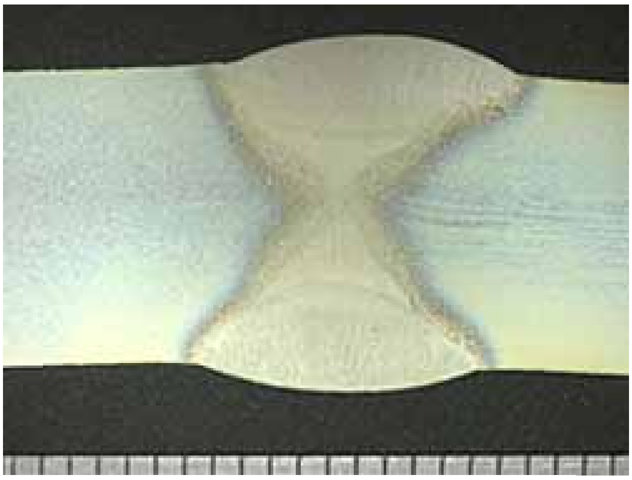
Welding Job Knowledge

Duplex Stainless Steel - Part 1



The name 'duplex' for this family of stainless steels derives from the microstructure of the alloys which comprises approximately 50/50 mixture of austenite and delta-ferrite. They are designed to provide better corrosion resistance, particularly chloride stress corrosion and chloride pitting corrosion, and higher strength than standard austenitic stainless steels such as Type 304 or 316. The main differences in composition, when compared with an austenitic stainless steel is that the duplex steels have a higher chromium content, 20 - 28%; higher molybdenum, up to 5%; lower nickel, up to 9% and 0.05 - 0.5% nitrogen. Both the low nickel content and the high strength (enabling thinner sections to be used) give significant cost benefits. They are therefore used extensively in the offshore oil and gas industry for pipework systems, manifolds, risers, *etc* and in the petrochemical industry in the form of pipelines and pressure vessels.

In addition to the improved corrosion resistance compared with the 300 series stainless steels duplex steels also have higher strength. For example, a Type 304 stainless steel has a 0.2% proof strength in the region of 280N/mm^2, a 22%Cr duplex stainless steel a minimum 0.2% proof strength of some 450N/mm^2 and a superduplex grade a minimum of 550N/mm^2.

Although duplex stainless steels are highly corrosion and oxidation resistant they cannot be used at elevated temperatures. This is due to the formation of brittle phases in the ferrite at relatively low temperatures, see below, these phases having a catastrophic effect on the toughness of the steels. The ASME pressure vessel codes therefore restrict the service temperature of all grades to below 315°C, other codes specify even lower service temperatures, perhaps as low as 250°C for superduplex steels.

Duplex alloys can be divided into three main groups; lean duplex, 22%Cr duplex and 25%Cr superduplex, and even higher alloyed, hyperduplex grades have been developed, this division being based primarily on the alloy's alloying level, *eg* in terms of 'PREN' (pitting resistance equivalence number), a measure of the alloy's resistance to pitting corrosion. PREN is calculated from a simple formula: PREN = %Cr + 3.3%Mo +16%N and an allowance for W is sometimes made, having a factor of 1.65. A duplex steel has a PREN less than 40; a superduplex a PREN between 40 and 45 and hyperduplex a PREN above 45, whilst the lean grades typically have lower nickel and hence lower price.

The commonest shorthand method of identifying the individual alloys is by the use of the trade name, particularly for the superduplex grades, *eg* UR52N+, Zeron 100, 2507 or DP3W, whilst the most common 22%Cr grade, UNS S31803 has widely become known as 2205 regardless of its supplier, although this is a trade name.

The UNS numbering system offers an independent alternative. Typical compositions and minimum proof strengths of the more common duplex alloys are given in the *Table*. Note that the commonly used 2205 applies to two UNS numbers, S31803 and S32205, with S32205 being a more recent and controlled composition.

Typical compositions and proof strengths of common duplex stainless steels

Common Name	UNS No	BS EN No	Steel Type	Typical Chemical Composition %						0.2% proof strength N/mm^2 (min)
				%C	Cr	Ni	Mo	N	Cu	
2304	S32304	1.4362	duplex	0.015	23.0	4.0	0.055	0.13		400
2205	S31803	1.4462	duplex	0.015	22.0	5.5	3.0	0.14	-	450
2205	S32205	1.4462	duplex	0.015	22.5	5.5	3.3	0.17		450
255 (UR52N)	S32520	1.4507	super duplex	0.015	25.0	7.0	3-5	0.28	0.13	550
2507	S32750	1.4410	super duplex	0.015	25.0	7.0	4.5	0.28	0.3	550
Zeron 100	S32760	1.4501	super duplex	0.015	25.0	7.0	3.5	0.25	0.8	550
Sandvik SAF3207	S33207	-	hyper duplex	0.03	31	7.5	4.0	0.50	0.75	700

The metallurgy of the duplex stainless steel family is complex and requires very close control of composition and heat treatment regimes if mechanical properties and/or corrosion resistance are not to be adversely affected. To produce the optimum mechanical properties and corrosion resistance the microstructure or phase balance of both the parent and weld metal should be around 50% ferrite and 50% austenite. This precise value is impossible to achieve repeatably but a range of phase balance is acceptable. The phase balance of parent metals generally ranges from 35 - 60% ferrite.

Whilst composition and, perhaps more importantly, heat treatment parameters are relatively easy to control this is not the case during welding. The amount of ferrite is dependant not only on composition but also on the cooling rate; fast cooling rates retain more of the ferrite that forms at elevated temperature. Therefore to minimise the risk of producing very high ferrite levels in the weld metal it is necessary to ensure that there is a minimum heat input and therefore a maximum cooling rate. A rule of thumb is that heat input for duplex and superduplex steels should be not less than 0.5kJ/mm although thick sections will need this lower limit to be increased.

Welding consumables are also generally formulated to contain more nickel than the parent metal, nickel being one of the elements that promotes the formation of austenite. A duplex filler metal may contain up to 7% nickel, a superduplex up to 10% nickel.

Reference to the phase diagrams and CCT curves shows that the duplex stainless steels fall within the area where the production of brittle intermetallic phases is a major risk during welding and heat treatment, markedly reducing both toughness and corrosion resistance.

The main culprits are sigma phase, chi phase and 475°C embrittlement. Sigma and chi phases form at temperatures between 550 and 1000°C with the fastest rate of formation around 850°C. The time to form these phases can be as short as 30 or 40 seconds in a superduplex alloy. 4750C embrittlement, as the name suggests, occurs at lower temperatures of some 350 - 550°C with times for the start of formation of perhaps 7 - 10 minutes.

Short times such as these are within the ranges that may be encountered during interpass cooling so, once again, heat input and cooling rates become very important welding parameters except that this time it is the maximum heat input that needs to be controlled. A maximum heat input of 2.5kJ/mm should be acceptable for the duplex steels and 2.0kJ/mm maximum for superduplex. Many codes and contract specifications, however, further restrict heat inputs to less than 1.75 - 2kJ/mm for duplex steels and 1.5 - 1.75kJ/mm for superduplex.

Two other factors that also affect cooling rates are preheating and interpass temperatures. Preheat is not generally regarded as necessary for duplex stainless steels unless the ambient conditions mean that the steel is below 5°C or there is condensation on the surface. In these situations a preheat of around 50 - 75°C should be adequate. Very thick section joints, particularly those welded with the submerged arc process, can also benefit from a low preheat of around 100°C.

Interpass temperature can have a significant effect on the microstructure of the weld and its heat affected zones. For a duplex steel 250°C is regarded as an acceptable maximum and for a superduplex 150°C maximum. Note, however, that many codes do not separate the grades into duplex and superduplex and 150°C is often required as the norm. Such low interpass temperatures can have a serious effect on joint completion times and forced cooling by blowing dry air through the bore of a pipe once the bore purge has been removed has been used. This is generally only beneficial when thick wall vessels or pipes are being welded using a rotated pipe mechanised TIG process or submerged arc. If this technique is used then it is advisable to force cool the procedure qualification test piece to ensure that cooling rates (and the resultant microstructures) are within the permissible range.

Care therefore needs to be taken to read through code and contract specification requirements and to ensure that the requirements with respect to heat input, interpass temperature *etc*. are incorporated in welding procedure documentation prior to welding procedure qualification. The next *Job Knowledge* will provide some guidelines for the welding of the duplex stainless steels.