

USER
MANUAL

DUPLEX STAINLESS STEEL



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ABBREVIATIONS

%C	Carbon
%Cr	Chromium
%Cu	Copper
DSS	Duplex Stainless steel
FCAW	Flux Cored Arc Welding
FN	Ferrite Number
GMAW	Gas Metal Arc Welding
GTAW	Gas Tungsten Arc Welding
HAZ	Heat Affected Zone
%Ni	Nickel
%N	Nitrogen
%M	Molybdenum
%Mn	Manganese
%P	Phosphorus
PREN	Pitting Resistance Equivalent Number
PAW	Plasma Arc Welding
S%	Sulfur
SCC	Stress corrosion cracking
SAW	Submerged Arc Welding
%Si	Silicon
SMAW	Shielded Metal Arc Welding

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1.0 PRODUCT RANGE

PRODUCTS	Width (mm)	Thickness (mm)	
	Max	Min	Max
Slab	1650	160	220
Hot Rolled Coil	1620	2	12
Plates/Sheets	1620	2	80
HRAP Coil/2E	1600	1.4	10
CRAP Coil	1600	0.3	5
Hot Rolled Bonded Clad Plates	1200	9	25
Chequered Plates	1250/1500	2.8	6
Rebars	-	8 ø	32 ø
Precision Strips	435	0.05	0.5
Razor Blade Steel	340	0.076	0.45

Alloy Group	Grades
Austenitic (Cr- Mn)	201, 201L, 201LN, 202, 204Cu, JSL AUS, J4, JSLUDD, JSLU SD, JT
Austenitic (Cr- Ni)	301, 301L, 301LN, 304, 304L, 304H, 304LN, 309S, 310S, 316L, 316LN, 316Ti, 317L, 317LMN, 321, 347, 904L, 6% MOLY
Duplex	Lean Duplex 2101, 2304, Duplex 2205, Super Duplex 32750, 32760
Ferritic	405, 409L, 410S, 430, 430Ti, 432, 436L, 439, 441, 444, 446, 430J1L, 409M (FERRITIC+ MARTENISTIC)
Martensitic	410, 415, 420, 431, 420J1, 420J2, JBS

JSL holds the competency to develop grades specific to process requirements

2.0 General

Stainless Steel in modern world is not just the material but a solution to achieve sustainable and safe environment while offering Lower Life cycle cost, enhanced safety, Aesthetics and means to optimise your carbon emissions and significantly towards lean design, construction.

In our endeavour to capture special grades in this handbook, we would like to highlight how these special grades will offer attractive benefits whether it is Oil & Gas, Power, Petrochemical, Chemical, ZLD, Desalination Plants or your any facility or infrastructure.

A stainless steel is known to have minimum 10.5% Chromium, Manganese, Nickel and Phosphorous composition. Chemical Composition of your grade shall suit your process requirements and we at JSL would love to take this challenge.

Special Grades, Lean Duplex, Duplex, Super Duplex have been covered in this handbook.

Duplex Grades make them very attractive compared to equivalent austenitic grades: higher resistance to stress corrosion cracking, higher mechanical properties and lower alloy cost.

2.1 Chemical Compositions

Table 1 below covers chemical composition of popular Duplex Stainless Steels.

Table 1:

Category	Lean Duplex		Standard Duplex	Super Duplex	
Grades	2101	2304	2205	2507	2506
UNS Designation	S32101	S32304	S32205	S32750	S32760
EN Designation	1.4162	1.4362	1.4462	1.4410	1.4501
%C	0.040 max	0.030 max	0.030 max	0.030 max	0.030 max
%Mn	4.00-6.00	2.50 max	2.00 max	1.20 max	1.00 max
%S	0.030 max	0.030 max	0.020 max	0.020 max	0.010 max
%P	0.040 max	0.040 max	0.030 max	0.035 max	0.030 max
%Si	1.00 max	1.00 max	1.00 max	0.80 max	1.00 max
%Cr	21.0-22.0	21.50-24.50	22.0-23.0	24.0-26.0	24.0-26.0
%Ni	1.35-1.70	3.0-5.5	4.5-6.5	6.0-8.0	6.0-8.0
%Mo	0.10-0.80	0.05-0.60	3.0-3.5	3.0-5.0	3.0-4.0
%N	0.20-0.25	0.05-0.20	0.14-0.20	0.24-0.32	2000-3000
%Cu	0.10-0.80	0.05-0.60	-	Cu: 0.50 Max	Cu: 0.50-1.00, W: 0.50-1.00

2.2 Mechanical Properties

Table 2 below covers mechanical properties of popular Duplex Stainless Steels.

Table 2:

Grades	UNS	EN	0.2% Y.S. Min, (MPa)	U.T.S. Min, (MPa)	% EL (50 mm GL)
Lean Duplex 2101	S32101	1.4162	450	650	30
Lean Duplex 2304	S32304	1.4362	400	600	25
Standard Duplex2205	S32205	1.4462	450	650	25
Super Duplex 32750	S32750	1.4410	550	795	15
Super Duplex 32760	S32760	1.4501	550	750	25

3.0 DUPLEX STAINLESS STEEL:

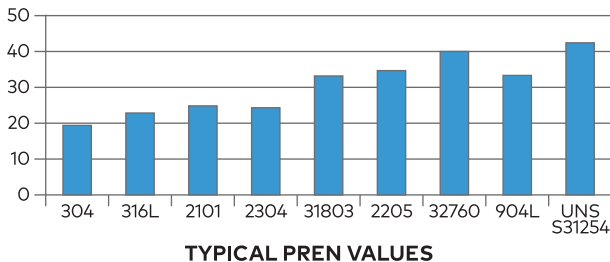
3.1 Characteristics & Advantages

- Duplex stainless steel combines the best properties of both ferrite and austenite.
- Duplex stainless steels have approximately double the strength of regular austenitic or ferritic stainless steels.
- Duplex stainless steels are extremely corrosion resistant in chloride and sulphide environments
- Duplex stainless steels exhibit very high resistance to stress corrosion cracking (SCC)
- Low nickel content of the duplex grades also makes them price stable. High resistance to stress corrosion cracking. - Significantly greater strength than the austenitic grades while exhibiting good ductility and toughness.
- Thickness of duplex stainless steel can be reduced as it has an increased yield strength. Thinner products mean that significant weight savings can be achieved.

3.2 Corrosion Resistance

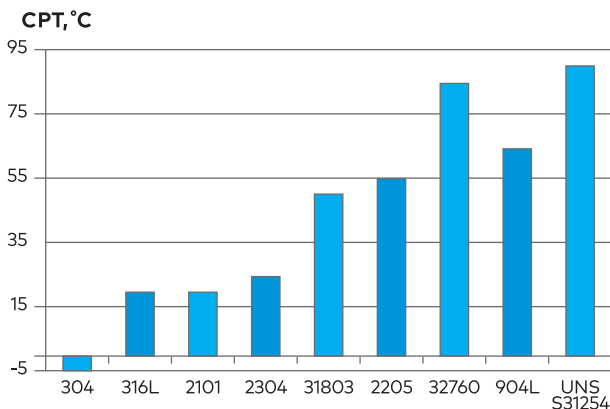
Pitting Resistance Equivalent Number

Pitting Resistance Equivalent number (PREN) illustrates the resistance to pitting corrosion and is denoted by using the formula $\%Cr + 3.3*\%Mo + 16*\%N$



Critical Pitting Temperature (CPT)

Pitting corrosion has to be taken into account for applications involving chloride ions. The CPT is defined as the minimum temperature to produce pitting attack generally measured in a ferric chloride solution according to ASTM G48E. The lean duplex S32201 is more resistant to pitting corrosion than the standard austenitic grades 304L and 316L. S32205 has an equivalent resistance to 904L, while the 25%Cr super-duplex grades present the same pitting resistance as some of the more alloyed UNS S31254 (6% MOLY) super-austenitic materials.

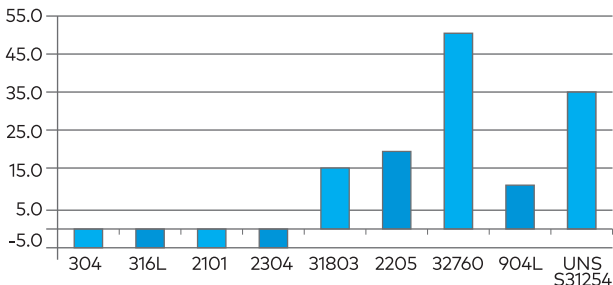


Critical Pitting Corrosion: (As per ASTM G150)

Critical Crevice Temperature (CCT)

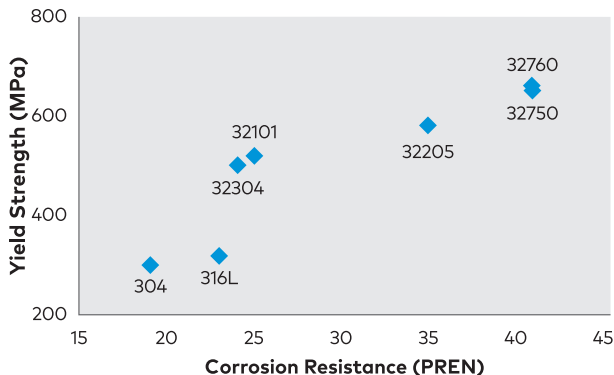
Crevice corrosion has to be taken into account when confined areas are likely to be formed (for instance under deposit, flanges, gaskets). S32205 offers a significantly higher resistance to crevice corrosion than the standard austenitic steels including 904L. S32760 presents an equivalent resistance to some 6%Mo super-austenitic grades.

CCT, °C



Critical Crevice Corrosion: (As per ASTM G48 Method F)

Performance: Strength vs. Corrosion resistance



Stress Corrosion Cracking (SCC)

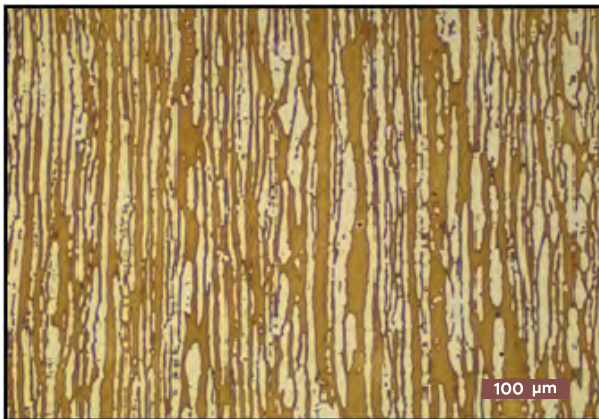
SCC is due to the combined influence of a corrosive environment and stress (applied or residual). Standard austenitic grades are highly sensitive to SCC in chloride-containing environments, especially above 50°C. The combination of ferrite and austenite makes duplex steels significantly more resistant to SCC.

Intergranular Corrosion

Thanks to their two-phase microstructure and their low carbon content, duplex steels present an excellent resistance to intergranular corrosion. Duplex stainless steel such as UNS S31803, UNS S32205, UNS S32750 & UNS S32760 are resistant to intergranular corrosion and satisfies the requirements of ASTM A923 (Standard Test Methods for Detecting Detrimental Intermetallic Phase in Duplex Austenitic/Ferritic Stainless Steels). Lean duplex grades such as UNS S32101 & UNS S32304 satisfies ASTM A1084 (Standard Test Method for Detecting Detrimental Phases in Lean Duplex Austenitic/ Ferritic Stainless Steels).

Metallurgical Properties:

Duplex stainless steel contains both ferritic (α) and austenitic (γ) phases. This two-phase structure enhances the yield strength while maintaining the ductility. This structure shows good resistance to both stress corrosion cracking and intergranular corrosion.



3.3 Main applications

Duplex stainless steels are commonly used in various applications including Process equipment's (Pressure Vessels, Heat Exchangers, Storage Tanks/ Silos, Tubes & Pipes etc.), Infrastructure & ancillaries. Major markets using Duplex Stainless Steel are:

- Oil & Gas industry
- Petrochemical and Chemical Industry
- Fertilizer Industry
- Ethanol, Sugar and Bioprocess Industry
- Wastewater / Sea Water Treatment / ZLD
- Emission / Carbon control / FGD / Carbon Capture
- Pulp & Paper industry
- Marine and Ship Building
- Architecture, building and construction
- Food industry and many more

4.0 OVERVIEW OF WELDING OF STAINLESS STEELS

'Weldability' is defined as 'The capacity of a material to be welded under the imposed fabrication conditions into a specific, suitably designed structure and to perform satisfactorily in the intended service'.

In general, stainless steel does not have any problem in achieving a sound weld, however higher alloy contents and the need to maintain corrosion resistance create additional challenges.

The portion of a welded structure that are affected by the welding process are weld metal and heat affected zones. The weld metal is a miniature casting consisting of associated structure and properties that can arise in casting, e.g. large grain size, entrapped gases, inclusions, shrinkage cracks and stresses. The heat-affected zone referred as "HAZ" contains a non-uniform structure,

different than base metal, because of the heating from the weld metal and the rapid cooling generated by surrounding mass of cold metal. In both weld metal and heat affected zone, there can be metallurgical effects that can cause a marked changes in both mechanical and corrosion resistance of stainless steels.

The **electrical resistivity** of stainless steels is much higher than mild steels. Hence, stainless steel electrodes get hotter relatively faster. Thus, this are made shorter to avoid excessive heat build-up and also has importance in electric fusion methods. The higher electrical resistance of stainless steels generates more heat for the same current or generate the same heat with lower current, when compared with mild steel.

The **thermal conductivity** of ferritic and martensitic stainless steels is nearly half than alloy steels. However, thermal conductivity of austenitic & duplex stainless steels is nearly only 1/3rd of carbon steels. Hence, stainless steels extract heat from the weld zone much slower than mild steels. This effect needs to be taken care so that distortion control and micro-structural stability can be maximised during welding process.

The **coefficient of thermal expansion** of ferritic, martensitic & duplex stainless steels is similar to carbon steels. It is approx 50% higher for austenitic stainless steels. Hence shrinkage stresses is much higher in austenitic stainless steels and creates distortion relatively faster in thick and thin plates. Subsequently, austenitic stainless steels require more tack welds than ferritic, martensitic & duplex stainless steels and carbon steels.

Stainless steels can be welded using any standard arc welding process. Preheat and Post weld heat treatment is also not required in most of stainless steels such as austenitic and duplex stainless steels. Usually matching or near matching welding consumables is selected for stainless steel welding.

5.0 WELDING OF DUPLEX STAINLESS STEELS

Solidification of any duplex stainless steels occurs through ferrite phase transformation and at the end of solidification microstructure becomes fully ferrite. The ferrite phase, depending on composition, is stable over some ranges of elevated temperature, before it falls below the ferrite solvus temperature & transformation to its austenite begins. The ferrite-to-austenite transformation nature is dependent on both the composition and the cooling rate. This transformation only, determines the final ferrite-austenite balance in weld metal. The transformation sequence which the duplex stainless steel follows is given below:



5.1 Oxidation

During welding where material is exposed in the temperature range of above 300°C, heat tint or weld discoloration is observed at its adjacent surface. The weld oxides form rapidly near the weld zone and its composition is far from equilibrium. These oxides generally impair corrosion resistance and have sensitiveness to localized corrosion attack when compared with parent material. Low-alloyed stainless steel are more sensitive than steel having high corrosion resistance such as duplex stainless steels.

Oxidation of parent metal and weld metal diffusion leads to formation of heat tint. There is demonstration which repeatedly shows that removal of oxide can be done by using mechanical and chemical cleaning, which can restore corrosion properties similar to bulk material. Various techniques for removal of heat tint are available. Pickling is proven to be most efficient in all. This chemical cleaning will be performed either by dipping the whole component into a

bath, or by spraying the pickling agent or by applying a paste. Various constraints like pickling agent, pickling temperature, material composition, weld quality and surface roughness determines pickling time. If surface is clean and have a good shielding or backing gas protection, pickling time is expected to be shorter. When there is no post-weld cleaning option, usage of proper gas purging becomes essential where shiny weld and straw yellow HAZ is desired for proper corrosion resistance.

5.2 Solidification Cracking

From figure 1, the WRC-1992 diagram was used in determining potential susceptible in weld solidification cracking. This diagram also indicates the fraction of austenite (A, AF) and ferrite (FA, F) phases form during solidification for a specific chemical composition. Austenitic stainless steels maintains its composition of weld region in FA region. If composition of weld metal lies in FA or F region, susceptibility of solidification cracking becomes low. For duplex steels, solidification generally occurs in F mode as it is extremely resistant in weld solidification cracking.

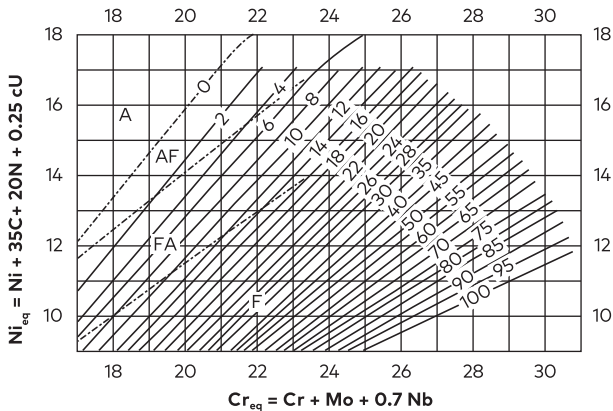


Figure 1: The WRC-1992 diagram for austenitic and duplex stainless steels

Weld solidification cracking is functionally dependent on its composition as shown in figure 2 which is a plot showing cracking susceptibility versus Cr_{eq} / Ni_{eq} ratio. All the duplex alloys solidifies in F mode and have lower solidification cracking susceptibility than austenitic alloys which solidify in FA mode. Susceptibility to solidification cracking in duplex alloy is much lower as compared to austenitic alloy which solidifies in A mode.

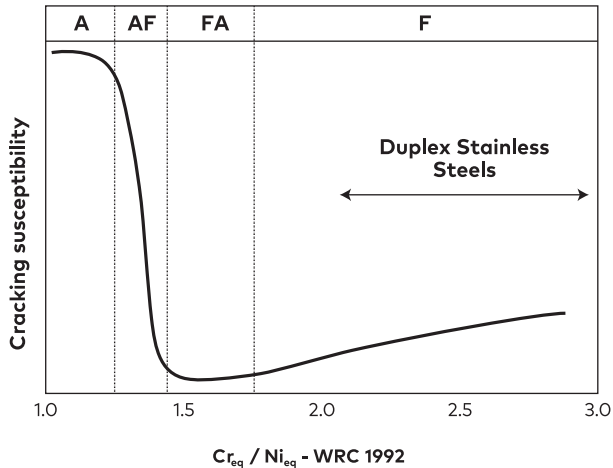


Figure 2: Weld solidification cracking susceptibility versus Cr_{eq} / Ni_{eq}

5.3 Embrittlement

Intermetallic phase formation degrades ductility, toughness and its corrosion resistance. Since content of Cr and Mo is higher in Duplex stainless steel, precipitation of these phases forms only if they are subjected to appropriate temperature range as shown in Figure 3.

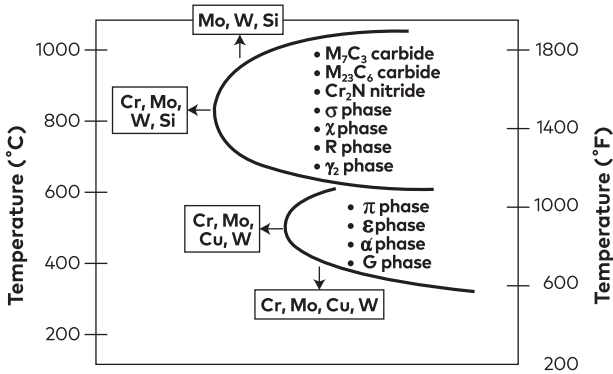


Figure 3: Precipitate formation in Duplex Stainless Steels

Duplex stainless steel limits service temperature to a maximum of 280°C. When welding procedures are done with proper heat inputs which does not causes embrittlement. However, weld metals and HAZs are more prone to intermetallic formation when it is exposed at elevated temperature.

Figure 4 shows, Precipitation kinetics for Lean duplex grades (2101, S32304), Standard Duplex (S32205) and Super duplex (S32750). This has been evaluated as the conditions are required to give a 50% reduction in the impact toughness, which is mainly governed by sigma phases and also by carbides & nitrides. The change in

microstructure phenomenon can occur if duplex stainless steels are subjected to slow cooling. It may occur in conjunction with the welding containing very high heat input, or inappropriate heat treatment in the temperature range of 300-1000°C. These intermetallics formed will also impact corrosion performance of the material.

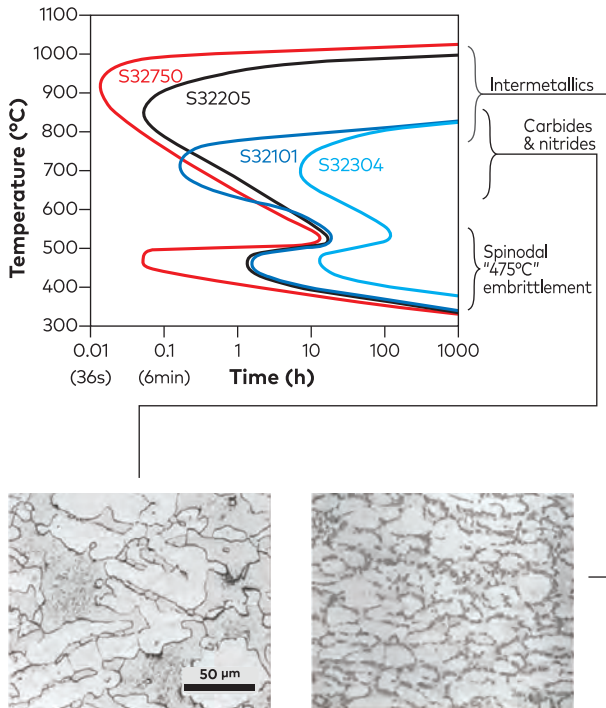


Figure 4: Precipitation kinetics for Lean, Standard & Super duplex grades

The weld HAZ and reheated weld metal have areas that experience single or multiple exposure in temperature range of 570 to 1000°C in which sigma and other intermetallic phases forms. In case of 22% Cr duplex stainless steel formation of intermetallic phase is not significant in welded condition. But in 25% Cr duplex stainless steel, formation of intermetallic phase is much more rapid and it is difficult to avoid such phases in as-welded conditions. However, when these phases are confined to small discontinuous zones, it has little effect on weldment properties.

To optimize the microstructure, Duplex stainless steel weldment especially those involves casting requires annealing. Annealing is required by both ASTM A240 standard for wrought stainless steel and ASTM 890 standard for cast duplex stainless steel at a temperature of minimum 1040°C which is followed by water quench. To select annealing temperature for weldments, use of weld filler metal with more nickel content needs to be taken in account.

5.4 Hydrogen-Induced Cracking:

Usually duplex stainless steels are considered to be resistant to hydrogen-induced cracking's, but still number of costly failures occurred in duplex stainless steel weldments. This is due to combinations of high hydrogen contents and also poor microstructure control. If sufficient hydrogen and stress are present, high FN deposits are susceptible to the hydrogen cracking.

When there is hydrogen concentration of around 9.5 Nml/100 g in lean duplex stainless, ductility significantly deteriorates in grade UNS 2101. The elongation to fracture gets reduced by about 25%, but no major impact of hydrogen occurs on standard duplex stainless steel UNS S32205 weld.

For SMAW and SAW processes in moist environment, low hydrogen welding practice is recommended. Hydrogen addition can sometime be used for argon gas shielding for GTAW or GMAW, which is sometimes used for welding of austenitic stainless steels is however inadvisable due to its cracking possibilities. If the weld metal ferrite content can be maintained below 70 FN or after welding solution

annealing is performed, then use of 2 to 5% hydrogen in argon shielding gas may be used for GTAW. By controlling deposit FN, we can possibly ensure prevention of hydrogen cracking in duplex alloys. When there is sufficient austenite in structure, there will be continuous networks of austenite, not only along its grain boundaries but also within its ferrite grains, and thus effectively limits hydrogen diffusion and this encapsulation of ferrite phase effectively limits the hydrogen diffusion in microstructure. The austenite also sometimes provides a sink for hydrogen and impedes the crack growth.

5.5 Stress Corrosion Cracking (SCC):

In comparison to austenitic stainless steels, duplex stainless steels are often chosen due to their superior corrosion resistance. Duplex stainless steels are resistant to SCC in chloride environments due to their low-Ni and high-Cr contents. Resistance to SCC as a function of the temperature and Cl⁻ ion concentrations and is shown in figure 5. Alloy 2205 (UNS S31803) is considered to be superior to Alloy 2304. No susceptibility to SCC is shown in figure 5 under the temperature and Cl⁻ ion concentrations by super duplex Alloy 2507 (UNS S32750).

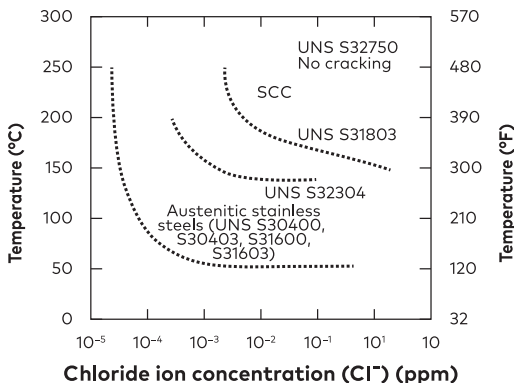


Figure 5: Stress corrosion cracking resistance of Duplex Stainless Steels

6.0 WELDING PROCESSES OF DUPLEX STAINLESS STEEL

Fusion welding processes involves material joining by melting and addition of filler material. Among other methods available for joining of stainless steel, fusion welding process predominates. Choice of welding method is dependent on availability and practically suitability of specific application. The material thickness, steel grade, required properties, welding positions and the surrounding environments is normally taken in account while choosing the welding method. During **fusion welding**, the melt pool is protected by the use of shielding gas or through formation of a slag, the arc stability is given. During **Gas tungsten arc welding (GTAW)** also called tungsten inert gas (TIG) welding, an arc is formed between non-consumable tungsten electrode and work piece in shielding gas atmosphere. This arc melts the base material and if necessary, filler metal is added from side. GTA welding could result in beautiful and smooth welds having high surface and weld quality and with the highest impact toughness and the best fatigue properties.

The productivity is however low and method consequently is used only where high demands are set. GTA welding is successfully used in many areas such as tube mills, within nuclear and process industry; also it can be primarily used for thin materials and to produce high quality root beads in joints which are otherwise filled with more productive methods. Hence in order to maintain the satisfactory corrosion resistance, high demand on root protection is done when welding is from one side.

While using pure argon to shield GTAW joints, the result normally has a nitrogen loss, particularly of super duplex grades. But also, while adding a few per cent of nitrogen to the shielding gas may result in an increase in the weld metal nitrogen content. 2 to 4% nitrogen (bal. Argon) seems necessary for super duplex weld metal. However, for grade S31803/S32205 this equates to some 0.5 to 1.5% nitrogen in the argon shield. Hence too much nitrogen may lead to weld metal porosity, spatter or sparkling of the weld pool and may even change in the solidification mode.

In Gas metal arc welding (GMAW) and also metal inert or active gas (MIG/MAG) welding, arc is formed in between work piece and a continuously fed solid wire electrode that melts in a shielding gas atmosphere. GMA welding have considerably higher welding speed and also impact toughness is equally high. This method is suitable for a material which is thicker than 2 mm and is primarily used in fillet joints and when butt welding is done from both sides. Main disadvantages of this method is it causes some spatter formation and also some embedded surface slags which can only be removed through grinding and also there is an increased risk of forming defects like lack of fusion. To improve the conditions for GMA welding, modern synergic pulse power sources are being used. GMA welding also performs as **flux core arcwelding (FCAW)** where an electrode can be filled with a flux which forms slag and also supplies alloying elements. In comparison to welding with a solid wire, higher welding speed & deeper penetration can be obtained in it, having smoother welds and also its improved resistance to fatigue. Lower risk of the spatter formation and embedded slag makes post-weld cleaning easier. However, its disadvantage is it needs to be removed after welding process and shielding gas is also required.

Shielded metal arc welding (SMAW) also called as Manual metal arc welding (MMAW) is usually performed manually with covered electrode. The flux coating gives arc stability and also forms a slag that protects filler and the melts during the process of welding and cooling. Weld properties and its weldability can be improved by choosing the different covers. Since the method is flexible and also cheap and is often used for outdoors and repair welding. When multipass welding is done, SMAW is used for the root welding, but this method has fairly low productivity and also it cannot be automatized. Other disadvantage of it includes slag removal and also covered electrodes of it easily absorb moist and hence must be stored in a controlled atmosphere.

Submerged arc welding (SAW) provides very high productivity and is mainly used when thick material is welded. The melt is here is covered with a flux in order protect the melt and also the arc from reacting it with surrounding atmosphere. The drawbacks of it include

handling of the flux and slag requirement and also flux which often restricts the welding position to the horizontal. This method may also increase risk of hot crack formation in some of the stainless steels. Also all slag forming welding methods gives out more oxides and slag particles in weld metal, which decreases impact toughness as compared with the gas shielded methods.

Additional consideration like SAW of duplex stainless steels is usually done for the recovery of alloy elements, especially chromium, while choosing the flux. Low silica and high basicity flux is normally preferred for duplex and super duplex stainless steels.

The optimum welding conditions required for duplex stainless steels hence depends on thickness of the plates that is welded and also of their chemical composition. So the welding parameters should be set accordingly with following rules:

Heat input: Here an optimum value results comes in between need for rather slow cooling below melting point and that of fast cooling below of nearly 1000°C.

Filler metal composition: In this, we have higher Ni content than base metal, so that it can help the formation of austenite. However nitrogen content is lower than base metal to reduce its potential for the precipitation of chromium nitrides.

Shielding gas: It can contain nitrogen to promote the austenite formation also. But in all cases, moisture and hydrogen should be avoided.

Preheating should be avoided. If necessary, the temperature can be taken in about 100°C.

For lean and standard duplex, the requirement for maximum interpass temperature is mainly at 150°C. For super duplex maximum interpass temperature is at 100°C. Stress relief treatment at a low temperature of nearly 600-650°C must be avoided. For Post-weld heat treatment, solution annealing should be done followed by the fast cooling.

Processes without filler metal like spot welding should also be avoided.

Table 3

Duplex Stainless Steels (DSS) with recommended welding filler:

Grades	ASTM	EN	Chemical composition (in wt%)					
			C	N	Cr	Ni	Mo	Mn
2101	S32101	1.4162	0.02	0.22	21.5	1.5	0.3	5
Filler 2101	–	–	0.03	0.16	23.5	7	<0.5	0.8
2304	S32304	1.4362	0.02	0.10	23	4	<0.3	1.5
Filler 2304	–	–	0.02	0.12	24.5	8	<0.3	0.8
2205	S32205	1.4462	0.02	0.17	22	5.5	3.1	1.5
Filler 2205	E2209	–	0.02	0.16	23	9.5	3.2	0.8
2507	S32750	1.4410	0.02	0.27	25	7	4	1.5
Filler 2507	E2594	–	0.03	0.23	25.5	10	4	1.2

Table 4

Welding methods vs plate thickness vs advantages / disadvantages

Method	Plate thickness	Advantages	Disadvantages
SMAW	>1.5 mm	Flexibility position Flexibility grades Ergonomic	Productivity Slag remains
GMAW	>1.5 mm	Welding Speed Cost Impact Toughness	Surface appearance Parameter adjustment
GTAW	0.3-3.0 mm Root runs	Surface appearance Impact Toughness	Productivity Shielding and Purging Gas
SAW	>10 mm	Productivity Surface appearance No fume and radiation	High heat input Only horizontal
FCAW	>2.5 mm	Productivity Wide parameter box	Fume emission Impact strength
PAW	1.0-8.0 mm	Welding speed Surface appearance	Fit up Expensive equipment
Laser	1.0-8.0 mm	Welding speed Surface appearance	Fit up Expensive equipment
Laser hybrid	4.0-15 mm	Productivity Weld metal properties	Expensive equipment Parameters set up

Table 5

Shielding gases in DSS welding

Method	Grades	Shielding Gas
GMAW	2101, 2304, 2205	1. Ar + 1-2% CO ₂ or Ar + 1-3% CO ₂ 2. Ar + 1-2% CO ₂ or Ar + 2-3% CO ₂
	2507	1. Ar + 1-2% CO ₂ or Ar + 1-3% CO ₂ 2. Ar 3. Ar + 30% He + 1-2% N ₂ + 1-2% CO ₂
GTAW	2101, 2304, 2205, 2507	1. Ar + 10-30% He + 2% N ₂ 2. Ar
FCAW	2101, 2304, 2205	1. Ar + 16-25% CO ₂ 2. 100% CO ₂
Plasma	2101, 2304 2205, 2507	1. Ar* 2. Ar + 20-30% He + 1-2% N ₂ * *also as plasma gas
Laser	2101, 2304 2205, 2507	1. Ar

General guidelines:

- Gas flow should be MIG 12-16 l/min
- Gas flow of TIG 8-12 l/min
- A too low or too high flow may result in porosity

Table 6

Recommended parameters of DSS and SDSS for different processes

Process	Material	Filler dia. (mm)	Bead	Current (A)	Voltage (V)	Speed (cm/min.)
MMA	2205	2.50	Root	50-60	20-22	4-6
		3.25	Cap	80-95	23-25	7-9
MMA	2507	4.00		125-135	24-26	15-25
MIG	2205	1.20		180-200	28-30	30-40
TIG	2205	1.60	Root	45-50	9-10	3-5
TIG	2205	2.40	Root	100-120	16-18	5-8
FCAW		1.20	Cap	190-210	28-30	17-22
SAW	2205	3.20		400-450	30-32	40-50
SAW	2507	2.40		350-400	28-30	40-50
FCAW	2205	1.20	Root	135-145	24-26	20-25
			Cap	200-220	28-30	30-45

7.0 DISSIMILAR WELDING OF DUPLEX STAINLESS STEEL

Dissimilar welding of stainless steels with other materials like low alloy steels, Ni alloys etc. is required when transition in mechanical properties or there is requirement of performance of service.

Dissimilar material welding is also used in purposes like weight reduction, cost saving and increasing efficiency of devices & components. This welding method is extensively used in automotive, chemical & petrochemical industries, oil refineries, desalination & electronic industries and power plants.

Filler Material Selection in Dissimilar Welds

Duplex stainless steel can be welded with other duplex stainless steels, with austenitic stainless steels and with carbon and low alloy steels. To weld duplex stainless steels with other duplex grades, most frequently used method is duplex stainless steel filler material, in which nickel content is more as compared to its base metal. Adequate level of austenite formation in the weld during cooling is ensured through increased nickel content in filler material.

Welding to austenitic grades requires austenitic filler metals, which has low carbon and molybdenum content intermediate between two steels that are typically used. AWS E309LMo/ER309LMo is also used to join duplex stainless steels to carbon and with low alloy steels. Nickel –base filler metals can also be used when it is free of niobium (columbium). This is due to the fact that austenitic stainless steels have lower strength than the duplex. Hence, weld joints which is made with the austenitic filler metals will not be stronger than duplex base metal.

Welding of duplex stainless steels with other dissimilar metals requires following filler metals as shown in table 5. Depending on process, joint geometry and other possible considerations, bare wire (AWS designation ER) and flux cored wire can be considered. However the given examples show the usage of AWS SMAW electrode designation 'E'.

Table 7

Welding consumables used for dissimilar metal welding

Type	Lean Duplex	Standard Duplex	Super Duplex
Lean Duplex	E2307 E2209 E309L	E2209	E2209
Standard Duplex	E2209	E2209	E2594
Super Duplex	E2209	E2594	E2594
304/304L	E2209 E309L E309LMo	E2209 E309LMo	E2209 E309LMo
316L	E2209 E309LMo	E2209 E309LMo	E2209 E309LMo
Carbon Steel Low Alloy Steel	E2209 E309L E309LMo	E2209 E309L E309LMo	E2209 E309L E309LMo

Heat Exchanger Tubes



8.0 INDUSTRIAL & FABRICATOR TRAINING PROGRAMMES

Jindal Stainless emphasizes on providing hands-on training to industrial and general stainless steel fabricators across the nation through its monthly fabrication training programmes and workshops. These programmes educate grass-root fabricators about the features and applications of stainless steel (<https://www.jindalstainless.com/applications-of-stainless-steel/>) and empower them to earn a livelihood. Every year thousands of fabricators across India undergo these trainings. Jindal Stainless' skill development programmes have been endorsed by the Ministry of Steel, Government of India and National Skill Development Corporation (NSDC). The Company continues to support the Indian government's programmes like Skill India in order to up-skill India's youth.

In the last few Years JSL has conducted 200+ Training Programs across India, Training more than 18000 Fabricators of different Industries & Segments.



9.0 TRAINING & DISPLAY VANS

In an effort to efficiently showcase the various applications of stainless steel across a plethora of segments, Jindal Stainless has developed 4 stainless steel display vans. They include display of several applications like tableware, cabinets, planters, gates and railings, water management applications, roofing sheets, shutters, chequered flooring, UV printed SS sheets, special finishes & textures, and miniature industry models and accessories (nuts, bolts, hinges etc.), and modern day smart city applications like foot and rail over bridges, metros and stations, bus queue shelters, gas pipelines, building construction applications, and electric smart poles, etc. These vans provide a benchmark reference to the fabricators about the possibilities, quality, and fabrication techniques of stainless steel in specific applications by giving them a live tour. These state-of-the-art showcase vans traverse the length and breadth of the country and continue to inspire fabricators and welders. These vans can be tracked online and invited by consumers for educational purposes



10.0 STAINLESS STEEL COURSES

As industry leader, Jindal Stainless endeavours to educate and equip metallurgy and architecture students from prestigious Indian institutes with stainless steel, its manufacturing and fabrication processes, and benefits. The Company has successfully launched a Stainless Steel and Ferro Alloys' course in premier Indian institutes like IIT Roorkee, IIT Kharagpur, IIT BHU, UPES Dehradun, OP Jindal University, Raigarh, and Indian Institute of Engineering Science and Technology, Shibpur. The programme's curriculum is aimed at helping students learn about the characteristics, properties, and uses of stainless steel. It also has a module where the students visit the plant facilities of Jindal Stainless and acquaint themselves with various processes involved in stainless steel manufacturing.



11.0 CASE STUDY

(i) LEAN DUPLEX UNS S2101 FOR PXTA STORAGE SILOS OFFERS GREATER WEIGHT SAVINGS

Application – API 620 PTA Storage Silos
Location – PE Unit, IOCL Refinery Paradip
Client - Indian Oil Corporation Limited
Contractor - Technip

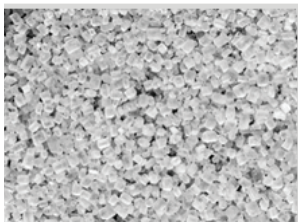
Introduction

Lean Duplex Stainless steel 2101 (UNS S32101 / EN 1.4162) possesses high strength coupled with corrosion resistance comparable to austenitic grades like 304/304L & 316/316L. Being a cost-effective grade owing to low nickel and molybdenum contents, along with its superior mechanical properties and good corrosion resistance, they can be utilized in various applications thus providing durability and long-term cost efficiency and Low Life Cycle Cost.

PTA (Purified Terephthalic Acid) is primarily used to produce polyester fibers and yarn. It is also used to manufacture plasticizers, liquid crystal polymers, and polybutylene terephthalate

The Lean Duplex 2101 was preferred over SS 304L considering detailed engineering done to offer longevity along with weight savings. The Storage Silo Lower Shells and Cone lining is majorly of Lean Duplex and clearly used at the bottom of the structure to handle high loads with optimal shell thickness.

Quantity of LDSS 2101 Supplied – 852MT
Approximate Tank Dimensions – L – 21 meters, D - 9.5 Meters
Design Standard of PXTA Storage Silo – API 620



COMPARISON B/W COMMON AUSTENITIC & LEAN DUPLEX GRADE(S)

Parameter	SS 304/304L	SS 316/316L	Lean Duplex UNS S32101
Wear Resistance	Low	Low	High
PREN	~19	~23-24	~26
Resistance to Pitting / Crevice corrosion	Low	Medium	High
Stress Corrosion Cracking	Yes	Yes	No SCC. Perform well in environments which cause premature failure of austenitic grades.
Heat Resistance (Upto 250°C)	Good high temperature oxidation resistance	Good high temperature oxidation resistance	Good high temperature oxidation resistance
Suitability in Marine Environment	Negligible / Not Suitable	Negligible / Not Suitable	Moderately Suitable
Mechanical Properties	UTS (MPa)-485 Min YS (MPa)-170 Min %EL-40% Hardness-190 BHN	UTS (MPa)-515 Min YS (MPa)-205 Min %EL-40% Hardness-210 BHN	UTS (MPa)-650 Min YS (MPa)-450 Min %EL-30 %min Hardness - 290 BHN
Strength	Low	Medium	High
Weight of Structure	Heavy	Heavy	Light weight structure possible
Welding	Weldable by all standard electric methods	Weldable by all standard electric methods	Weldable by all standard electric methods. Unlike other duplex grades welding of 2101 without filler metal may be possible
Price Per KG	Low	Higher than SS 304 and comparable to Lean Duplex	Low

We at Jindal Stainless can support you to find the most cost-effective solution to your specific application from our comprehensive product portfolio of stainless steel. Significant cost savings can be achieved by avoiding unnecessary maintenance and longer service life.

(ii) STAINLESS STEEL 409M REPLACED MS IS 2062 GR B FOR CRUDE OIL APPLICATION

Application – Upper Floating Roof Plate for 60,000KL
Crude Oil Tank

Location – ParadipHaldiaBarauni Pipeline Limited, Paradip

Client - Indian Oil Corporation Limited (Pipelines Division)

Introduction

The landscape of Upper deck plate is spread across span of 78.6m which is in direct exposure to saline environment along with rainwater retention.

MS plates painted with high quality paint has been a traditional practice however faced challenges in terms of regular maintenance, painting.

PHBPL along with Jindal Stainless Limited have installed 10 MT of 409M grade UDP (Upper Deck Plate) without any painting in 2021, which have given better performance and trends towards lower maintainace cost / Lower Life Cycle Cost and offers sustainability by reduction in CO2 footprint.

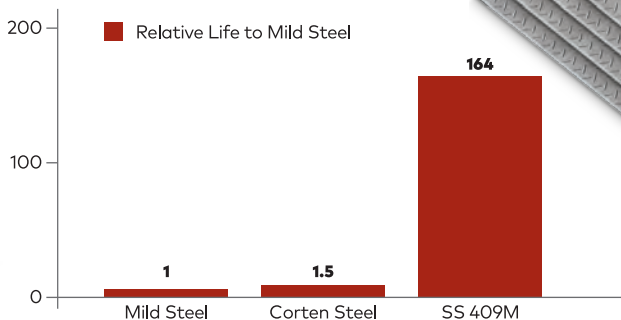
Typical Size of Plate – 1.5m x 5mm thick x 6.3m L

Total Weight for One Tank – 195.365 MT

Whereas the Fire Water pipes and the AFFF pipeline are of Lean Duplex Stainless Steel UNS S32101 / Duplex UNS 32205 / Equivalent grades which have been proven suitable material for similar ambient conditions.



164 TIMES MORE CORROSION RESISTANT 1 LASTING PROMISE.



This graph is taken from a report 'Atmospheric corrosion testing in Southern Africa-Results of a twenty year exposure programme' conducted by BG Callaghan, Division of Materials Science and Technology, CSIR (South Africa).



(iii) SUPER DUPLEX STAINLESS STEEL FOR ZLD EFFLUENT OF FERTILIZER UNIT & DESALINATION

Application – Evaporator Unit and Piping of ZLD
Client –A Government Fertilizer Company
Material Grade - UNS32750 / UNS32760

Introduction

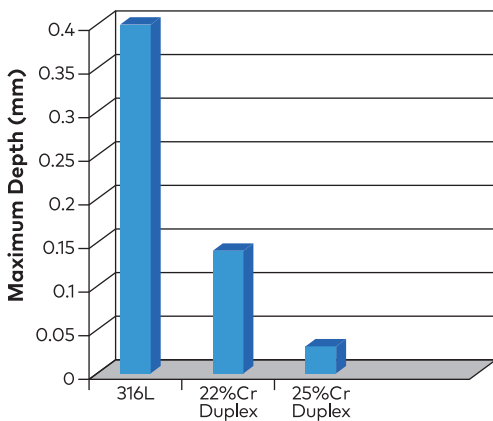
Jindal Stainless Limited accelerated efforts in advertising Sustainable and Make in India, our R&D unit at Hisar, Haryanahas tested various material in encapsulated environment at elevated temperatures to understand the corrosion rate in the effluent collected from client site.

After suitable trial of the material JSL suggested the use of Super Duplex Grades against imported material aiding client to have Suitable material with Low Life cycle cost. Project's lead time is also estimated to be exponentially reduced enabling an early kick start to the entire fertilizer unit.

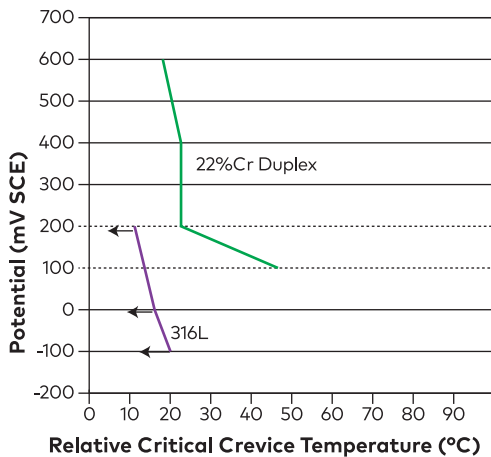
Super Duplex Grades are also suitable for SWRO plants for Vessels, Tanks and Piping

The results, in Figure below show that 316L stainless steel would be totally unsuitable for SWRO plants because of the low temperature at which crevice corrosion initiates. Alloys such as 22%Cr duplex and 25% Cr Super Duplex (SS2507) showed good crevice corrosion resistance





Depth of crevice corrosion in seawater at 16°C with 1mg/L chlorine.



(iv) DUPLEX STAINLESS STEEL UNS32205 FOR ROAD OVER BRIDGE

Application – Mrinal Tai Gore Road Over Bridge, Mumbai
Client –Municipal Corporation of Greater Mumbai
Material Grade - UNS32205

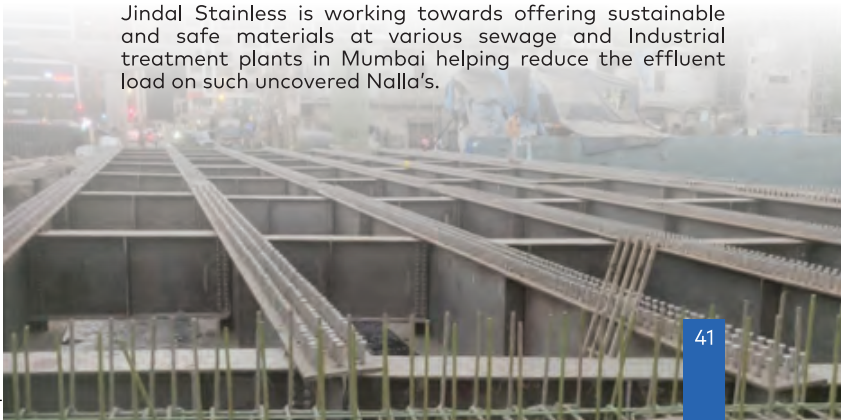
Introduction

Mrinal Tai Gore Flyover at Cama Industrial Estate, Mumbai was constructed over Ram MandirNalla to ensure smooth transit of traffic from Goregaon West to East in Using Majorly Mild Steel and Stainless Steel and inaugurated in Year 2017.

Due to Industrial and Municipal effluent discharge in to the Ram MandirNalla, high content of Methane (CH₄), Hydrogen Sulphide (H₂S), Microbes and various other air borne pollutants that are found in a Typical Sewage Treatment Plant acted as a catalyst in the corrosion and the bridge was found unsafe for commuting and later decided to be abandoned within couple of years.

Jindal Stainless expertise in knowing the corrosion and it's commitment towards creating a sustainable and safe environment contacted BMC and offered various suitable proposalsamongst which usage of approximately 400 MT of Duplex Stainless UNS32205 in bridge construction was considered after detailed design engineering.

Jindal Stainless is working towards offering sustainable and safe materials at various sewage and Industrial treatment plants in Mumbai helping reduce the effluent load on such uncovered Nalla's.



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