Shielding gas developments for TIG welding of duplex and super duplex stainless steels

by R Wiktorowicz and J Crouch*

The TIG welding of duplex and super duplex stainless steels is discussed with particular reference to obtaining the optimal phase balance between austenite and ferrite. This is mainly achieved by control of the cooling rate and the weld chemistry. The latter is dependent upon the filler wire chosen and the shielding gas used. The authors highlight the effects that N_2 additions to the argon shielding gas have on the weld metal composition and the resultant microstructure.

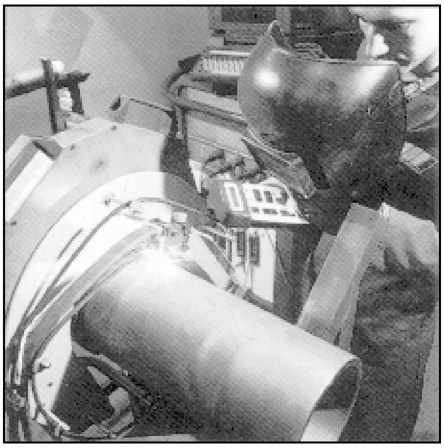

Fig 1. Orbital TIG welding of tube.

Duplex and super duplex stainless steels are a relatively recent innovation, which attempt to combine the favourable properties of austenitic and ferritic stainless steels, In addition to a high strength to weight ratio, these materials possess excellent resistance to stress corrosion cracking (SCC) and pitting and general corrosion. They are finding increasing use as an alternative to austenitic stainless steel where chloride SCC is of concern, for instance in hot liquor vessels in the chemical industry, and even as an alternative to carbon steel pipelines, to reduce long term maintenance and service costs[1].

The properties of duplex materials result from a microstructure comprising similar proportions of austenite and ferrite phases. When welding duplex materials, particular care must be taken to ensure that the phase balance in both the weld deposit and the heat affected zone is maintained, otherwise the optimum combination of mechanical properties and corrosion resistance will not be achieved. For this reason, welding of duplex materials presents additional challenges to the welding engineer.

TIG welding of duplex stainless steel

The TIG welding process allows a high degree of control and the low oxygen content of the weld metal results in excellent notch toughness characteristics. Little slag is formed during TIG welding, which means that penetration bead slag crevices, which can act as corrosion initiation sites, are avoided[2]. The incidence of defects is lower than for the pulsed MIG process,

Shielding gas	Duplex %	Super duplex %
Parent material (typical anal)	0.16	0.25
Argon	0.0966	0.169
Duplex 7	0.1538	-
Ar-2% N2	0.1927	0.2559
Duplex 2	-	0.2465

Table 1. Weld metal nitrogen analysis.

TIG welding with filler wire is conventionally used for root runs and hot passes in single sided welds and, where exceptional toughness is required, to complete pipe welds up to 7mm wall thickness, fig 1. For manual welding, the filler wire used is typically 1.6mm diameter or, for joints thicker than approximately 3mm, 2.4mm diameter is used. Orbital welding utilises 0.8mm precision wound wire.

When TIG welding a duplex stainless steel joint, in order to achieve the desired austenite-ferrite phase balance and the optimum combination of mechanical properties and corrosion resistance, two factors are normally controlled:

- The cooling rate of the joint.
- The weld metal chemistry.

The cooling rate of the joint is normally controlled by specifying the arc energy and inter pass temperature[1]. The weld metal chemistry is influenced by the filler wire and the shielding gas[3]. An increase of 2-3% in the nickel content of the wire, relative to the parent metal, increases the austenite forming tendency of the weld metal and allows the desired austenite-ferrite phase balance to be achieved without post-weld heat treatment. However, concerns have been expressed that the nickel addition, by effecting the phase balance and the distribution of chromium molybdenum and nitrogen between the ferrite and the austenite[4], may be detrimental to the corrosion resistance. Recent work has highlighted the potential of the shielding gas in TIG welding to assist in achieving the austenite-ferrite phase balance[1,5,6]. In addition, shielding gas developments have allowed an increase in productivity and an improvement in the welding environment.

Optimising the austenite-ferrite phase balance

The weld metal chemistry is thought to be the most important factor in influencing the phase balance of the weld metal. Recent attention has focused on the level of nitrogen in the weld metal, which encourages the formation of austenite. In duplex stainless steel, the nitrogen content is typically between 0.15 and 0.180/o. In super duplex stainless steel, the nitrogen content is typically between 0.22 and 0.28%. When TIG welding with argon shielding gas, nitrogen is lost from the weld pool, table 1. This can result in a ferrite-rich weld metal, with inferior corrosion resistance to the parent metal.

The loss of nitrogen from the weld pool appears to be due to the difference in partial pressure between the nitrogen dissolved in the weld pool and the gas directly above the weld pool. The partial pressure of nitrogen in the shielding gas, and hence the loss of nitrogen from the

Table 2. Results of corrosion tests on duplex stainless steel.

	Corrosion performance†		
Shielding gas	**Charpy* Joules kv**	**Weight loss mg**	**Acceptance criteria**
Argon	103	52.9	Fail
Argon +2% N2	106	39.4	Fail
Duplex 1	109	10.2	Pass

†Ferric chloride pitting corrosion test method TWI 5632/1 9/93
‡Procedure TPO6, BSCN 1 0045-1:1990

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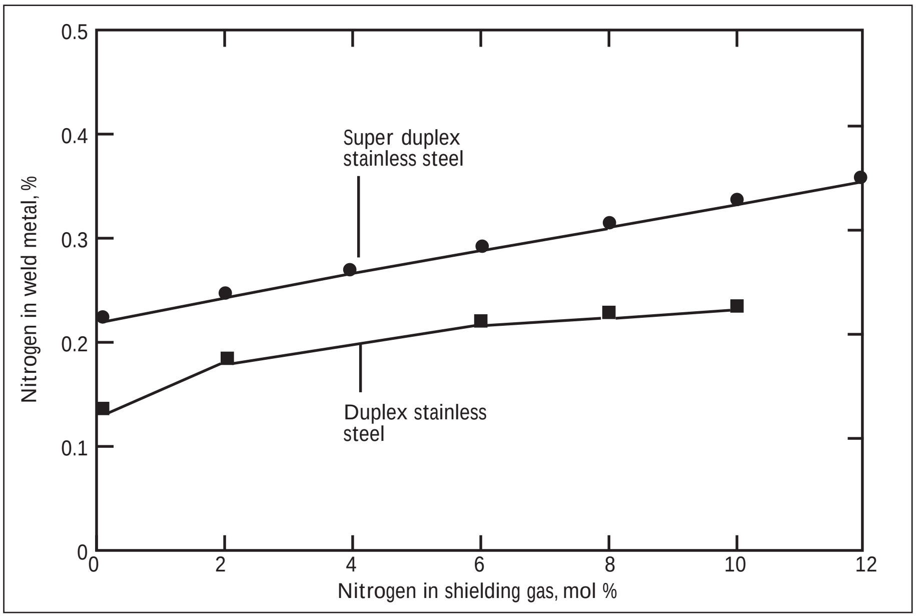


Fig 2. Relationship between nitrogen in the shielding gos and nitrogen in the weld metal for TIG welding of duplex and super duplex stainless steels.

weld pool, can be modified by using a shielding gas containing a proportion of nitrogen, fig 2. It should be noted that the level of nitrogen in the shielding gas needed to match the nitrogen level in the parent metal is different for duplex and super duplex stainless steel. For duplex stainless steel, with a typical nitrogen content of 0.16%, to obtain a similar nitrogen content in the weld metal, the shielding gas should contain 1.0 - 1.2% N2. For super duplex stainless steel, with a typical nitrogen content of 0.25%, to obtain a similar nitrogen content in the weld metal, the shielding gas should contain 2.0 - 2.5% N2.

Macrosections of joints manufactured with argon shielding gas and shielding gases containing the suggested proportions of nitrogen are shown in fig 3. It can be seen that the welds produced under arson shielding, with a significant reduction in the weld metal nitrogen, table 1, exhibited a much coarser, more ferritic structure than the welds with a nitrogen content matching the parent metal.

It has been suggested that an increase in the nitrogen content above that of the parent metal may further improve the corrosion resistance[7], through the passivation of hydrogen ions at the base of any pits which form. However, the results of corrosion tests, table 2, demonstrate that a nitrogen level either below or above that of the parent material may lead to inferior corrosion performance. The inferior corrosion resistance of the weld metal containing a higher proportion of nitrogen than the parent metal may be due to the nitrogen adjusting the phase balance and the distribution of alloying elements between the ferrite and the austenite. This is a similar effect to that suggested when using filler wires over-alloyed in nicke14.

It should be noted that if the proportion of nitrogen in the shielding gas exceeds the suggested values, then the partial pressure of nitrogen in the shielding gas will exceed that of the molten weld pool, and the nitrogen level of the weld pool will rise. This may lead to an austenite-rich weld metal. Concerns have been expressed that if the proportion of nitrogen in the shielding gas exceeds the suggested values, then the nitrogen content of the weld will increase along the weld length, fig 4 (refs 6, 8). It has also been observed that the nitrogen level may increase through the thickness as successive passes are deposited. It should be noted that the nitrogen solubility in the liquid metal is significantly higher than the nitrogen solubility in the solidified meta1[6]. If the nitrogen content of the liquid weld pool exceeds the solubility limit for nitrogen in the solidified material, the 'excess' nitrogen will attempt to escape from the pool on solidification, This may be responsible for practical observations of porosity when TIG welding duplex stainless steel with shielding gases containing greater than 2% nitrogen. In addition, this 'outgassing' may be responsible for the 'spitting' or 'sparking' of the weld pool, observed during the TIG welding of duplex stainless steel with levels of nitrogen between 2 and 5% in the shielding gas[7]. It is claimed that this problem may be suppressed by grinding out end craters, and ensuring that the filler wire remains within the gas shield. However, the 'spitting' or 'sparking' may give rise to fine spatter, which has a detrimental effect on the corrosion resistance of the joint. These difficulties reinforce the need for the nitrogen content of the shielding gas to be tailored to prevent excessive nitrogen absorption by the weld pool.

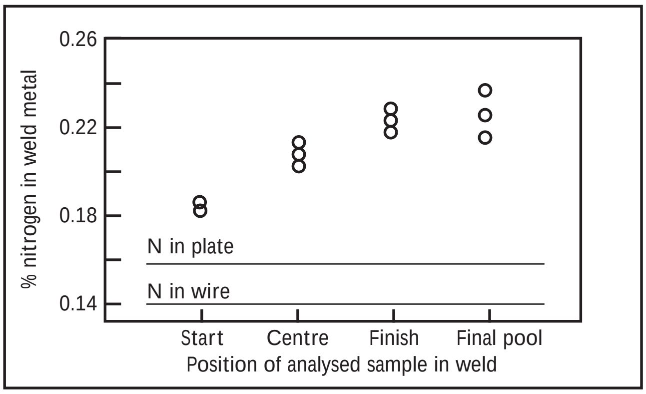
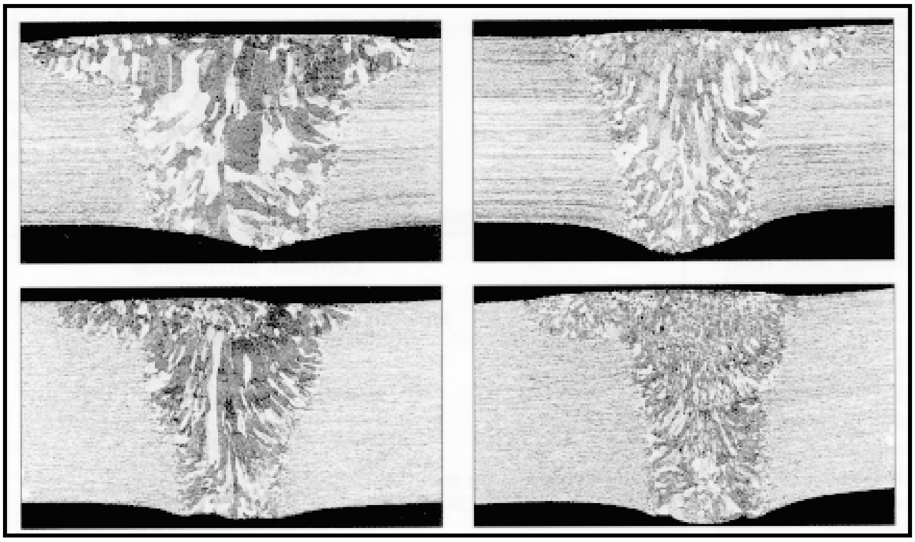


Fig 4. Variation in nitrogen along the length of a weld in duplex stainless steel. Heat input 7.5kJlmm with Ar-2% N2 shielding gas.

Fig 3. Macrostructure of welded joints of duplex and superduplex stainless steels produced using argon shielding gas cind with Duplex I and Duplex 2 gas mixtures.Top left - duplex stainless steel with argon gas;Top right - duplex stainless steel with Duplex 1 gas; Bottom left - super duplex stainless steel with argon and Bottom right - super duplex stainless steel with Duplex 2 gas.



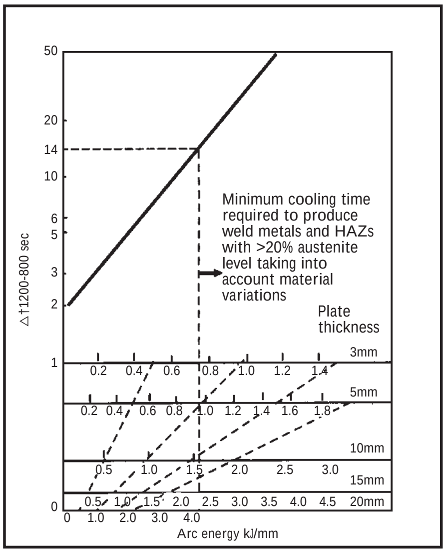


Fig 5. Nomogram for prediction of AT72-8.

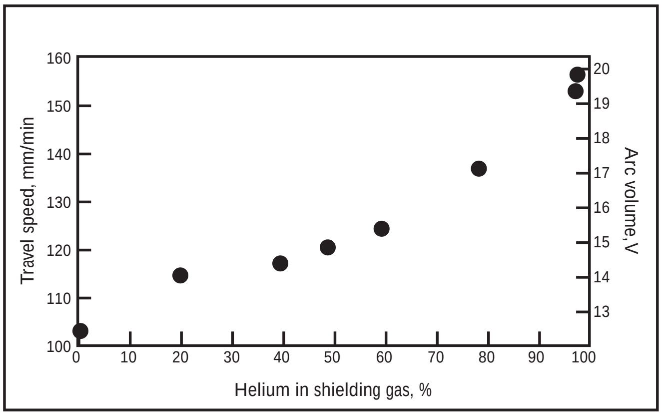
Increasing productivity

The austenite-ferrite phase balance is significantly affected by the rate of cooling of the joint between 1,200 and 800°C. In practice, for a given joint Geometry and component thickness, the welding engineer controls the cooling rate in this critical range by specifying the arc energy and a maximum interpass temperature.

The arc energy for the root pass should be chosen to obtain a balance between the joint completion rate, the metal deposition rate, weld pool control and the metallurgical limits of the generic alloy system[2]. Guidance in the selection of a suitable heat input is available using nomograms, such as fig 5. If the arc energy is too low, this results in rapid cooling of the weld metal and heat affected zone, and a microstructure containing a high proportion of ferrite. If an excessively high arc energy is used, this will result in a microstructure containing a high proportion of austenite. Furthermore, for multipass welds or welds in thin material, if the arc energy is high, super duplex stainless steels have a tendency to precipitate undesirable phases, particularly the intermetallic sigma phase. This may lead to a reduction in the mechanical and corrosion properties of the joint.

In effect, the arc energy is selected to provide the optimum combination of mechanical properties and corrosion resistance. The joint completion rate can be increased without increasing the arc energy by the replacement of a proportion of argon in the shielding gas with helium6. Helium produces a hotter arc through an increase in the arc voltage, For an arc energy identified as providing a suitable cooling rate, the replacement of argon in the shielding gas with helium allows an increase in the welding travel speed in proportion to the increase ill are voltage, fig 6. However, a high proportion of helium may lead to difficulty in controlling the weld pool. Recent work indicates that the optimum proportion of helium in the shielding gas is 20 - 40%, which allows an increase in the welding speed of up to 20% (ref 6).

Fig 6. Effect of helium on welding speed, arc voltage and filler wire.



An alternative way to increase the arc voltage is to add hydrogen to the shielding gas, although the use of hydrogen containing gas mixtures, such as Ar-3%H2 shielding gas or Formier gas for purging, must be treated with caution. There may be a risk of hydrogen cracking[2], although duplex and super duplex stainless steels are less sensitive to hydrogen embrittlement and subsequent cracking than, for example, carbon steel, as the austenite can absorb a significantly higher volume of hydrogen than the ferrite phase. There are also concerns that the corrosion resistance can be significantly reduced where the austenite phase has absorbed a noticeable level of hydrogen.

Improving the welding environment

There is an increasing awareness of the factors in the working environment which may the health of welders. In particular, recent attention has been focused on the levels of ozone generated during gas shielded arc welding, which, some applications, has been shown to exceed the permitted limits[10]. Ozone is a vital naturally occurring constituent of earth's atmosphere. It is produced by ultraviolet radiation from the sun, the maximum concentration occurring approximately 25 km above sea level, Mankind has always breathed air containing ozone in concentrations of 0.005 - 0.05 parts per million (ppm). However, exposure to higher concentrations of ozone can adversely affect health. The occupational exposure standard (OES) for ozone is 0.1 ppm (=0.2 mg m^{-3}) for an eight hour time weighted average (TWA) reference period, and 0.3 ppm (=0.6 mg m^{-3}) for a ten minute TWA reference period[11]. These are statutory limits.

Ozone is also produced by the ultraviolet radiation emitted during arc welding, the level generated being process dependant. The only way to determine the welders exposure to ozone for comparison with the OES is to carry out practical trials with measurements in the breathing zone. Breathing zone measurements should be taken in accordance with BS 6691, part 2: 'Fume from welding and allied processes'[12]. This involves measurements taken behind the welders face mask, from a point opposite the right or left cheek of the welder and at a distance of approximately 25 mm from the cheek. Breathing zone measurements in the working environment have shown that, in some applications, the OES may be exceeded.

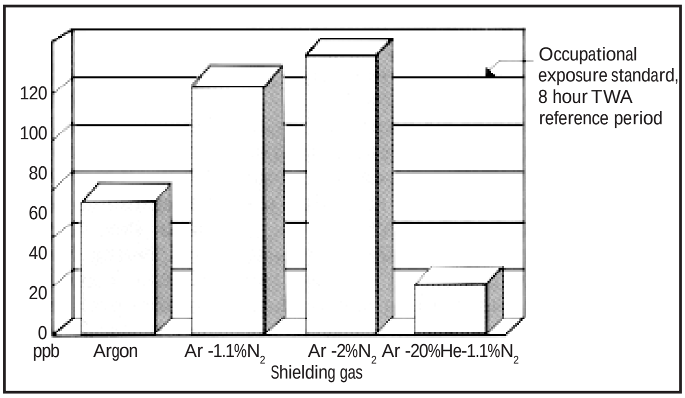


Fig 7. Ozone concentration in the breathing zone during TIG welding of duplex stainless steel with 22.8.3L filler wire.

The composition of the shielding gas can have a significant influence on the ozone level, as it affects the intensity of ozone forming radiation emitted from the arc. The highest ozone forming radiation is emitted by the arc plasma formed with nitrogen. This is ten times stronger than the radiation emitted by a pure argon arc plasma, and several hundred times stronger than the radiation emitted by a pure helium arc plasma.

Practical trials have demonstrated that the replacement of a proportion of argon shielding gas with nitrogen can significantly increase the ozone concentration, to levels above the OES.

The replacement of a proportion of argon shielding gas with helium can significantly reduce the ozone concentration, to levels below the OES, fig 7.

Therefore, it appears that whilst it is necessary to use a small proportion of nitrogen to achieve the required phase balance and properties of the joint, in order to satisfy the health and safety requirements the shielding gas must contain a proportion of helium.

Summary

The practical implications of these results are:

- TIC welding with argon as the shielding gas results in a loss of nitrogen from the weld pool. This can result in a ferrite rich weld metal with poor corrosion properties.
- The level of nitrogen in the shielding gas to match the nitrogen level in the parent metal is different for duplex and super duplex stainless steel.
- For duplex stainless steel, with a typical nitrogen content of 0.16%, to obtain a similar nitrogen content in the weld metal, the shielding gas should contain 1.0 1.2% N2.
- For super duplex stainless steel, with a typical nitrogen content of 0.25%, to obtain a similar nitrogen content in the weld metal, the shielding gas should contain 2.0 - 2.5% N2.
- The addition of 20 - 400/o helium to Ar-N2 shielding gas allows an increase in the welding speed of up to 20%.
- To ensure that the welders exposure to ozone is below the occupational exposure standard, the shielding gas should contain a proportion of helium.

These results have been used to formulate two shielding gas mixtures for commercial use: For duplex stainless steel, there is *Duplex I* shielding gas, containing Ar-20% He-1.1% N2, and for super duplex stainless steel there is *Duplex II* shielding gas, containing Ar20% He-2.25% N2. These products are finding increasing use due to their many advantages over argon or Ar-N2 shielding gases.

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