Welding Knowledge

Part 2

Introduction to Stainless Steels

It comes as a surprise to many that 'stainless steel' is not stainless. Discolouration is not uncommon and salt water environments in particular can give rise to corrosion: this is even noticeable at domestic level where dark spots appear caused by the mild salt solutions used during automatic dishwashing cycles.

The importance of stainless steel 1 is best reflected by the worldwide annual consumption which was reported at over 50 million tonnes in 2019. Generally recognised for its corrosion properties the material range is also widely used where strength coupled with elevated temperature resistance to oxidation.

The most common alloying elements include chromium, nickel, manganese carbon and molybdenum and these may be added for corrosion and high temperature oxidation resistance, or to improve mechanical properties. Varying proportions of alloying elements give rise to different phase structures in the steels, generally classified as austenitic, ferritic and martensitic.
To preserve continuity, references to steel grades and classifications in this publication will use the SAE System[2].

In the 1930s the American Iron and Steel Institute (AISI) and Society of Automotive Engineers (SAE) were both involved in efforts to standardise the numbering system for steels. These efforts were similar and overlapped significantly and in 1995 the AISI turned over future maintenance of the system to SAE International.

The diversities in alloy balance require different approaches to welding. Most of the problems arising during fabrication have been resolved, but attention to filler metal composition and welding technique is essential if high quality joints are to be produced.

Principle applications arise in the domestic, architecture, transport, chemical, pharmaceutical, oil and gas, medical, food and drink sectors, but these alloys are also widely used in the manufacture of fasteners and wire.

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Austenitic alloys

Austenitic stainless steels are classified in the SAE 200 and SAE 300 series, with 16% to 30% chromium and 2% to 20% nickel. Other metals such as molybdenum, nitrogen may be added to improve corrosion and mechanical strength. Together they constitute 75% of the world stainless steel market.

With care all the stainless steels can be welded using all the principal arc (GTAW, GMAW and SAW) processes.

Welding

Their single-phase structure means that hardening does not occur during cooling so no post-weld heat treatment is necessary. Joints exhibit good toughness.

However, some of the compositions are prone to ‘sensitisation’. During cooling, chromium carbides form at grain boundaries so the chromium content of the alloys is reduced leaving the grain boundaries at risk of corrosion. This sensitisation can be reduced by adding small additions of titanium and/or niobium.

Filler metals to match the parent alloys are available for most of the austenitic range of alloys. Prominent exceptions are type 304 for which a type 308 filler metal is commonly used and type 321 which may be welded using a type 347 filler.

Ferritic Alloys

All falling within the SAE 400 series of alloys, ferritic stainless steels contain 10.5 to 27 percent chromium and some of these metals may contain molybdenum, aluminium and titanium. The nickel content is small and this accounts for them being much less expensive than austenitic grades.

Confusion often arises because some of the SAE 400 grades can have a martensitic structure. Typical ferritic alloys are SAE 409, 430, 434 and 446.

SAE 400 alloys are magnetic.

Together they constitute 20% of the world stainless steel market.

Welding

Although less corrosion-resistant than austenitic alloys, ferritic grades generally have better mechanical properties. Many are readily weldable, but care needs to be exercised since some are prone to sensitisation within the heat-affected zone and to weld metal hot cracking, particularly in thicker sections.

Austenitic filler metals, particularly the low carbon SAE 309 alloy are the most commonly used. The higher chromium content helps to prevent too much chromium dilution, and hence a reduction in strength and corrosion resistance.

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Martensitic alloys

The most common martensitic steels are SAE 410, 420, 422 and 431 and these contain up to 18% chromium with additions of carbon and manganese.

The combination of elements coupled with heat treatment result in the production of martensitic rather than ferritic structures and these exhibit superior mechanical properties.

They are widely used for their creep strength combined with erosion and corrosion resistance.

Welding

Fusion welding presents some challenges. Most require pre- and post- weld heating to avoid weld cracking problems and to provide a tough, but ductile joint.

Filler metals with similar composition to the base alloys are most suitable and these are readily available. Some contain additions of nickel so that the weld ferrite content is kept low to avoid loss of mechanical strength.

Duplex Stainless steels

The concept of duplex alloys was to develop materials with corrosion resistance coupled with strength. Only from the 1980s however were satisfactory production techniques developed.

The alloys are complex and demand specialist manufacturing skills so that production has been limited to intrinsic steelmaking operations.

For this reason, many of the duplex alloys are not categorised internationally but named commercially.

Sandvik's hyper-duplex alloys are representative of materials with the best combinations of strength, corrosion resistance and weldability.

These typically offer;
- Double the design strength of austenitic and ferritic stainless steels
- A wide range of corrosion resistance to match application
- Good toughness down to minus 80°C
- Weldability in thick sections

They are however more difficult to form and machine than austenitic alloys and have limited high temperature applications.

Duplex stainless steels are now used extensively in the offshore oil and gas industry and in the petrochemical sector for pipework systems and pressure vessels.

Welding

Duplex steels can be complex materials, relying on their properties for a careful balance of differing microstructures. Thermal cycles experienced during welding and any heat treatment can make significant differences to mechanical strength and tendency to cracking.

Filler metals are generally formulated to contain more nickel than the parent alloy in order to maintain an adequate balance of austenite in the weld metal. Up to 7% nickel is typical, but as much as 10% may be required in the super duplex materials.

General Welding Precautions

Dissimilar metals

Filler metals need to be selected to maintain an optimum weld metal that meets the need to accommodate any differences in expansion co-efficient and maintain acceptable mechanical properties. Matching filler alloys with the martensitic composition are often satisfactory but the nickel-based Inconel 625 is useful if a close match with the coefficient of expansion is mandatory.

Purging

Loss of chromium during welding because of oxidation can reduce the corrosion resistance significantly so it is essential to protect the molten weld metal using a shield of inert gas. The upper bead protected by the arc shield but special attention to protecting the weld root is essential.

References

1. British Stainless Steel Association. https://www.bssa.org.uk

2. AISI Steel grades, SAE and Werkstoff numbers - Steel Express.
   https://www.steelexpress.co.uk › aisi-sae