SCI Steel Knowledge

Design of stainless steel offshore structures

Stainless steels are inherently corrosion resistant. In the presence of oxygen, a tightly adherent protective layer of chromium oxide spontaneously forms on their surface, which means they can perform satisfactorily in a wide range of environments without protective coatings. This intrinsic characteristic of stainless steel is particularly important for offshore structures situated in harsh environments exposed to chlorides from sea water.

There is a wide range of stainless steels with varying levels of corrosion resistance and strength. Due to their superior strength and excellent corrosion resistance and ductility, duplex stainless steels are particularly suitable for structural components in offshore structures where low weight and low maintenance materials are essential. They have a long track record of successful performance in the oil and gas industry and are finding increasing application in offshore wind and wave structures.

Structural applications on offshore structures include:

- blast and fire walls and cladding, accommodation units, relief walls,
- cable ladders,
- pipe support systems, clamps and pipe racks,
- working platforms and other support structures,
- skids for equipment and machinery,
- bridges, walkways and floor panels,
- stairway towers and handrails,
- boat landing systems.

In addition to structural components, stainless steels are widely used for process equipment including piping, vessels, caissons, and umbilical tubing.

Fig 1 Blast and fire rated escape tunnel on offshore platform (Photo: Natabelle Technology & Booth Industries)

Mechanical and physical properties

The stress-strain behaviour of stainless steel is characterised by a gradual yielding with no well-defined yield plateau and significant strain hardening. For this reason, the yield strength is conventionally defined for a 0.2% offset permanent strain. Table 1 compares specified minimum mechanical properties for stainless steels against those of carbon steel.

Table 1: Specified minimum mechanical properties of stainless and carbon steel plate

Alloy	Mod. of elasticity E ksi (MPa)	Yield strength f_y ksi (MPa)	Ult. tens. strength f_u ksi (MPa)	Elong. (%)
Duplex (S32205)	29 000 (200 000)	65 (450)	95 (655)	25
Austenitic (S31600)	28 000 (193 000)	30 (205)	75 (515)	40
Carbon steel (Grade 50)	29 000 (200 000)	50 (345)	65 (450)	21

Austenitic stainless steels have exceptional toughness and do not exhibit a ductile to brittle transition; their toughness slightly reduces with decreasing temperature. They are commonly used for cryogenic applications. Although duplex stainless steels exhibit a ductile to brittle transition like carbon steels, they have adequate toughness for most low temperature applications, e.g. a lean duplex (i.e. less highly-alloyed) typically shows an average toughness of 30 ft-lb (40 J) in base and weld metal at -58 °F (-50 °C) for up to 1.2 in. (30 mm) thick material. The more highly-alloyed duplexes show even better toughness.

Stainless steels can absorb considerable impact at high speeds without fracturing due to their excellent ductility and their strain hardening characteristics (especially the austenitic alloys). They also show a stronger strain rate dependency at high strain rates compared to carbon steel, i.e. a proportionally greater strength increase can be realised at fast strain rates than for carbon steel [1]. Both these characteristics are useful in blast resistant applications.

The thermal properties of stainless steels differ from those of carbon steels, and due allowance should be made in design and fabrication (see Table 2).

Table 2: Thermal properties of stainless and carbon steel

Alloy	Thermal conductivity at: 68 °F (BTU/(hr-ft-°F)) 20 °C (W/(m-K))	Thermal expansion between: 68 and 212 °F (10^{-6}/°F) 20 and 100 °C (10^{-6}/°C)
Duplex	8.2 (14.1)	7.4 (13)
Austenitic	8.2 (14.1)	9.1 (16)
Carbon steel	35.0 (60.5)	6.5 (12)

Design

Alloy selection

Within the austenitic and duplex families of stainless steels, there is a wide range of corrosion resistance. Guidance on material selection is given in AISC Design Guide 27 *Structural Stainless Steel* [2].

The molybdenum-alloyed austenitic stainless steels S31600 or S31603 are widely used for components on offshore structures. However, they are not suitable for use at operating temperatures above 140 °F (60 °C) due to their susceptibility to chloride induced stress corrosion cracking (SCC). Super austenitic (‘6% Mo’) alloys such as S31254. S34565 or N08926 are more highly alloyed alternatives to S31600/S31603. Their higher level of molybdenum and nitrogen provides better resistance to crevice corrosion, pitting corrosion, and SCC.

Duplex stainless steels are more resistant to SCC than austenitic alloys, and have the additional important advantage of being twice as strong. Lean duplex stainless steels such as S32101 are used for structural elements such as cable trays, pipe supports, and other secondary structures. S32304 is widely used for blast and fire walls on the topsides of offshore platforms. Greater corrosion resistance is provided by standard duplex alloy S32205 or the super duplex alloys S32750, S32760, or S32520.

For submerged applications, a super austenitic or super duplex is appropriate. Note that regular salt spray or splashing may cause as much attack as complete immersion because the surface chloride concentration is raised by the evaporation of water.

Member design

Although the structural performance is very similar to carbon steel, its non-linear stress strain characteristics mean that different design rules are needed for stainless steel members. The nonlinearity primarily affects the local and global buckling response, while strain hardening affects the yielding response. Stainless steel members are likely to exhibit larger deformations compared to carbon steel.

Connection design

In general, the same rules for carbon steel bolted connections can be adopted for austenitic and duplex stainless steel bolts, though different provisions for bearing are required to prevent excessive deformation. The corrosion resistance of the bolts should be equivalent to, or better than, the corrosion resistance of the parent metal, i.e. at least austenitic S31600/S31603 bolts should be used for connecting lean duplex plate; duplex S32205 bolts for connecting standard duplex plate. When bolting stainless steel to galvanised or painted carbon steel, bimetallic corrosion should be prevented by isolating the stainless steel electrically from the carbon steel. For example, using insulating washers and bushes on both sides of the joint or protective coatings applied to the carbon steel component effectively separates the two materials. Stainless steel bolts are suitable for connecting carbon steel or aluminium components, and have better corrosion resistance and, if correctly specified, a much longer service life than hot dip galvanized bolts.

Carbon steel design rules for welded connections generally can be applied to stainless steel. A compatible consumable should be selected to ensure the corrosion resistance of the weld metal is at least as good as that of the material being welded. Stainless steel is easily weldable to carbon steel; for dissimilar joints, the filler metal should be over-alloyed to avoid cracking. To prevent bimetallic corrosion, the painted coating on the carbon steel should be extended over the weld and onto the stainless steel for a distance of at least 2 in. (50 mm).

Fatigue

Fatigue behaviour of welded joints mostly depends on the weld geometry rather than the type of steel, and the design rules for carbon steel can be safely adopted for austenitic and duplex stainless steel.

Fire resistance

The different chemical compositions of stainless steels lead to different strength and stiffness degradation at elevated temperatures [3]. Austenitic stainless steels retain a higher proportion of their strength than carbon steel above about 1000 °F (550 °C). Both austenitic and duplex stainless steels retain a higher proportion of their stiffness than carbon steel over the entire temperature range.

Case study 1: Cable ladders

Fig 2 Cable ladder (Photo: Vantrunk)

Austenitic stainless steel S31603 is widely used for cable ladders on offshore platforms. The cable ladder above is 1/16 in. (1.5 mm) thick, designed on the basis of tests in accordance with IEC 61537 [4]. S31600/S31603 fasteners are used to fasten it to the carbon steel support structure, with insulating nylon bushings and washers to prevent bimetallic corrosion.

Fabrication

Stainless steel structural components may be fabricated by cold forming or welding strip or plate into angles, channels, or I-sections. Hollow sections and hot rolled or extruded sections less than about 6 in. (150 mm) in size are also available.

Stainless steel is not a difficult material to work with, although it differs from carbon steel in some respects and should be treated accordingly. Many fabrication and joining processes are similar to those used for carbon steel, but the different characteristics of stainless steel require special attention in a number of areas [5],[6]. It is important that effective communication is established between the designer and fabricator early in the project to ensure that appropriate fabrication practices are adopted. It is best to use a fabricator with a proven track record of working with structural stainless steel.

The same mechanical fabrication techniques typically used for bending, straightening, or cutting carbon steel can also be used for stainless steels. However, power requirements are greater than those for similar thicknesses of carbon steel due to the higher work hardening rate of stainless steels, and the higher strength of duplex stainless steels. Also, when bending or straightening stainless steel due allowance should be made for spring-back deformations.

Austenitic stainless steels are generally readily welded using common processes. Heat input should be minimised to reduce welding distortion which is generally greater in austenitic stainless steel than in carbon steel. Duplex stainless steels may be less prone to distortion but require control of the minimum and maximum heat input during welding. Austenitic and duplex stainless steels are not normally preheated but special care must be taken to restore the full corrosion resistance of the welded zone, for example by post-weld acid cleaning.

All fabrication processes should be carried out in a clean environment, with tools dedicated exclusively for stainless steel to avoid contamination by carbon steel and iron which increases the potential for surface corrosion. If there is a risk of residual contamination when fabrication is complete, the structure could be sprayed with an acid formulation, and then rinsed. Greater care is also required in storing and handling stainless steel to avoid damaging the surface finish.

Case study 2: Åsgard A lifeboat skid

Fig 3 Åsgard A lifeboat skid (Photo: Stalatube)

Åsgard A is a Floating Production Storage and Offloading (FPSO) unit in the Norwegian North Sea. As part of an upgrade in 2019, the carbon steel lifeboat skid was replaced by a structure made from an enhanced version of lean duplex S32304, leading to a significant weight saving of 0.63 tons (0.56 tonnes). The floor beams are I-shape sections, and the rest of the structure was made from C-shape and hollow sections.The gratings were also made from this alloy.

Duplex stainless steel gratings have also been used in offshore wind farms. For example, an enhanced version of duplex S32304 was selected for the gratings for the Dogger Bank offshore wind farm A, located off the North East coast of England. As well as being lighter than hot dip galvanized steel gratings, they have longer design lives and are simple to adjust and reshape on site.

Fig 4 Stainless steel gratings (Photo: Outokumpu)

Life cycle cost and sustainability

The use of stainless steel in offshore structures leads to an increased service life with reduced maintenance, since no painted coatings or cathodic protection is required. The high material cost of stainless steel, compared to carbon steel, can be offset if the entire life cycle cost (LCC) is considered. Moreover, the superior strength of duplex alloys over conventional carbon steel can be used to reduce the overall weight of the component, which can lead to cost savings arising from both less material used and reduced installation costs. The benefit of the little or no maintenance required by stainless steel is particularly important for offshore structures where the material cost is a small proportion of the overall cost of the structure.

Stainless steel is 100% recyclable and can be indefinitely recycled into new high-quality stainless steel. Typical recycled content for all types of stainless steel is at least 60%.

Product, design and fabrication standards

In the US, the technical requirements for the design, fabrication and erection of stainless steel structures is covered by the new specification ANSI/AISC 370 *Specification for Structural Stainless Steel Buildings* [3]. AISC 313 *Code of Standard Practice for Structural Stainless Steel* [7] is a companion specification which sets out the responsibilities of each member of the construction team and the standards of quality required of fabricators and erectors. AISC Design Guide 27 gives worked examples and tables of section properties and member capacity tables for a range of structural sections. Guidance is also available on the design of stainless steel blast walls [8].

Relevant ASTM product specifications include ASTM A240 for plate [9], ASTM A276 for bars and shapes [10], and ASTM 1069 for laser welded built-up shapes [11]. These specifications give the chemical composition and technical requirements of the different stainless steels that are used in structural applications.

The most common standard for smaller diameter (up to 1½ in. (38 mm) austenitic stainless steel bolts is ASTM F593 [12]. Other standards are available for specifying bolt diameters over 1½ in. ASTM A1082/A1082M [13] covers duplex stainless steel bolts.

Case study 3: Skid for process plant

Fig 5 Skid in an offshore regasification plant (Photo: Montanstahl)

A number of these stainless steel skids were used on a Norwegian offshore platform to hold equipment for a regasification process of liquefied natural gas (LNG). Austenitic stainless steel S30400 was chosen because the temperature of the processed liquid was -360 °F (-180 °C) and austenitic stainless steels have excellent low temperature toughness. The skids were made up of laser welded stainless steel I-sections and square hollow sections. Each skid was 30 ft (9 m) long, 6 ft (2 m) wide, and almost 16 ft (5 m) tall.

References

[1] Design Manual for Structural Stainless Steel – 4th Ed., The Steel Construction Institute, P413, 2017 www.steel-stainless.org/designmanual

[2] AISC Design Guide 27 Structural Stainless Steel, American Institute of Steel Construction, Chicago, 2021

[3] ANSI/AISC 370 Specification for Stainless Steel Buildings, American Institute of Steel Construction, Chicago, 2021

[4] EN 61537 Cable management. Cable tray systems and cable ladder systems. CEN; 2007

[5] IMOA, Practical Guidelines for the Fabrication of Duplex Stainless Steels, 3rd Ed., International Molybdenum Association, London, UK, 2014

[6] IMOA, Practical Guidelines for the Fabrication of Austenitic Stainless Steels, 2nd Ed., International Molybdenum Association, London, UK, 2021.

[7] AISC 313 Code of Standard Practice for Stainless Steel Buildings, American Institute of Steel Construction, Chicago, 2021

[8] FABIG Technical Note 5: Design guide for stainless steel blast walls, The Steel Construction Institute, 1999, www.fabig.com

[9] ASTM A240/A240M Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications

[10] ASTM A276/A276M Standard Specification for Stainless Steel Bars and Shapes

[11] ASTM A1069/A1069M Standard Specification for Laser and Laser Hybrid Welded Stainless Steel Bars, Plates, and Shapes

[12] ASTM F593 Standard Specification for Stainless Steel Bolts, Hex Cap Screws, and Studs

[13] ASTM A1082/A1082M Standard Specification for High Strength Precipitation Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications

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