon_{u,\vartheta}$
Grade 1.4541		
20	0.04	0.63
200	0.04	0.49
300	0.03	0.4
400	0.03	0.42
500	0.02	0.4
600	0.02	0.39
700	0.02	0.52
800	0.02	0.55
900	0.02	0.89

Steel Temperature ϑ_a	Reduction factor (relative to E_a) for the slope of the linear elastic range $k_{Ect,\vartheta} = E_{ct,\vartheta} / E_a$	Ultimate strain $\varepsilon_{u,\vartheta}$
STR 18		
20	0.04	0.47
200	0.04	0.40
300	0.04	0.38
400	0.03	0.42
500	0.03	0.43
600	0.02	0.35
700	0.02	0.21
800	0.02	0.15
900	0.01	0.12

One could expect grade 1.4541 to behave similarly to the other stabilised grade 1.4571, but the tests results show different behaviours for the two materials.
Indeed, EN 1.4571 tests results have been obtained as mean values from tests carried out at constant and variable temperature [1], where anisothermal tests give less performing results (that is, obtained data are more conservative). EN 1.4541 specimens, instead, have all been tested by CSM in anisothermal way only. So, EN 1.4571 seems to work better than EN 1.4541, but under similar thermal conditions the two materials behaviour would be the same.

5 Sensitivity analysis

The sensitivity of two column buckling design methods to the material parameters measured in WP4 has been evaluated. This analysis had the scope of supporting the decision on the method to be adopted for stainless steel column buckling design. The two methods compared, the Euro Inox and the CTICM method, are extensively described in ANNEX B.

The analysis involved experimental data provided by CTICM, SCI and VTT concerning fire tests on stainless steel columns compared with the design curves ($N_{b,fi,Rd}$ vs. *Temperature*) generated with both methods and using actual values of strength.

The curves generated with the two different methods are not very different each other: both of them seem to match well the available experimental data; an example is shown in Figure 11.

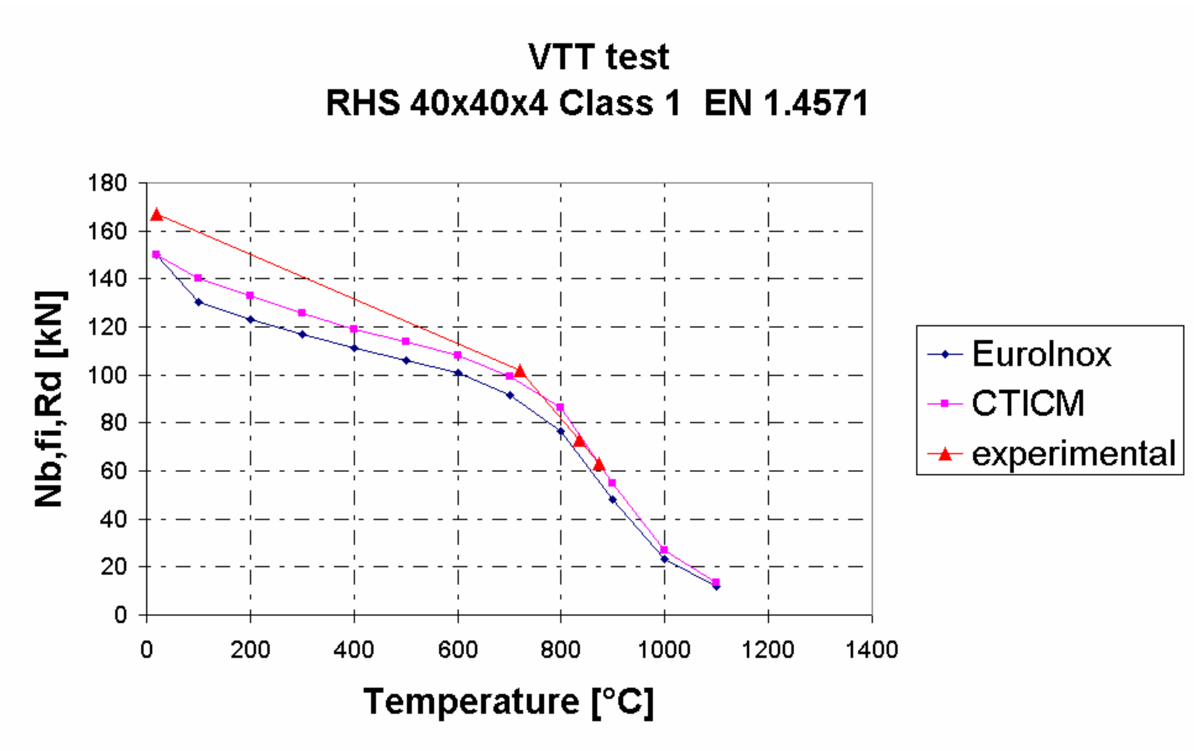


Figure 11 – Column buckling behaviour of a stainless steel rectangular hollow section. Other details are reported in ANNEX B.

Figure 12 and Figure 13 show the temperature influence on different material reduction factors and imperfection factors for grade EN 1.4301 adopted by the two methods in Equations (10) and (17) in ANNEX B: the figures show that these factors are counterbalanced each other, and this the reason for a not substantial difference between the two methods.

The Euro Inox method involves a larger number of material parameters at elevated temperatures (f_u, f_y) to be determined experimentally with the procedure adopted in this WP4, while the CTICM method is simply an extension of design buckling method for stainless steel at room temperature (EN 1993-1-4). Due to the fact that the generated curves are very similar each other, it should be better to adopt the easier method because it will lead to an easier utilization of stainless steel in constructions.

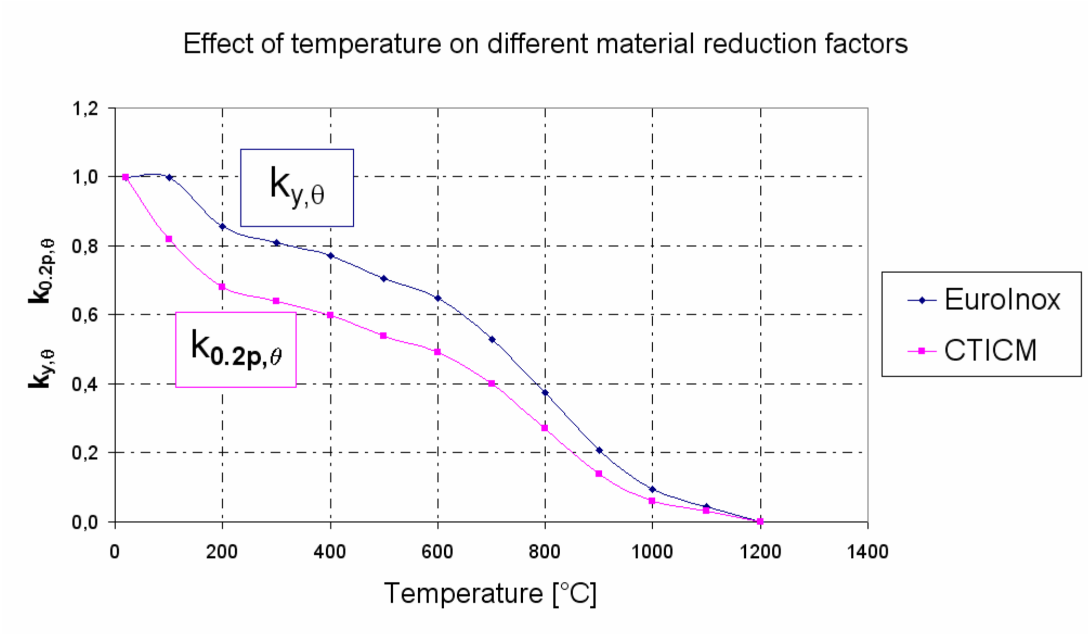


Figure 12 – Grade EN 1.4301: temperature influence comparison between material reduction factors for the two methods.

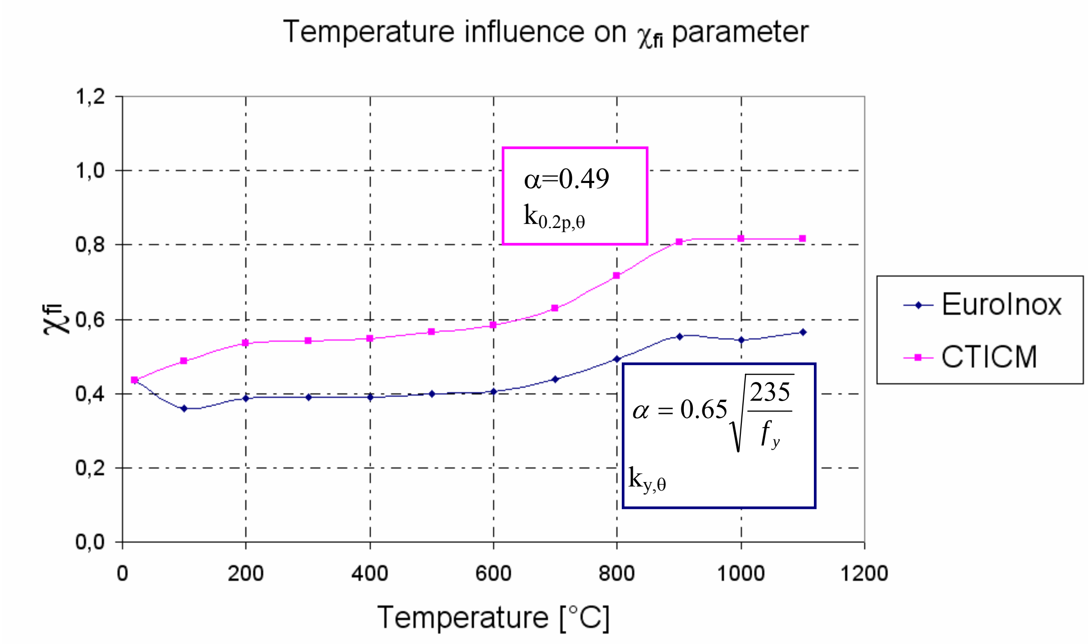


Figure 13 - Grade EN 1.4301: comparison between temperature effects on the χ_{fi} parameter for the two methods.

6 Problems encountered

The difficulties encountered in the elaboration of experimental data related with the definition of “parasite strains” and evaluation of elastic modulus suggest the need of develop a well defined procedure for transient state tests execution and for the subsequent elaboration of experimental data with the scope of retention parameters evaluation.

No other problem has been encountered.

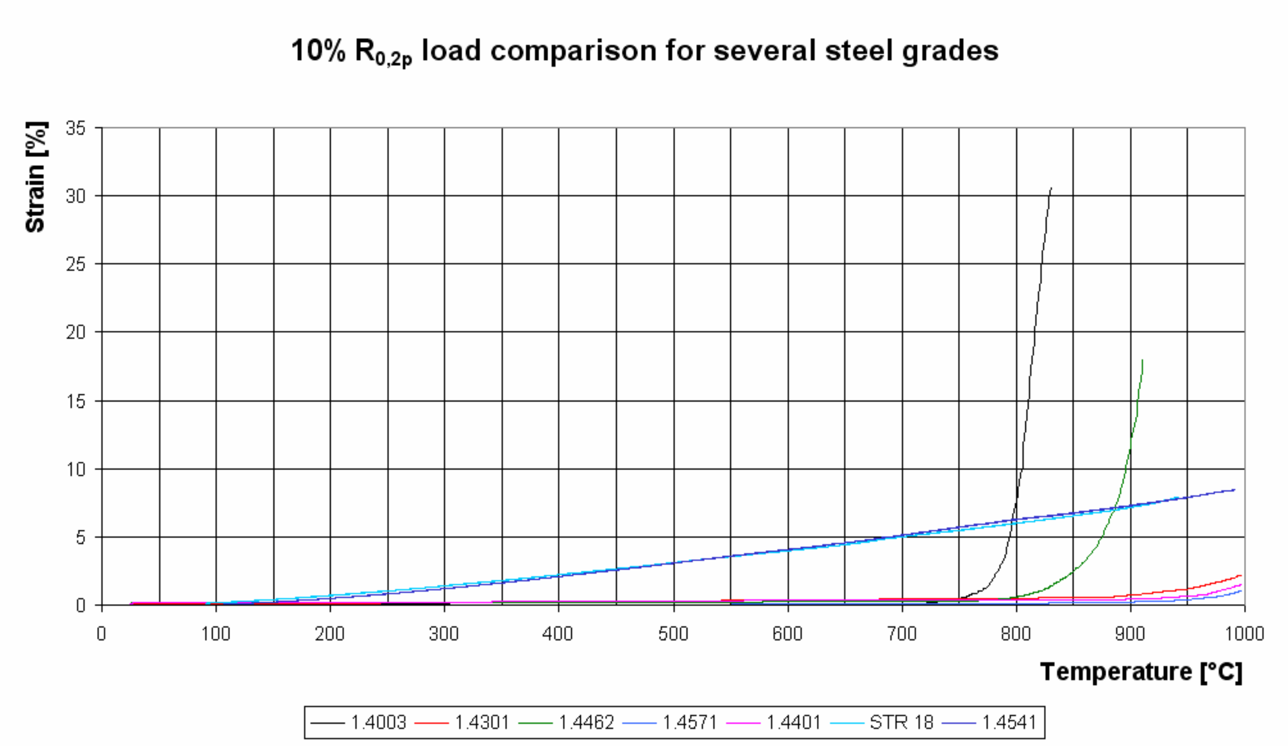
References

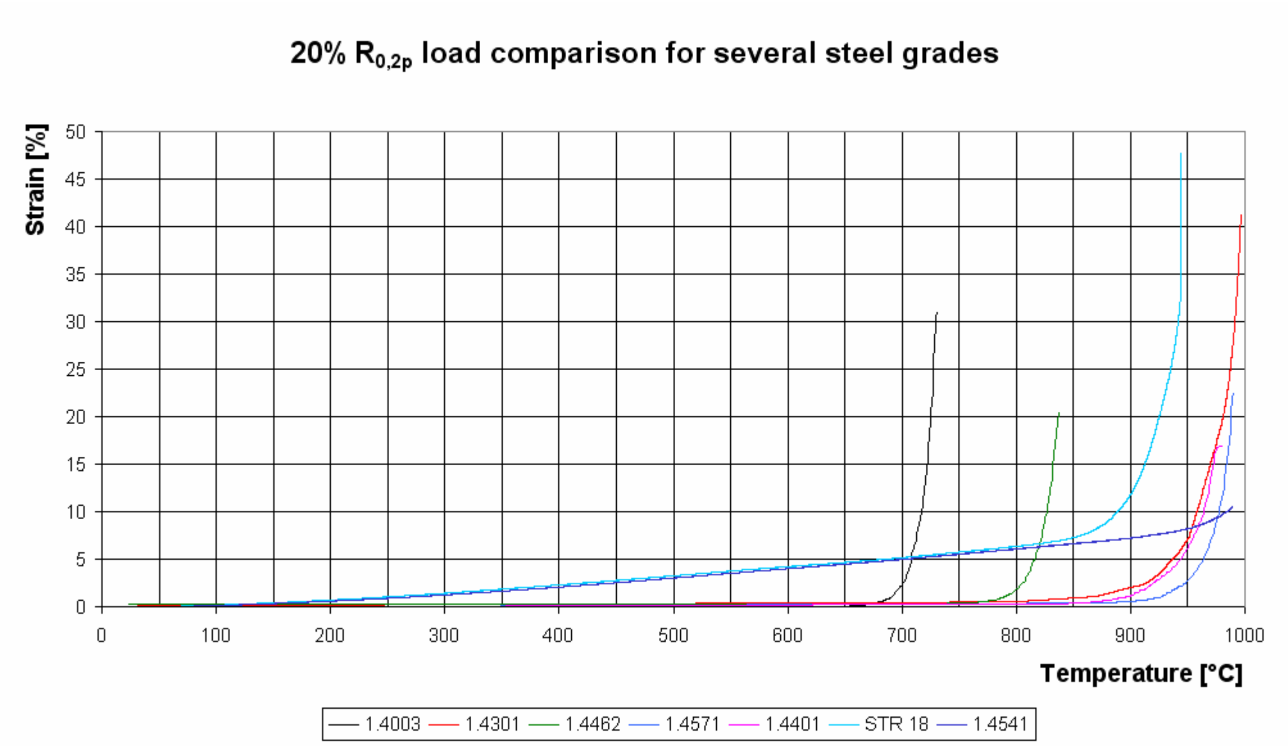
[1] Zhao, B. – ECSC Project “Development of The Use of Stainless Steel in Construction. Contract no. 7210-SA/842, 903, 904, 327, 134, 425” WP5.1 - Material behaviour at elevated temperatures. Final Report to European Coal and Steel Community. CTICM (FR) and SCI (UK), March 2000.

[2] Ala-Outinen, T. & Oksanen, T. – “Stainless steel compression members exposed to fire.”, VTT Research Notes 1864. Espoo Technical Research Centre of Finland, 1997.

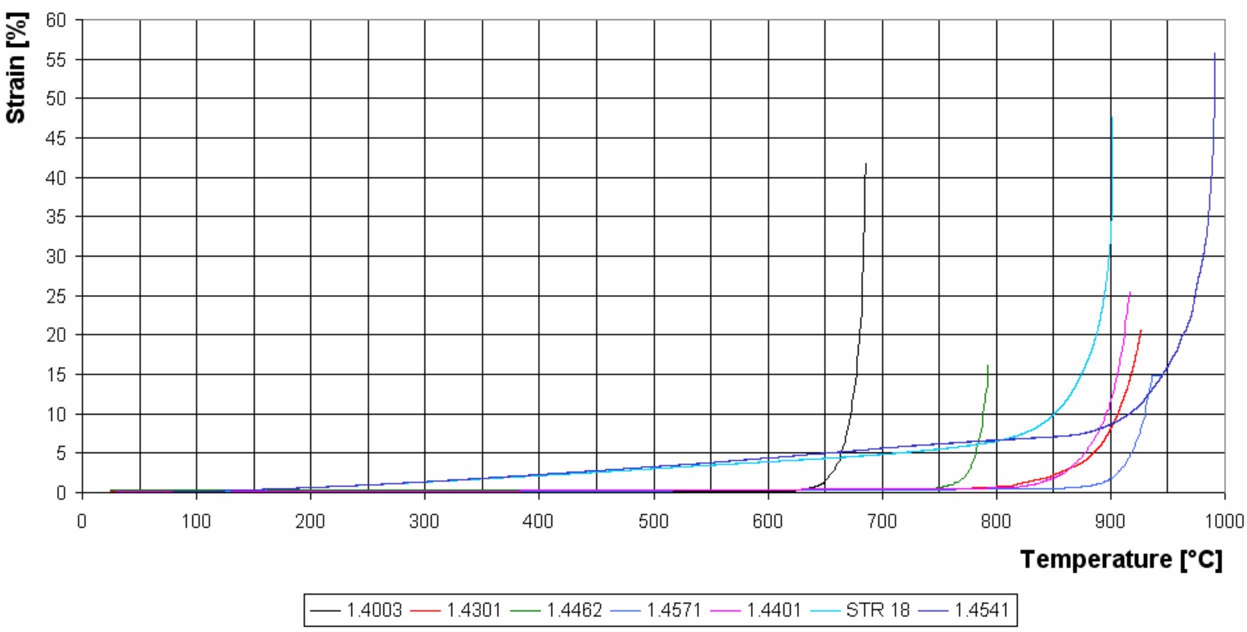
ANNEX A

Anisothermal curves comparison between SSIF project and the previously obtained ones

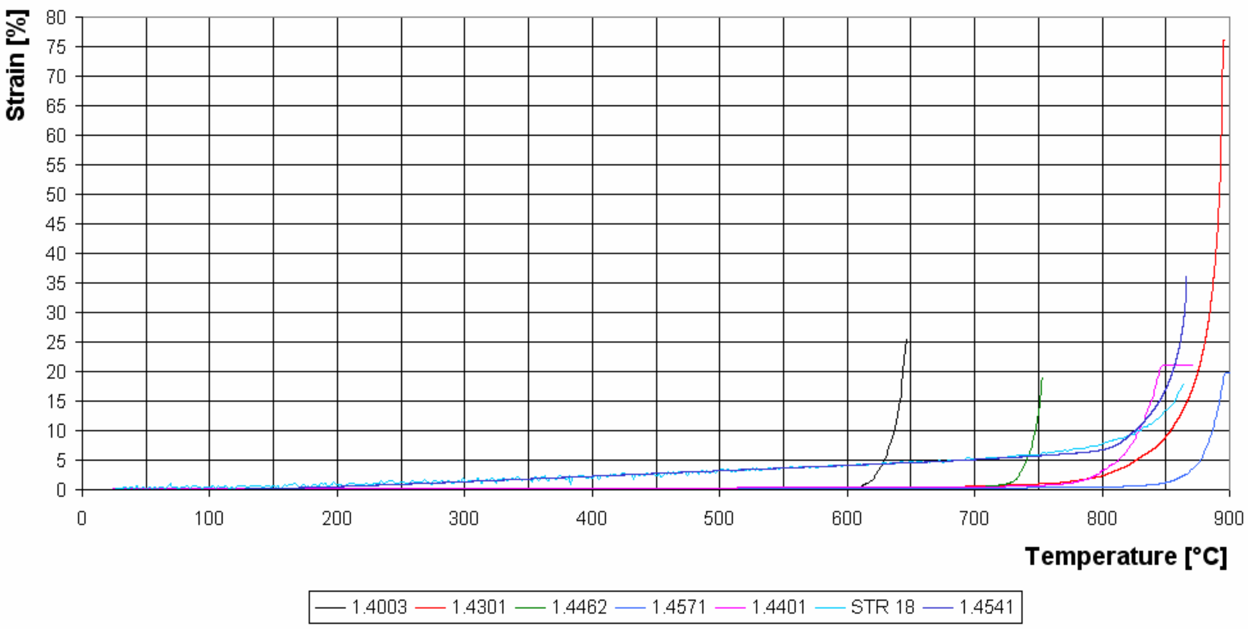


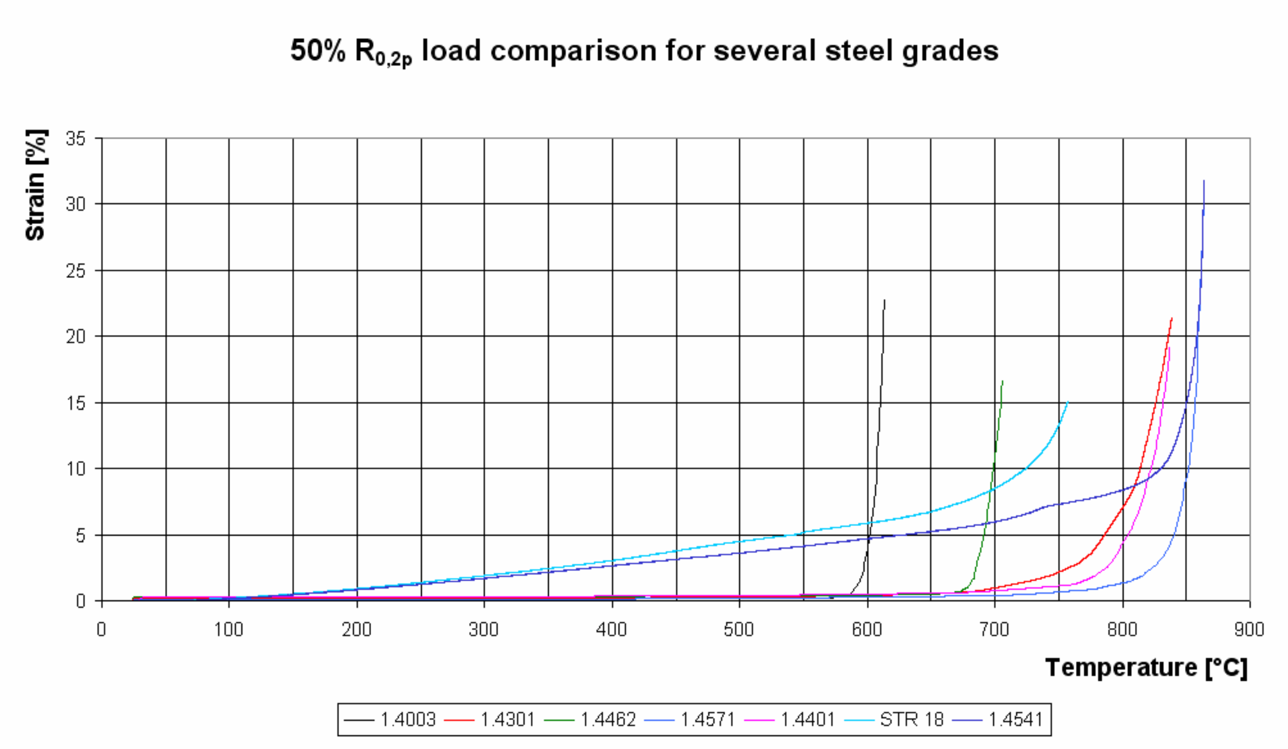


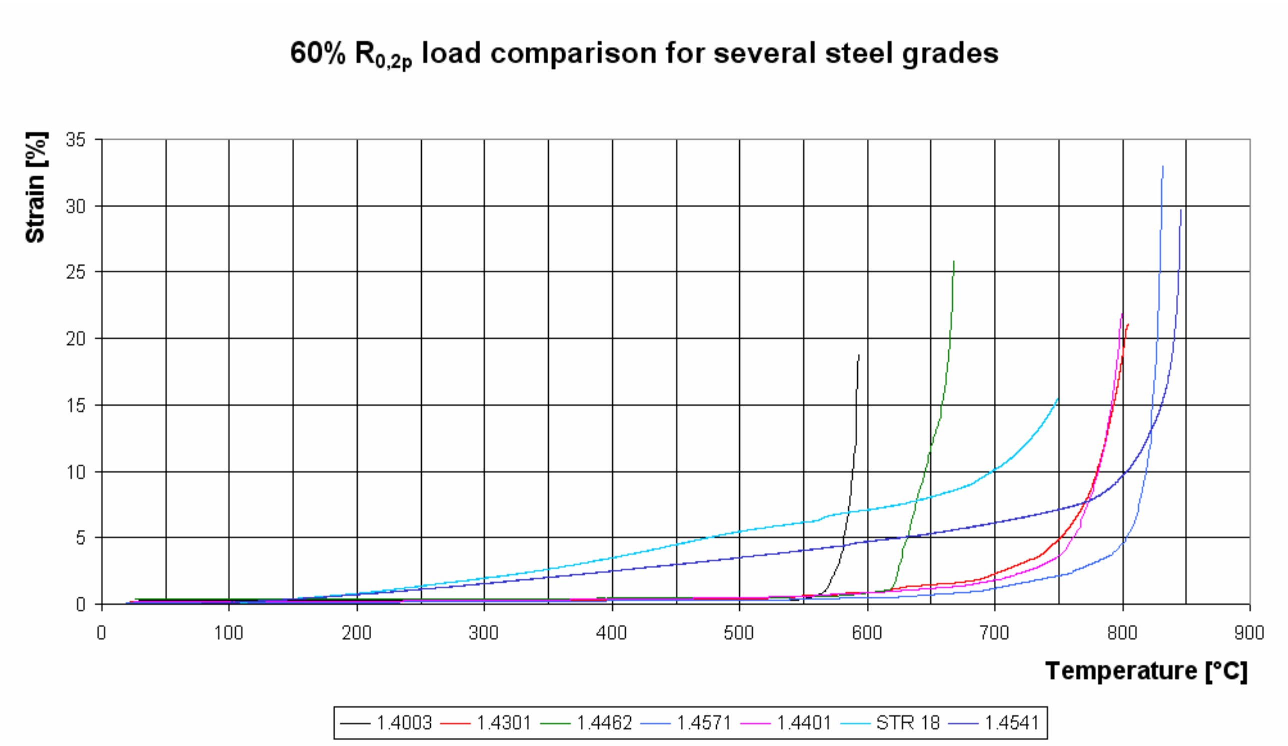
30% $R_{0,2p}$ load comparison for several steel grades

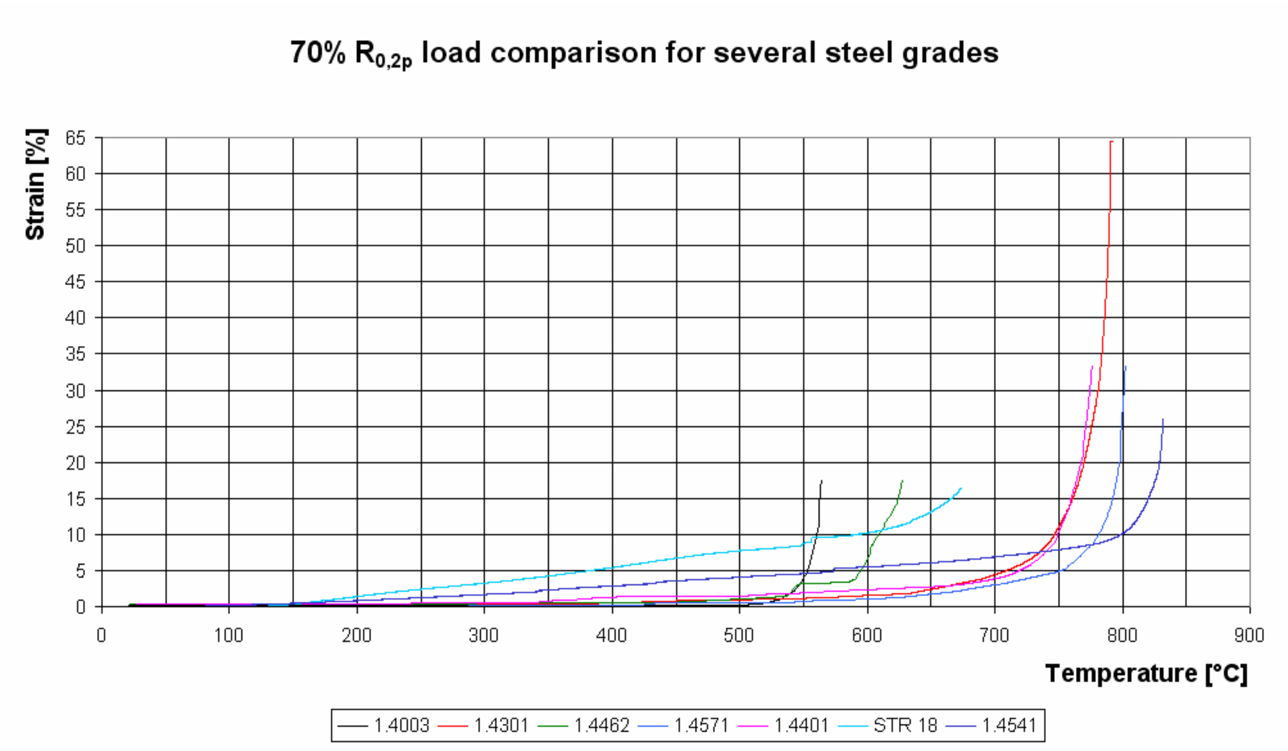


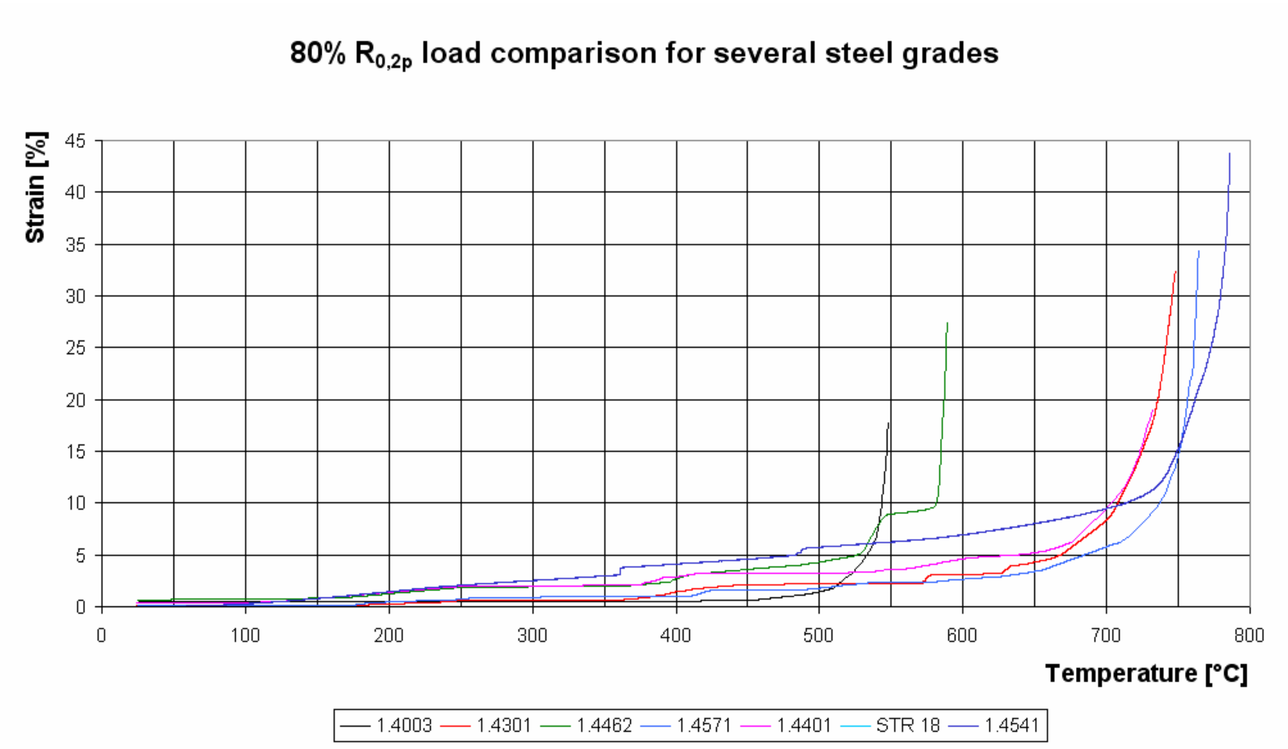
40% $R_{0,2p}$ load comparison for several steel grades

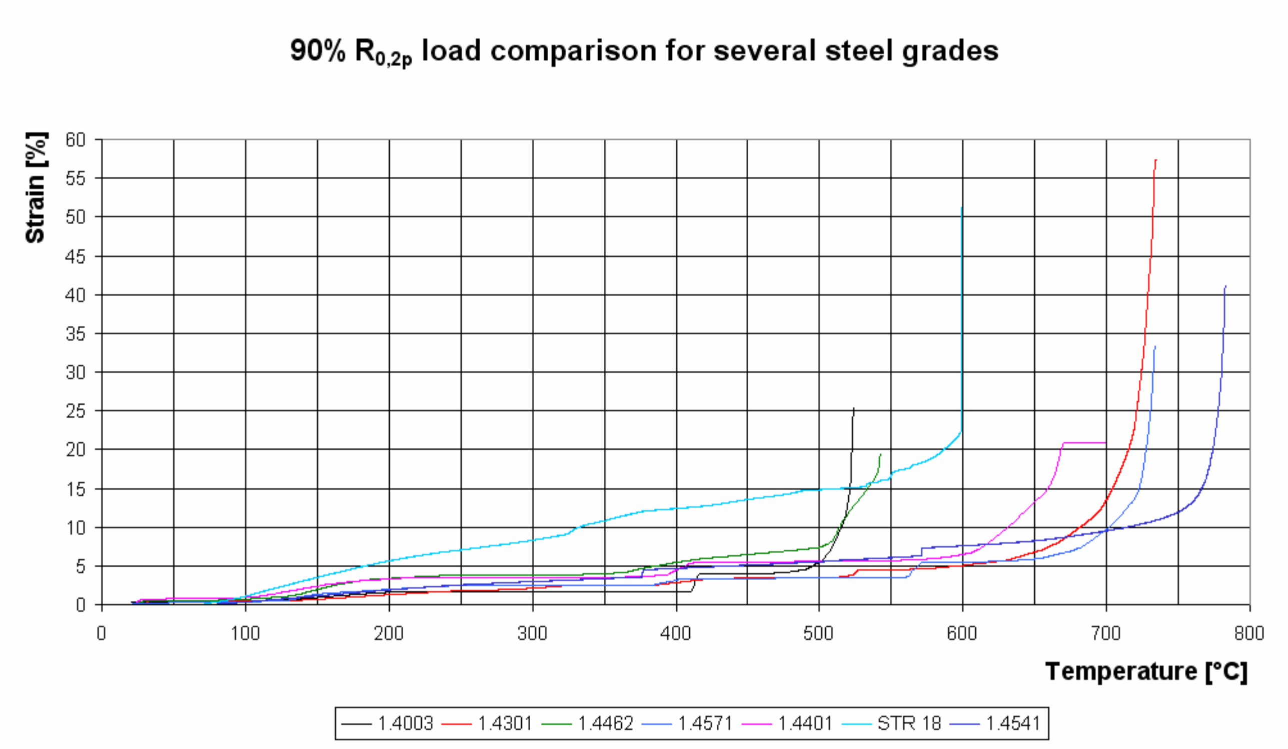



50% $R_{0,2p}$ load comparison for several steel grades
Strain [%]
35
30
25
20
15
10
5
0
0
100
200
300
400
500
600
700
800
900
Temperature [°C]
1.4003
1.4301
1.4462
1.4571
1.4401
STR 18
1.4541


60% $R_{0,2p}$ load comparison for several steel grades
Strain [%]
35
30
25
20
15
10
5
0
0
100
200
300
400
500
600
700
800
900
Temperature [°C]
1.4003
1.4301
1.4462
1.4571
1.4401
STR 18
1.4541


70% $R_{0,2p}$ load comparison for several steel grades
Strain [%]
0
5
10
15
20
25
30
35
40
45
50
55
60
65
0
100
200
300
400
500
600
700
800
900
Temperature [°C]
1.4003
1.4301
1.4462
1.4571
1.4401
STR 18
1.4541


80% $R_{0,2p}$ load comparison for several steel grades
Strain [%]
0
5
10
15
20
25
30
35
40
45
0
100
200
300
400
500
600
700
800
Temperature [°C]
1.4003
1.4301
1.4462
1.4571
1.4401
STR 18
1.4541


90% $R_{0,2p}$ load comparison for several steel grades
Strain [%]
0
5
10
15
20
25
30
35
40
45
50
55
60
0
100
200
300
400
500
600
700
800
Temperature [°C]
1.4003
1.4301
1.4462
1.4571
1.4401
STR 18
1.4541

ANNEX B

Stainless steel column buckling behaviour at elevated temperatures

The scope of the present document is to compare some experimental data concerning column buckling behaviour at elevated temperatures with the predictions of the methods proposed by EuroInox design manual and CTICM method.
These two methods for generating design column buckling curves ($N_{b,fi,Rd}$ vs. *Temperature*) are briefly described in the following.
The experimental data available, provided by SCI, CTICM and VTT, are reported in Table 6.

For each tested column, the design buckling resistance curves at elevated temperature have been generated and compared with experimental data (see figures from 15 to 18).

The comments on the two compared methods are reported at the end of the document.

Euro Inox and CTICM methods for room temperature

The formula to be used in the case of Class 1, 2 and 3 cross-section is the following one:

$$N_{b,Rd} = \chi \cdot A \cdot f_y / \gamma_M \quad (1)$$

where:

$$\chi = \frac{1}{\varphi + \sqrt{\varphi^2 - \bar{\lambda}^2}} \leq 1 \text{ (reduction factor for flexural buckling)} \quad (2)$$

$$\varphi = \frac{1}{2} \cdot \left(1 + \alpha \cdot \left(\bar{\lambda} - \bar{\lambda}_0\right) + \bar{\lambda}^2\right) \quad (3)$$

$$\alpha = 0.49 \text{ (product typology-dependent imperfection factor)} \quad (4)$$

$$\lambda_0 = 0.20 \text{ (limiting non-dimensional slenderness)} \quad (5)$$

$$\bar{\lambda} = \sqrt{\frac{A \cdot f_y}{N_{cr}}} \text{ (non-dimensional slenderness)} \quad (6)$$

$$N_{cr} = AE\left(\frac{i\pi}{L_{cr}}\right)^2 \text{ (elastic critical force for the relevant buckling mode)} \quad (7)$$

i and L_{cr} are, respectively, the radius of gyration about the relevant axis, and the buckling length in the considered buckling plane; γ_M is the partial safety factor.
In the case of Class 4 cross-section, the same formulas as for the other Classes shall be used, but the area (A) shall be replaced by the effective area (A_{eff}) in (1) and in (6):

$$N_{b,Rd} = \chi \cdot A_{eff} \cdot f_y / \gamma_M \quad (8)$$

$$\overline{\lambda} = \sqrt{\frac{A_{eff} \cdot f_y}{N_{cr}}} \quad (9)$$

Euro Inox method for high temperatures

The design buckling resistance of a compression member in the case of Class 1, 2 and 3 cross-sections is given by:

$$N_{b,fi,Rd} = \chi_{fi} \cdot A \cdot k_{y,\theta} \cdot f_y / \gamma_{M,fi} \quad (10)$$

where, in addition to the parameters already explained:

$$\chi_{fi} = \frac{1}{\varphi_\theta + \sqrt{\varphi_\theta^2 - \overline{\lambda}_\theta^2}} \text{ (reduction factor for flexural buckling in the fire design situation)} \quad (11)$$

$$\varphi_\theta = \frac{1}{2} \cdot \left(1 + \alpha \cdot \overline{\lambda}_\theta + \overline{\lambda}_\theta^2\right) \quad (12)$$

$$\alpha = 0.65\sqrt{\frac{235}{f_y}} \text{ (steel grade-dependent imperfection factor)} \quad (13)$$

$$\overline{\lambda}_\theta = \overline{\lambda} \cdot \sqrt{\frac{k_{y,\theta}}{k_{E,\theta}}} \text{ (modified non-dimensional slenderness)} \quad (14)$$

$\gamma_{M,fi}$ is the in-fire situation partial safety factor for the relevant material property. In the case of Class 4 cross-section, the formula to be used is the same as for the other Classes, but the area shall be replaced by the effective area and the design yield strength of steel should be taken as the 0,2 percent proof strength:

$$N_{b,fi,Rd} = \chi_{fi} \cdot A_{eff} \cdot k_{0.2p,\theta} \cdot f_y / \gamma_{M,fi} \quad (15)$$

$$\overline{\lambda}_\theta = \overline{\lambda} \cdot \sqrt{\frac{k_{0.2p,\theta}}{k_{E,\theta}}} \quad (16)$$

CTICM method for high temperatures

For Class 1, 2 and 3 cross-section the following formula is given:

$$N_{b,fi,Rd} = \chi_{fi} \cdot A \cdot k_{0.2p,\vartheta} \cdot f_y / \gamma_{M,fi} \quad (17)$$

where:

$$\chi_{fi} = \frac{1}{\varphi_\vartheta + \sqrt{\varphi_\vartheta^{\,2} - \overline{\lambda}_\vartheta^{\,2}}} \leq 1 \tag{18}$$

$$\varphi_\vartheta = \frac{1}{2} \cdot \left(1 + \alpha \cdot \left(\overline{\lambda}_\vartheta - \overline{\lambda}_0\right) + \overline{\lambda}_\vartheta^{\,2}\right) \tag{19}$$

$\alpha = 0.49$ (product typology-dependent imperfection factor) (20)

$\lambda_0 = 0.20$ (limiting non-dimensional slenderness) (21)

$\overline{\lambda}_\vartheta = \overline{\lambda} \cdot \sqrt{\frac{k_{0.2p,\vartheta}}{k_{E,\vartheta}}}$ (modified non-dimensional slenderness) (22)

In the case of Class 4 cross-section, the area shall be replaced by the effective area in (17):

$$N_{b,fi,Rd} = \chi_{fi} \cdot A_{eff} \cdot k_{0.2p,\vartheta} \cdot f_y / \gamma_{M,fi} \tag{23}$$

Table 6 – Experimental data on stainless steel column buckling behaviour at elevated temperature.

ID	Cross-section	Class	A (A_{eff}) [mm^2]	J (J_{eff}) [mm^4]	Grade	f_y [MPa]	f_u [MPa]	E [GPa]	l_0 [mm]	$\bar{\lambda}$	$N_{b,Rd}$ [kN]	$F_{applied}$ [kN]	Critical temp. [°C]
SCI (1)	RHS 150x100x6	1	2852	4472392	1.4301	262	625[1)]	200	1700	0,49	705	268	801
SCI (2)	RHS 150x75x6	1	2555	2299500	1.4301	262	625[1)]	200	1700	0,65	561	140	883
SCI (3)	RHS 100x75x6	1	1973	1799455	1.4301	262	625[1)]	200	1700	0,65	435	156	806
SCI (4)	Double C 200x150x6	4	3233	[2)]	1.4301	262	625[1)]	200	1700	0,66	704	413	571
CTICM (1)	RHS 100x100x4	2	1470	2260000	1.4301	298	625[1)]	200	3990	1,25	190	80	835
CTICM (2)	RHS 200x200x4	4	2111	[2)]	1.4301	298	625[1)]	200	3990	0,51	587	230	820
CTICM (3)	RHS 100x100x3	4	979	1770000	1.4318 C700	360,5	750[1)]	200	3140	1,00	207	52	835
CTICM (4)	RHS 100x100x3	4	813	1770000	1.4318 C800	629	850[1)]	200	3140	1,20	236	52	880
VTT (1)	RHS 40x40x4	1	535	111000	1.4301	592	736	170	887	1,16	237	8 different points [2]	
VTT (2)	RHS 40x40x4	1	535	111000	1.4571	545	670	170	887	1,11	237	4 different points [2]	
VTT (3)	RHS 30x30x3	1	301	35000	1.4301	576	712	170	887	1,52	75	4 different points [2]	

[1)] experimental value not available, so value indicated by the Standard is used.
[2)] value not available.

Material reduction factors ($k_{0.2p,\vartheta}$, $k_{2\%,\vartheta}$, $k_{E,\vartheta}$, $k_{y,\vartheta}$) used in the analysis are those suggested by prEN 1993-1-2:2004.
For the steel grade 1.4318 (C700 and C850) both the reduction factors referred to EN 1.4301 and those proposed by CTICM in the Coldworked project are used.

The buckling resistance curves, of course, are sensitive to the actual material strength parameters f_y , f_u and *E*, but in a different way depending on the method applied:

- in the Euro Inox method, for cross-sections other than the Class 4 classified ones, $k_{y,\vartheta}$ is used instead of $k_{0.2p,\vartheta}$, so buckling resistance is dependent on actual values of both f_y and f_u (the parameter f_y is used for the determination of the imperfection factor α too);

- in the CTICM method, actual values of f_y are used only to determine $N_{b,fi,Rd}$. The actual value of f_u has no influence on the buckling strength at elevated temperature: the buckling reduction coefficient χ_{fi} depends on (standardized) material reduction factors and on the cross-sectional typology (open section, hollow section, etc.) for the determination of the imperfection factor α .

The sensitiveness of the two methods to the f_u parameter is shown in Figure 14. The values of f_y , f_u and *E* shown in Table 6 have been obtained as follows:

f_y experimental values (indicated in the documents from SCI and VTT);

f_u experimental values are available only for VTT tests. Data concerning SCI and CTICM tests are the average values in the range indicated by the relevant Standard (EN 10088, EC3-1-4); more in detail:

Grade	f_u [MPa]	Standard
1.4301	625	EN 10088
1.4318 C700	750	EN 10088
1.4318 C850	850	prEN 1993-1-4

E standard value 200 GPa, except for VTT tests where a value of $0.85 \cdot E$ (= 170 GPa) is suggested.

Due to the fact that for SCI and CTICM tests actual value of f_u is not available, some curves have been generated with two different values for this parameter: a mean value in the range indicated by the relevant standard, and the maximum consented value. For example, stainless steel grade EN 1.4301 has an R_m value ranging from 500 to 750 MPa according to EN 10088, so values of f_u equal to 625 MPa and 750 MPa have been used in the analysis.

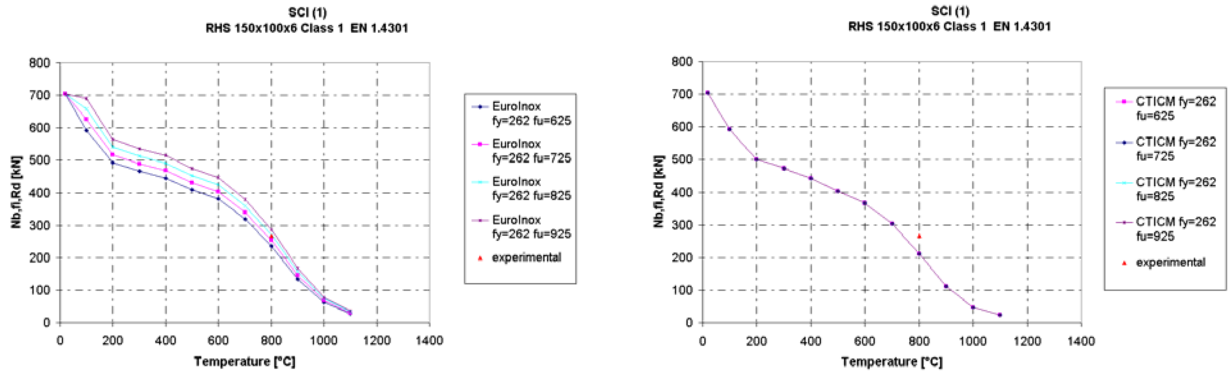


Figure 14 – Sensitiveness of the two methods to the f_u parameter: on the left, the EuroInox method, on the right the CTICM method.

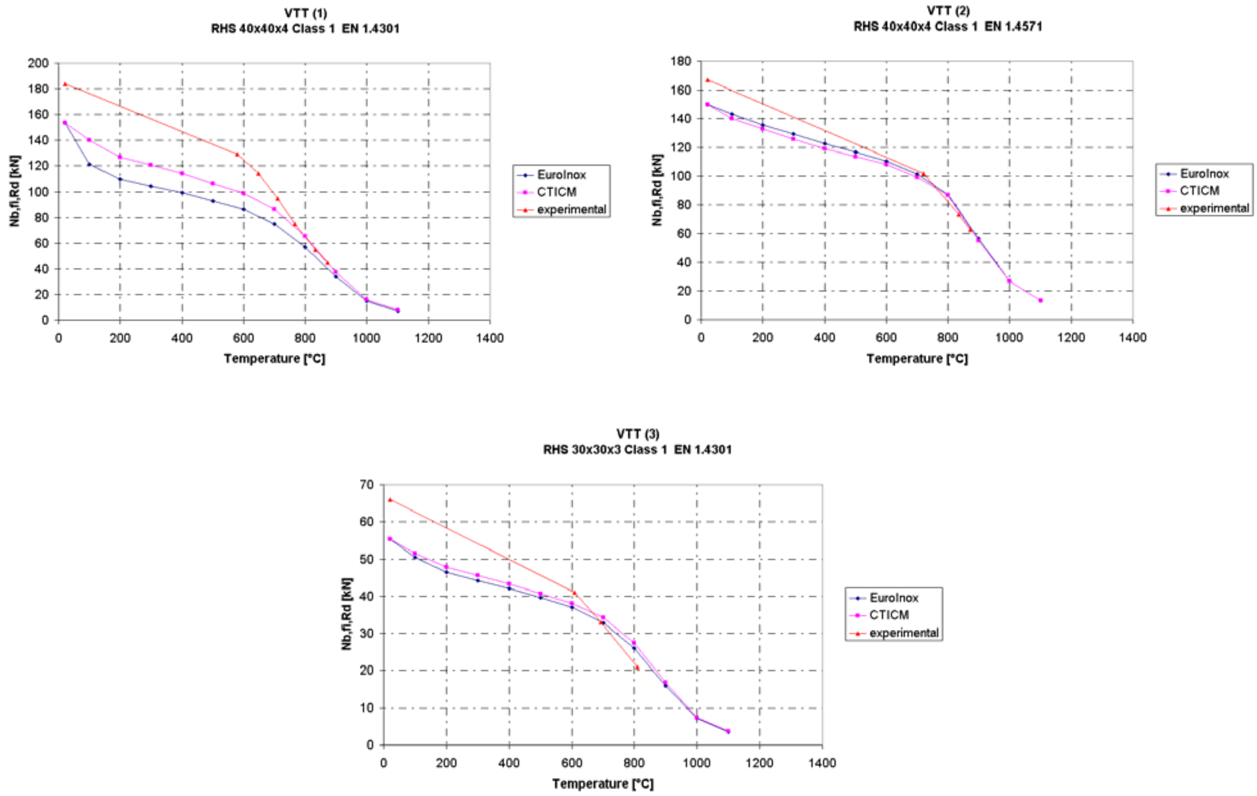


Figure 15 - Column buckling tests from VTT, data reported in Table 6.

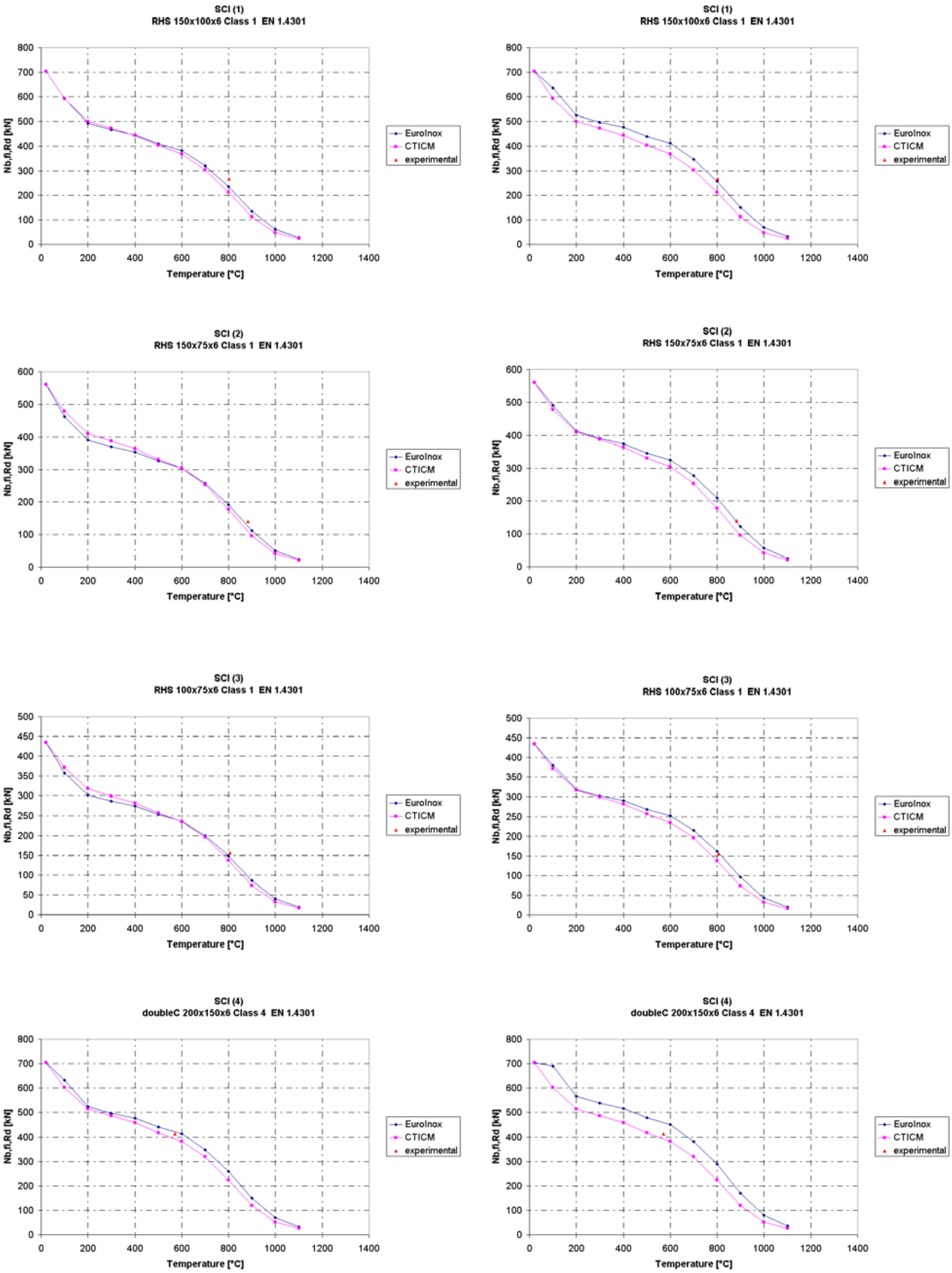


Figure 16 - Column buckling tests from SCI, data reported in Table 6. On the left, the Euro Inox curve is generated for f_u = 625 MPa, on the right for f_u = 750 MPa.

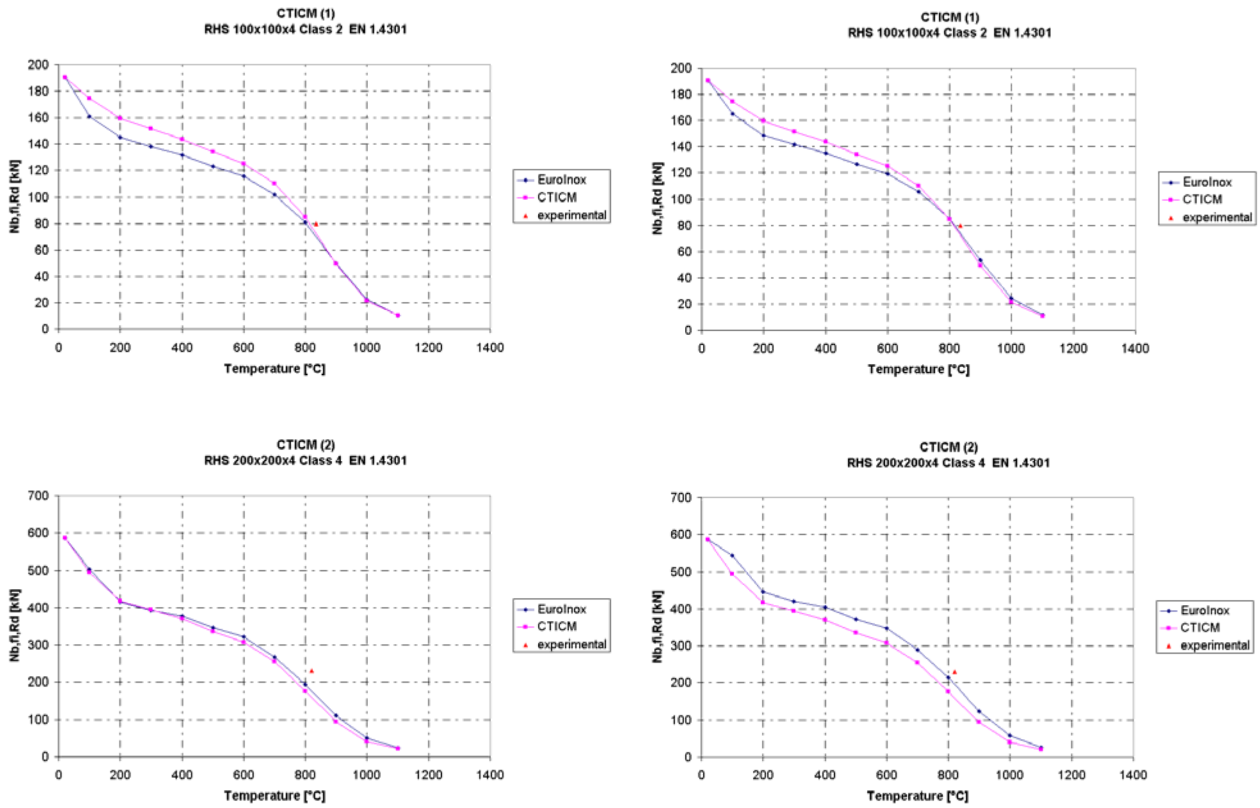


Figure 17 - Column buckling tests from CTICM, data reported in Table 6. On the left the Euro Inox curve is generated for f_u = 625 MPa, on the right for f_u = 750 MPa.

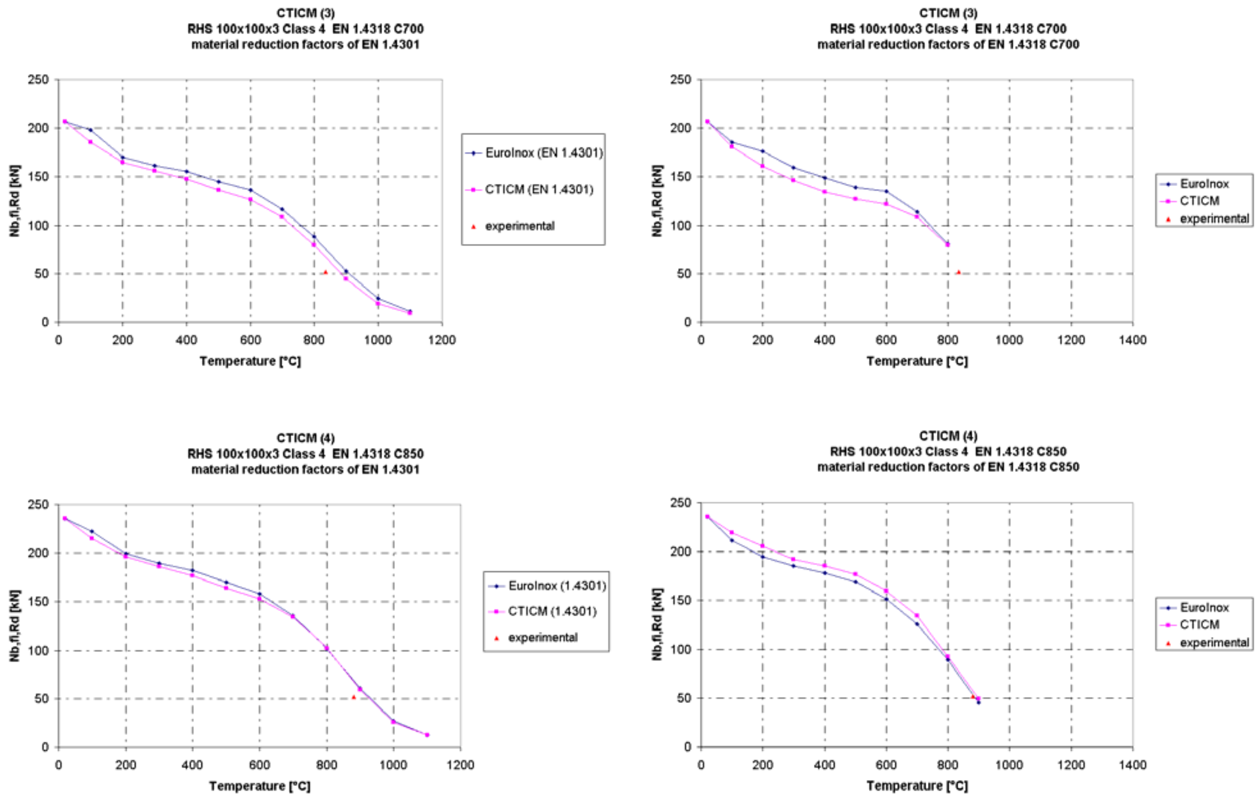


Figure 18 - Column buckling tests from CTICM (Coldworked project), data reported in Table 6. On the left, both of the design curves are generated with material reduction factors of grade EN 1.4301; on the right, the material reduction factors used are those experimentally derived during Coldworked project.

Comments

The curves generated with the two different methods are not very different each other, at the temperatures which experimental data are available of: both of them seem to match well the available experimental data; the exception is the case of coldworked stainless steel (see Figure 18).

The Euro Inox method is less easy to be applied by the designers because it involves a parameter in addition, f_u, which has to be determined experimentally, while the CTICM method is an easy extension of design buckling method for stainless steel at room temperature (EN 1993-1-4).

Due to the fact that the curves generated are very similar each other, it would be better to adopt the easier method because it will lead to an easier utilization of stainless steel in construction.

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PRECEDENTI RIFERIMENTI SULLA COMMESSA
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