Stainless steel in construction

Stainless steels may appear to be more suitable for teaspoons and kitchen sinks than for structural elements, but they can be used for support and other structures in aggressive environments, says Nancy Baddoo of SCI.

The main property that distinguishes stainless steel from carbon steel is that it possesses inherent corrosion resistance, due to the tightly adherent protective layer of chromium oxide which spontaneously forms on its surface in the presence of oxygen. This means that stainless steel components can be exposed to a wide range of environments without the need for protective coatings.

Stainless steels are highly versatile materials, possessing a unique selection of useful properties which can be exploited in load-bearing applications where cost is not a primary consideration. Figures 1 and 2 show stress-strain characteristics at low and high strains, compared against carbon steel. Austenitic stainless steels are generally used for structural applications, though the use of duplex stainless steel is increasing, where the higher strength is beneficial. The distinctive mechanical properties - considerable strain-hardening and ductility - make austenitic and duplex stainless steel particulary well suited for structures required to withstand accidental loading.

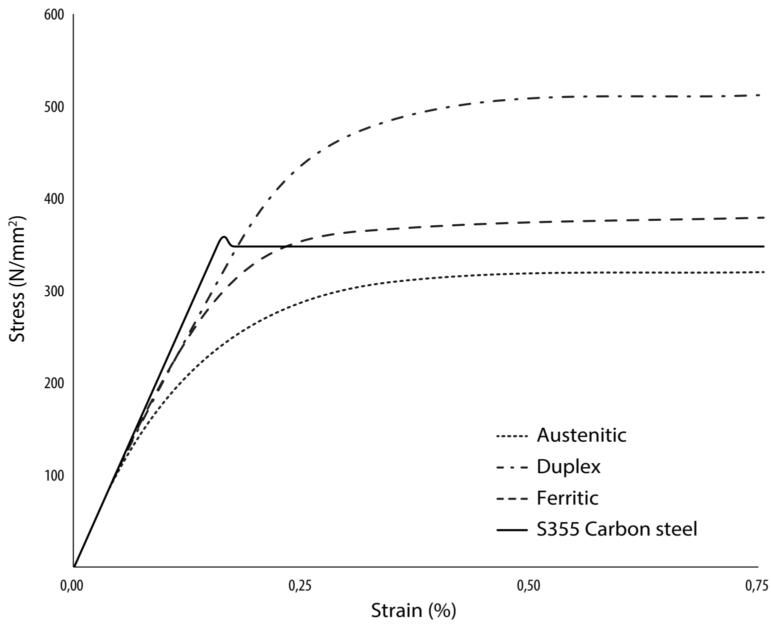

Figure 1 Stress-strain curves for stainless steel and carbon steel from 0 to 0.75 % strain

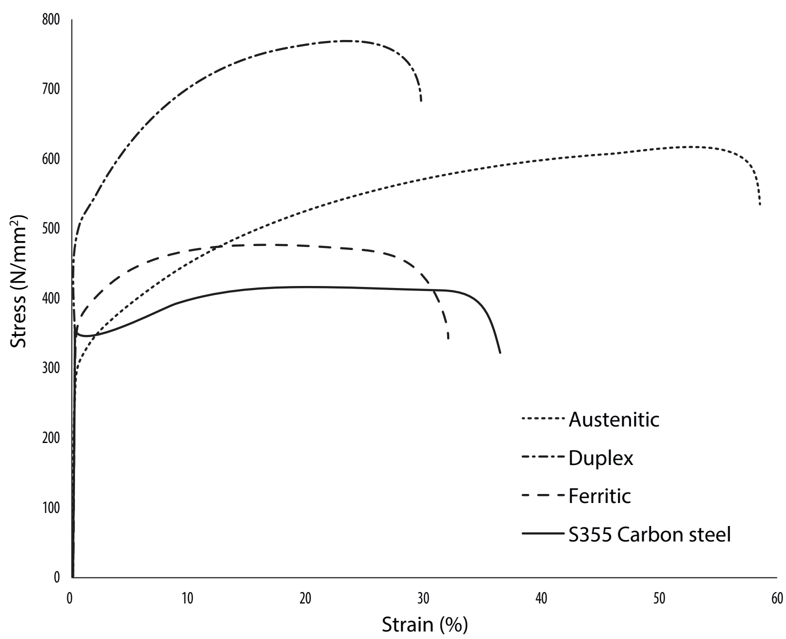

Figure 2 Full range stress-strain curves for stainless steel and carbon steel

Typical load-bearing applications include:

- Platforms and supports in processing plant for the water treatment, pulp and paper, nuclear, biomass, chemical, pharmaceutical, and food and beverage industries where the aggressive environment requires it.
- Pins, barriers, railings, cable sheathing and expansion joints in bridges
- Seawalls, piers and other coastal structures
- Reinforcing bar in concrete structures
- Curtain walling, roofing, canopies, tunnel lining
- Support systems for curtain walling, masonry, tunnel lining etc
- Security barriers, hand railing, street furniture
- Fasteners and anchoring systems in wood, stone, masonry or rock
- Structural members and fasteners in swimming pool buildings (special precautions should be taken for structural components in swimming pool atmospheres due to the risk of stress corrosion cracking in areas where condensates may form).
- Explosion- and impact- resistant structures such as security walls, gates and bollards
- Fire and explosion resistant walls, cable ladders and walkways on offshore platforms

In 2017, a new 160 m footbridge was constructed adjacent to the Grade 2 listed Countess Wear Bridge (figures 3 & 4 over page) in order to create a 3 m wide pedestrian and cycle route. The new footbridge comprises nine spans using conventional carbon steel and is supported in part by five hidden cantilevers embedded into the piers of the stone bridge, made from 1.4462 (2205) duplex stainless steel box sections.

The use of cantilevers avoided the need for work to be carried out in the river and complemented the appearance of the historic bridge rather than obscuring it. For these structurally critical components stainless steel was chosen for strength (grade 1.4462 stainless steel has a design strength of 450 MPa), to meet the 120 year design life target and because they were difficult to inspect and maintain.

The cantilevers are supported by piles carrying tension forces through the stone bridge into the bedrock 20 m below by means of stainless steel threaded bars. The parapet posts and handrails along the bridge were also made from duplex stainless steel. The client and designer for the project was Devon County Council and the steelwork was fabricated and installed by Taziker Industrial.

▶28

Figures 3 & 4: Countess Wear Footbridge: Left: Stainless steel cantilevers being lifted into position during a night closure Right: Stainless steel parapet posts and handrails

Although sharing many similar mechanical properties with carbon steel, the non-linear stress-strain characteristics mean that different design rules are needed for stainless steel. The non-linearity primarily affects local and global buckling response with some section classification limits being stricter.

Design standards for stainless steel have developed around the world. In Europe, when Eurocode 3: Part 1.4 was published in 2006[1], it was the first design standard for stainless steel in almost all European countries and the only design standard in the world which covered hot rolled, welded and cold formed products, as well as design in the fire situation. EN 1993-1-4 is a brief standard, just giving supplementary rules where the rules for carbon steel given in EN 1993-1-1[2], EN 1993-1-3[3], EN 1993-1-5[4] and EN 1993-1-8[5] are not applicable.

In certain places the rules in the 2006 edition of EN 1993-1-4 were very conservative with limited scope due to a shortage of test data. However, over the last 10 years or so there has been a very significant increase in research into the structural performance of stainless steel in Europe and worldwide and much useful information has been generated. The international database of structural tests is now three times larger than what was used to derive the original stainless steel Eurocode rules. As a result of the availability of these new research data, it was possible to develop improvements to the rules in the 2006 edition of EN 1993-1-4 and an amendment to the rules was published in 2015. The new rules permit less conservative design and extend the range of grades to which the rules apply (the grades listed in the standard did not reflect current usage). Efficient design methods are essential for stainless steel because of its high cost relative to carbon steel.

The most significant revision to the structural design rules in the 2015 amendment concern section classification: the limiting width to thickness ratios have been increased to align with those for carbon steel, except for internal compression elements. Additionally, less conservative shear buckling guidance has been included and clearer guidance on how to design cold worked stainless steel.

A key difference between stainless steel and carbon steel is that there are a wide range of stainless steel grades, each with slightly different compositions and hence corrosion resistance. Another significant revision in the 2015 amendment of EN 1993-1-4 was the inclusion of a step-by-step procedure for grade selection. The procedure involves the following steps:

- Determination of the **Corrosion Resistance Factor (CRF)** for the environment
- Determination of the **Corrosion Resistance Class (CRC)** from the CRF

The CRF depends on the severity of the environment and is calculated as follows:

$$CRF = F_1 + F_2 + F_3$$

where

F_1 = Risk of exposure to chlorides from salt water or de-icing salts;

F_2 = Risk of exposure to sulphur dioxide;

F_3 = Cleaning regime or exposure to washing by rain.

The CRF considers all corrosion risks including pitting, crevice corrosion and stress corrosion cracking of stainless steels that may affect integrity of load bearing parts. The assumption in the selection procedure is that no corrosion of stainless steel will occur that would impact the structural integrity of a load-bearing component. However, in some instances cosmetic corrosion (staining or minor pitting) could occur. These effects may be unsightly and unacceptable where appearance is important but are not detrimental to integrity.

Grades of stainless steel are classified in one of five CRCs, with CRC V being the most durable (e.g. containing grades suitable for the highly corrosive atmospheres above indoor swimming pools). The final choice of a specific grade within a CRC will depend on other factors in addition to corrosion resistance, such as strength and availability in the required product form. It is sufficient for the designer to specify the material by CRC and design strength, e.g. CRC II and $f_y = 450$ N/mm^2.

The publication of the amendment rendered all existing resources for designers relating to the stainless Eurocode obsolete. A new collection of supporting design resources is being prepared in order to help designers to use the new rules in the European dissemination project PUREST (Promotion of new Eurocode rules for structural stainless steel), part funded by the EU's Research Fund for Coal and Steel. The 18 month project started in 2016 and finishes in December 2017 and involves partners from Germany, Belgium, Spain, Portugal, Czech Republic, Finland, Sweden, Poland and Italy. SCI co-ordinates the work with support from Imperial College London and Arup.

Activities are mostly targeted at design practitioners and include:

- Updating and extending the *Design Manual for Structural Stainless Steel*,
- Translating the *Design Manual* from English into 9 languages,
- Developing online design software and design apps,
- National seminars and recording webinars for distance learning.

SCI published the Fourth Edition of the *Design Manual for Structural Stainless Steel* in 2017[6] (Figure 5). It consists of three parts:

- **Recommendations**, which give the design guidance and essential information needed by designers concerning grade selection, durability, material properties, design rules and fabrication
- **Commentary**, which explains how the design expressions in the Recommendations were derived and gives background information and references
- **Design Examples**, which demonstrate the use of the Recommendations

As well as updating the design rules to align with the 2015 amendment to EN 1993-1-4, the *Design Manual* also includes information on ferritic stainless steels. These grades are generally used in gauges of 4 mm and below, and offer a corrosion resistant alternative to many light gauge galvanized steel applications.

Additionally two new design methods are included. The first gives rules on how to take advantage of the work hardening associated with cold forming operations during fabrication (a strength enhancement of about 50 % is typical in the cold formed corners of cross sections, and the strength of the material in the flat faces also increases). The second gives a method for calculating the enhanced cross-section design resistances due to the beneficial influence of work hardening in service using the Continuous Strength Method.

All the design resources developed in the PUREST project will be accessible at www.steel-stainless.org/designmanual from the start of 2018.

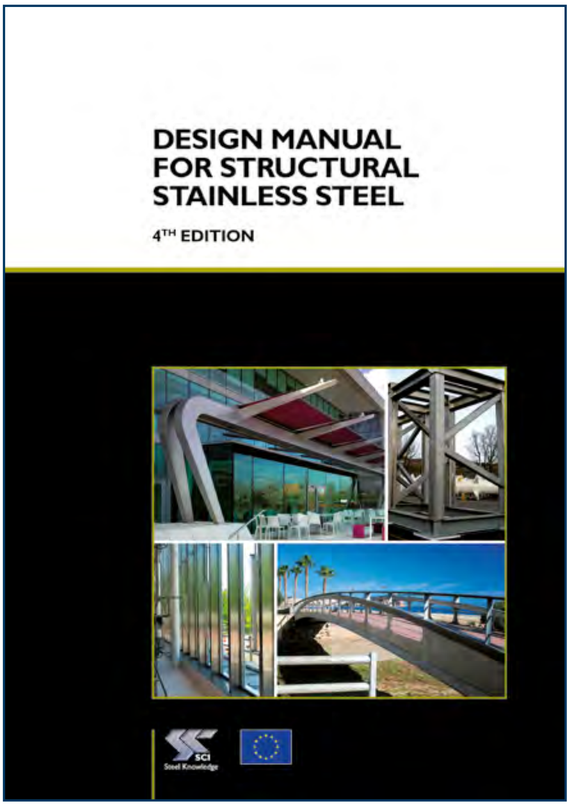

Figure 5: Design Manual for Structural Stainless Steel, Fourth Edition, 2017

For more information, please contact Nancy Baddoo at SCI (n.baddoo@steel-sci.com).

References:

1 EN 1993-1-4:2006+A1:2015 Eurocode 3. Design of steel structures. General rules. Supplementary rules for stainless steels
2 EN 1993-1-1:2005+A1:2014 Eurocode 3. Design of steel structures. General rules and rules for buildings
3 EN 1993-1-3:2006 Eurocode 3. Design of steel structures. General rules. Supplementary rules for cold-formed members and sheeting
4 EN 1993-1-5:2006 Eurocode 3. Design of steel structures. Plated structural elements
5 EN 1993-1-8:2005 Eurocode 3. Design of steel structures. Design of joints
6 Design Manual for Structural Stainless Steel, SCI Publication P413, 2017