Technical information sheet ED023

Steel Knowledge

Structural Design of Ferritic Stainless Steels

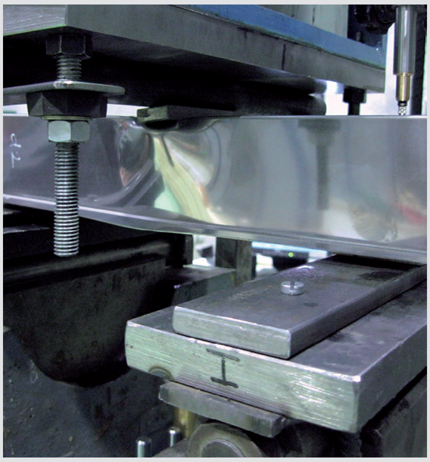
This information sheet is written for engineers and architects and gives guidance on the structural design of ferritic stainless steels. Much of the information was developed as part of the EU's Research Fund for Coal and Steel project *Structural Applications of Ferritic Stainless Steels (SAFSS)*. This was a three year research project which was completed in 2013. The project partners included stainless steel producers, research institutes, universities and design consultants. Through experimental tests, field trials and numerical analysis, the project developed design guidance for a group of ferritic stainless steels which are suitable for structural applications.

Key advantages of ferritic stainless steels

- Good atmospheric corrosion resistance.
- Higher yield strength relative to carbon steel S275 and austenitic stainless steels.
- Less non-linear yielding behaviour compared with the austenitic grades.
- Lower cost than other grades of stainless steel of equivalent corrosion resistance.
- Easier to roll form and achieve flatness, and less weld distortion, compared to austenitic stainless steels.

Summary

Ferritics are a family of stainless steels which are low cost, price-stable and versatile. They display considerably better atmospheric corrosion resistance than carbon steels, as well as having good ductility and formability. Their structural performance in terms of strength and stiffness lies between that of carbon steel and the more highly alloyed stainless steel austenitics and duplexes. These factors combine to make ferritic stainless steels a corrosion resistant alternative to many light gauge galvanized steel applications such as purlins, cladding or service support systems, and composite floor decking. The Summary Final Report and detailed reports for each work package of the SAFSS project, from which this technical information is derived, can be downloaded from www.steel-stainless.org/ferritics.



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Introduction

What are ferritic stainless steels?

Stainless steel is the name given to a family of corrosion and heat resistant steel alloys containing a minimum of 10.5% chromium. There is a range of stainless steels meeting different corrosion resistance, strength, weldability and toughness requirements. With a chromium content above 10.5%, a clean surface and exposure to air or any other oxidizing environment, a transparent and tightly adherent layer of chromium-rich oxide forms spontaneously on the surface of the stainless steel. If scratching or cutting damages the film, it will reform immediately in the presence of oxygen.

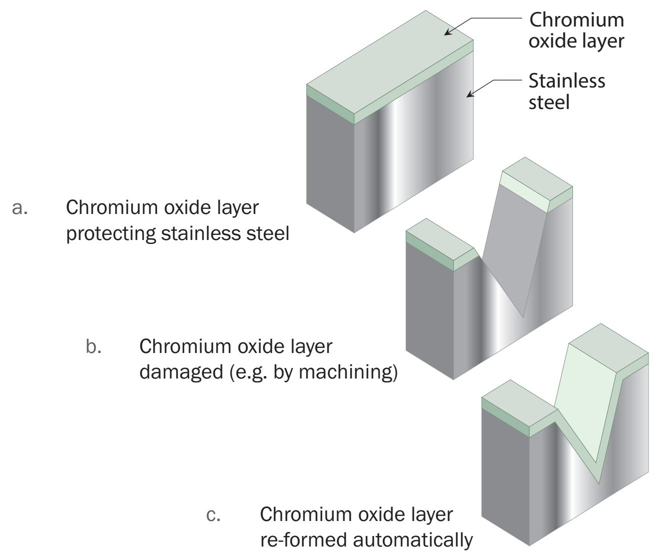


Figure 1 Stainless steel has a protective chromium oxide surface film

The stability of the film depends on the composition of the stainless steel and the corrosiveness of its environment, as well as other factors. Its stability increases as the chromium content increases and is further enhanced by alloying additions of molybdenum. Unlike galvanized or painted steel, there are no applied protective surface layers and no remedial work is needed at cut edges.

Ferritic stainless steels ('ferritics') contain little, or no, nickel additions. This makes them relatively cost-effective and price-stable compared with austenitic stainless steels, the family of stainless steels more commonly used in structural applications, which do contain nickel. The cost of nickel-containing materials is strongly dependent on the LME (London Metal Exchange) nickel price which has traditionally been highly volatile and periodically shows dramatic increases (e.g. between 2005 and 2008), that distort the market price.

Apart from enhanced durability, ferritics have similar properties to structural carbon steels, although the toughness is somewhat limited at low temperatures and in heavy sections, except for grade 1.4003. As for other families of stainless steel, the non-linear stress-strain characteristics mean that some differences are required in structural design, compared to carbon steel, for example the buckling curves for cross-sections and members.

Why use ferritic stainless steels in structures?

Ferritics are used for cladding and roofing and in the transportation sector for load-bearing members, for example tubular bus frames. They also have a good track record of usage in coal wagons, where wet sliding abrasion resistance is important. The characteristics of ferritics make them appropriate for structures requiring strong and moderately durable structural elements with attractive metallic surface finishes. For composite structures where a long service life is required, or where the environmental conditions are moderately corrosive, ferritic decking may provide a more economically viable solution than galvanized decking which would struggle to retain adequate durability for periods greater than 25 years.

In South Africa, the ferritic grade 3Cr12 (similar in composition to the European grade 1.4003) has been successfully used for a range of industrial structures for more than 30 years, including structural steelwork for shaft supports in gold mines and railway electrification masts along the coast. Although these structures have shown surface corrosion and pitting, their structural integrity has not been affected. This grade has also been used recently in large quantities in Australia's coal industry for rail wagons.

In addition to composite floor systems, other potential applications where ferritic stainless steels are a suitable substitute for galvanized steel include permanent formwork, roof purlins and supports to services such as cable trays. They could also be used economically in semi-enclosed unheated environments (e.g. railways, grandstands, bicycle sheds) and in cladding support systems, windposts and for masonry supports.

One possible new application for ferritics is the supporting structure for solar panels, particularly in desert locations where the abrasive effect of the sand can be harmful to galvanized steel.

Ferritics can be seen as complementary to duplex stainless steels, which are more likely to be used in heavier gauges, say 2 mm and above, with the ferritics generally finding application in gauges of 3 mm and below.

Specification of Ferritic Stainless Steels

Material grades

There are a range of ferritic grades satisfying different requirements of corrosion resistance, strength, weldability and toughness. They are specified in accordance with European Standard EN 10088[1]. The relevant parts for use in construction applications are Part 4 and Part 5 which are harmonised standards.

Harmonised standards have been prepared on behalf of the European Commission against a mandate under the Construction Products Regulation (CPR). They incorporate information defined by the European Commission as being relevant to CE marking. As a result, compliance with them can allow the manufacturer to affix CE marking.

Part 1 of EN 10088 defines chemical compositions and reference data on some physical properties relevant for structural applications such as modulus of elasticity, E.

Part 4 of EN 10088 defines the properties and compositions for sheet, strip and plate. Part 5 gives the equivalent information for long products, such as bar and rod. These standards also define the type of process route and surface finish.

This information sheet covers the ferritic grades shown in Table 1 and guidance is limited to applications involving flat material less than 6 mm thick. Table 1 gives the grade designations in accordance with EN 10088, the US system specified by the American Iron and Steel Institute (AISI) and the Unified Numbering System (UNS). Hereafter, this information sheet refers to the grades only by their European number. The table also gives the product forms in which each grade is available. The durability and cost of the grades increase going down the table as the content of additional alloying elements increases.

Surface finish

Stainless steels offer a significant advantage over carbon steels because they can be used unprotected in a range of surface finishes from mill finish through dull finishes to bright polish. Although the various finishes are standardised in EN 10088, variability in processing introduces differences in appearance between manufacturers and even from a single producer. For structural applications, the common finishes are 1D (hot rolled) and 2B (cold rolled). Bright finishes are frequently used in architectural applications though they will exaggerate any out-of-flatness of the material, particularly on panel surfaces.

EN	AISI	UNS	CHROMIUM CONTENT (%)	OTHER KEY ALLOYING ELEMENTS (%)	PRODUCT FORMS
1.4003	-	S41003 / S40977	10.5 - 12.5	-	Cold rolled strip (generally $t < 3$ mm), Hot rolled strip, Hot rolled plate, Tubular sections (generally $t < 4$ mm)
1.4016	430	S43000	16.0 - 18.0	-	Cold rolled strip (generally $t < 4$ mm), Hot rolled strip, Hot rolled plate, Tubular sections (generally $t < 2.5$ mm)
1.4509	441	S43932	17.5 - 18.5	Titanium, Niobium	Cold rolled strip (generally $t < 4.5$ mm), Hot rolled strip, Tubular sections (generally $t < 2.5$ mm)
1.4621	445	S44500	20.0 - 21.5	Niobium, Copper	Cold rolled strip (generally $t < 2$ mm)
1.4521	444	S44400	17.0 - 20.0	Molybdenum, Titanium and/ or Niobium and/or Zirconium	Cold rolled strip (generally $t < 4$ mm), Tubular sections (generally $t < 2.5$ mm)

Table 1 Grades of ferritic stainless steels covered in this information sheet

The following grades can be described as 'standard' ferritic and are commonly available:

1.4003 is a basic ferritic grade with the lowest chromium content of the ferritic grades in the table ($\approx$ 11%). It is sometimes called a 'utility' grade.

1.4016 contains around 16.5% chromium, and has a greater resistance to corrosion than 1.4003. It is the most widely used ferritic stainless steel grade.

The following grades can be described as 'special' or 'stabilised' ferritic grades, and are less widely available. They contain additional alloying elements such as niobium or titanium which improve weldability and formability:

1.4509 contains about 18% chromium.

1.4621 is a recently developed ferritic grade that contains around 20% chromium. It has improved polishability compared to 1.4509 and 1.4521.

1.4521 contains a similar amount of chromium as 1.4509 and 2% molybdenum which gives better pitting and crevice corrosion resistance in chloride containing environments.

Material Selection and Durability

Corrosion resistance

The selection of stainless steel for a particular application is dependent on the exposure condition and service environment. The more severe the environment, the more highly alloyed stainless steel is required to provide corrosion-free performance. The corrosion resistance of stainless steels in naturally occurring atmospheres is generally good, but specific exposure conditions can result in poor performance with respect to corrosion. In particular, chlorides from the sea, road de-icing salts or other sources can result in general staining or pitting of exposed surfaces.

For structural components, structural integrity is rarely affected by staining and pitting, however it is unsightly for applications where appearance is important. Generally, the higher the content of chromium and molybdenum, the better the corrosion resistance. The corrosion performance may also be affected by the quality of the surface finish: generally, the smoother the finish, the less risk of staining and pitting corrosion.

There is no accepted or standardised method of classifying the environments and corrosion performance of stainless steels used in construction. Instead, guidance for using austenitic and duplex stainless steels is based on experience, both good and bad, built up over many years. Such experience does not exist for most ferritic grades.

For carbon steels and galvanized steels, the most widely used classification method of atmospheric corrosivity is that given in ISO 9223[2]. This method links the corrosion rate of steel to three measurable environmental parameters: time of wetness (TOW), chloride deposition rate and sulphur dioxide deposition rate. It establishes well-known classifications, C1 to C5 and CX, which are used to determine the appropriate protection method for carbon steel.

Atmospheric exposure tests

The SAFSS project included a comprehensive study into the durability of ferritic stainless steel in various atmospheric environments. Flat sheets, as well as welded and bolted specimens, were investigated by exposing samples for up to 18 months in Seville (Spain), Isbergues (France), Ljubljana (Slovenia) and Tornio (Finland), representing a range of typical environments (Figure 2). Both hot rolled and cold rolled samples were studied. The grades studied were 1.4003, 1.4509, 1.4621 and 1.4521.

The atmospheric variables given in ISO 9223 were measured at the four locations for the 18 month period. The test sites all used standard panels fully exposed at an angle of 45° (other orientations, which are more representative of real structures, may give different performance).

The environmental data obtained were used to calculate a predicted corrosion rate of carbon steel using the dose response function given in ISO 9223. This corrosion rate was then related back to the environment category in ISO 9223. The original site selection intended to cover rural, industrial / urban and coastal locations. However, the actual data gathered indicated that the coastal site (Tornio, Finland) recorded very low chloride deposition rates and could not be considered representative of European coastal locations, which typically have higher chloride deposition. The resulting environment categories for the four test locations were C2 for Tornio, Seville and Ljubljana, and C3 for Isbergues.

Based on a qualitative assessment of the extent of corrosion on the panels, a correlation between the environment category and appropriate use of the different alloys was assumed.

Figure 2 Ferritic stainless steel atmospheric exposure tests

Table 2 provides guidance on alloy selection with no tolerance of visible staining on the exposed surface. Table 3 provides guidance where cosmetic corrosion, staining and minor pitting may occur but will not affect the structural integrity of the component.

ALLOY DESIGNATION	ENVIRONMENT CATEGORY					
	C1	C2	C3	C4	C5	CX
1.4003						
1.4509						
1.4621						
1.4521						

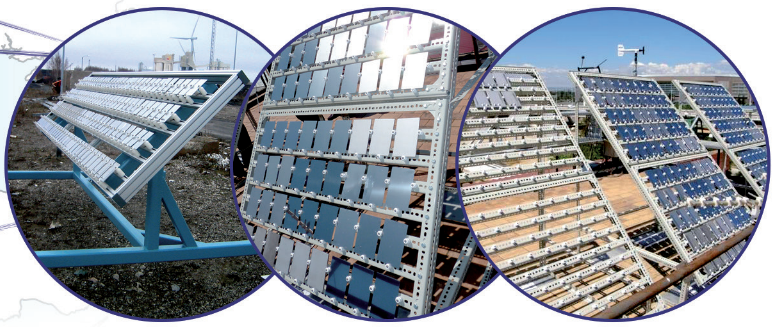
Table 2 Alloy selection for high quality finish

ALLOY DESIGNATION	ENVIRONMENT CATEGORY					
	C1	C2	C3	C4	C5	CX
1.4003						
1.4509						
1.4621						
1.4521						

Table 3 Alloy selection with tolerance of cosmetic corrosion

Notes to Tables

1) Green cells indicate the alloy is appropriate for the environment classification.
2) Red cells indicate the alloy is inappropriate for the service environment.
3) Yellow cells indicate caution is required for these combinations of alloy and environment. There is a risk of staining and localised corrosion at exposed welds and fixings. This risk is greatest where stagnant water and/or atmospheric pollutants (particularly chlorides) may accumulate.
4) None of the test locations were classified as C4, C5 or CX so it is not possible to provide guidance for these environments based on the SAFSS research.
5) The C1 classification assumes the service condition is an internal environment with no direct exposure to the weather or chlorides. This would include unheated areas of buildings such as roof spaces, perimeter walls and steel behind cladding.
6) Welds and mechanical fixings through stainless steels produce crevices which may be more susceptible to corrosion on exposed panels. This risk is greatest where the surfaces allow accumulation of water or atmospheric pollutants.
7) There are variations in the performance of steels from different producers at the same test site due to variations in surface condition, including whether the steel is hot or cold rolled: the guidance in the tables is based on the worst case performance of a given alloy at the test sites.
8) None of the test sites showed significant chloride deposition rates on the sample panels. The designer should take this into account when considering applications close to roads where de-icing salts may be used or where wind-blown chlorides from the sea may contaminate surfaces of the structure.



Laboratory corrosion tests

In addition to the atmospheric exposure tests, accelerated corrosion and electrochemical tests were carried out under the SAFSS project. These tests are useful in comparing the relative performance of different alloys, but the environments to which the samples are exposed during these laboratory tests are not representative of typical atmospheric environments.

For the accelerated corrosion tests, samples of various grades and surface finishes were subjected to alternate cycles of salt spray fog, humidity and temperature variations and the extent of corrosion quantified. Grade 1.4003 suffered the most corrosion, followed by 1.4016, then 1.4509. The best response was obtained from 1.4621 and 1.4521. The surface finish (1D or 2B) did not appear to have a strong influence on the corrosion resistance of the highly corroded samples of grade 1.4003.

Electrochemical tests were carried out on samples in the supply condition and those with a 600 grit polish finish. In the uniform corrosion tests, the poorest performance was from grade 1.4003 and the best performance was from 1.4521, with austenitic grade 1.4301 performing better than all the ferritic grades tested. In the pitting corrosion tests, 1.4521 performed better than the austenitic grade 1.4301.

Properties of Ferritic Stainless Steels

Physical properties

The physical properties of ferritics are given in Table 4; equivalent values for carbon steel and austenitic stainless steel are also shown for comparison. These values are taken from EN 10088-1 for stainless steel and EN 1993-1-2[3] for carbon steel. Because 1.4621 is a relatively new grade, the data were taken from the draft of the next revision of EN 10088-1, which is due to be issued in 2014.

Ferritics have a higher value of thermal conductivity than austenitics, though it is still only about half the conductivity of carbon steels. The thermal expansion coefficient for ferritics is much lower than that of austenitics and approximately equal to that of carbon steels. The lower thermal expansion coefficient, coupled with the higher thermal conductivity, results in less distortion when heated compared to austenitics. Unlike austenitics, ferritics are magnetic.

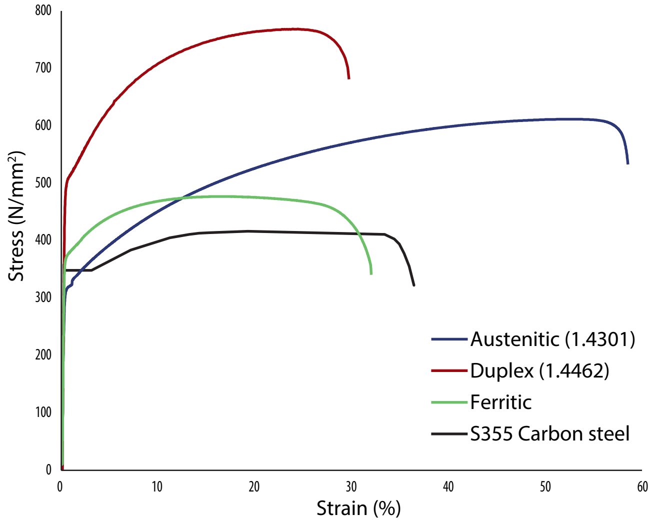


Figure 3 Full range stress-strain curves for stainless and carbon steels

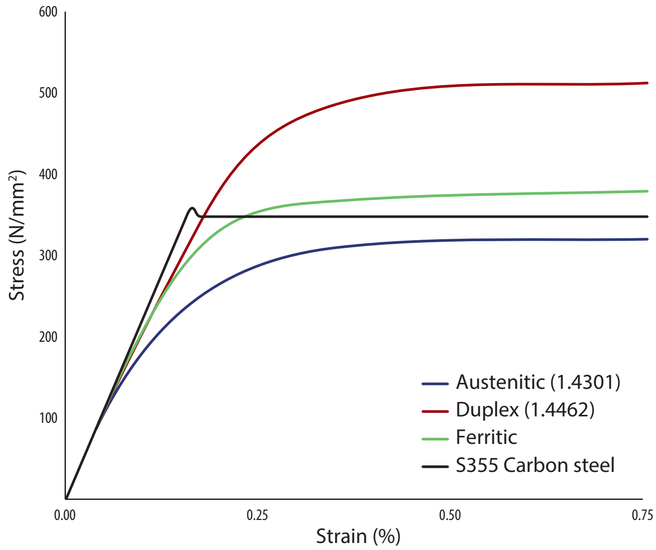


Figure 4 Stress-strain curves for stainless and carbon steels from 0 to 0.75% strain

Strength and stiffness

The stress-strain behaviour of stainless steels differs from that of carbon steels in a number of respects. The most important difference is in the shape of the stress-strain curve. Whereas carbon steel typically exhibits linear elastic behaviour up to the yield stress and a plateau before strain hardening is encountered, stainless steel has a more rounded response, with no well-defined yield stress.

The response of ferritic stainless steel lies somewhere between that of carbon steel and austenitic stainless steel in that it is not quite as 'rounded' or non-linear as the austenitic grades but offers more strength and ductility than carbon steel. Figure 3 compares the stress-strain curves for ferritic, duplex, austenitic stainless steels and S355 carbon steel for the full strain range. Figure 4 shows the stress-strain characteristics at low strain.

GRADE	DENSITY kg/m³	SPECIFIC THERMAL CAPACITY AT 20°C J/kgK	THERMAL CONDUCTIVITY AT 20°C W/mK	COEFFICIENT OF THERMAL EXPANSION 10^{-6}/K 0~100°C
1.4003	7700	430	25	10.4
1.4016	7700	460	25	10
1.4509	7700	460	25	10
1.4621	7700	460	21	10
1.4521	7700	430	23	10.4
Austenitic stainless steel 1.4301	7900	500	15	16
Carbon steel S355	7850	440	53	12

Table 4 Physical properties of ferritic stainless steels

In the absence of a clearly defined yield point, the '0.2% proof strength' is conventionally adopted as the design strength. It is the strength at 0.2% permanent strain.

The mechanical properties of ferritics make them suitable for a number of structural applications, for example where strong and moderately durable structural elements with attractive metallic surface finishes are required. The design values for the 0.2% proof stress ($f_{0.2}$), tensile strength (f_u) and elongation (A) for each grade are presented in Table 5, taken from EN 10088-4. Because 1.4621 is a relatively new grade, the data were taken from the draft of the next revision of EN 10088-2 which is due to be issued in 2014. Values for austenitic grade 1.4301 and carbon steel grades S355 and S390 are also presented for comparison.

Note that the ratio of $f_u/f_{0.2}$ for ferritics is typically between 1.4 and 1.9, which is a similar value to carbon steel; the same ratio for austenitics is around 2.5.

For structural design, it is recommended that a value of 200×10^3 N/mm^2 is adopted for the elastic modulus for all ferritic grades. This value is used in all design calculations except for estimating deflections, where it is necessary to use a secant modulus.

Toughness in the unwelded condition

Ductile to brittle transition temperatures (DBTTs) for a range of thicknesses are given in Table 6. The values were derived from impact tests under the SAFSS project, and are based on a 95% confidence interval. The transition temperatures for all grades increase with increasing thickness. The lower alloyed grades 1.4003 and 1.4016 have the lowest transition temperatures.

The plane stress condition prevails for thin material loaded in tension, and fracture is characteristically in a ductile manner. Therefore, a brittle fracture is unlikely to occur in thin sections. Grade 1.4003 has a modified microstructure which leads to significantly greater toughness properties than the other grades and is likely to be the most suitable grade for structural applications in thicker sections. It is not recommended that grade 1.4016 is used in thicknesses above 3 mm for applications where the service temperature is likely to fall below 0°C. For grades 1.4509, 1.4521 and 1.4621, the maximum recommended thickness is 2 mm for sub-zero temperatures.

Welding and cold working reduces toughness. Guidance on the toughness of welded ferritics is given on page 10.

GRADE	CONDITION	0.2% PROOF STRENGTH $f_{0.2}$ (N/mm^2)	MINIMUM TENSILE STRENGTH f_u (N/mm^2)	ELONGATION AFTER FRACTURE A (%)
1.4003	HR	280	450	20
	CR			
1.4016	HR	240	450	18
	CR	260		20
1.4509	CR	230	430	18
1.4621	HR	230	400	22
	CR			
1.4521	HR	280	400	20
	CR	300	420	
Austenitic stainless steel 1.4301	HR	210	520	45
	CR	230	540	45
Carbon steel S355 to EN 10025-2[4]	HR	355	510	14-20
Carbon steel S390 to EN 10346[5]	See note	350	420	16

HR = hot rolled strip

CR = cold rolled strip

EN 10346 gives properties for continuously hot-dip coated steel suitable for cold forming

Table 5 Minimum specified mechanical properties of ferritic stainless steels

GRADE	THICKNESS (mm)	MIN TEMP (°C)
1.4003	1	-100
	3	-50
	5	-30
	6	-15
1.4016	1	-70
	2	-25
	3	-15
	4	RT
1.4509	1	-70
	2	-20
	3	0
	4	0
1.4621	1.5	-50
1.4521	1	-75
	2	-30
	3	RT

RT = room temperature

Table 6 Summary of DBTTs for ferritic stainless steels (95% confidence level)

Design of Structural Members

Eurocode 3: Part 1.4 (EN 1993-1-4) covers the structural design of stainless steels[6]. EN 1993-1-4 has 'supplementary' status, which means it only gives expressions where the carbon steel rules are unsuitable. It therefore must be used alongside the other Parts of Eurocode 3 which give design rules for carbon steel structures, e.g. EN 1993-1-1[7], EN 1993-1-3[8], EN 1993-1-5[9].

The following guidance is based on a series of bending tests under the SAFSS project, investigating the resistance of ferritic sections to local buckling and web crippling. The tests were on a range of rectangular hollow and top hat sections with thicknesses from 1 to 3 mm, made from grade 1.4509 ferritic stainless steel. Material tension tests measured the actual strength of the test specimens. Numerical modelling extended the scope of the study and included analysis of the flexural, torsional and torsional-flexural buckling of ferritic columns. Ferritic stainless steels with different stress-strain characteristics (i.e. varying degrees of non-linearity) were studied to gain a clearer understanding of the impact of the shape of the stress-strain curve on the buckling resistance.

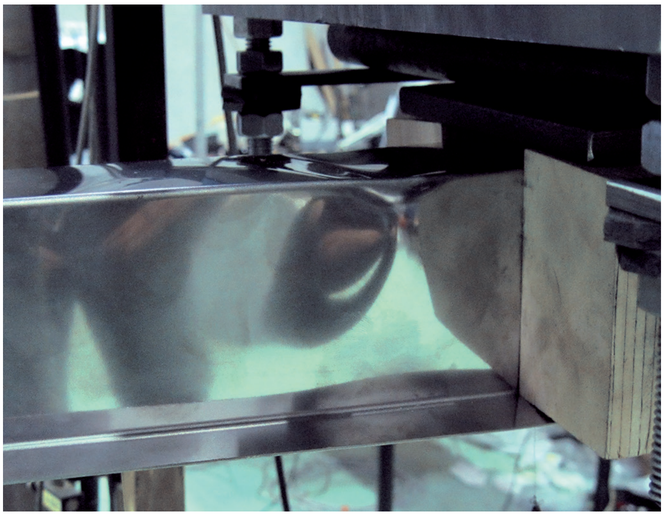


Figure 5 Failure of a top hat section beam by local buckling

Figure 6 Failure of a SHS beam by web crippling

Cross-section classification

The current guidance in EN 1993-1-4:2014, clause 5.2 can safely be applied to ferritics. The less conservative design rules for cross-section classification to be published in the amended version of EN 1993-1-4 in 2006 can also be safely applied.

Resistance of cross-sections

The current guidance in EN 1993-1-4, clause 5.3 can safely be applied to ferritics.

Buckling resistance of members

In general, the current guidance in EN 1993-1-4, clause 5.4 can safely be applied to ferritics. However, it is recommended that a more conservative buckling curve for hollow sections is used for ferritics (this curve is also under review for other grades of stainless steel). A revised version of Table 5.3 from EN 1993-1-4 is given below; it includes the new recommendation for hollow sections:

BUCKLING MODE	TYPE OF MEMBER	α	$\bar{\lambda}_0$
Flexural	Cold formed open sections	0.49	0.40
	Hollow sections (welded & seamless)	0.49	0.20 ǂ
	Welded open sections (major axis)	0.49	0.20
	Welded open sections (minor axis)	0.76	0.20
Torsional & torsional-flexural	All members	0.34	0.20

ǂ The current version of EN 1993-1-4 gives $\bar{\lambda}_0 = 0.4$.

Table 7 Buckling curves for flexural, torsional and torsional flexural buckling

Design of Steel-Concrete Composite Floor Systems

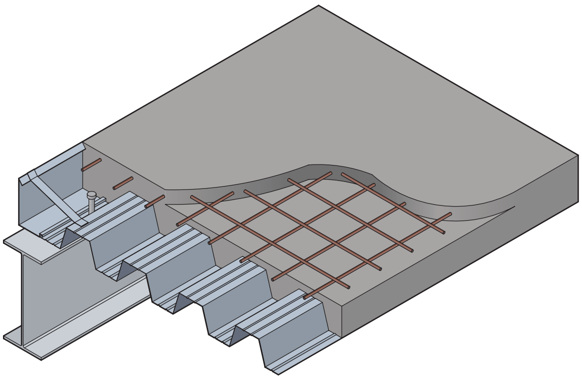


Figure 7 Schematic of a composite slab

Steel-concrete composite floors with galvanized steel decking are a popular form of construction (Figure 7). Exposing the soffit of a composite floor enables the thermal capacity of a slab to be mobilised and can contribute to regulating the temperature in a building since the composite slab absorbs heat during the day and releases it by night. Stainless steel decking is more architecturally appealing than galvanized steel decking, so exposed stainless steel decking is more likely to be acceptable as part of a composite floor system.

Figure 8 Composite floor with exposed soffit in a car park

It has been verified under the SAFSS project that the structural performance of composite slabs using profiled decking rolled from ferritic strip does not differ significantly from that of galvanized decking. The SAFSS tests were carried out on a typical deck profile of approximately 60 mm depth corresponding to one that is currently rolled in galvanized steel strip.

Decking tests at the construction stage

Simply supported and continuous decking tests were carried out, along with small scale moment rotation and web crushing tests. The tests confirmed that the guidance for predicting the resistance of decking given in EN 1993-1-3 can safely be applied to ferritic stainless steel.

Composite slab tests

Three long and three short span tests were carried out on composite slabs using ferritic decking, and were compared against the results of two additional tests on galvanized steel decking. The tests demonstrated that the guidance in EN 1994-1-1[10] for determining the resistance of composite floors (both the m-k method and the partial connection method) can safely be applied to ferritic decking.

Shear connection performance

Welding trials verified the practicality of the through-deck welding technique commonly used in the UK for ferritic decking. Shear connection tests were also conducted and the results analysed to assess the applicability of Eurocode design provisions for ferritic decking as well as to compare the performance with galvanized decking. Slabs with ferritic stainless steel decking behaved at least as well as slabs with galvanized decking and the existing design rules in EN 1994-1-1 can be safely applied to ferritic stainless steel decking.

Figure 9 Continuous decking tests at the construction stage

Connections

Welded connections

Ferritics can be welded using a range of processes such as manual metal arc (MMA) welding, metal-arc inert gas (MIG) welding, metal-arc active gas (MAG) welding, tungsten inert gas (TIG) welding and plasma arc welding. Correct weld procedures should be followed, using compatible consumables, with suitably qualified welders.

Mechanical tests on welded samples of different ferritic grades completed under the SAFSS project showed that austenitic filler metals give welds with superior toughness compared with ferritic fillers. Autogenous welding (i.e. without using a filler material) is possible with the TIG welding method, although this may result in lower corrosion resistance, ductility and toughness and hence should only be used with care. Figure 10 gives mean impact toughness values measured for the base metal, Heat Affected Zone (HAZ) and welds.

Ferritics are susceptible to grain growth at temperatures above 950°C, resulting in decreased toughness. To counter this, welding heat input should be low by keeping the weld pool small and using faster travel speeds. With good heat input control, tough welds are achievable in light gauges, up to 2-3 mm, where toughness is better anyway due to the lack of thickness restraint. Shielding gases should be argon-based mixtures which do not contain carbon dioxide, hydrogen and/or nitrogen, in order to minimise the susceptibility to embrittlement.

Bolted connections

Under the SAFSS project, 54 bolted connection tests on ferritic samples were conducted. Both single and double lap specimens were included and a number of different bolt arrangements and material thicknesses were examined in order to observe net section, bearing and block tearing failure modes. 54 screwed connection tests were also conducted using self-drilling screws: the tests were single lap specimens in various arrangements in order to observe shear, bearing and tilting failure modes.

The tests showed that the existing Eurocode design expressions given in EN 1993-1-1, EN 1993-1-8, EN 1993-1-3 and EN 1993-1-4 can be used for ferritic bolted and screwed connections. The EN 1993-1-1 approach uses f_u (instead of the reduced value $f_{u,red}$ in EN 1993-1-4) and this approach is recommended for net section resistance and for bearing and block tearing resistances of ferritic connections.

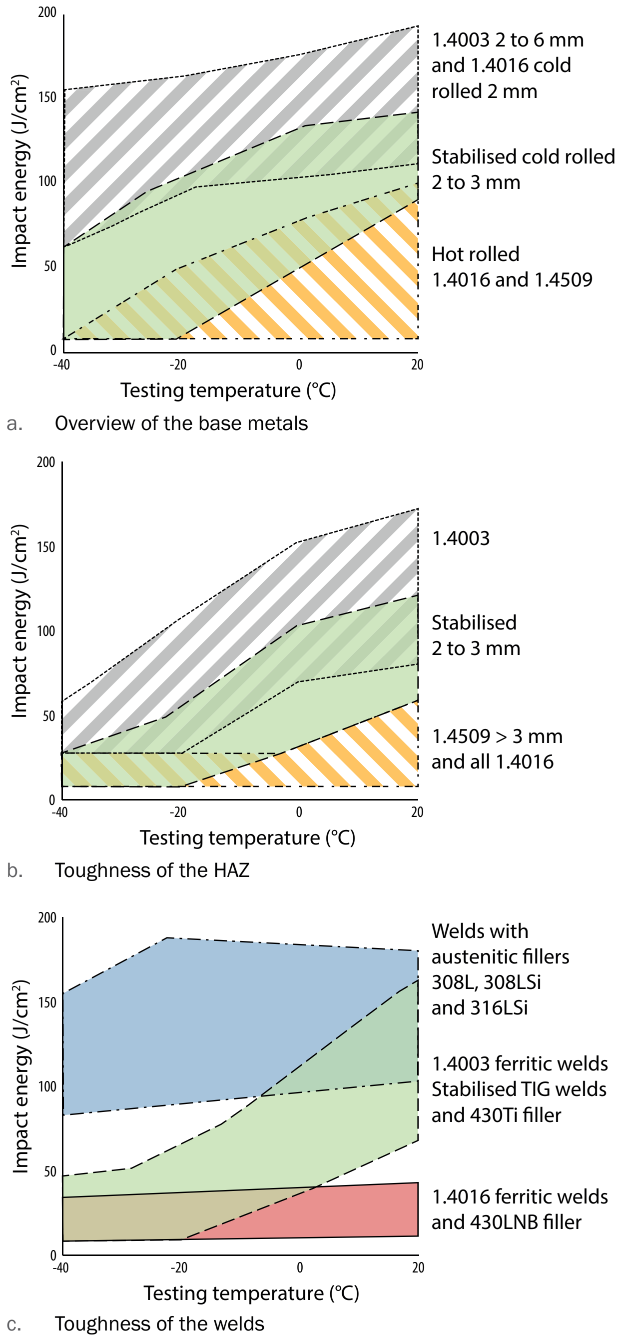


Figure 10 Impact toughness of ferritic stainless steels: base metal, HAZ and weld

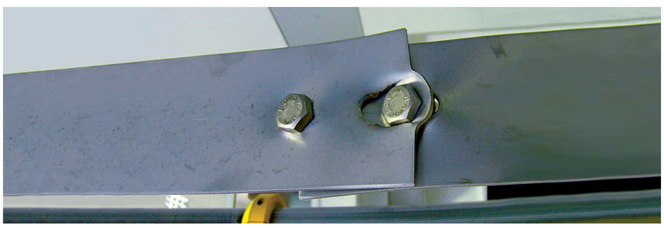


Figure 11 Failure of bolted specimen by block tearing and net section failure mode

Fire Resistance

Under the SAFSS project, a programme of iso- and aniso-thermal tests was carried out on five ferritic grades. The recommended design values are given in Figures 12 and 13, which show the mechanical properties of ferritics at high temperature lie between those of carbon steel and austenitic stainless steels. In the figures, the data for carbon steel are taken from EN 1993-1-2 and the data for austenitic and duplex stainless steel are based on a recent re-evaluation of all available test results [11].

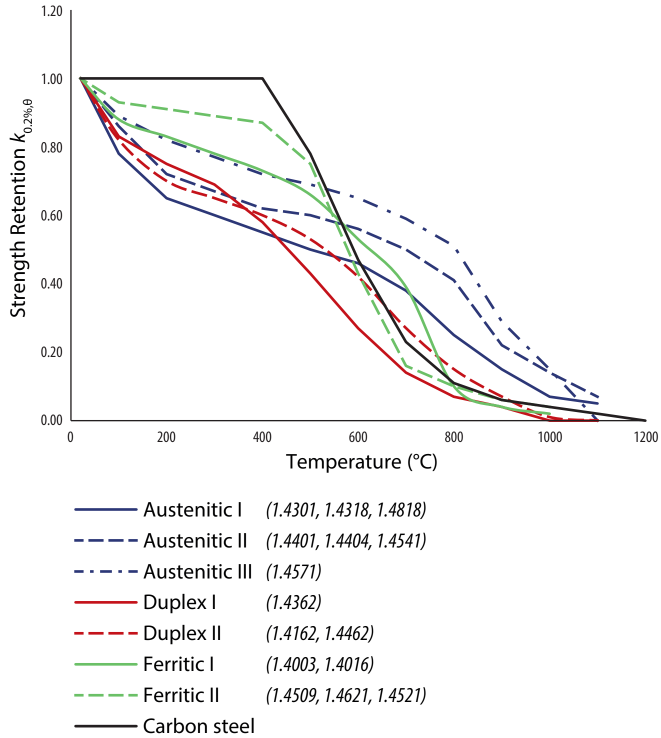


Figure 12 Strength versus temperature

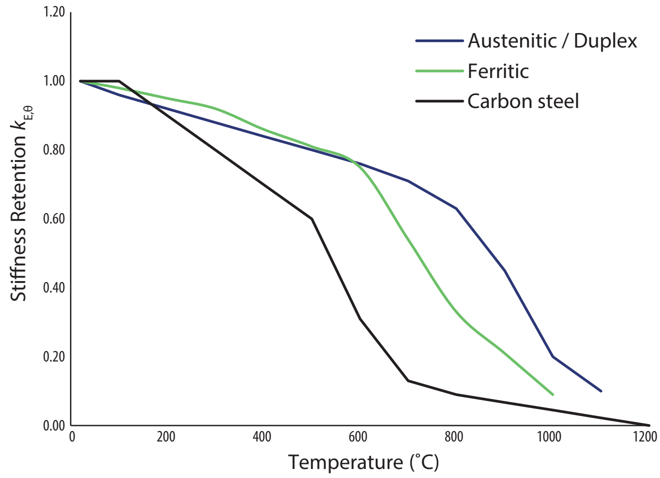


Figure 13 Stiffness versus temperature

Fabrication and Life Cycle Cost

Additionally, three columns and two beams were tested until failure at elevated temperatures. The tests, supplemented by numerical analysis, demonstrate that the current rules in 4.2.1 to 4.2.3 of EN 1993-1-2 for determining the fire resistance of structural steel members can safely be applied to ferritic stainless steels.

Fabrication

Stainless steels are relatively easy materials to work with and many of the fabrication and joining techniques are similar to those of carbon steel. Appropriate storage and handling procedures should always be adopted to avoid iron contamination from contact with non-stainless steel items, which will lead to corrosion in the presence of moisture.

Ferritics demonstrate equivalent forming behaviour to carbon steels as they are equally malleable, making them suitable for most forming operations. Roll forming, press braking, bending and pressing can be readily applied. The ferritics exhibit greater spring back than carbon steel and this should be compensated for by slight over bending. They do not undergo significant work hardening when cold formed or machined.

EN 1090-2 [12], the European Standard for fabrication and erection of structural carbon and stainless steel, gives requirements for storage and handling, forming, cutting, joining methods, tolerances, and inspection and testing. Specific guidance for stainless steels, based on this Standard, has also been published [13].

Life cycle costing

Unlike galvanized or painted steel, ferritics have a naturally occurring corrosion resistant surface layer so there is no requirement for applying protective surface layers and no remedial work or corrosion risk at cut edges.

Although stainless steel has a higher initial cost than carbon steel, savings in future maintenance, downtime and replacement costs often outweigh the higher initial material costs.

Ferritics are 100% recyclable. Information on recycling ferritics has recently been published[14].

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