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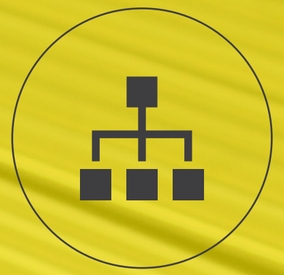
DUPLEX BUT NOT COMPLEX!

7 POINTERS TO UNDERSTANDING DUPLEX STAINLESS STEELS



Duplex stainless steels are a branch of the stainless steel family tree.

They have several useful properties and are widely available in various product forms thus rendering them construction materials of great relevance in today's engineering world.

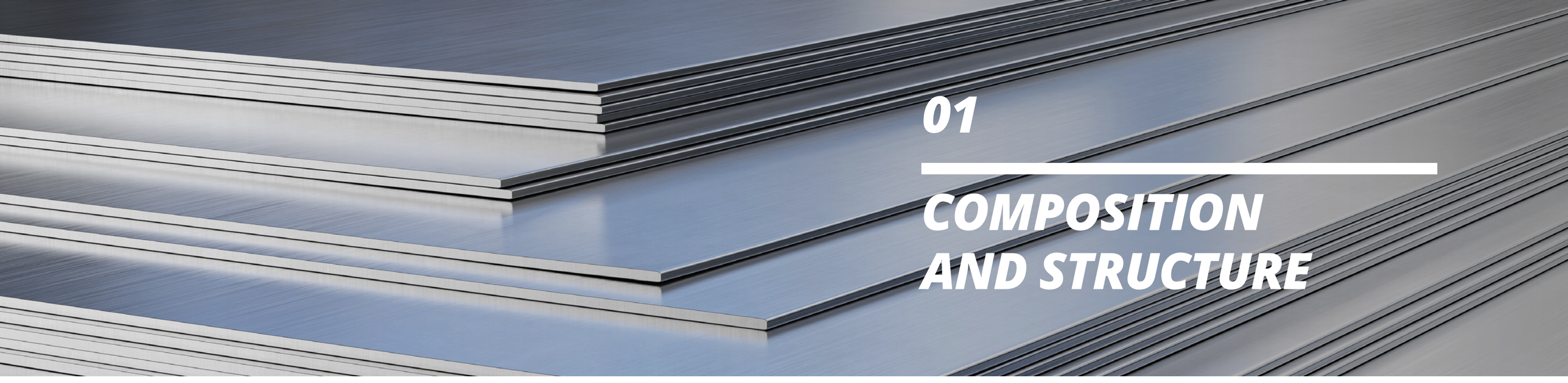
In this e-book we focus on the features and benefits of these alloys

INTRODUCTION

Duplex stainless steels offer an extremely valuable combination of properties – primarily high strength and corrosion resistance. This, combined with good fabrication properties and pricing that is not as sensitive to nickel as are the austenitic grades, has resulted in the increased use of these metals.

They made their appearance in the 1930's but there were limitations with corrosion resistance and toughness in the welds. With the development or the argon oxygen decarburisation process in the 1960's these shortcomings were addressed. Further property enhancements arose in the late 1970's from the research into the role of nitrogen in stainless steel in general but specifically in these grades and this has resulted in a rapid growth in the range of alloys available and their usage. Although a search would indicate the existence of more than 30 distinct duplex stainless steels there are only a few frequently used alloys and these are listed in Table 1.

For duplex stainless steels to attain their favourable properties the target is to have a microstructure with approximately equal amounts of austenite and ferrite. This requires a balanced composition which in turn means good control of those elements that promote the formation of each phase as indicated in Fig1.



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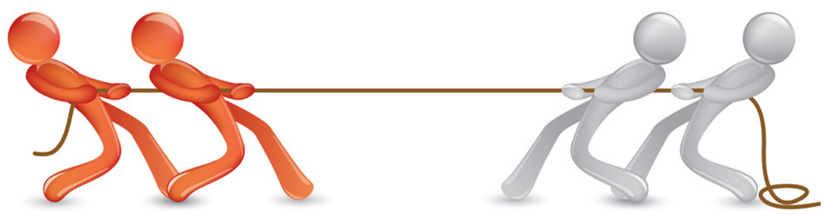
COMPOSITION AND STRUCTURE

Figure 1:



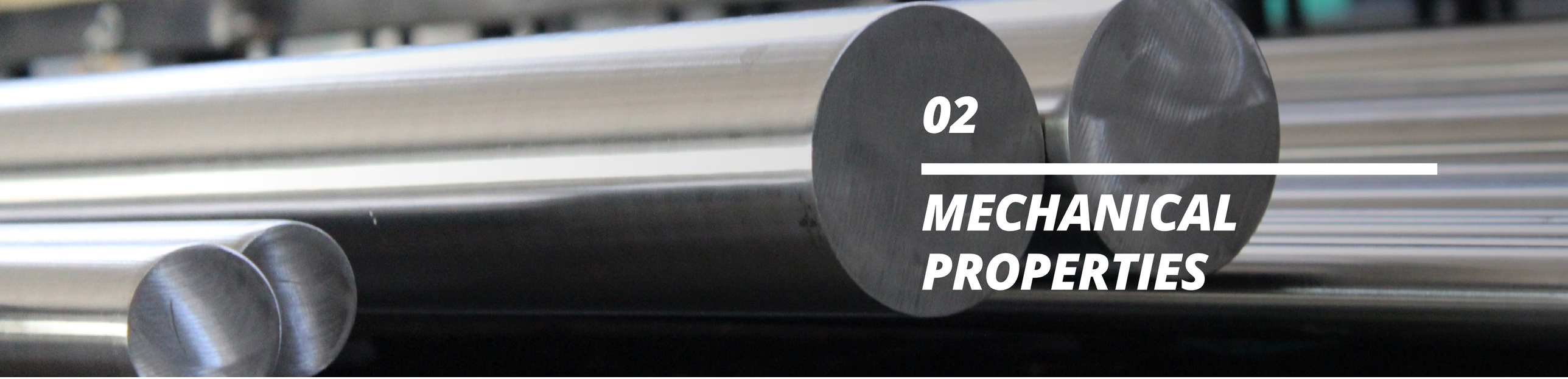
Austenitisers
C, N, Ni, Cu, Mn, Co

Ferritisers
Cr, Mo, Si, Nb, Al, Ti

The metallurgy of this family of stainless steels is such that apart from the austenite and ferrite deleterious phases may form. This is again a function of composition as well as thermal processing. This is referred to further in #6.

Table 1:

ALLOY COMPOSITIONS (*:maximum)									
Type	**Grade**	**% Cr**	**%Ni**	**%Mo**	**%C**	**%Cu**	**%Mn**	**%N**	**Other**
Austenitic	316L	16.0-18.0	10.0-14.0	2.0-3.0	0.03*		2.0*		
	Alloy 904L	19.0-23.0	23.0-28.0	4.0-5.0	0.02*	1.0-2.0	2.0*	0.10*	
	254SMO	19.5-20.5	17.5-18.5	6.0-6.5	0.02*	0.5-1.0	1.0*	0.18-0.22	
Early Duplex	3RE60	18.0-19.0	4.3-5.2	2.5-3.0	0.03*		1.2-2.0	0.05-0.10	Si:1.4-2.0
Lean Duplex	LDX2101	21.0-22.0	1.35-1.70	0.1-0.8	0.04*	0.1-0.8	4.0-6.0	0.20-0.25	
Standard Duplex	Alloy 2205	21.0-23.0	4.5-6.5	2.5-3.5	0.03*		2.0*	0.08-0.20	
	Alloy 2205	22.0-23.0	4.5-6.5	3.0-3.5	0.03*		2.0*	0.14-0.20	
Super Duplex	Alloy 2507	24.0-26.0	6.0-8.0	3.0-5.0	0.03*	0.5*	1.2*	0.24-0.32	
	S32760	24.0-26.0	6.0-8.0	3.0-4.0	0.03*	0.5-1.0	1.0*	0.20-0.30	W:0.5-1.0
	Alloy 255	24.0-27.0	4.5-6.5	2.9-3.9	0.04*	1.5-2.5	1.5*	0.10-0.25	



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MECHANICAL PROPERTIES

The high strengths of duplex stainless steel grades are an important feature of this family of alloys and some comparative data is included in Table 2.

The benefit of the high yield strength, when compared with austenitic grades, is that it may allow a reduction of the load bearing section and hence the mass of metal used. The strength benefit of duplex grades has been put to good use in tank and vessel design as well bridges and rotating equipment. And in process industry applications it may be possible to use a lighter wall pipe without compromising the operating pressure. All design aspects do of course need to take in to account the applicable codes and standards. Duplex stainless steels are covered by ASME Section Vlll pressure vessels design codes with Div 2 allowing higher design stresses than Div 1 but covering fewer grades.

The grain structure of wrought duplex grades gives rise to anisotropy– mechanical properties which may not be the same in the transverse and longitudinal directions. The strength is higher perpendicular to the rolling direction than it is in the rolling direction and impact toughness is higher when the notch is perpendicular to the rolling direction.

Challenges may arise from the high strength of duplex grades when it comes to fabrication. This is referred to further in #5.

3RE60® is an alloy that was patented in the late 1960's and has been used extensively for heat exchanger tubing applications in South Africa. Although the understanding of duplex stainless steels has developed significantly this grade is still produced and used.

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CORROSION RESISTANCE

Implicit in the words “stainless steels” is a material that can resist corrosion and the duplex range have a high resistance to attack in many environments.

The high chromium content of the duplex alloys ensures passivation in oxidising environments while there is sufficient molybdenum and nickel for resistance to mildly reducing environments as well. Copper, as is found in a few of the grades is beneficial for corrosion resistance in some concentrations of sulphuric and phosphoric acids.

But a primary feature of the duplex range is their resistance to chloride stress corrosion cracking (SCC) and this is, in turn a consequence of the ferrite in the microstructure. SCC is one form of localised corrosion, and it may occur catastrophically and thus the ability to resist this form of corrosion is a major benefit.

There are many screening tests to compare and rank the alloys but in general terms the higher the alloy content in the duplex grade the better their resistance to stress corrosion cracking. Conditions that promote this form of damage are chlorides and other halides, tensile stresses – residual or applied, and acidic conditions. Temperature also plays a part in accelerating the onset of this form of failure. The common austenitic grades, 304 and 316, are most susceptible to this form of corrosion.

Pitting and crevice corrosion are another 2 forms of localised corrosion and resistance to these are also important features of the duplex range. A measure of this resistance may be ranked using the formula:

PRE = %Cr + 3.3 (%Mo+%(0.5W)) + 16 %N.

This formula really serves as a broad but useful guideline to compare stainless steels and has been used as an indicator to define super duplex grades - PRE > 40. Again, environments that promote pitting result from the synergistic interaction between chlorides / halides that are present, temperature and pH. Table 2 compares the pitting resistance and SCC resistance of several alloys.

03

CORROSION RESISTANCE

Corrosion resistance in the presence of chlorides makes the duplex stainless steel most useful in a range of applications. These may involve waters – seawater, brine, re-circulated process plant waters etc or process streams in the chemical and petrochemical industries.

Duplex stainless steels are useful in addressing 2 further corrosion phenomena viz corrosion fatigue and erosion corrosion. This is because of the combination of the mechanical and corrosion resistance characteristics of these grades.

Test 1: NaCl drop evaporation test at 120°C; value in the table is the % of 0.2% strength at which cracking will commence. (Read from a bar chart)

Test 2: 26% NaCl autoclave U-bend tests at 155°C.

Table 2:

COMPARATIVE MECHANICAL AND CORROSION PROPERTIES								
Grade	**UNS**	**Mechanical Properties***				**Corrosion Resistance**		
		UTS (MPa)	**0.2% Proof (MPa)**	**Elong(%)**	**Hardness**	**SCC Test 1**	**SCC Test 2**	**PRE****
316L	S31603	485	170	40	95HRB	<10%	Anticipated	24
Alloy 904L	N08904	490	220	35	90HRB	70%	Not Anticipated	34
254SMO	S31254	655	310	35	96HRB	90%	Not Anticipated	43
3RE60	S31500	630	440	30	30HRC	-	Anticipated	27
LDX2101	S32101	650	450	30	-	25%	-	26
Alloy 2205	S31803	620	450	25	31HRC	-	-	31
Alloy 2205	S32205	655	450	25	31HRC	25%	Possible	35
Alloy 2507	S32750	795	550	15	32HRC	70%	Not Anticipated	42
S32760	S32760	750	550	25	-	-	-	41
Alloy 255	S32550	760	550	15	32HRC	-	Anticipated	40

**: From ASTM A240; ASTM A789 for 3RE60*

*** PRE = %Cr+3.3(%Mo+0.5(%W))+16%N*

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PHYSICAL PROPERTIES

In general terms, the physical properties of duplex stainless steels fall between those of austenitic and ferritic stainless steels. Two of these properties that merit specific mention are:

- Ferromagnetism: Duplex grades will display some ferromagnetism in line with their ferrite content whilst austenitic grades are non-magnetic unless they are cold work or contain tiny amounts of ferrite.

- Coefficient of thermal expansion: This is a further useful property of duplex stainless steels in that its value is lower than that of the austenitic alloys and thus less likely to give rise to thermal stresses. Such situations may arise with temperature fluctuations upon welding, heat exchangers with stainless steel tubes in a carbon steel shell and large surface areas exposed to intense sunlight.

329 is a grade that was developed prior to extensive use of nitrogen as an alloying element. In many respects it has been superseded by Alloy 2205 but in round bar it is still used for components for pumps and other equipment used in the pulp and paper industry.

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FABRICATION

The fabrication of duplex stainless steels is different but not difficult.

The above quote takes as its reference point the common austenitic stainless steels, 304 and 316, which make up the bulk of stainless steels used and thus are the grades with which users are most familiar.

When compared with these the noteworthy points are:

- Higher forces are needed to form the duplex material and springback may be greater.
- Increased bend radii may be required because of the lower ductility of the duplexes.
- The duplex and super duplex grades are more demanding to machine; they require high cutting forces and gives rise to more rapid tool wear.
- The lean duplex grade, LDX2101, has good machinability.
- Whilst duplex and super duplex grades are at risk of the formation of harmful phases in modern alloys this can be avoided during welding by following procedures that control heat input. This requires the balancing of, amongst other things, the welding speed, filler diameter and interpass temperature.
- In an analogous way, hot forming of the duplex and super duplex grades needs to be carried out within a narrow temperature range.

For detailed information relating to fabrication the reader should consult Ref 2

Sanmac® 2205 is a free machining variant of Alloy 2205 and it has the same general attributes as the base grade.

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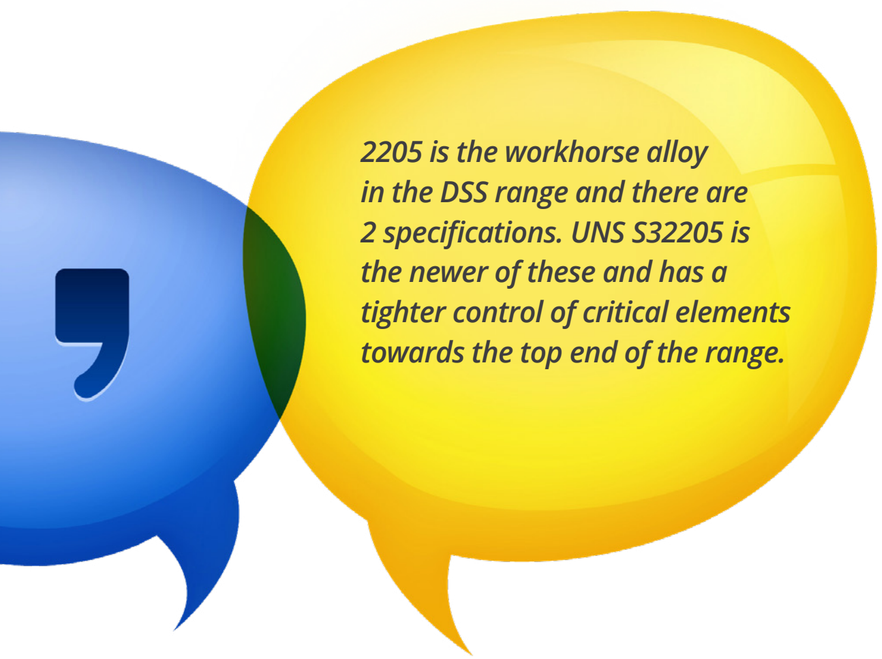
LIMITATIONS



The metallurgy of duplex stainless steels is, by its very nature more complex than that of the austenitic grades and to avoid the formation of embrittling secondary phases, some design codes may limit their use to temperatures below the range 260-315°C. (grade dependent). Duplex grades will also undergo a ductile to brittle transition and for the alloys that are the focus of this e-Book, this may occur at approximately -50°C.

Whilst the duplex grades have resistance to chloride stress corrosion this may vary; they are not immune and failure may occur under certain conditions. They are also susceptible to hydrogen induced stress corrosion cracking which may occur in applications in which sour gas, brine, elevated temperatures and applied stresses and material strength all play a role. These complex applications need to be analysed in detail before any material selection can proceed.

07

APPLICATIONS

The strength and corrosion resistance benefits of duplex stainless steels are such that their application is wide ranging.

The weighting for nitrogen in the PRE formula may vary to as much as 30X whilst the emergence of the higher manganese grades has given rise to a formula that deducts 1.5 x %Mn as it is suggested that this element facilitates pit initiation.

APPLICATION BY INDUSTRY

Water treatment and desalination

Pollution control

Pulp and paper

Marine and offshore

Chemical and petro-chemical

Mineral processing and recovery

Construction and civil engineering

APPLICATION BY EQUIPMENT

Tanks and pressure vessels

Heat exchangers and water heaters

Piping systems

Fasteners

Impellers, shafts and mixers

Bridges, bus shelters and similar public use structures

CONCLUSION

In this review we have only touched on the more common of the duplex stainless steels but the range extends to:

- Hyper Duplex grades which are highly alloyed and thus have a PREN of 48 or greater. Heat exchanger tubing is an application which capitalises on the combined physical, mechanical and corrosion benefits of duplex stainless steels and the hyper duplex grades extend the operational window for stainless steel usage in this application.
- Formable duplex grades which have the optimum combination of strength and ductility to enable the creation of lightweight formed components.

Duplex stainless steels, although a sub-group of stainless steels, have developed into a broad range of alloys over a period of some 50 years. The technical understanding and developments that have made this possible have resulted in stainless steels which, in summary have the following features:

- High resistance to chloride stress corrosion cracking.
- About double the strength of the more common austenitic grades.
- They are readily weldable.
- Are less sensitive to nickel availability and price.

The selection and use of duplex stainless steels is no longer subject to the uncertainties that may have existed in years gone by. However, as new applications emerge there may be a need to consult, and we are available to assist.

Alloy 2304 is Lean Duplex Stainless steel which does not makes less use of Mn to maintain the austenite phase balance but relies on nitrogen and approximately 4% Ni.

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REFERENCES:

1. Practical guide to using duplex stainless steels. Nickel Institute Publication No. 10044, 2020
2. Practical Guidelines for the Fabrication of Duplex Stainless Steels. International Molybdenum Association, 2009
3. Enhanced structural efficiency with duplex stainless steel in pressure vessels. Outokumpu White Paper Issue 1, 2016
4. Sandvik SAF 2707HD® - a hyper-duplex stainless steel for severe chloride containing environment LECTURE S51-63 11/2006, SANDVIK RESEARCH AND DEVELOPMENT CENTRE
5. Duplex: Complex or Simplex. J H Potgieter et al. FWP JOURNAL January 1991
6. High Performance Stainless Steels Nickel Institute Publication No. 11021,