Structural Applications of Ferritic Stainless Steels (SAFSS)

Task 8.1 – Recommendations for amendments to EN 1993-1 and EN 1994-1

Introduction

A three year research project has been completed studying the applicability of ferritic stainless steels to structural applications. As a result of this work, the following recommendations are made to. Some of the recommendations are specific and some are general in nature, i.e. that a given topic requires further investigation and analysis because the outcomes of the SAFSS project did not lead to a definitive design recommendation. A few of the recommendations have an impact on the design of other families of stainless steel, which will need assessing in the future.

Recommendations for EN 1993-1-4:2014

(Note that these recommendations are in relation to the forthcoming version of EN 1993-1-4 which is due to be published in late 2014 or early 2015)

Clause	Current text	Recommendation and justification
Table 2.1 Grades to which the design rules apply	Current ferritic grades: 1.4003, 1.4016 and 1.4512	Add more ferritic grades: 1.4509, 1.4521, 1.4621 *Unless noted below, the SAFSS project showed that the rules in EN 1993-1-4:2014 can safely be applied to these ferritic grades [1].* Remove grade 1.4512 *This grade is not used for structural applications.*
2.1.3(1) Design values of material coefficients	The following values of the material coefficients may be assumed for the global analysis and in determining the resistances of members and cross-sections: - Modulus of elasticity, E: E = 220 000 N/mm^2 for the ferritic grades in Table 2.1	For design purposes, the following values of the material coefficients are recommended: - Modulus of elasticity, E = 200,000 N/mm^2 *Tests have shown that E=220,000 N/mm^2 is too high for ferritic stainless steels, even though this is the value given in EN 10088-1:2005.*
2.1.4(2) Fracture toughness	For ferritic stainless steels, the rules in EN 1993-1-10 give guidance. Required testing temperature and required CVN-values may be determined from Table 2.1 of EN 1993-1-10. NOTE 1: Ferritic steels are not classified into sub-grades. NOTE 2: The National Annex may provide further information on fracture toughness of ferritic stainless steels.	Delete current clause. Perhaps consider some limits on thickness, grade and service temperature for ferritics. *EN 1993-1-10 does not give guidance relevant to ferritics. Generally, ferritics are only likely to be used in thin sections, apart from 1.4003 which has superior toughness. More work needed to derive definitive guidance based on fracture toughness measurements.*
2.1.5(1) Through-thickness properties	Guidance on the choice of through-thickness properties is given in EN 1993-1-10. NOTE: The National Annex may provide further information on the choice of through thickness properties	Revise *Lamellar tearing has not been observed in stainless* steels

Clause	Current text	Recommendation and justification
Table 4.1 Values of n	1.4003: n_{longit} = 7, n_{trans} = 11 1.4016: n_{longit} = 6, n_{trans} = 14 1.4512: n_{longit} = 9, n_{trans} = 16	*Discuss replacing these values with one conservative value which represents all ferritics and both load directions. A conservative value of 7.9 has been recommended for cold formed ferritics [2], but it might be too conservative for non-cold formed material. To be discussed further.*
Table 5.2 Classification of cross-sections		Outstand elements of channel sections should be classified according to width-to-thickness definition of EN 1993-1-1. Relevant slenderness of square/rectangular hollow sections should be defined using the flat part of the section.
Table 5.3 Flexural buckling curves	For hollow sections made from **any** stainless steel, use the buckling curve (α=0.49 and $\overline{\lambda}_0$ = 0.4)	For cold-rolled hollow sections made from ferritic stainless steel, use the carbon steel buckling curve (α=0.49 and $\overline{\lambda}_0$ = 0.2)
5.8 Web crippling *(New section needed)*		Clause 6.1.7.3 of EN 1993-1-3 is not <u>always</u> safe when applied to ferritic stainless steel RHS under IOF loading for lower values of f_y and smaller bearing lengths (depending also on the slenderness and *r*/*t*). *Section 6 of the SAFSS Final Report gives a recommended expression, still undergoing refinement* [1].
6.2 Bolted connections (and screwed connections)		To ensure that the deformation at the fasteners is limited to about 1 mm at SLS, an extra reduction factor of 0.9 should be considered for block tearing resistance of bolted connections and bearing resistance of screwed connections
8(1) Fatigue **EN 1993-1-9 Fatigue 1.1(4)**	For determining the fatigue strength of stainless steel structures, reference should be made to EN 1993-1-9. The assessment methods given in this part are applicable to all grades of structural steels, stainless steels and unprotected weathering steels except where noted otherwise in the detail category tables. This part only applies to materials which conform to the toughness requirements of EN 1993-1-10.	Discuss with EG for EN 1993-1-9 about the requirement in EN 1993-1-9 that the rules only apply to materials which comply with EN 1993-1-10. *Ferritics do not comply with EN 1993-1-10. But from the literature, there is no indication that the carbon steel ferritic rules do not apply to ferritics.*
Annex A Material selection and durability	Guidance currently only covers austenitic and duplex stainless steels	Include guidance given in Section 12 of the SAFSS Final Report [1].

Clause	Current text	Recommendation and justification
Annex C, C.2(2) Material modelling		Replace the existing expressions with the following *The existing expressions do not describe the material behaviour of all the families of stainless steel correctly:*
	$n = \frac{\log 20}{\log\left(\frac{\sigma_{0.2}}{\sigma_{0.01}}\right)}$	$n = \frac{\log 4}{\log\left(\frac{\sigma_{0.2}}{\sigma_{0.05}}\right)}$ All families
	$m = 1 + 3.5\frac{\sigma_{0.2}}{\sigma_u}$	$m = \begin{cases} 1 + 2.3\frac{\sigma_{0.2}}{\sigma_u} & \text{Austenitic \& ferritic} \\ 1 + 3.5\frac{\sigma_{0.2}}{\sigma_u} & \text{Duplex} \end{cases}$
		$\frac{\sigma_{0.2}}{\sigma_u} = \begin{cases} 0.2 + 185\frac{\sigma_{0.2}}{E_0} & \text{Austenitic \& duplex} \\ 0.46 + 145\frac{\sigma_{0.2}}{E_0} & \text{Ferritic} \end{cases}$
	$\varepsilon_u = 1 - \frac{\sigma_{0.2}}{\sigma_u}$	$\varepsilon_u = \begin{cases} 1 - \frac{\sigma_{0.2}}{\sigma_u} & \text{Austenitic \& duplex} \\ 0.5 - 0.5\frac{\sigma_{0.2}}{\sigma_u} & \text{Ferritic} \end{cases}$

Recommendations for EN 1993-1-2:2005 Structural Fire Design

Clause	Current text	Recommendation and justification
3 Material properties and **C.1(1)**	The thermal and mechanical properties of following stainless are given in this annex: 1.4301, 1.4401, 1.4571, 1.4003 and 1.4462.	Modify the text to extend the scope of Annex C to cover 1.4016, 1.4509, 1.4521, 1.4621
Table C.1	Factors for determination of strain and stiffness of stainless steel at elevated temperatures	Add new data for ferritics from SAFSS Final Report Section 8 [1].
C.3.1 Thermal elongation		Add expression for ferritic stainless steel

EN 10088-1 (1.4003) extrapolated

Thermal expansion coeff x 10^{-6}/°C	Temp °C
0.00	20
10.39	100
10.82	200
11.22	300
11.60	400
11.95	500
12.28	600
12.58	700
12.86	800

<table>
<tr><th>Clause</th><th>Current text</th><th>Recommendation and justification</th></tr>
<tr><td>C.3.2
Specific heat</td><td></td><td>Add expression for ferritic stainless steel

<table>
<tr><td colspan="2">Stahldaten mean specific heat (1.4003) extrapolated</td></tr>
<tr><td>Specific heat J/kgK</td><td>Temp °C</td></tr>
<tr><td>429</td><td>20</td></tr>
<tr><td>464</td><td>100</td></tr>
<tr><td>492</td><td>200</td></tr>
<tr><td>511</td><td>300</td></tr>
<tr><td>531</td><td>400</td></tr>
<tr><td>554</td><td>500</td></tr>
<tr><td>585</td><td>600</td></tr>
<tr><td>626</td><td>700</td></tr>
<tr><td>642</td><td>800</td></tr>
</table>
</td></tr>
<tr><td>C.3.3
Thermal conductivity</td><td></td><td>Add expression for ferritic stainless steel:

<table>
<tr><td colspan="2">Stahldaten (1.4003) extrapolated</td></tr>
<tr><td>Thermal conductivity W/mK</td><td>Temp °C</td></tr>
<tr><td>20.83</td><td>20</td></tr>
<tr><td>22.49</td><td>100</td></tr>
<tr><td>24.29</td><td>200</td></tr>
<tr><td>25.79</td><td>300</td></tr>
<tr><td>26.98</td><td>400</td></tr>
<tr><td>27.88</td><td>500</td></tr>
<tr><td>28.47</td><td>600</td></tr>
<tr><td>28.76</td><td>700</td></tr>
<tr><td>28.74</td><td>800</td></tr>
</table>
</td></tr>
<tr><td>4
Structural fire design</td><td></td><td>Consider modifying the structural fire design rules to enable less conservative design.</td></tr>
</table>

Recommendations for EN 1993-1-3:2005 Supplementary rules for cold-formed members and sheeting

<table>
<tr><th>Clause</th><th>Current text</th><th>Recommendation and justification</th></tr>
<tr><td rowspan="2">6.1.7.3
Local transv. forces - Cross-sections with two or more unstiffened webs</td><td>Eqn 6.18

$R_{w,Rd} = \alpha t^2 \sqrt{f_{yb} E}\left(1 - 0{,}1\sqrt{r/t}\right)\left[0{,}5 + \sqrt{0{,}02\, l_a / t}\right]\left(2{,}4 + (\phi/90)^2\right)/\gamma_{M1}$</td><td></td></tr>
<tr><td></td><td>This expression is not applicable to RHS.

Consider revising this equation, or including another expression which is applicable to RHS.</td></tr>
</table>

Recommendations for EN 1994-1-1:2005 Design of composite steel and concrete structures. General rules and rules for buildings

Clause	Current text	Recommendation and justification
3.3(1) Structural Steel	Properties should be obtained by reference to EN 1993-1-1, 3.1 and 3.2.	Discussion about extending the scope to ferritic stainless steels – but further investigation needed regarding first slip at SLS.

References

[1] Structural Applications of Ferritic Stainless Steels, Final Summary Report, March 2014, and 36 WP deliverables, downloadable from www.steel-stainless.org/ferritics

[2] Afshan, S., Rossi, B., and Gardner, L. 2013. Strength enhancements in cold-formed structural sections - Part I: Material testing . Journal of Constructional Steel Research, Vol 83, 177-188.