DUPLEX AND SUPER DUPLEX STAINLESS STEEL AND THEIR WELDING *

INTRODUCTION

Materials and weldments used in severe environments, specially involving chloride containing aequeous fluids, require improved corrosion resistance properties and/or higher strength properties compared to stainless steel grades, say AISI 316L. To meet this need a stainless steel grade with two phases was commercially first introduced in 1970s which had high ferrite (30–70%) and austenite.

The ferrite/austenite ratio is accomplished in wrought alloys by composition adjustment along with controlled hot working and annealing practices at the mill. The alloys could properly be called ferritic-austenitic stainless steel but the term "DUPLEX" is more widely used. A typical microstructure is shown in Figure 1. The matrix which appears as the darker

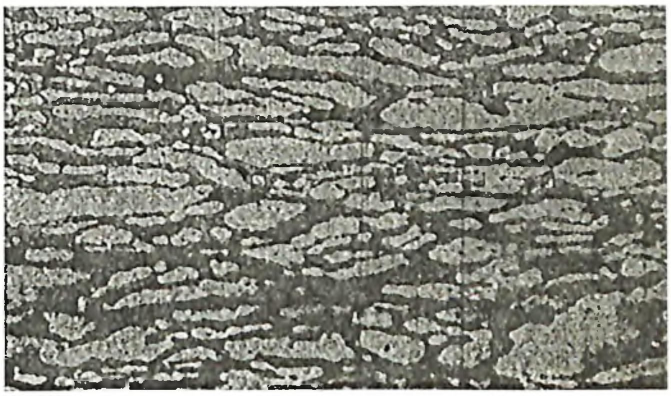

Figure 1. Typical microstructure of cold rolled, quench annealed Alloy 2205, seamless tube. Dark phase - ferrite, light phase - austenite.

Table 1: Applications of duplex and super-duplex welded structures in various segments of industry

Industrial segment	Steel grades 23% Cr, Mo free	22% Cr duplex PRE$_N$ 30-36	25% Cr duplex PRE$_N$ 32-40	25% Cr super-duplex PRE$_N$>40
Chemical process	Piping	Pumps, fans, centrifuges, sulphur melting coils, chemical tankers	Urea strippers and reactors agitators	Salt evap. tubing
Petrochemical	Tubular reactors with C steel shell	Desalting, desulphurization and distillation unit	Desulphurization equipment. Pump casings	Tubes and pipes Cl or HCl environments
Pulp and paper	Digesters, preheaters and evaporators	Sulphate and sulphite plant digesters	Digesters and digester preheaters	Chloride cont. bleaching equipment
Power generation (nuclear, fossil)	Reheaters, feed water heaters	High velocity injection pipe in geothermal wells	Heat exchangers and systems in geothermal conditions or saline brines	
Oil and gas (on and off shore)	Coolers, piping flow lines tensioning systems	Flare boom framework, slotted oil liners	Sour gas transportation pumps, seawater injection pumps, diving bells	Seawater cooling systems. Pumps, separator pressure vessels. X-mas tree valve blocks

* Adapted from NiDI Report No. 11011 of 1993.

background is ferrite and the elongated, island-like lighter phase is austenite.

The duplex and super duplex stainless steel grades are used in a large number of other applications due to their favourable mechanical and corrosion properties. In general the two main reasons are higher strength properties which enable lighter support structures to be used, and the higher corrosion resistance, in particular against stress corrosion cracking, compared to standard stainless steel grades such as AISI 304L/316L resulting in a longer life-cycle.

In Table 1, an attempt has been made to exemplify typical applications of the four main duplex stainless steel groups for different areas of industry.

Base Material

Commercial grades of Duplex and super-duplex stainless steel grades are established in various product forms like plate, pipes castings, forgings and fittings, bars, wires, etc.

The steels are almost exclusively produced by the argon-oxygen-decarburization (AOD) method, in conjunction with electric arc melting processes.

The distinction between duplex and super-duplex is usually associated with about 25% Cr,≥ 3.5% Mo and ≥ 0.2% N, providing an increased Pitting Resistance Equivalent (PRE_N = %Cr + 3.3 5 %Mo + 16 5 %N ≥ 40). The regular Mo alloyed duplex grades have a PRE_N value of between 30 and 36.

Few well known commercial grades in the market have been included in Table 2. To structure the terminology, the following duplex stainless steel families can be distinguished:

(a) 23% Cr Mo-free duplex stainless steel PRE_N 25

(b) 22% Cr duplex stainless steel PRE_N 30-36

(c) 25% Cr (2.5% Cu) duplex stainless-steel PRE_N 32-40

(d) 25% Cr super-duplex stainless steel PRE_N ≥ 40.

WELDING PROCEDURES

Welding processes:

Depending on process and economy related conditions, the following welding processes can be applied :

- SMAW (MMA) — Shielded Metal Arc Welding (welding with covered electrodes).
- GTAW — Gas Tungsten Arc Welding
- GMAW — Gas Metal Arc Welding
- FCAW — Flux Cored Arc Welding
- SAW — Submerged Arc Welding
- PAW — Plasma Arc Welding.

Table 2: Duplex stainless steels (chemical analysis of major elements. %)

Commonnaem (UNS)	C	Cr	Ni	Mo	Others
7-Mo PLUS (S32950)	0.03	26.0-29.0	3.5-5.2	1.0-2.5	0.10-0.35N
Alloy 2205 (S31803)	0.03	21.0-23.0	4.5-6.5	2.5-3.5	0.08-0.20N
FERRALIUM 255 (S32550)	0.03	24.0.27.0	4.5-6.5	2.0-4.0	0.10-0.25N 1.5-2.5Cu
SAF 2507 (S32750)	0.03	24.0-26.0	6.0-8.0	3.0-5.0	0.24-0.32N
Zeron 100 (S32760)	0.03	24.0-26.0	6.0.8.0	3.0-4.0	0.5-1.0 Cu 0.5-1.0 W 0.2-0.3 N

In selecting welding process, the process characteristics are determining considerations. The important ones are listed in Table 3.

SMAW and GTAW are the most versatile processes, but the welder's duty cycle is lowest (15-25%), whereas other manual processes achieve higher duty cycles > 50%.

Table 3: Welding process characteristics

Process	Characteristics
SMAW (MMA)	Consumables readily available, all position welding, slagon weld surface to be removed, low deposition rate.
GTAW/TIG	Requires good skill, most suitable for pipe welding, high effect of dilution in root runs, low deposition rate, can be

	mechanized/automated, *e.g.*, orbital welding systems.
GMAW / MIG-MAG	Requires good skill, more setup work, metal transfer depends on wire quality (spattering), commonly used only for filling of joints, high deposition rate, can be mechanized / automated.
FCAW	Limited availability of consumables, used only for filling of joints, limited positional welding capability, high deposition rate, slag protection.
SAW	Only mechanized, requires set-up arrangements, only downhand (flat) welding, high dilution affects weld properties, highest deposition rate, slag removal in joint may be difficult.
PAW	Requires complex equipment, only mechanized welding, no filler metal added, plate composition determines weld properties, high welding speed.

WELDING CONSUMABLES:

The standardization of welding consumables designed for welding duplex and super-duplex stainless steels is limited. Reference can only be made to the following national and international standards of working documents for covered electrodes and bare wires :

- AWS A 5.4-96
- AWS A5.9-96

Welding consumable for duplex and super duplex stainless steel grades are manufactured and marketed by most leading welding consumable manufacturers.

Covered electrodes are available with a rutile or basic covering. Basic elctrodes are some what easier for all position welding but rutile (sometimes called rutile / basic) electrodes perform well in almost all practical applications.

FILLER MATERIALS:

Duplex stainless steel welds made with matching composition filler metal or autogenously welded (no filler metal) may exhibit 80% or more ferrite in the fusion zone in the as-welded condition. A weld with such a high ferrite level has poor toughness and ductility and often will not pass a bend test. The higher ferrite content of such welds also markedly reduces corrosion resistance in many aggressive environments. An anneal at 1040°C to 1150°C restores the desired ferrite/austenite balance but the treatment is not practical for many fabrications and is expensive. Increasing the nickel content of the filler metal allows more austenite to form so that welds in the as-welded condition have typically 30% to 60% ferrite. Welds made with nickel enriched filler metals have good as-welded ductility, are able to pass bend tests, and have corrosion resistance comparable to the base metal.

It is desirable that all weld passes be made with substantial filler metal addition to provide a nickel enhanced weld metal composition. A large amount of base metal dilution can result in welds having a high ferrite content with lower ductility and toughness. An example of where this can occur is the root pass of a pipe weld with high base metal dilution. Special care should be taken to add sufficient nickel-enriched filler metal. Joints with a feather edge and tight fit-ups favour high dilution and are best avoided. Joints with an open root spacing and a land are preferred since they require the addition of filler metal.

Nickel-enriched filler metal products for the duplex alloys are available as covered electrodes, bare filler metal and flux cored wire as shown in Table 4.

SHIELDING AND BACKING GASES

Shielding gases suitable for the various gas shielded processes are listed in Table 5.

Backing gases for internal protection of one sided welded pipes can be either industrial pure argon (Ar 99.996%) or high purity nitrogen (99.996%). Some manufacturers recommend the use of 90% N_2 + 10% H_2 as backing gas. In all cases, gases should be dry.

Table 4: Duplex stainless steel-typical composition of welding consumables.

Consumable (UNS)	For welding of	C	Cr	Ni	Mo	Others
Covered electrodes						
2209-16	2205	0.03	23	9.7	3.0	0.10N
(W39209) tentative	(S31803)					
22.9.3.L-16	3RE60 (S31500)	0.03	22	9.5	3.0	0.15N
22.9.3.L-15	2205 (S31803)					
22.9.3.LR	2304 (S32304)					
7-Mo PLUS	7-Mo PLUS	0.03	26.5	9.5	1.5	0.20N
Enriched Ni	(S32950)					
FERRALIUM 255	FERRALIUM 255	0.03	25	7.5	3.1	0.20N
(W39553) tentative	(S32550)					2.0Cu
Bare filler wire						
22.8.3L	3RE60 (S31500)	0.01	22.5	8	3	0.10N
	2205 (S31803)					
	2304 (S32304)					
7-Mo PLUS	7-Mo Plus	0.02	26.5	8.5	1.5	0.20N
Enriched Ni	(S32950)					
FERRALIUM 255	FERRALIUM 255	0.03	25	5.8	3.0	0.17N
(S39553) Tentative	(S32550)					
Zeron 100 filler wire	Zeron 100	0.03	25	10	3.5	0.25N
	(S32760)					0.7Cu
						0.7W
Flux Cored Wire						
In-Flux 2209-0	2205	0.02	22.0	8.5	3.3	0.14N
(W31831)	(S31803)					
In-Flux 259-0	FERRALIUM 255	0.02	25	10	3.2	0.14N
	(S32550)					2.0 Cu

Table 5: Shielding gas recommendation

Welding Process	Gas Types
GTAW/TIG	Ar 99.996%, Ar + 2% N_2, Ar+5% N_2
GMAW/MIG-MAG	Ar + 1% O_2, Ar 30% He + 1% O_2
	Ar + 2%CO_2, Ar + 15% He + 2% CO_2
FCAW	Ar + 1% O_2, Ar + 20% CO_2,
	Ar + 2% CO_2, CO_2
PAW	Ar 99.996%

WELDING IN PRACTICE

In welding duplex and super-duplex stainless steel, considerations valid for standard stainless steel welding are most relevant. They include :

- similar joint preparation and cleaning;
- prevention of arc strikes outside the joint;
- allowance for high workpiece displacements, due to shrinking or distortion effects;
- prevention of overheating of root zones and thin sections by limiting the interpass temperature and heat input;
- protection of weld and parent material against excessive oxidation;
- prevention of residual slag and excessive oxidation on the side exposed to the corrosive environment.

Weld metal shall fulfil a FN (Ferrite Number) requirement of FN = 30-100 (approximately 22-70%) in GTA weldments. With other processes and at locations exposed to the corrosive environment and / or where diffusible hydrogen and strain may initiate hydrogen cracking, restriction to FN = 30-85 (approximately 22-60%) may be required. Postweld annealing is usually applied when very high ferrite levels can not be prevented in the as-welded condition (*e.g.*, longitudinal pipe welds).

Essential variables in the welding procedure for a given material are :

- welding consumable
- joint preparation
- welding position
- setting of current (wire feed speed), voltage, polarity
- heat input
- shielding gas type
- preheat and interpass temperature.

Selection of welding consumables requires consultation of the manufacturer's product documentation.

Preheating of duplex and super-duplex material is not required except where heavy restraint on high ferrite containing structures (weld, HAZ) may cause (hydrogen-induced) cracking. In such cases preheating up to 150°C is recommended. For 23% Cr Mo-free duplex and 22% Cr duplex the interpass temperature shall be max. 200°C. For 25% Cr duplex and super-duplex steel grades the interpass temperature shall not exceed 150°C, a maximum of 100°C is recommended for optimal weld metal properties. In cases where postweld annealing will be applied, no limitation in interpass temperatures are required.

POST WELD HEAT TREATMENT

By preference, welded structures are put in service in the "as welded" condition. Weldments, highly strained or deteriorated due to detrimental phase transformations resulting in low corrosion resistance and low ductility, are to be solution annealed. 23% Cr Mo-free and 22% Cr duplex stainless steel grades shall be heat treated to 1050 -1100°C. Whereas the 25% Cr duplex and super-duplex grades require an annealing temperature in the range 1070-1120°C. This higher end of the temperature range given shall be selected for weldments with overmatching weld metal composition (Ni = 8 to 10%). The heating shall be as fast as possible, and the annealing is immediately followed by water quenching. Most effective is inductive heating.

Duration at the annealing temperature shall be 5 to 30 minutes and shall be sufficient to restores phase equilibrium, including solution of intermetallic phases (sigma and chi phase in particular).

Duplex and super-duplex grades deform easily at the annealing temperature. Special attention is needed to maintain product dimensions.

CLEANING AND PASSIVATION

Standard stainless steel cleaning practice can be applied. This includes cleaning of welded joints from residual slag by fine grinding. Rotating brushing (power brushing) shall not be applied, due to excessive surface deterioration (fine crevices). Welded structures with a smooth weld surface, but lightly oxidized or contaminated, are successfully cleaned by pickling with common pickling pastes or liquids. Attention shall be paid to complete removal of the pickling agent after treatment.

Passivation of welded structures shall only be carried out if the treatment can be followed by complete rinsing. The aqueous passivation solution contains 20 vol. % HNO_3.

CONCLUSION

This article has been compiled to provide a general idea of duplex and super-duplex stainless steels and their applications. With the introduction of second generation and super duplex steel grades the application scope has widened significantly as the weldability has improved to an acceptable level. This article, therefore, also touches upon various aspects of welding of these grades of steels. However, for actual practice it will be necessary to consult the manufacturer of the steel.

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