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Research, Education, Technical Support & Information

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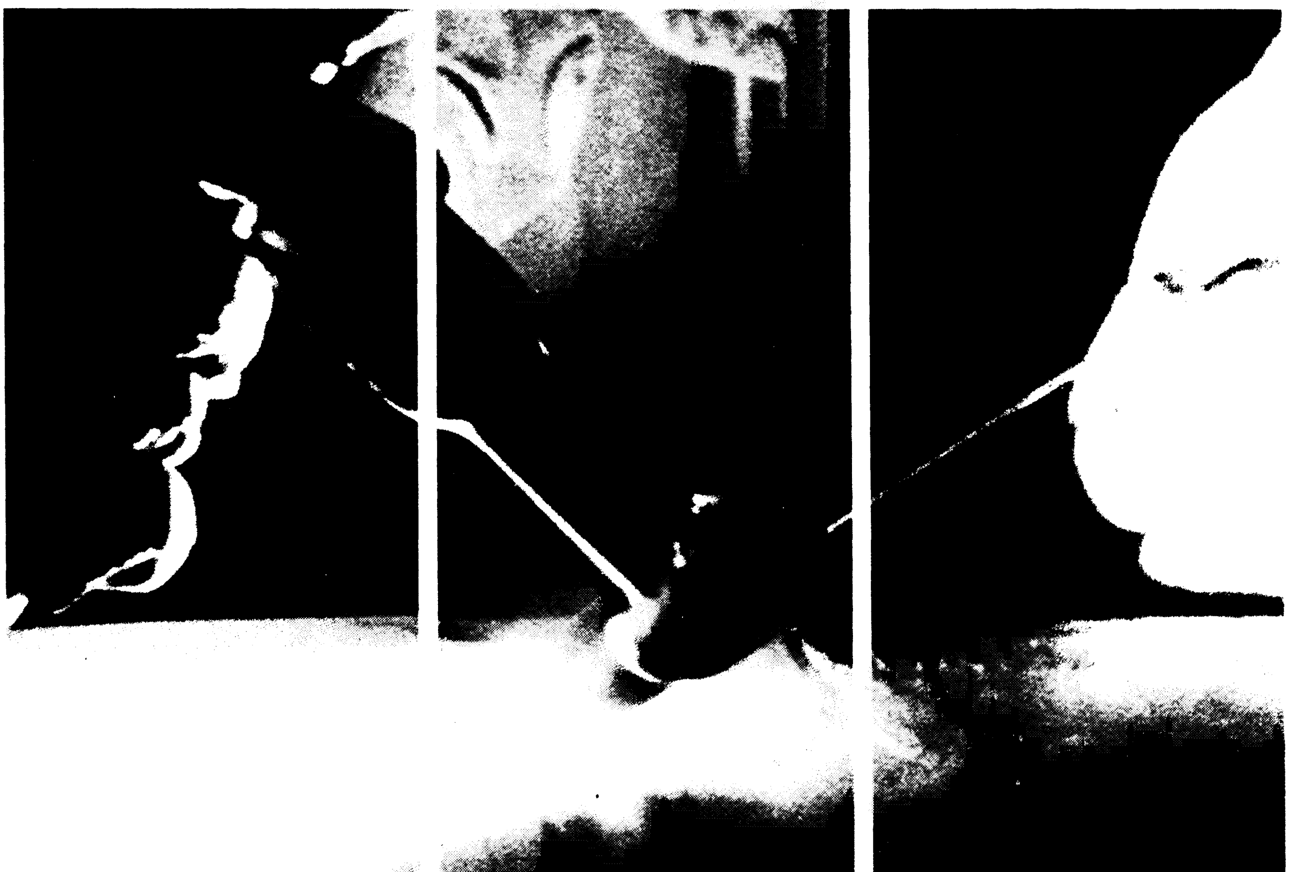
WELDING STAINLESS STEELS



This Technical Note:

- is designed to give practical guidance on the welding of stainless steels
- provides basic information on all commonly used stainless steels
- is intended to assist all personnel engaged in the design and fabrication of stainless steel vessels, structures and components
- will serve as an educational text for students of materials engineering
- has been prepared by AWRA under the direction of Project Panel (11) "Welding and Corrosion" consisting of:

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This Technical Note will be revised in due course and comments would be most welcome.

Acknowledgement is given of the special contributions made by Drs Bursle and Ward in the preparation of this Technical Note. Sandvik Australia also supplied a significant amount of technical information.

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CONTENTS

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1 INTRODUCTION

Stainless steels are a very important class of structural material in Australian industry. Stainless steels may be specified in a particular application for a variety of reasons such as:—

1) inherent corrosion or heat resistance in a particular environment
2) low maintenance requirement compared, for example, with coated or plated mild steel
3) aesthetic appeal
4) hygienic nature, ease of cleaning and sterilising
5) high strength to weight ratio
6) exceptional cryogenic properties
7) low magnetic permeability

There is a general lack of knowledge and understanding throughout industry of the way in which the correct grade selection, fabricating techniques, and methods of design and maintenance can ensure that stainless steels are utilised to provide the maximum benefit. No Australian national standard deals specifically with the fabrication of these materials. The selection of stainless steels for corrosive environments is dealt with in the companion Technical Note 13, "Stainless Steels for Corrosive Environments".

It cannot be too strongly emphasised that the successful application of these materials is very heavily reliant upon the adequate restoration, after fabrication, of the sub-microscopic film upon which the corrosive resistant properties of these materials are entirely dependent. Attention is therefore especially directed to that section dealing with post-weld passivation. (Section 5.6).

2 SCOPE

This Technical Note aims to provide information which will enable satisfactory fabrication of stainless steels. It deals with the austenitic, martensitic, ferritic and ferrite-austenitic (duplex) grades of stainless steel materials. The Technical Note does not deal with precipitation hardening grades of stainless steels.

3 GRADES OF WROUGHT STAINLESS STEELS, THEIR COMPOSITIONS, GENERAL PROPERTIES AND APPLICATIONS

The term 'stainless steel' is used to cover a wide variety of grades and compositions. Generally speaking, a stainless steel is considered to be an iron-based alloy containing more than 10% chromium. These steels can be classified into four groups based on their structure which has a large bearing on the physical and mechanical properties and weldability of the various grades. These groups are:

a) Austenitic stainless steels, AISI 200 and 300 series steels (UNS S 20000 and 30000 series)
b) Ferritic stainless steels (AISI 400, UNS S 40000 series)
c) Martensitic stainless (AISI 400, UNS S 40000 series)
d) Ferritic-austenitic stainless steels (duplex, AISI 300, UNS S 30000 series)

Figure 1 illustrates the general relationships between the different types of stainless steels.

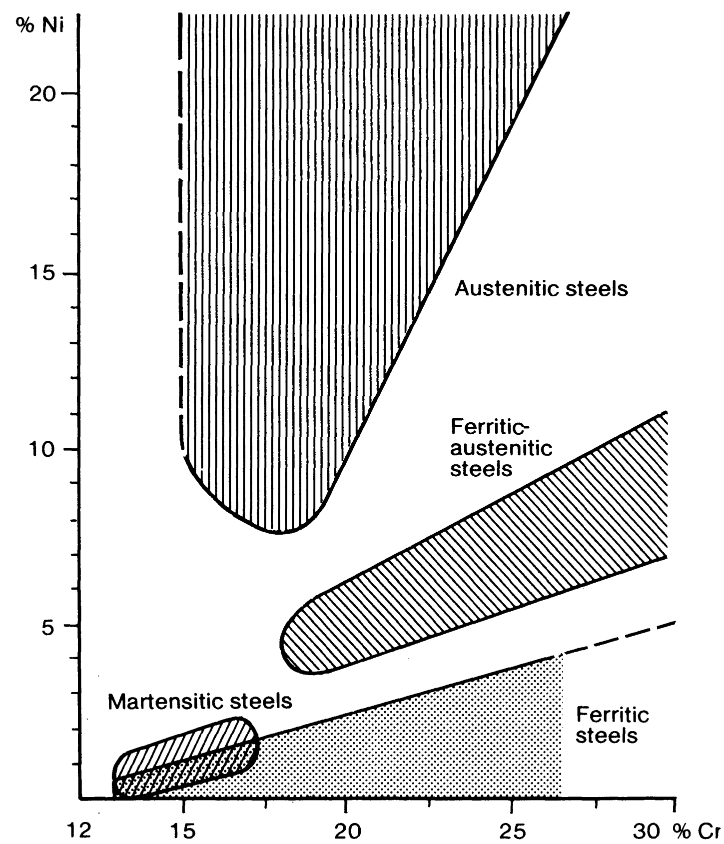


Fig. 1 Relationship between Chromium and Nickel Contents for the Basic Types of Stainless Steels

3.1 Austenitic Stainless Steels

These steels are all alloys of iron, chromium and nickel. They have a crystalline structure similar to copper and aluminium, ie. face centred cubic, and are non-magnetic in the annealed condition. They are not hardenable by heat treatment, but are readily strengthened by cold work with the rate of work hardening being affected mainly by the nickel content of the alloy. Higher nickel contents reduce the propensity to work harden.

These alloys are easy to weld, using electric welding techniques (arc, seam, resistance), and generally require no pre- or post-weld heat treatment. The family of steels is illustrated in Figure 2 and listed in Table 1.

The austenitic steels are the most commonly encountered of all stainless steels types, accounting for over 70% of consumption in Australia. The Types 302 and 304 are the closest current equivalents to the so-called "18/8" stainless steel, with which many people are familiar.

Other grades of austenitic stainless steel which do not appear in the AISI standard range are also in commercial use. These are usually more highly alloyed steels, developed for specific chemical plant applications.

For very aggressive chemical environments, such as hydrochloric acid, halogen salts and high temperature oxidation resistance, which cannot be handled by stainless steels, higher nickel alloys (Incoloys) and nickel base alloys (Inconels) are available. They generally behave in a similar manner to stainless steels in their welding and forming characteristics.

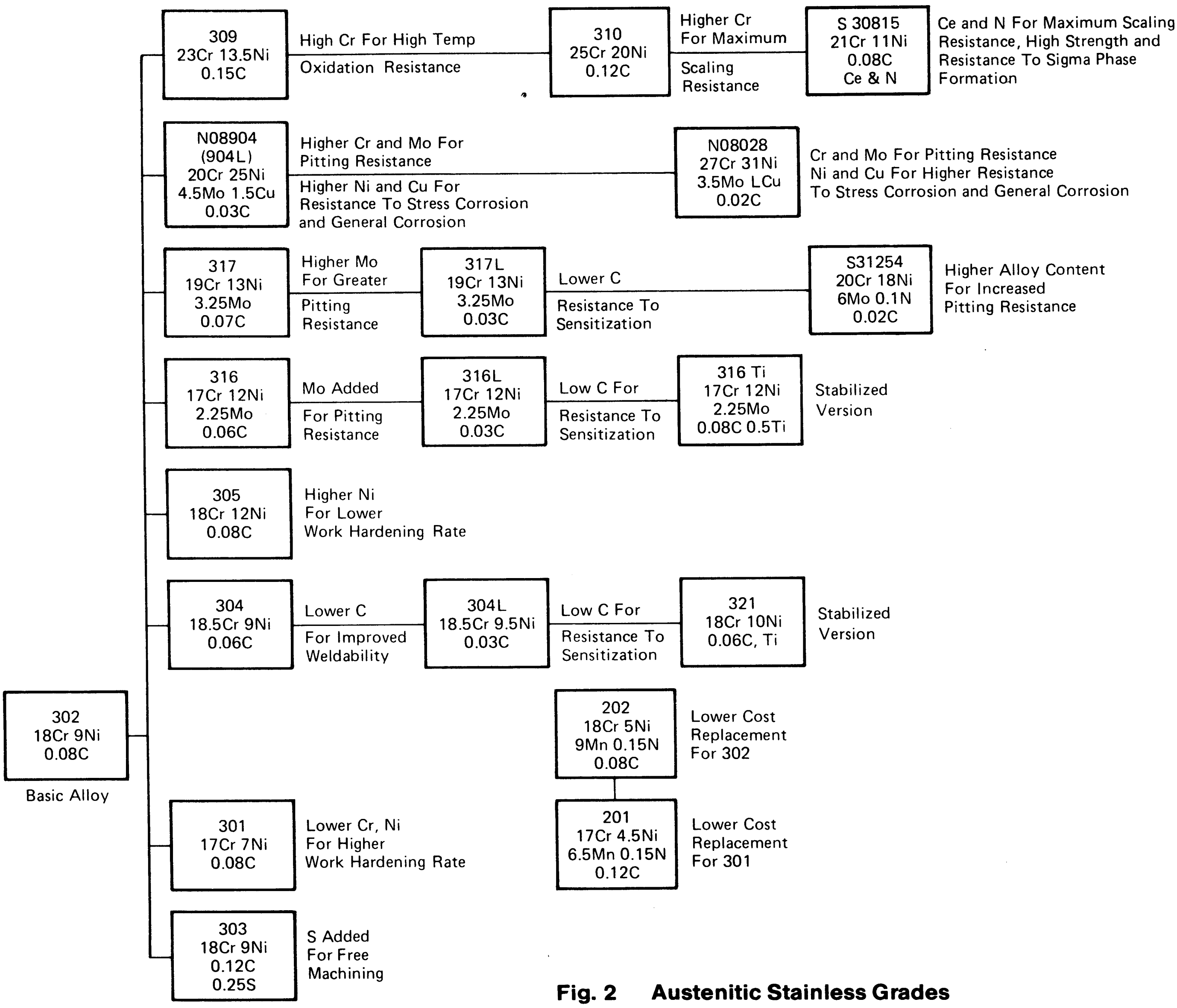


Fig. 2 Austenitic Stainless Grades

Table 1 Common Austenitic Stainless Steel Grades and their Applications

AISI No.	UNS No.	Forms Available	Typical Analysis (%)						Typical Applications
			C	Cr	Ni	Mo	Ti	Other	
301	S30100	Steel & Coil	0.08	17.0	7.00	–	–	–	General purpose steel with good corrosion resistance for most applications. Employed where the high work-hardening exponent is desirable. Can be supplied cold worked to give high strength and ductility. Used for structural applications such as rail carriages and wagons.
302	S30200	Sheet & Coil, Bars	0.08	18.0	9.0	–	–	–	General purpose steel with good corrosion resistance for most applications. Used for architecture, food processing, domestic sinks and tubs and deep drawing applications.
303	S30300	Bars	0.12	18.0	9.0	–	–	.25S	Free machining steel used where extensive machining is required. Corrosion resistance and weldability inferior to 302.
304	S30400	Sheet & Coil Plate & Bars	0.06	18.5	9.0	–	–	–	Similar corrosion resistance to 302. Used where higher resistance to weld decay is needed in brewing, etc.
304L	S30403	Sheet & Coil Plate	0.03	18.5	9.5	–	–	–	Chemical plant and food processing equipment, where freedom from sensitisation is required in plate.
305	S30500	Sheet & Coil, Wire	0.08	18.0	12.0	–	–	–	Spun sheet parts, cold headed screws.
309	S30900	Sheet & Coil, Plate, Bar	0.15	23.0	13.5	–	–	–	High temperature, oxidation resistant. Furnace parts.
309S	S30903	Sheet, Plate, Bar, Tube & Pipe	0.08	23.0	13.5	–	–	–	A low carbon version of 309. Used where superior corrosion resistance to 316 is required.
310	S31000	Sheet & Coil, Plate & Bars	0.12	25.0	20.0	–	–	–	Furnace parts and equipment. Resistant to temperature 900°C to 1100°C.
–	S30815	Sheet, Plate, Bar, Tube & Pipe	0.10	21.0	11.0	–	–	0.15N 0.4Ce	Used for furnace parts, radiant shields, fluidised beds. Resistant to temperatures up to 1150°C. Possesses high strength and resistance to sigma phase formation.
310S	S31003	Sheet, Plate, Bar, Tube & Pipe	0.08	25.0	20.0	–	–	–	A low carbon version of 310 used to resist nitric acid corrosion.
316	S31600	Sheet & Coil Plate, seamless welded tube pipe	0.06	17.0	12.0	2.25	–	–	Used where higher corrosion resistance is required, ie. marine equipment. Can be welded up to 3 mm without subsequent heat treatment.
316L	S31603	Sheet & Coil, Plate, seamless welded tube pipe	0.03	17.0	12.0	2.25	–	–	A low carbon modification of 316 where heavy section weldments are required without the risk of intergranular corrosion.
316Ti	S31608	Plate, Pipe Tube	0.08	17.0	12.0	2.25	0.5	–	A titanium stabilised version of 316 used where good resistance to intergranular corrosion and high temperature strength is required.

Continued over page

Table 1 Common Austenitic Stainless Steel Grades and their Applications (continued)

AISI No.	UNS No.	Forms Available	Typical Analysis (%)						Typical Applications
			C	Cr	Ni	Mo	Ti	Other	
317	S31700	Sheet & Coil Plate	0.07	19.0	13.0	3.25	–	–	For chemical plant—has a greater corrosion resistance than 316 in certain applications, notably in contact with brines and halogen salts. Also available in the low carbon "L" grade.
904L	N08904	Sheet, Plate Bar, Pipe, Tube	0.02	20.0	25.0	4.5	–	1.5Cu	High resistance to: general corrosion in eg. sulphuric and acetic acids; crevice corrosion; stress corrosion cracking; pitting in chloride bearing solutions. Good weldability.
–	N08028	Sheet, Plate Tube, Pipe, Bar	0.02	27.0	31.0	3.5	–	1Cu	Used against all types of corrosion under severe conditions. Used in sour oil and gas production pipe, heat exchangers, heat exchangers for acid concentration, piping, evaporation.
–	31254	Sheet, Plate Tube, Pipe, Bar	0.02	20.0	18.0	6.0	–	0.2N	Used where high resistance to chloride pitting and crevice corrosion is required, eg. seawater heat exchangers, bleach vats and washers in the pulp and paper industry.
321	S32100	Sheet & Coil, Plate & Bar	0.06	18.0	10.0	–	0.5	–	Heavy weldments in chemical and other industries. Suitable for heat resisting applications to 800°C. Not suitable for bright polishing.
201	S20100	Sheet & Coil, Plate	0.12	17.0	4.5	–	–	6.5Mn 0.15N	Lower cost, reduced nickel version of Type 301.
202	S20200	Sheet & Coil, Plate	0.08	18.0	5.0	–	–	9.0Mn 0.15N	Lower cost, reduced nickel version of Type 302.

3.2 Duplex Ferritic-Austenitic Stainless Steels

The duplex ferritic-austenitic stainless steels have a two-phase structure consisting of approximately 50% ferrite and 50% austenite. In the recent development of these steels, the aim has been:

- to take advantage of the high strength, hardness, erosion, fatigue and stress-corrosion cracking resistance, high thermal conductivity and low thermal expansion produced by this structure, and
- to produce steels with good corrosion resistance and similar weldability to the austenitic types at a much lower cost.

These steels have high chromium contents, low amounts of nickel and generally contain molybdenum. They are moderately magnetic, and are not hardenable by heat treatment. They are readily welded in all section thicknesses by electrical resistance, gas shielded arc, manual metal arc and submerged arc techniques.

Examples of these steels are UNS S32900 (AISI 329), UNS S31500 and UNS S31803. These alloys have recently been approved for pressure vessel manufacture under AS 1210.

Duplex steels are less notch sensitive than ferritic types but both can suffer loss of impact strength if held for extended periods at high temperatures (above 300°C). Duplex stainless steels undergo a ductile-brittle transition at around -100°C and the recommended service temperature range is therefore -100° min. to 300°C max.

Ferritic-austenitic stainless steels have higher strengths than the austenitic stainless steels and ferritic stainless steels, but lower strengths than the martensitic and precipitation hardening stainless steels. They are mainly used in marine and chemical process industries but have also been used to overcome stress-corrosion failures of the austenitic grades in applications such as hot water tanks and calorifiers. The family of duplex grades is illustrated in Figure 3 and listed in Table 2.

Fig. 3 Duplex Stainless Grades

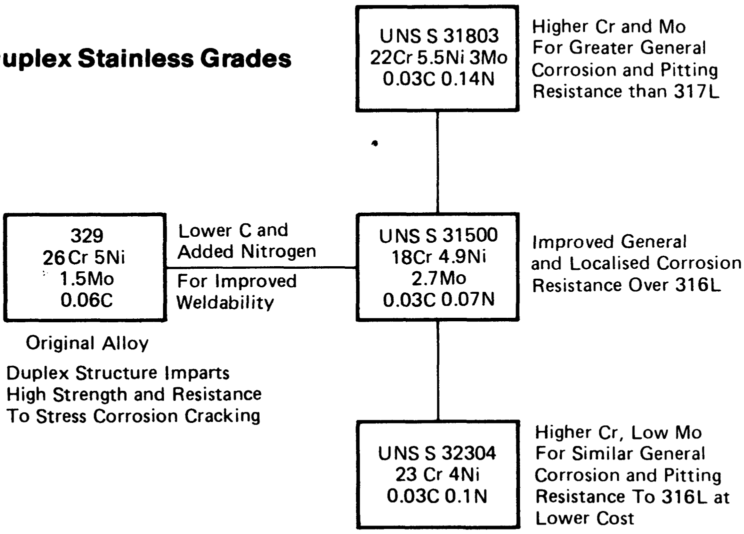


Table 2 Ferritic-Austenitic Stainless Steels and their Applications

AISI No.	UNS No.	Forms Available	Typical Analysis (%) C	Cr	Ni	Mo	Other	Typical Applications
329	S32900	Bars	0.08	26.0	4.5	1.5	–	Shafting for pumps, boats. Superior corrosion resistance and strength to 316L, poor weldability.
–	S31500	Sheet, Plate Bar, Pipe Tube, Fitting	0.03	18.0	4.9	2.7	–	Superior corrosion resistance to 316L, high resistance to stress corrosion. General fabrication in chemical industry equipment. Suitable for welding in heavy sections without risk of intergranular corrosion.
–	S31803	Sheet, Plate Bar, Pipe Tube, Fitting	0.03	22.0	5.5	3.0	.14N	Superior corrosion resistance to 317L. Excellent stress corrosion resistance. Typically used in heat exchangers, scrubbers, calorifiers, fans, in chemical process tanks, oil and gas and refining industries where outstanding corrosion resistance is required. Suitable for welding heavy sections without risk of intergranular corrosion.
–	S32304	Sheet, Plate Bar, Pipe Tube	0.03	23.0	4.0	–	.1N	Similar corrosion resistance to 316L. High resistance to stress corrosion and erosion, high yield strength. Used where high corrosion resistance is required, ie. marine, mining, chemical, food, metallurgy and power industries.

3.3 Ferritic Stainless Steels

These steels are alloys of iron and chromium. They have body centred cubic structures similar to mild steel, they are magnetic and they are not hardenable by heat treatment. They may be readily welded by resistance spot or seam or inert gas methods in thin sheet form. They are, generally speaking, not suitable for thick welds requiring large heat inputs, or multiple pass welding, due to their susceptibility to grain growth. In bar form, they are used because of their free machining and cold bending properties. The family of ferritic steels is illustrated in Figure 4, and listed in Table 3.

For specific application (see Technical Note 13) in chemical and process industries, special ferritic alloy grades have been developed which provide exceptional corrosion resistance and relatively good weldability.

Fig. 4 Ferritic Stainless Grades

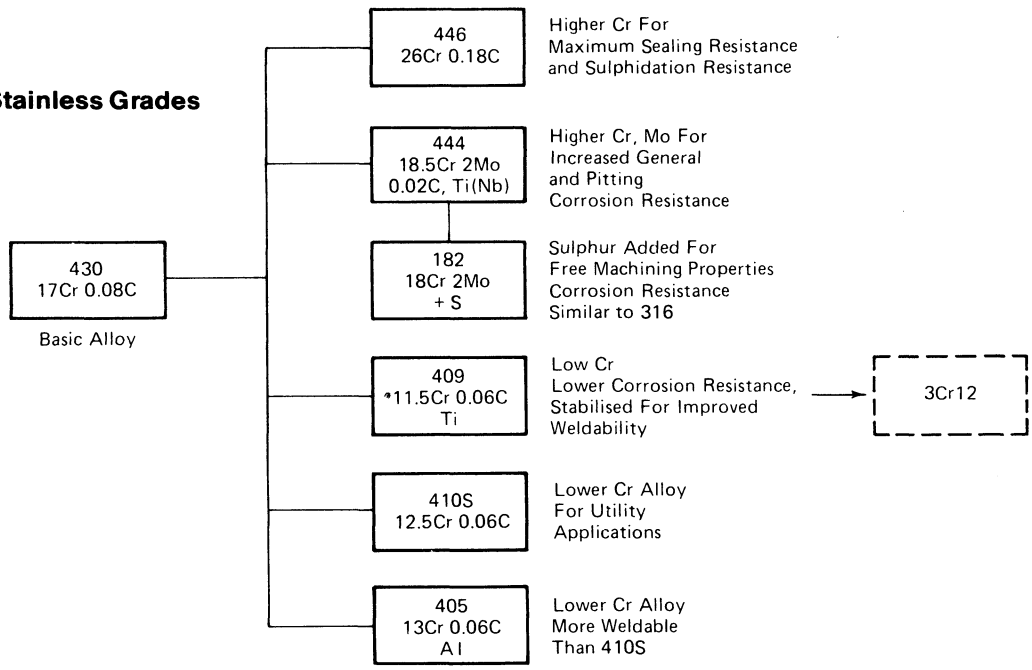


Table 3 Common Ferritic Stainless Grades and their Applications

AISI No.	UNS No.	Forms Available	Typical Analysis (%) C	Cr	Mo	Ti	Other	Typical Applications
405	S40500	Sheet & Coil	0.06	12.0	–	–	0.2A1	Welded fabrications for mildly corrosive environments and in heat resistant applications.
409	S40900	Sheet & Coil	0.06	11.5	–	0.5	–	Heat resistant steel, easily formed and welded. Mainly used for automotive exhausts or welded applications where superior performance to galvanised steel is required.
446	S44600	Tube, Pipe	0.08	26.0	–	–	–	Used for severe heat resistant applications up to 1200°C. In recuperators, highly resistant to sulphidation and oil ash corrosion.
410S	S41008	Sheet & Coil, Plate & Bar	0.06	12.5	–	–	–	Used for heat resistant applications up to 650°C in power plant and oil refineries, where high strength at elevated temperatures is not required.
430	S43000	Sheet & Coil, Plate & Bar	0.08	17.0	–	–	–	Interior architectural component, stove and automotive trim. Welds tend to be brittle.
444	S44400	Sheet & Coil	0.02	18.5	2.0	0.4	–	Heat exchanger and hot water tanks, and in chloride containing waters. Not prone to chloride stress corrosion – superior resistance to pitting, crevice and intergranular corrosion. Possesses excellent deep drawing properties.
182	S18200	Bar	0.07	18.25	2.0	–	0.20S	Free machining bar variant of 444. Superior machinability to 303.

3.4 Martensitic Stainless Steels

These steels are alloys of iron and chromium, which can be hardened by heat treatment. They are magnetic. Generally speaking, they are difficult to weld, due to their susceptibility to hardening in the weld zone. Pre- and post-weld heating is required.

The major use of martensitic stainless steels is in corrosion and heat resistant castings where their high strength gives them an advantage over the more expensive austenitic alloys. Wrought products are mainly used in bar form. A family of steels has evolved with varying carbon contents to provide a range of strength and hardness levels. The composite, strength and hardness of typical wrought products are illustrated in Figure 5 and listed in Table 4.

Fig. 5 Martensitic Stainless Grades

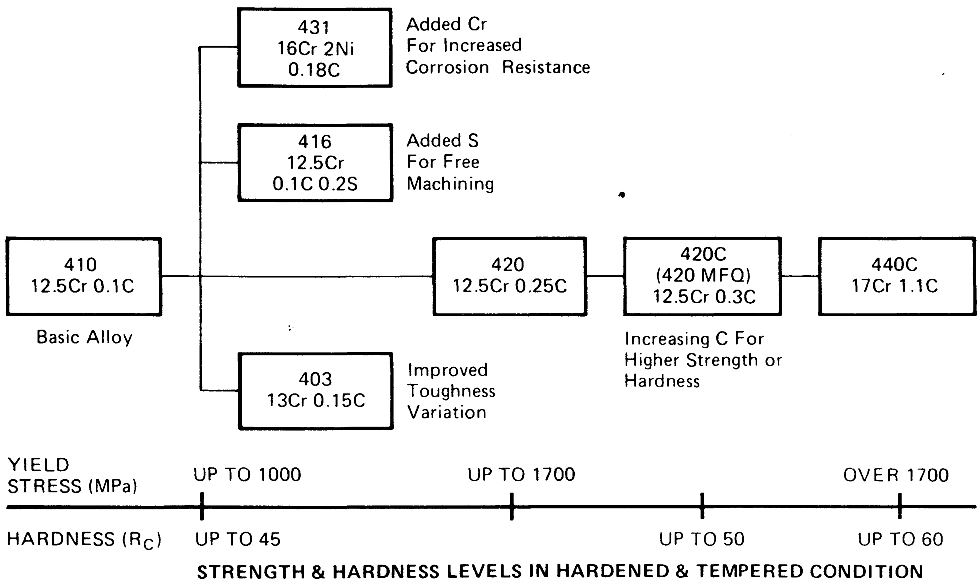


Table 4 Common Martensitic Stainless Grades and their Applications

AISI No.	UNS No.	Forms Available	Typical Analysis (%) C	Cr	Ni	Mo	Other	Typical Applications
410	S41000	Bars	0.10	12.5	–	–	–	General purpose grade for use in mildly corrosive environments.
403	S40300	Bars	0.15	13.0	–	–	–	Capable of attaining higher hardness than 410.
416	S41600	Bars	0.10	12.5	–	–	0.20S	Free machining variation of 410.
420	S42000	Bars	0.25	12.5	–	–	–	General engineering uses, such as pump and valve shafts.
420C	–	Sheet & Coil, Plate & Bars	0.30	12.5	–	–	–	Developed for high hardness after heat treatment. Used for cutting tools, surgical knives, etc.
431	S43100	Bars	0.18	16.0	2.0	–	–	Hardenable steel with corrosion resistance approaching 302. Used for pump shafts etc. Should be double tempered after hardening.
440C	S44004	Bars	1.10	17.0	–	0.40	–	Capable of being hardened to 60 Rc. Highest hardness and abrasion resistance of all the stainless steels. Corrosion resistance similar to 410.

3.5 Steel Suppliers' Designations

Table 5 lists some stainless steel suppliers' grade designations and the corresponding AISI and UNS numbers.

Table 5 Steel Suppliers' Designations

AISI No.	UNS No.	BHP	Comsteel	Sandvik	Bohler	Assab	Avesta	Wright & Co.
Austenitic Grades								
201	S20100	201		11RM10				
202	S20200							
301	S30101	301		12R11				
302	S30200	302	302	12R10	A505			302
303	S30300		303	5RA50	A506			303
304	S30400	304	304	5R10	A500	304	832MV	304
304L	S30403	304L	304L	5R12	A604	304L	832MVR	304L
305	S30500							
309	S30900		309					
309S								
310	S31000	310	310	15RE10	H522		254EM	310
310S		310S		7RE10	H525			310S
	S30815			253MA		253MA	253MA	
316	S31600	316	316	5R60	A120	316	832SF	316
316L	S31603	316L	316L	3R60	A200	316L	832SFR	316L
317	S31700	317	317	5R64			832SN	
317L	S31703			3R64			832SNR	
	S31254			254SMO			254SMO	
321	S32100	321	321	8R30	A700	321	832MVT	321
347				8R40	A750		832MVNb	
904L	N08904			2RK65			254SLX	904L
	N08028			Sanicro 28			928	
Ferritic and Martensitic Grades								
409	S40900	409	409					
410			410	1C27	N100			
410S	S41008	410S			N104			
416			416					
420			420	6C27	M310	420		
430	S43000	430	430	17Ti	N200			430
431			431		N350	431		
444	S44400	444		ELI-T-18-2			ELI-T-18-2	
446	S44600			4C54	H102		446	
182	S18200			1802				
	S44635			MONIT			MONIT	
Duplex Grades								
329	S32900			10RE51	A900		453S	
	S31500			3RE60			3RE60	
	S31803			SAF 2205		2205	2205	
	S32304			SAF 2304				
	S32550							Ferralium 255

Note: This table lists the main alloys — others may be available on request.

4 WELDABILITY OF STAINLESS STEEL

4.1 General

The term 'weldability' is a non-specific concept describing in general terms the ease with which a material may be fabricated by welding. It includes the ability of a welded joint to withstand the stresses and conditions experienced in service. Stainless steels range in weldability from excellent, in the case of the austenitic stainless steels, to poor in the case of the martensitic stainless steels.

AWRA Technical Note 13 contains a summary of stainless steels with reference to wet and high-temperature corrosion. Nearly all stainless grades contain about 12%Cr or more. Other alloying elements are added to meet a wide variety of requirements concerning both corrosion resistance and mechanical strength, and welding too has to be adapted accordingly.

The weldability of stainless steels depends to a great extent on the composition. The alloying elements in stainless steel can be grouped according to their influence in the formation of ferrite or austenite as the stable phase.

Ferrite Formers	Austenitic Formers
Chromium	Nickel
Molybdenum	Manganese
Silicon	Carbon
Niobium	Nitrogen

The most commonly used welding methods involve fusion welding which is the localised application of intense heat in order to raise the material temperature above the melting point in a very rapid heating and cooling cycle. This minimises structural changes and/or precipitations which can affect the properties of the welded joint. The weld metal microstructure, composition and properties can be controlled by the use of an appropriate filler metal. However, the properties of the heat-affected zone (HAZ) are determined by the parent metal composition and the weld thermal cycle which together control the transformations and reactions in the HAZ, ie. they affect weldability.

The particular effects of welding on each of the stainless steel types is discussed in more detail under the appropriate heading.

Many grades of stainless steels may suffer either a deterioration in corrosion-resistant properties or embrittlement if subjected to temperatures within critical temperature ranges. It is therefore usual in the welding of these materials to minimise arc energy and interpass temperature. Austenitic grades of stainless steel have a coefficient of thermal expansion approximately 50% greater than common structural steels. This, associated with their low thermal conductivity, can cause problems of distortion and residual stress which are much greater than for common structural steels.

4.2 Schaeffler and De Long Diagrams

The American Anton L. Schaeffler was the first person to make a systematic study of the connection between composition and structure in stainless steel weld metals. He summarised his findings in a diagram (Figure 6) which shows the structure of freely cooled all-weld metal test specimens as a function of what are known as the Cr and Ni equivalents. The equivalents can be calculated as follows:

Cr equivalent, ECr= %Cr+%Mo+1.5 x%Si+0.5 x%Nb

Ni equivalent, ENi= %Ni + 30 x%C + 0.5 x%Mn

It will be noticed that Schaeffler has not made any allowance for nitrogen content, though nitrogen is also an austenite former. In the De Long diagram (Figure 7), which is a further development of the central portion of Schaeffler's diagram, two improvements have been made. Firstly, nitrogen has been included in the Ni equivalent and has been given the same coefficient as carbon, and secondly, ferrite content classification has been refined and termed ferrite number, eg. FN 10.

Once the Cr and Ni equivalents of a material have been worked out, the diagrams make it possible to estimate the structural state which will be assumed by the weld metal. These diagrams, however, are not applicable to weld metal which has been heat-treated, nor are they applicable to the HAZ. The diagram reflects the microstructure obtained in cast materials cooled at a rate comparable to those of normal arc welds. Weld metals cooled extremely quickly or unusually slowly can have vastly different microstructures from those predicted. Hence, wrought base metal or high energy density welds such as laser or electron beam and many spot welds may have significantly different microstructures and properties from arc weld metal of identical composition.

The Schaeffler diagram is particularly useful in predicting weld metal compositions resulting from joining dissimilar metals. Refer to Section 6.3 and Figures 33 and 34.

4.3 Welding Processes

This Technical Note deals primarily with the fusion welding of stainless steels. It should however, be noted that stainless steels may also be readily joined utilising resistance welding techniques and can under certain circumstances be brazed and soldered.

The different welding processes may have differing effects on the various types of stainless steel. In addition to the general comments made below particular comments are made in the specific sections where appropriate.

Fusion welding of stainless steels is generally carried out using the electric arc processes, principally manual metal arc (MMAW) metal inert gas (GMAW) submerged arc (SAW) and tungsten inert gas (GTAW). Plasma-arc welding (PAW) can also be used and is a good alternative in highly mechanised welding production. Material thicker than 50mm has successfully been joined by electroslag welding. Gas welding techniques such as oxyacetylene are usually unsuitable for use on stainless steel because of excessive distortion caused by a wide heat-affected area and the detrimental metallurgical effects of slow cooling rates. It is possible to use electron-beam welding and laser welding. These processes normally give narrow welds and have very steep temperature gradients.

GMAW and GTAW are two of the most successful and widely used processes for welding stainless steels both in the continuous current mode and the pulsed mode.

In pulse arc welding the current is not constant but is modulated between background current and pulse current. The background current maintains the arc whilst the pulse current transfers the electrode material to the weld pool in GMAW welding but simply adds extra controlled heat in GTAW welding. With the GMAW process one droplet of molten metal is deposited on the work piece for each current pulse, allowing it to partially solidify before the next droplet is deposited. The frequency of the droplets is controlled by the pulse rate.

Several benefits result from the use of these pulse processes. A narrow arc cone ensures excellent controlled penetration with a minimum heat affected zone. Thin materials can be welded with less distortion due to controlled heat input. Out of position welding can be easily performed and penetration on the root run can be more easily controlled because pool fluidity can be adjusted through pulse level and pulse frequency.

In order to maximise the performance of welded joints it is necessary to choose the wire filler metal to match the properties of the parent material. Table 6 illustrates typical filler metals for various grades of stainless steel. Filler metal is normally not involved in electron-beam and laser welding. Use of such processes also leads to rapid cooling, a fact which may impair corrosion resistance and ductility in some alloys. Resistance welding may also yield welds which are unsuitable for some applications.

The choice of welding process finally depends upon the type of stainless steel, the design of the structure to be welded and the material thickness.

Fig. 6 Schaeffler Diagram

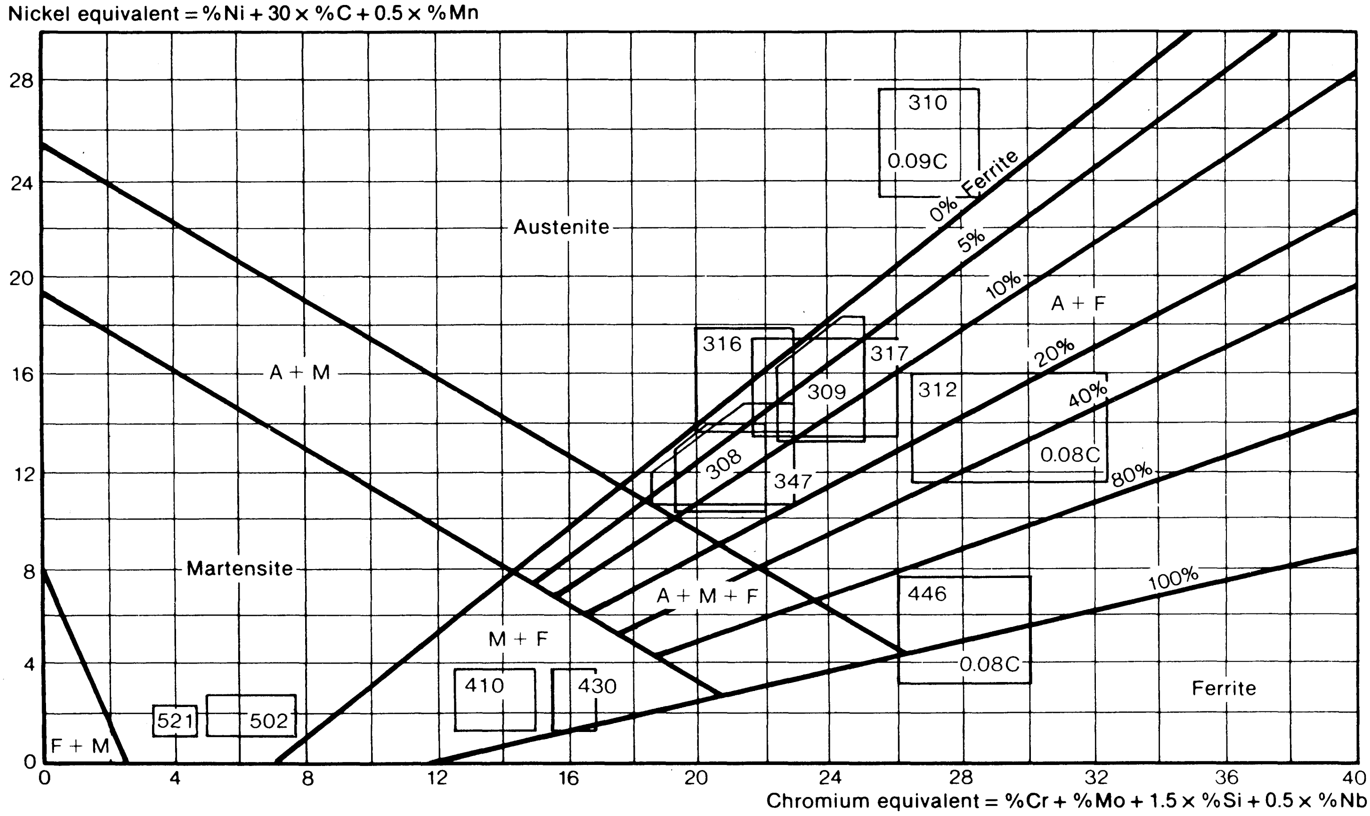


Fig. 7 De Long Diagram

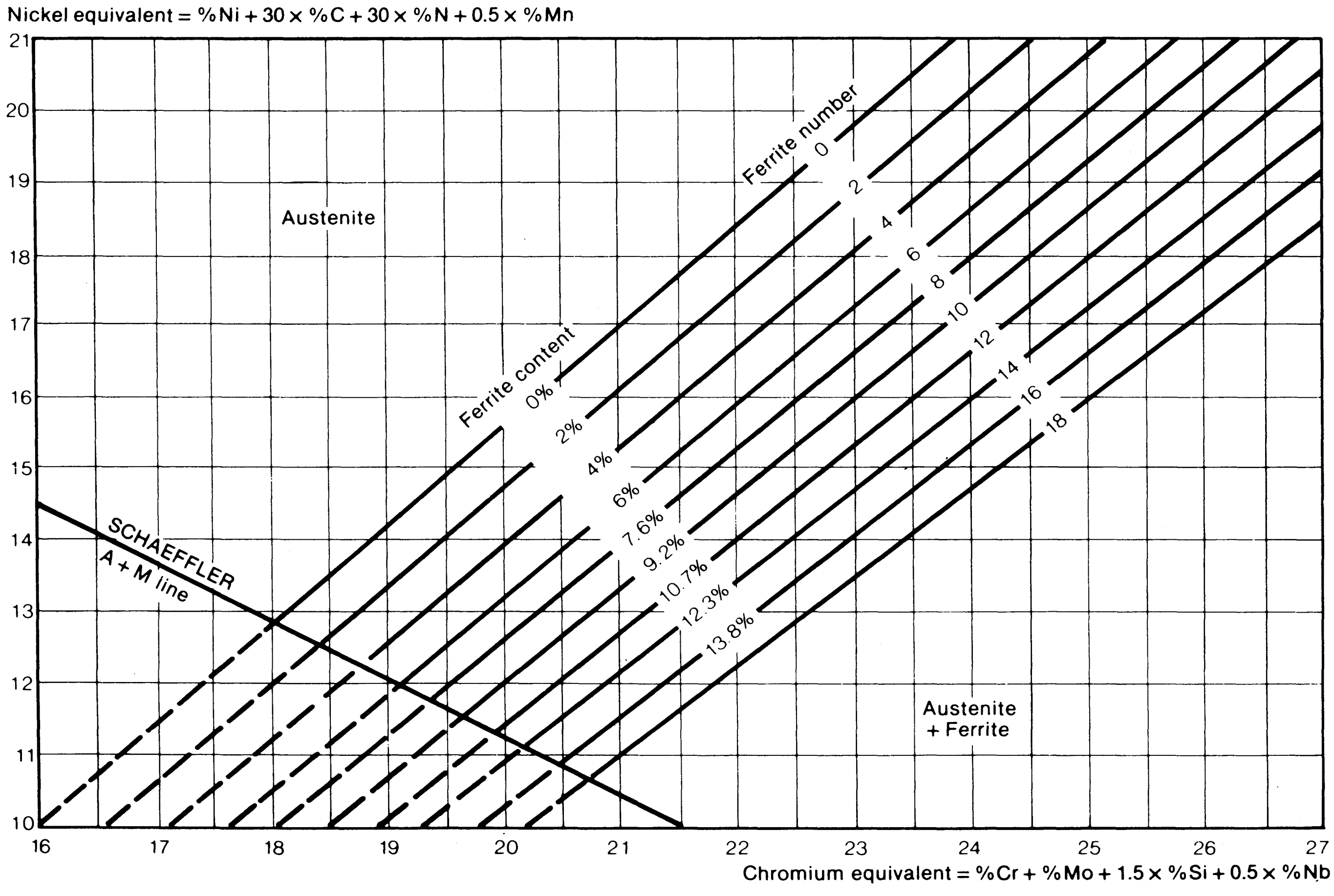


Table 6 Selection of Typical Filler Metals †

Parent Metal Grade	Filler Designation AS*	ISO3581	AWS
Austenitic			
201	308	19.9	308L
202	308	19.9	308
301	308	19.9	308
302	308	19.9	308
303	312	29.9	312
304	308L	19.9L	308L
304L	308L, 347	19.9L, 19.9Nb	308L, 347
305	308	19.9	308
309	309	23.12	309
310	310	25.20	310
316	316	19.12.2	316
316L	316L	19.12.2.L, 22.15.3.L	316L
316Ti	318	19.12.3.Nb	318
317	317	19.13.4	317
317L	317L	19.13.4.L, 22.15.3.L	317L
321	347	19.9.Nb	347
347	347	19.9.Nb	347
S30815 +		22.12.HT	
N08904 +		20.25.5.LCu	
N08028 +		27.31.4.LCu	
Ferritic			
405	430, 309, 308	17, 23.12, 19.9	430, 309, 308
409	309	23.12	309
410S	309	23.12	309
430	430, 308, 309	17, 19.9, 23.12	430, 308, 309
444	316L	19.12.2L	316L
Martensitic			
410	410, 309, 310	13, 23.12, 25.20	410, 309, 310
403	410, 309	13, 23.12	410, 309
420	410, 309, 310	13, 23.12, 25.20	410, 309, 310
Duplex			
329		25.5.1	329, 312
S31500 +		22.8.3L, 22.15.3L	
S31803 +		22.8.3L, 22.15.3L	
S32304 +		22.8.3L, 22.15.3L	

+ UNS Designation
* From draft of AS 1167.2 to replace AS 1588-1974
† For dissimilar metal joint welding see Table 7.

4.4 Austenitic Stainless Steels

4.4.1 General

Austenitic steels generally contain 12-30%Cr as well as austenite-forming elements, in particular nickel. They have approximately 50% greater thermal expansion and approximately 30% less thermal conductivity than ferritic stainless steels. This means greater shrinkage and higher stresses are developed as a result of welding.

Austenitic steels have far better weldability than ferritic steels. No real phase transformation takes place during heating and cooling, and they are much tougher. Figure 8 shows that austenitic steels are tougher than the others at low temperatures. The austenite in certain standard grades can be partially converted to martensite at **very** low temperatures, but a steel like AISI 304 is still tough enough to be serviceable down to -196°C. ELC steels in the welded state are tougher than high-carbon or stabilised austenitic steels.

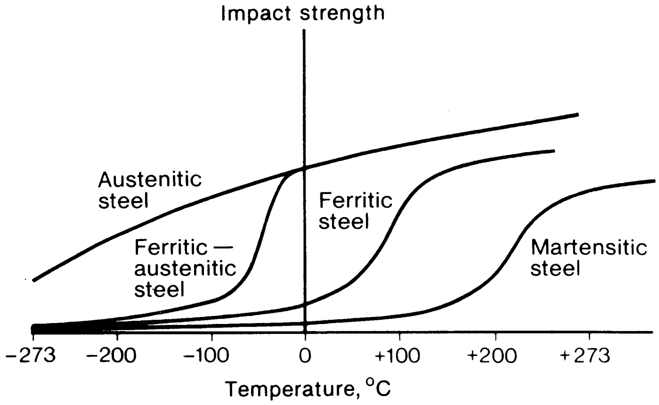


Fig. 8 Essential Difference in Impact Strength between Austenitic, Ferritic, Ferritic-Austenitic and Martensitic Stainless Steels

4.4.2 Pre- and Post-Weld Heating

Austenitic steels are not preheated before welding, because this usually impairs their corrosion resistance. Welding energy input should be limited to 1.5kJ/mm with a maximum interpass temperature of 150°C.

Austenitic welds are post-weld heat treated only in exceptional cases. More complicated weldments, however, may be stress-relieved at 850-950°C or at 400-500°C. One should always select a temperature and time which will not cause carbide precipitation, (see Figure 12 and the following section on corrosion resistance 4.4.3.1).

4.4.3 Effect of Welding on Properties

4.4.3.1 Corrosion Resistance

One basic rule is that all parts of the welded joint must have at least the same content as the parent metal of substances which are important for corrosion resistance. Usually this means chromium and molybdenum and also, if there is a risk of stress corrosion cracking, nickel. The filler metal often has a slightly higher content than the parent metal, in order to make up for the burn-off (mainly Cr) occurring during welding and for the segregation* occurring when the weld metal freezes.

Austenitic steels are used mostly in the quench-annealed condition, ie. they are rapidly cooled or quenched from about 1050-1100°C. At a temperature this high, the austenite is capable of retaining carbon in a solid solution, and this condition will be preserved at room temperature if the steel is cooled rapidly. A steel containing 18%Cr and 8%Ni, for example, can have up to 0.07% carbon in solid solution. Figure 9 shows the microstructure of such a steel. Carbon solubility diminishes with rising Ni content. For example, AISI 309L which contains about 12%Ni, has a maximum soluble carbon content of 0.02%.

** Segregation: During solidification, some of the more easily fusible components (both alloying elements and impurities) separate from the homogeneous mixture and collect in the parts which freeze last, forming 'islands' containing higher than average concentrations of the substances concerned, ie. segregations. Molybdenum in particular segregates heavily in alloys containing 4% Mo or more. Thus special care must be taken with filler metal selection and post-weld heat treatment of such alloys.*

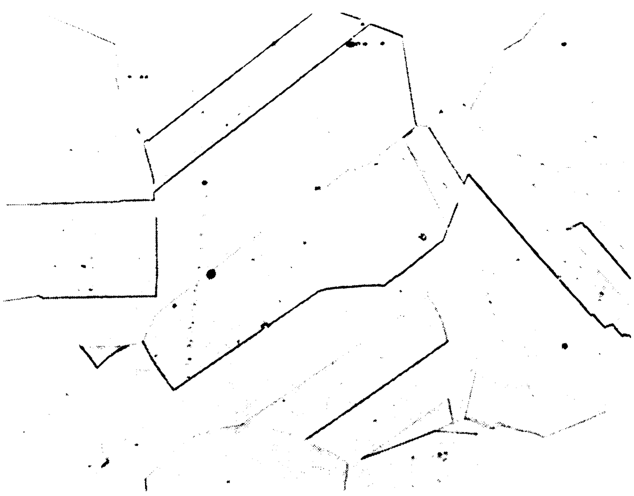


Fig. 9 Microstructure of Quench-Annealed Austenitic Stainless Steel x 500

The stainless steel microstructure becomes susceptible to intergranular corrosion in certain media when the weld or heat-affected zone remains within a critical temperature range (425°C to 815°C) for sufficient time. Chromium in the grain boundary regions combines with carbon to produce carbide networks, depleting the near grain-boundary area in chromium. This depleted zone, or in certain media, the carbides themselves, tend to dissolve preferentially giving the phenomenon of weld decay. (See Figures 10 and 11).

Fig. 10 Intergranular Corrosion round a Weld in a Austenitic Stainless Steel x 2

Fig. 11 Intergranular Corrosion photographed through a Scanning Electron Microscope

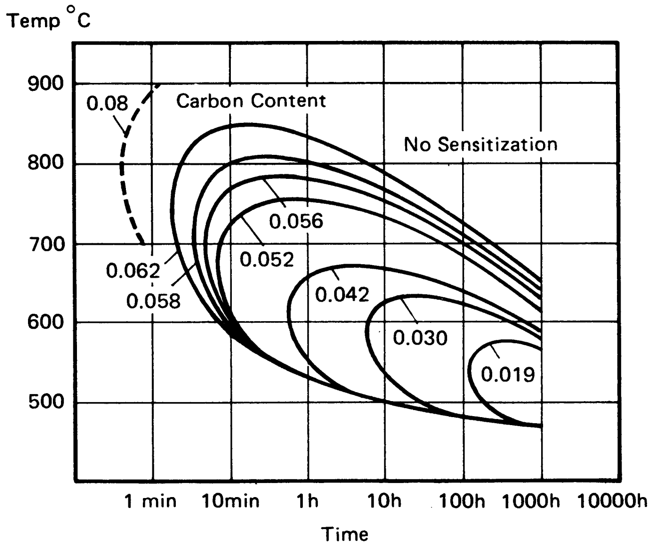


Fig. 12 TTS Diagram for Austenitic Steels containing 18% Cr, 8% Ni and varying amounts of Carbon

(TTS = Time — Temperature — Sensitization). If the heating time at a particular temperature exceeds that indicated by the relevant curve, carbide precipitation will occur.

The Time-Temperature-Sentisation relationships for the common Type 304 austenitic grade, with different carbon contents, are illustrated in Figure 12. This shows that a steel with 0.058% carbon can be held at 700°C for about 6 minutes without suffering intergranular attack in subsequent corrosion testing.

Such a typical Type 304 composition can readily be welded in moderate thicknesses without problem, since the heat input would not be high. With heavy plate thicknesses, however, the time in the critical region can be much longer so that a lower carbon content is required. A Type 304L steel containing less than 0.03% carbon, can be seen from Figure 12 to be capable of being heated for up to 10 hours without suffering sensitisation. It should be noted, however, that the cooling rate from the holding temperature can have an overwhelming influence upon sensitisation behaviour.

In weldments, sensitisation may occur in the weld or heat-affected zone depending on the chemical composition of the weld and the base material.

Intergranular corrosion of welded austenitic steels is dependent on the degree of sensitisation produced in the HAZ and the corrosivity of the environment. Problems of intergranular corrosion are frequently over-emphasised. The degree of sensitisation is dependent on the time spent in the critical temperature range, and hence to a large extent on the thickness of steel to be welded. Experience has shown that austenitic stainless steels with the following maximum carbon levels will not usually be sensitised to a degree which will seriously impair corrosion resistance:—

Up to 1 mm	0.10%C	(eg. 301)
1 to 3 mm	0.08%C	(eg. 304)
3 to 12 mm	0.06%C	
12 to 19 mm	0.05%C	
19 to 25 mm	0.04%C	
> 25 mm	0.03%C	(eg. 304L, 316L)

These are generalisations. Welding of complicated sections, or of heavy sections to light sections, with higher heat inputs would lower these recommended maximum carbon contents as would the use of higher heat input welding processes, such as submerged arc. With careful selection of parameters, heavier sections can be welded successfully.

The problem of sensitisation can be overcome by heat treatment. By heating the austenitic steels to between 1000°C-1100°C the carbide networks are redissolved and rapid cooling by water quenching or air cooling, depending on size, prevents their reprecipitation. Heat treatment at 900-950°C followed by slow cooling can be particularly harmful. Carbides, nucleated at this temperature, grow during cooling and can readily cause the development of an extremely narrow sensitised region, even in low carbon grades.

Due to scaling, distortion and often the size of the fabrication, heat treatment is not always a practical solution. Selection of a stabilised or extra low carbon (L) grade is often more appropriate.

It is important to note that weld sensitisation is seldom encountered in modern stainless steels owing to the low carbon content. With modern welding techniques it is unlikely that weld sensitisation will be encountered in any commonly used stainless steels with the possible exception of the H grades which have higher strength at elevated temperatures.

4.4.3.2 Hot Cracking

Fully austenitic weld metals tend to suffer hot cracking. It is believed that these cracks are caused by the segregation of impurities at grain boundaries of the weld metal with consequent diminuition of the ductility of these areas. Generally, impurity elements such as sulphur, phosphorus, antimony, bismuth, tin, lead, niobium and on occasion silicon contribute to this problem. When submerged-arc welding, pick up from the flux must be controlled by the selection of the appropriate flux type. The hot cracking tendencies of these weld metals can be avoided by utilising special filler materials in which these elements are severely restricted or more usually, by increasing the grain boundary area of the weld metal with the introduction of a new phase known as delta ferrite, which reduces the embrittling influence of a grain boundary segregation. It is usual to adjust the chemistry of the weld deposit to produce delta ferrite contents of between 4-12% (Figure 13).

Higher levels of delta ferrite are often undesirable since in acid or highly oxidising atmospheres the continuous networks of delta ferrite may be selectively attacked so causing ultimate failure of the weld. Additionally, high levels of delta ferrite make the weld metal increasingly prone to the formation at high temperatures of the brittle phase known as sigma. Under most conditions ferrite contents between 4-12% will be adequate. In special circumstances, generally in chemical plant, even these levels may be undesirable and it may be necessary to restrict the delta ferrite content below these levels or even to ensure that it is completely absent. (See Notes in Table 7).

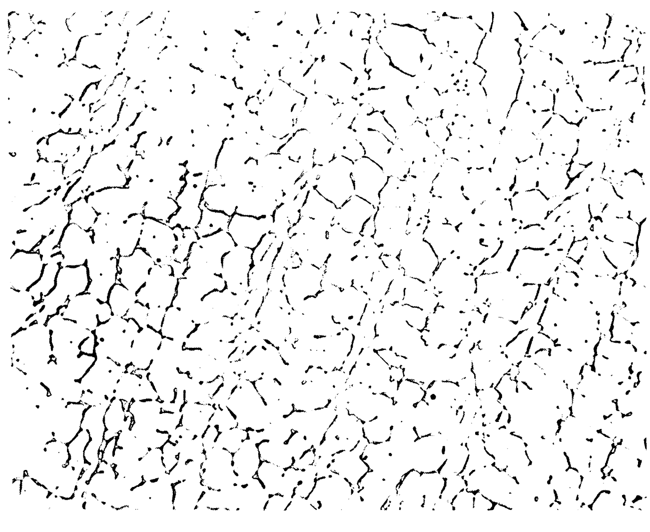


Fig. 13 Austenitic Weld Metal containing about 8% Ferrite x 500

The ferrite content of a weld metal may be quoted in either percentage (volume % ferrite) or as ferrite numbers. The systems are equivalent at low ferrite contents and the relationship is seen in Figure 7. The determination of the ferrite level in a weld metal may be done destructively by metallographic techniques as described in the paper by McDougall in Australian Welding Research, December 1974. More usually however, the ferrite content of a weld metal may be determined non-destructively by magnetic techniques. This is based on the fact that austenite is non-magnetic whilst delta ferrite is magnetic. A number of instruments are available based upon magnetic coating thickness gauges. More usually however, in Australia ferrite content is determined by means of the Severn Gauge* (see Figure 14). This employs a number of comparison standards fabricated by powder metallurgy techniques and containing various amounts of ferrite.

Where the ferrite content of ferritic-austenitic steels and their weldments are to be measured (typically 40-80% ferrite), the ferrite level is out of the range of most instruments. It is recommended that metallographic techniques are used until an extended ferrite number system is proven.

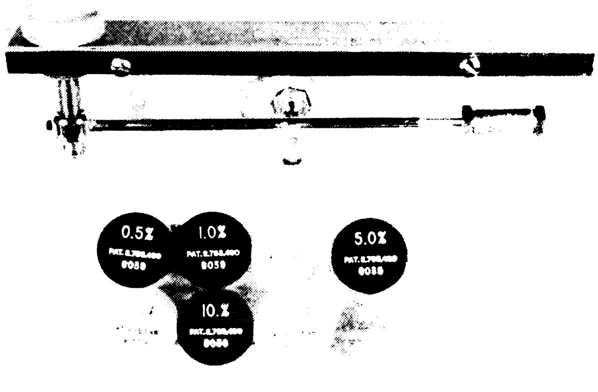


Fig. 14 Severn Gauge

If the chemical composition of a weld deposit is known, the ferrite content may be estimated from the Schaeffler or De Long diagrams (Section 4.2). In practice it will be found that compositional tolerances of stainless steel weld metals are such that considerable variations of ferrite content may be obtained between weld metals of nominally the same grade. It is often desirable therefore, in critical applications, to have a means of determining the ferrite content as welding proceeds. In the case of manual metal arc welding very little can be done to control the ferrite composition of a weld bead although some minor control is possible by modifying the arc length. In the case of MIG and TIG welding, some control is possible by the addition of nitrogen to the shielding gas. In submerged arc welding on the other hand, a good degree of control is possible by modifying the chromium content of the flux and in critical applications it is not unusual to supply the welding operator with two batches of flux of varying chromium content which he mixes in the proportions required to obtain the desired quantity of delta ferrite.

4.4.3.3 Embrittlement

Prolonged heating at 550-950°C, for example in multi-run welding, can cause sigma phase formation in the delta ferrite portion of the weld metal. The amount of sigma phase will depend on the delta ferrite content of the weld metal. If the ferrite content is less than about 5% however, sigma phase formation will be of very little practical importance. In heavy sections 10-15% ferrite can form. It is generally recommended that a maximum content of 10% is acceptable.

* *Severn Engineering Company Inc.*
Mfgs. of Ferrite & Permeability Indicators
PO Box 944, Annapolis, Maryland 21401, USA

Table 7 Recommended Filler Metals for Dissimilar Metal Joint Welding

Parent Metal ASTM Type (AISI)	201 202	303[1] 304 304L	309 309S	310 310S	317 316	317L 316L 316Ti	321 347	S30815 (253MA)	409 410 430	446	Duplex S31500 S31803 S32304
201 **202**	308 308L	308 308L 312	308 308L 347	308 308L 347	308 308L 347 318	308 308L 318	347 318 308	308 347	309 310	309 310	22.8.3L 309
304[1] **304L** **303**		308 308L 347	308 308L 347	308 308L 347	308 308L 347	308 308L 347	347 308 308L 318	22.12.HT 308 347	309 310	309 310	22.8.3L 309L 309
309 **309S**			309 309L	309 309L 310	309 309L	309 309L 316L 318	374 308 308L	22.12.HT 309 347	309 310	309 310	22.8.3L 309 309L
310 **310S**				310 310L	317L 316L 318 309	317L 316L 318 309 309L	347 308 308L 310	22.12.HT 310 309	309 310	310 309	22.8.3L 309 309L
317 **316**					317 316 318	317L 316L 316 318	347 318 316	22.12.HT 309	309 310	309 310	22.8.3L 309Mo 309
317L **316L** **316Ti**						317L 316L 318	347 318 308 316L	22.12.HT 309	309 310	309 310	22.8.3L 309Mo 317L 316L
321 **347**							347 318 308	22.12.HT 309 347	309 310	309 310	22.8.3L 309
S30815 **(253MA)**								22.12.HT	22.12.HT 309 310	22.12.HT 309 310	22.8.3L 309 310
409 **410** **430**									410 309	446 310 309	22.8.3L 309 309L
446										446 310 309	309 309L
S31500 **S31803** **S32304**											22.8.3L 309Mo
NiCrFe[2] **Alloys**											

NiCrFe[2] Alloys	Carbon[1] Steels	Low[1] Alloy Steels	501 502 505	Parent Metal ASTM Type (AISI)
NiCr-3 NiCrFe-6	309	309	309	**201** **202**
NiCr-3 NiCrFe-6	309	309	309	**304**[1] **304L** **303**
NiCr-3 NiCrFe-6	309	309	309	**309** **309S**
NiCr-3 NiCrFe-6	310 309	310 309	310 309	**310** **310S**
NiCr-3 NiCrFe-6	309	309	309	**317** **316**
NiCr-3 NiCrFe-6	309	309	309	**317L** **316L** **316Ti**
NiCr-3 NiCrFe-6	309	309	309	**321** **347**
NiCr-3 NiCrFe-6	22.12.HT 309 310	22.12.HT 309 310	22.12.HT 309 310	**S30815** **(253MA)**
NiCr-3 NiCrFe-6	309	309	309	**409** **410** **430**
Ni Cr-3 NiCrFe-6	309	309	309	**446**
NiCr-3 NiCrFe-6	22.8.3L 309	22.8.3L 309	22.8.3L 309	**S31500** **S31803** **S32304**
NiCr-3 NiCrFe Alloys	NiCrFe-6 312	NiCrFe-6 312	NiCrFe-6 312	**NiCrFe**[2] **Alloys**

Notes:

(1) This group includes free-cutting steels. When such a steel is a member of the joint certain precautions have to be taken. Buttering the free-cutting steel with 312 before welding the joint with a filler metal that suits the other part of the joint or welding the whole joint with 312 is normally a safe procedure.

(2) Higher strength can be obtained by using NiCrFe-6 with subsequent heat treatment.

General Notes

- If the dilution is high, eg. in submerged arc welding, special high ferrite grades are often preferred.
- If the working conditions require heat treatment, the filler metal choice may have to be reconsidered. Owing to the infinite combinations of materials and working conditions, no general rules can be applied.
- Filler metals are stated in order of preference. Normally, MMA, TIG, sub-arc welding is assumed. For MIG welding grades with higher silicon contents, eg. 308LSi, 308Si are preferred.
- Where 309 is specified 309Mo, 309MoL may be used. Where 309 is specified filler metals 310, 312, NiCr-3 may generally be used, however, care must be exercised with this selection: eg. i) to avoid high ferrite levels (312 consumable) which may lead to sigma phase embrittlement, ii) to avoid high nickel contents (NiCr-3) which can be attacked in sulphur bearing high temperature environments.
- Where designated consumables are not available, more highly alloyed grades may be used. However, due care must be taken with their selection.
- For high temperature transition joints carbon diffusion has to be considered. In such cases, 310 or NiCr-3 is recommended.
- When joining dissimilar but highly corrosion resistant steels, ferrite-free deposits are often demanded. Although each case has to be considered separately, the use of NiCr-3, 20.25.5LCu, or 27.31.4LCu can often be recommended.
- In addition to the grades specified here filler metals with specific properties are available, eg. low ferrite content, high carbon, extra low interstitials, high purity, etc.
- This table is not exhaustive. Other alloys may also be suitable.

4.5 Ferritic-Austenitic Stainless Steels (Duplex)

4.5.1 General

Ferritic-austenitic (FA) steels have a mixed structure consisting of about 40-80% ferrite and the rest austenite. They contain from 18 to 27% Cr and 5% Ni, and they can also be Mo alloyed.

All FA steels are superior in strength to both ferritic and austenitic grades and occupy an intermediate position with regard to thermal conductivity and thermal expansion.

The weldability of the more recently developed grades is similar to that of the austenitic grades but care should be exercised regarding the HAZ and to some extent, the weld metal itself.

Ferritic-austenitic steels undergo transformation to increasing amounts of ferrite with subsequent grain growth at temperatures above about 1050°C. These reactions will take place in areas of the HAZ heated up to and above this temperature. This part of the HAZ is called high-temperature HAZ (HTHAZ). On cooling, however, austenite will quickly reform, initially at the ferrite grain boundaries but also intergranularly. Typical HAZ structure of a welded joint in UNS S31803 is shown in Figure 15. Owing to the well balanced composition and in particular the presence of nitrogen in the steel, the coarse ferrite grains are entirely surrounded by austenite. Austenite reformation will also occur within the grains. This is very important as the austenite gives the HAZ good toughness and corrosion resistance in spite of a higher ferrite content than in the parent metal. Reheating by additional weld runs promotes austenite reformation in the HAZ.

Welding is done using similar or austenitic filler metal. The latter must have a composition which, after dilution with melted parent metal, will give a weld metal containing about 15-50% ferrite.

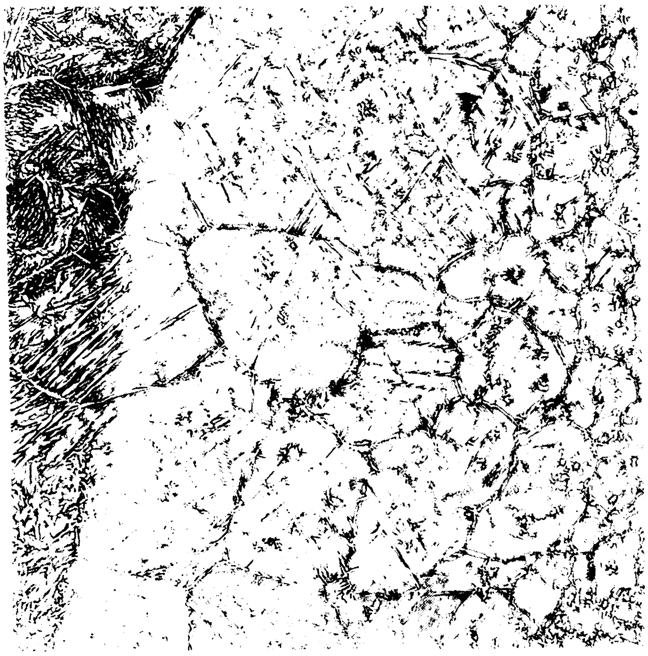


Fig. 15 Typical HAZ in UNS S 31803 Duplex Stainless Steels x 50

4.5.2 Pre- and Post-Weld Heating

The recently developed duplex grades are welded without preheating. Steels of the AISI 329 type, on the other hand, should be preheated at about 100-150°C to reduce the risk of brittle fracture.

The heat input should preferably be limited to a maximum of 1.5kJ/mm in order to keep the HTHAZ narrow. For the same reason the interpass temperature should not exceed 150°C.

There is normally no need for post-weld heat treatment. However, details which will be subjected to a high degree of cold deformation, ie. more than 15% are recommended to be quench-annealed. This recommendation is valid also when there are special demands on a structure which is homogeneous with the parent metal. Longitudinally welded tubing is one example when such demands may apply.

4.5.3 Effect of Welding on Properties

4.5.3.1 General

Welding has little influence on the mechanical and corrosion properties of duplex stainless steels with the use of the recommended filler metal and good technique.

The tensile strength may show a small change after welding. There is a tendency to higher strength and lower elongation at room temperature, while no difference can be seen at higher temperatures.

There is a certain reduction in impact strength after welding. For gas-shielded arc welding methods this reduction is of no practical importance. For joints made with MMAW or SAW, especially in heavy dimensions, the reduction in toughness must be considered (see Figure 16).

It can be noticed however that an impact energy above 27J, which for convenience is often considered to be the lower limit for ductile behaviour, is obtained at temperatures at least down to -50°C. This is also achieved for welded samples. With thinner material the toughness is higher and the reduction by welding is smaller.

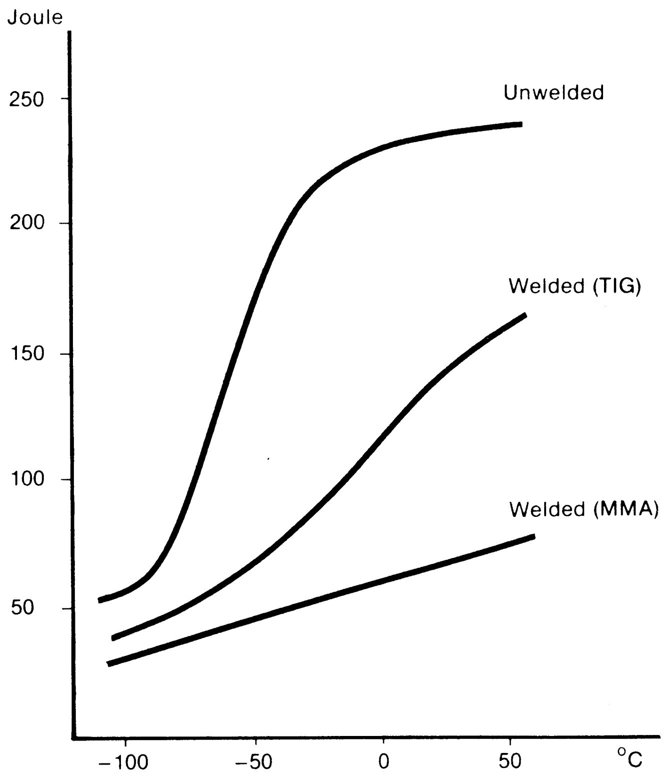


Fig. 16 Impact Energy, Charpy V, of UNS S 31803 Parent Metal and Welded Joint

The latter with notch across the fusion line.
Tube size 260 mm O.D. x 20 mm.

4.5.3.2 Corrosion Resistance

An important corrosion property of duplex stainless steels is their resistance to stress corrosion cracking. Practical experience has shown that this favourable behaviour is retained also after welding. Laboratory testing in 40% $CaCl_2$ at 100°C shows that welded samples as well as the parent metal can resist stresses up to yield point. When testing in the presence of H2S, as in the NACE test, welded samples are slightly less resistant than the parent metal (see Figure 17). The difference can partly be explained by residual stresses from the welding that add to the applied stress.

The resistance to pitting corrosion determined in chloride solutions in the laboratory shows values on the same level both for welds and parent metal. Immersion tests in sea water on the Swedish west coast show very good results on welded specimens of UNS S31803. On inspection after 5 years the welds were unattacked.

Decisive for the resistance to intergranular corrosion is the ability to reform austenite in the heat-affected zone. UNS S31803 and UNS S32304 have additions of nitrogen which is vital for the rapid reformation of austenite. Each of these grades passes the Strauss Test (ASTM A262 Practice E) and in addition UNS S32304 passes the Huey Test (ASTM A262 Practice C).

Use of welding processes which use no filler metal (eg. electron beam, laser, resistance) and which are also characterised by rapid cooling of the weld nugget can result in the weld being more ferritic than with other fusion processes. This may impair corrosion resistance and ductility.

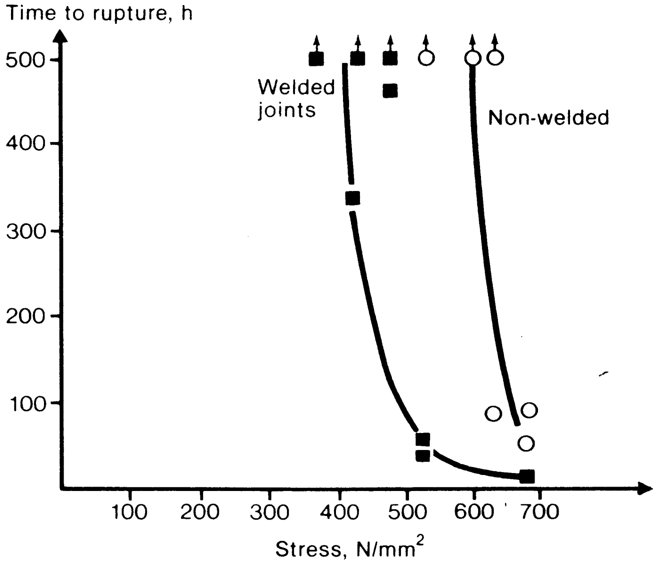


Fig. 17 Results of Stress Corrosion Cracking Tests with Tensile Specimens in UNS S 31803
Without notches, in NACE solution (5% NaCl, 0.5% HAc, saturated in H_2S) at 23°C.

4.5.3.3 Embrittlement

Heating to welding temperature can cause precipitation of both carbides and brittle phases, especially sigma phase (see Figure 18). The carbide precipitation will depend on how high the carbon content is and on whether or not the steel is stabilised. Sigma phase forms at about 550-900°C, and the higher the content of Cr, Mo and Nb, the faster this will happen. It should be noted however, that normal weld thermal cycles are too short for any detrimental sigma-phase formation or 475° embrittlement.

Embrittlement is accentuated by grain growth. Weld heating augments ferrite content, and grain growth is particularly pronounced in a ferrite structure. When the weld cools, the austenite is only partially reformed and the weld zone acquires quite a coarse-grained structure with less austenite content than before welding took place. The original FA grades, AISI 329, have such a high ferrite content even in the basic quench-annealed condition that they can become almost completely ferritic after welding. More recently developed FA grades have a higher austenite content and much better welding response and corrosion resistance. The latter alloys are also ELC steels (max. 0.030%C) and possess excellent resistance to intergranular corrosion. Because of a primary ferritic solidification mode, there is no risk of hot cracking.

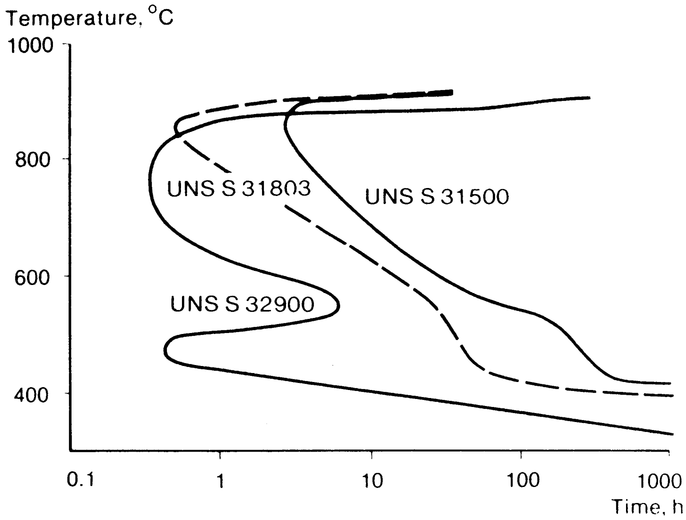


Fig. 18 Embrittlement in various FA Steels
Impact strength is at least 27J to the left of the curves, while at the times and temperatures to the right of the curves embrittlement can be expected.

4.6 Ferritic Stainless Steels

4.6.1 General

Ferritic steels contain from 12 to 30% of chromium as their main alloying element. The carbon content is normally less than 0.1%. In recent years, so-called ELI steels (Extra Low Interstitials) have been introduced. They have very low contents of carbon and nitrogen, carbon + nitrogen being in the order of 0.01-0.02%. These steels have better corrosion resistance than normal ferritic steels.

Ferritic steels have poorer weldability than the austenitic steels.

Ferritic steels can be welded with filler metals of a composition similar to that of the parent metal, or by using austenitic fillers. The best weld metal ductility is obtained with austenitic filler metal with a nickel content of about 20%. The ferritic steels are particularly resistant to corrosive attack in sulphurous atmospheres. In these environments austenitic filler metals should not be used as the nickel content reduces the corrosion resistance.

4.6.2 Pre- and Post-Weld Heating

Ferritic steels have a narrow temperature zone within which impact strength falls drastically. The temperature at which the transition from ductile to brittle fracture occurs, ie. the transition temperature, can be clearly established by means of impact strength testing. Figure 8 shows schematically a comparison between ferritic, austenitic, martensitic and duplex steels. As will be seen, impact strength is one of the respects in which ferritic steels differ appreciably from austenitic steels. Below the transition temperature, failures occur with practically no elongation at the fracture point. This is why impact tests are specified in AS 1210* for the use of ferritic and ferritic-austenitic steels at low temperatures.

In order to obtain good welds, it is necesary to weld with low heat input and preheat the work to about 100°C immediately before welding. The steel is tough at this temperature (above its transition temperature), and phase transformation can be avoided here. The temperature has to be decided according to the steel grade being used and the dimensions of the welded joint. Preheating reduces the temperature gradient and with it the welding and shrinkage stresses.

Unless the steels are used at high temperatures, welding has to be followed by heat treatment of the welded joint at 750-850°C for 30-60 minutes. This dissolves the carbides or gives them a better spherical shape, which improves corrosion resistance and also increases toughness. Heat treatment also reduces/eliminates welding and shrinkage stresses. Figure 19 and 20 show the structure of a welded joint before and after this annealing.

Titanium-stabilised grades do not always require this annealing, particularly if the purpose is to improve the corrosion resistance. Such carbide precipitation as reduces the corrosion resistance does not always have time to develop during the welding operation, at least not when welding material thicknesses below approximately 2mm.

Annealing is often unnecessary for structures which are to be used at high temperature as these will be heat-treated while in service, but the parts should be handled carefully during assembly.

During post-annealing, an effort should be made to pass through the temperature ranges where embrittlement can occur (refer to section 4.6.3) as rapidly as possible.

4.6.3 Effect of Welding on Properties

Chromium steels containing more than 13%Cr can develop what is called "475°" embrittlement when heated between 400-500°C. Brittle sigma phase will form in steels containing more than 15%Cr at 500-800°C and at even higher temperatures for molybdenum alloyed steels. Sigma phase can therefore be formed during the welding of heavy-gauge ferritic stock which requires prolonged heating. For such steels, annealing in the temperature range previously mentioned is consequently unsuitable although the time required to precipitate sigma phase at a given temperature is largely dependent on the composition of the steel.

A pronounced grain growth occurs in the HAZ of ferritic stainless steels. Carbide precipitate at the grain boundaries of the ferrite phase, causing embrittlement in the weld joint and a reduction in the corrosion resistance. This embrittlement may lead to brittle fracture when the steel has cooled down to its transformation temperature (see Section 4.6.2) which is in the range of 100-200°C. Moreover, there is a risk of transverse shrinkage cracks developing in the weld metal as it cools and as the welding stresses increase.

Post-heat treatment may be necessary (see Section 4.6.2) to impart optimum mechanical properties and corrosion resistance to the weld joint.

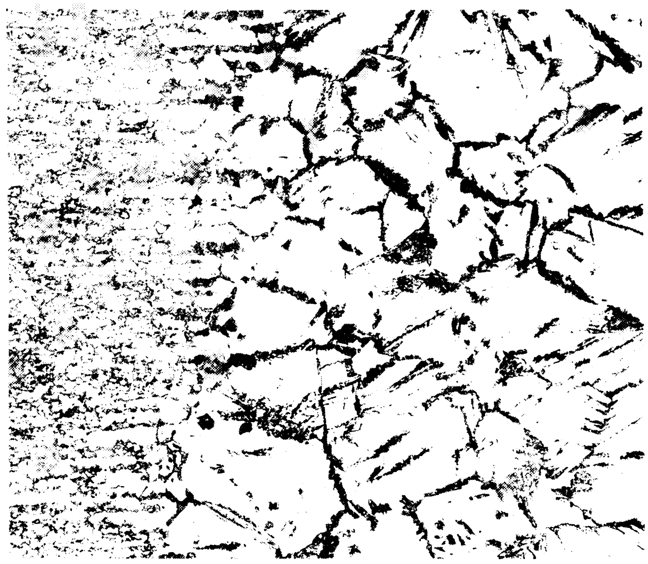


Fig. 19 Weld Metal and HAZ of Ferritic Stainless Steel (17% Cr) in the Untreated State. x 50
TIG welding using the corresponding filler metal.

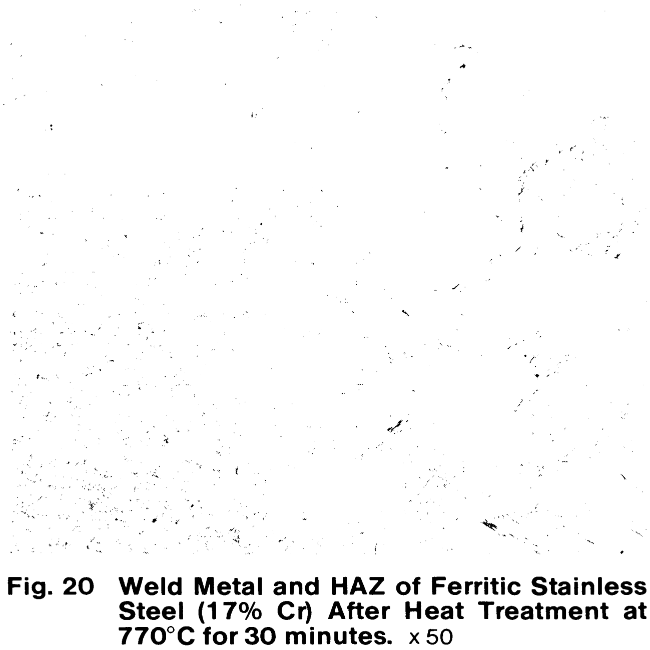


Fig. 20 Weld Metal and HAZ of Ferritic Stainless Steel (17% Cr) After Heat Treatment at 770°C for 30 minutes. x 50
TIG welding using the corresponding filler metal.

* *AS1210-1982 "SAA Unfired Pressure Vessels Code"*

4.7 Martensitic Stainless Steels

4.7.1 General

There are many variants of martensitic stainless steels, and we can distinguish between the following:

- martensitic
- martensitic-austenitic
- martensitic-ferritic, and
- martensitic-ferritic-austenitic.

4.7.2 Basic Martensitic Stainless Steels

4.7.2.1 General

Martensitic steels usually contain between 11.5 and 13.5%Cr. In practice all these steels are air-hardening, which means that the austenite is not decomposed into alpha ferrite and carbides during air-cooling as is the case with mild steels, but transforms to martensite between the Ms and Mf temperatures. For steel containing 0.12% C and 12%Cr, the Ms and Mf temperatures are 300-350 C and 150-180 C respectively.

To obtain the optimum mechanical properties, martensitic steels are generally employed in a quenched and tempered condition. Weld repairs also have to be tempered if properties similar to those of the parent material are to be obtained.

Martensitic steels have poor weldability due to the formation of hard and brittle martensite in the HAZ and weld metal. Particular precautions (see Section 4.7.2.3) have to be taken when welding straight 13%Cr steels to prevent cracking associated with martensite formation especially if the carbon content is above 0.1%. Special martensitic alloys containing 13%Cr, 4%Ni, 0.4-1.0Mo and 0.06%C have been developed for turbine and pump castings. These alloys have improved corrosion and cavitation resistance, and improved weldability. This latter being due to their low carbon content.

Austenitic electrodes are sometimes used for cosmetic repairs of cast components where pre- and post-heat treatments are not possible. The weld deposit is soft, has poor fatigue resistance and has a very high coefficient of thermal expansion. This can cause problems if temperature fluctuations occur.

The problems of cracking and the role played by pre- and post-heat treatment and interpass temperature cannot be over emphasised. It is desirable to know the chemical composition and metallurgical condition of a martensitic stainless steel component before any welding is attempted so that correct heat treatment parameters can be ascertained.

4.7.2.2 Effect of Welding on Properties

Martensitic stainless steels are air-hardening so that both the weldment and HAZ would be expected to be martensitic under the usual cooling rate conditions of the weld. The type of structure found in the weld and HAZ regions depends mainly on the welding parameters but it is also influenced by local enrichment of alloying elements during the solidification process making it possible to find retained austenite even at temperatures below the theoretical Mf temperature of the alloy content.

Cracking of both the weld metal and HAZ associated with the mechanical effects of martensite formation creates a major problem with the welding of martensitic steels. The risk of cracking can be minimised by the use of preheat and interpass temperature control to ensure that the least possible internal stresses are present in the weldment at the completion of welding.

Other factors remaining constant, the risk of cracking increases with increasing martensite hardness. As in the case of low alloy steels, the hardness of martensitic stainless steel rises rapidly with carbon content. Martensitic stainless steels with carbon contents above 0.1%C have to be given pre- and post-welded heat treatments and those above 0.3%C are normally not welded.

4.7.2.3 Pre- and Post-Welded Heating

Preheating is employed to reduce the effects of martensite transformation and usually involves heating the weld joint between 100 and 300 C depending on carbon content. To completely avoid martensite formation, it is necessary that, after allowing for weld heat input, the preheat temperature is high enough for the weld metal and HAZ to remain above the Ms temperature for a relatively long time. This is rarely achieved during the welding of a straight 13%Cr steel for which the Ms temperature is relatively high (approx. 350 C).

Experience has shown that cracking can be avoided even when a major portion of the weld metal becomes martensitic. The Mf temperature for martensitic stainless steel is relatively low (approx. 150 C) so that at temperatures between 150-200 C, small islands of untransformed austenite are retained which enable hydrogen to remain in solution and facilitates the relaxation of internal stresses. The behaviour of hydrogen in steel is greatly influenced by temperature and holding the weld between 150 and 200 C avoids the formation of high pressures, and allows rapid diffusion of the gas out of the weld.

Interpass temperature (ITP) also plays an important role in minimising the possiblity of cracking. If the ITP is kept between the Ms and Mf temperatures the martensite formed in the deposited weld is subjected to successive short tempering treatment as further weld runs are deposited.

Post-heat treatment of martensitic welds is carried out to obtain improved mechanical properties and to relieve stresses which could lead to cracking or fatigue failures. The martensite formed in the weld metal and HAZ on the cooling of the weld to ambient temperature tends to be hard and brittle and requires a tempering operation, usually at 750 C, to improve its ductility. For designs with complicated stress conditions, this heat treatment should be carried out immediately after welding, the work pieces not being allowed to cool down to room temperature between completion of welding and commencement of heat treatment. The work, however, should be allowed to cool to at least 150 C at the start of heat treatment to ensure complete transformation of the austenite to martensite.

Temper embrittlement can occur, especially with the straight 13%Cr steels, in the range 370 to 450 C. Maintaining martensitic steels in this temperature range for any length of time should be avoided.

When welding heavy-gauge martensitic stock, there may sometimes be practical difficulties involved in heat-treating the finished weldment. One way of solving this problem is by buttering, which means that the joint faces are first preheated and surfaced with austenitic filler metal, using a low current and a high rate of travel (see Figure 21). The parts to be welded together are then heat-treated, in addition to which the joint faces may be machined. Butt welding is then normally possible without preheating, and since the HAZ will come in the austenitic surfacing layer, no post-weld heat treatment will be necessary.

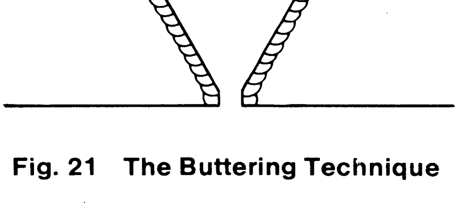


Fig. 21 The Buttering Technique

4.7.3 Martensitic-Austenitic Stainless Steels

4.7.3.1 General

These steels were developed in the 1950's primarily for hydro-turbines. Their approximate composition is 0.04-0.08%C, 13-16%Cr, 5-6%Ni and 1-2%Mo. They are hardened in oil or air from about 1000°C, whereupon a martensitic structure is formed, possibly containing residual austenite. In the tempering which then follows at about 600°C, austenite is formed which is so stable that it is not converted into martensite when it cools to room temperature. The final structure contains 65-80% tempered martensite and the rest austenite, which makes the material far more ductile than martensitic steels. In the tempered condition, therefore, these steels are easily welded. Preheating is not necessary, nor is there any serious risk of cracking in the HAZ.

The martensitic-austenitic steels are usually welded with austenitic filler metals even though the strength of the austenitic weld metal is lower than that of the parent material.

4.7.3.2 Effect of Welding on Properties

The region of the HAZ that is completely austenitised (heated above 900°C) transforms to a predominantly martensitic structure during subsequent cooling to room temperature. The martensite-austenitic relationship of the parent metal in the zone can be restored by tempering at approximately 600°C. The need to carry out a tempering operation, especially if austenitic filler metal is used, is normally unnecessary as the higher ductility of the surrounding weld metal and parent material is sufficient to accommodate any stress that could cause trouble in this zone.

4.7.3.3 Pre- and Post-Heat Treatment

The low carbon content and ductile nature of the duplex structure of martensitic-austenitic alloy allows them to be welded without any preheat.

4.7.4 Other Martensitic Stainless Steels

Martensitic-ferritic and martensitic-ferritic-austenitic stainless steels are also available. They are special grades not commonly used and are not included in this Technical Note. Further information can be obtained from suppliers of these materials.

5 STAINLESS STEEL WELDING PRACTICE

5.1 Transport and Packaging

Stainless steel should be packaged and transported in a manner that —

- will protect it from the environment
- will avoid use of continuous strip strapping
- will be undercover (ie. not deck cargo)

5.2 Storage and Handling

All stainless steels should be stacked and stored in a manner which will prevent contamination by ferrous material. Materials should be separated from all mild steel and should be protected from damage and from other deleterious material during storage and fabrication. Only rope slings or belts should be used for handling. Where it is necessary to use wire slings they should not come into direct contact with any stainless steel materials.

If carbon steel contacts the stainless then all such marked areas should be cleaned and passivated.

5.3 Joint Preparation and Cutting

Cutting or preparation of edges should be carried out by guillotine, machining, grinding or plasma arc. Edges cut by plasma arc should be smooth and free from gutters or notches and shall have oxides removed. All other edges should be deburred.

Any cutting or prepration carried out with the carbon arc process or by powder cutting should have 1.5mm dressed from the cut edge. Carbon arc gouging is not recommended for cutting of stainless steels under any circumstances.

All spatter is to be removed and the surface of the parent metal dressed smooth.

5.4 Electrode Care

Electrodes that have been removed from their packets should be transferred to a holding oven or welder's hot box and maintained at a temperature of 110°C to prevent moisture pick-up until required for use.

Electrodes that have become damp should be redried at 250°C for 2 hours prior to use.

5.5 General Welding Practice and Technique

5.5.1 Cleaning

Cleaning may be necessary before welding and during welding (interpass) and is usually essential after welding in order to ensure maximum corrosion resistance.

Pre-weld cleaning involves dressing the cut edge and removing all contaminants such as oil, paint, grease, crayon marks, adhesive tapes, etc. The area on both sides of the weld should be cleaned before welding by brushing with a clean stainless steel brush and wiped with a solvent moistened cloth. All moisture must be removed and if a flame is used care must be taken to see that any water (a product of combustion) does not remain on the surface or in the weld preparation. Liquid petroleum gas particularly creates a large amount of water when burnt.

Each welding run must be thoroughly cleaned to remove slag and spatter before proceeding with the next run. The cleaning method used (chipping, brushing, grinding) will depend on the welding process, bead shape, etc. but care should be taken to see that the weld area is not contaminated in the process. Any cleaning equipment should be suitable for stainless steel and kept for that purpose.

During welding a gas purge on the reverse side may be advantageous (see Section 5.6.1).

After welding, weld spatter, flux, scale, arc strikes and the overall heat discolouration should be removed. This can involve grinding and polishing, blasting and brushing with a stainless steel wire brush, or use of a descaling solution or paste. The preferred procedure is usually dictated by end use.

Grinding and dressing is to be carried out with iron-free brushes, abrasives, etc. and should not be so heavy as to discolour and overheat the metal. Rubber and resin bonded wheels are satisfactory. Wheels should be dressed regularly to prevent them becoming loaded thereby producing objectionable scratches. In any blasting process steel shot shall not be used. (See also Section 5.6 on pickling and passivation).

5.5.2 Welding Procedure

Efficient arc striking is essential in welding all types of stainless steels as indiscriminate arc striking tends to scar or burn the surface of the steel thus providing areas for premature chemical attack. Care and skill are required to obtain satisfactory weld starts and restarts on continuous seams. As both burn-through on light section material and cold lack of penetration starts on heavier material can easily result from imperfect technique, the suggested procedure is to strike the electrode in the joint approximately 8-10mm forward of the actual start point. With the arc established and electrode correctly angled it can then be rapidly taken to the start point for complete fusion of the previous weld and/or the joint root of a new weld.

Efficient tack welding on austenitic steels is essential in controlling distortion. The length of tack welds varies from 12-40mm depending on sheet or plate thickness. Generally tack welds are more closely spaced than when welding mild steel of similar dimensions.

The use of a long arc or excessive current is capable of causing losses of manganese and chromium which can impair the corrosion resistance of the weld joint. Arc length should therefore be kept as short as possible consistent with satisfactory welding performance, ie. minimum spatter, complete fusion, acceptable bead shape.

Welding should be carried out at the lowest current consistent with good fusion at the selected welding speed to minimise heat input and control distortion. Higher welding speeds can be an advantage.

Stringer beads are recommended in preference to weaving in order to keep the heat input to an acceptable level. Where weaving is necessary both the weave width and side dwell time should be kept to a minimum. Interpass temperatures generally should not exceed 150°C except in the case of martensitic alloys.

Breaking the arc in an abrupt manner can result in slag inclusions and shrinkage cracks. Craters should be filled by using a circular motion at the end of the weld followed by a gradual lengthening of the arc to the point of extinguishing it.

Welding conditions and welding technique should be such as to produce a smooth weld surface which requires minimum dressing.

Fillet weld beads shall be of full throat thickness and correct contour, consistent with good operation. Concave fillet welds are to be avoided.

The root side of the weld must be protected against oxidation especially in gas-shielded arc welding. Protection with shielding gas is commonly applied. Back-gouging (grinding) of the root and welding from the reverse side of the joint can also be used when the design so permits.

5.5.3 Weld Defects and Stress Raisers

5.5.3.1 General

The introduction of excessive heat into the weld joint as a result of using too high a current, too low a travel speed or a combination of both, causes, in addition to burn-through, a rough blob of unsound metal and overheating of the joint zone from which chemical attack may originate. Repair techniques are difficult and they also introduce additional heat to areas already overheated.

Undercut areas in stainless steel welds, in addition to forming stress-raisers, also tend to provide pockets from which premature corrosion may originate. Undercutting is mainly associated with over-size welds caused by the use of excessive current or unnecessary weaving of the electrode in the joint being welded.

Slag inclusions and lack of penetration can result from incorrect welding parameters (arc voltage, current, stick-out, welding speed, electrode size, etc.) and/or poor technique (electrode angle, excess weaving, etc.).

5.5.3.2 Stress Raisers

Stress raisers caused by welding can be undersirable in fatigue situations or where notch sensitive materials are used. In critical areas the following defects should be eliminated or minimised.

- excessive reinforcement
- undercut
- overroll
- convex fillets
- undersize welds
- unequal leg lengths
- unfilled craters
- non returned welds
- porosity
- slag inclusions
- lack of fusion
- gullies in multiple run welds
- stray arcs
- grind marks transverse to design stresses
- crossed welds
- continuous welds on small diameters or highly stressed shafts
- overwelding — maximum repairs = 3
- square corner welds and patches become highly stressed and should always be rounded. Suitable gaps should be allowed for shrinkage.

Table 8 Nominal Analyses for Bare Wire Electrodes and Filler Rods

AWS Classification ER (A5.9-81)	C	Cr	Ni	Mo	Si	Mn	P max.	S max.	Nb	Fe	Ti	Other Elements
307	0.10	21	9.0	1.0	0.4	4.0	0.03	0.03				
308	0.07	21	10	–	0.4	1.8	0.03	0.03				
308Si	0.07	21	10	–	0.8	1.8	0.03	0.03				
308L	0.03	21	10	–	0.4	1.8	0.03	0.03				
308LSi	0.03	21	10	–	0.8	1.8	0.03	0.03				
308Mo	0.07	20	10.5	2.5	0.4	1.8	0.03	0.03				
308MoL	0.03	20	10.5	2.5	0.4	1.8	0.03	0.03				
309	0.10	24	13	–	0.4	1.8	0.03	0.03				
309L	0.03	24	13	–	0.4	1.8	0.03	0.03				
309LMo	0.03	24	13	2.5	0.4	1.8	0.03	0.03				
310	0.12	26	21	–	0.4	1.8	0.03	0.03				
312	0.10	30	9.0	–	0.4	1.8	0.03	0.03				
316	0.08	19	12	2.5	0.4	1.8	0.03	0.03				
316Si	0.07	19	12	2.5	0.8	1.8	0.03	0.03				
316L	0.03	19	12	2.5	0.4	1.8	0.03	0.03				
316LSi	0.03	19	12	2.5	0.8	1.8	0.03	0.03				
317	0.07	19	13	3.5	0.4	1.8	0.03	0.03				
317L	0.03	19	13	3.5	0.4	1.8	0.03	0.03				
318	0.07	19	12	2.5	0.4	1.8	0.03	0.03	0.6			
347	0.07	20	10	0.5	0.4	1.8	0.03	0.03	0.6			
347Si	0.07	20	10	0.5	0.8	1.8	0.03	0.03	0.6			
410	0.10	12.5	0.4	0.5	0.4	0.4	0.03	0.03				
410NiMo	0.05	12	4.5	0.5	0.4	0.4	0.03	0.03				
420	0.30	13	0.4	0.5	0.4	0.4	0.03	0.03				
430	0.08	16.5	0.4	0.5	0.4	0.4	0.03	0.03				
502	0.08	5.0	0.4	0.5	0.4	0.4	0.03	0.03				
505	0.08	9.0	0.4	1.0	0.4	0.4	0.04	0.03				
NiCr-3	0.08	20	72	–	0.3	3.0	0.03	0.015	2.5	2.5	0.4	
NiCrFe-5	0.07	16	73	–	0.2	0.5	0.03	0.015	2.5	8	–	
NiCrFe-6	0.07	16	72	–	0.2	2.5	0.03	0.015	–	6	3	
NiFeCr-1	0.04	22	43	3.0	0.3	0.5	0.03	0.03	–	28	1	Cu = 2
NiCrMo-3	0.08	22	61	9.0	0.3	0.3	0.02	0.015	3.5	3	0.2	

5.5.4 Qualifications

5.5.4.1 Personnel

In the fabrication of pressure vessels personnel qualifications should be in accordance with the relevant standards. Structural fabrication standards give no guidance in this area and it may be necessary to specify in the tender documents what welder qualifications are required.

5.5.4.2 Filler Welds

Filler metals should be chosen in accordance with Tables 6 and 7. Other alternatives may be available although all aspects of corrosion and weldability should be taken into account. The chemical compositions of a selection of filler metals are given in Table 8. A selection of suppliers designations are given in Tables 9 and 10.

5.6 Pickling and Passivation

For optimum corrosion resistance, cleaning should always be followed by a 'pickling and passivation treatment'. Pickling involves dissolution of surface iron deposits and other contaminants using acids such as sulphuric and hydrofluoric. Passivation involves establishment of surface passivity with nitric acid solutions. The exception is welds cleaned by descaling agents which contain nitric and hydrofluoric acids. These function as both descaling (pickling) and passivating agents.

The importance of pickling and passivating stainless steel fabricated structures cannot be over-emphasised. The beneficial effects are threefold, namely:

(a) Pickling removes weld scale and discolouration. In aggressive media, the lower surface chromium content under the discolouration, and the masking effect on the surface, can lead to a form of crevice corrosion in the weld or HAZ. Crevice attack frequently initiates severe pitting attack if chlorides are present.

(b) Pickling removes iron contamination which can be picked up during fabrication and which can lead to the formation of "rust" spots and pitting attack.

(c) Passivation establishes a hydrated oxide film on the stainless steel surface which provides maximum passivity.

Descaling (pickling) and passivation solutions and their application are shown in Table 11.

Some appropriate solutions can be mixed with constituents such as Barium Sulphate or diatomaceous "Fullers earth" to form a paste which can be applied to weld discolouration and scale areas in vertical or difficult positions where the solution could not be contained.

Proprietary solutions and pastes are also available. It is important that they are completely removed by washing prior to service, that they are chloride free and that appropriate safety measures be taken with their use.

Final cleaning may be minimal if proper care has been exercised through the preceding fabrication and cleaning stages. This may be a hot water detergent wash followed by thorough rinsing.

5.6.1 Gas Purging

With fabrications which cannot readily be cleaned after welding, such as pipelines, it may be necessary to arrange an internal purge with an inert gas to minimise discolouration during welding. This will be particularly required if the material carried by the pipe is very corrosive, eg. hot, high chloride waters.

5.7 Procedure Qualification Weld Quality Levels and Inspection

Where components are designed and manufactured to a specific Standard, then the inspection procedures and weld quality requirements of that Standard should be observed. However, much of stainless steel fabrication is not covered by existing Australian or overseas Standards and the following is intended to provide guidance on procedure qualification, weld quality level and inspection.

5.7.1 Structural Steel Standards

Standards intended for the fabrication of ferritic-pearlitic steels, eg. AS1554 or AWS D1.1 are generally not applicable to stainless steels since they are designed largely to ensure only adequate mechanical properties in the welded joint while stainless steels are normally used only where specific surface properties, eg. resistance to scaling, are required. It follows therefore that structural steel Standards permit imperfections such as undercut, lack of fusion, etc. which may be quite unacceptable in stainless steel structures since they lead to premature corrosion and rapid failure. On the other hand stainless steels, particularly the austenitic grades, exhibit superior ductility and a freedom from ductile/brittle transitions which means they are much less susceptible to the influence of internal imperfections than the ferritic-pearlitic structural steels.

5.7.2 Procedure Qualification

Before fabrication commences, the procedures to be employed should each be qualified through the preparation of a procedure test plate. The test plate should as closely as practical simulate conditions in the actual job such as the material grades, weld preparation, degree of restraint, etc. Figure 22 illustrats a suitable test plate for a simple butt weld. The length of the test plate depends somewhat upon the number of tests to be undertaken. A minimum of two macro tests, one root bend, one face bend and any corrosion testing required by the specification should be carried out. In the case of procedures involving fillet welds only, procedure test plates need not be prepared if the weld is deposited with no more than five weld passes (excepting to AS1210).

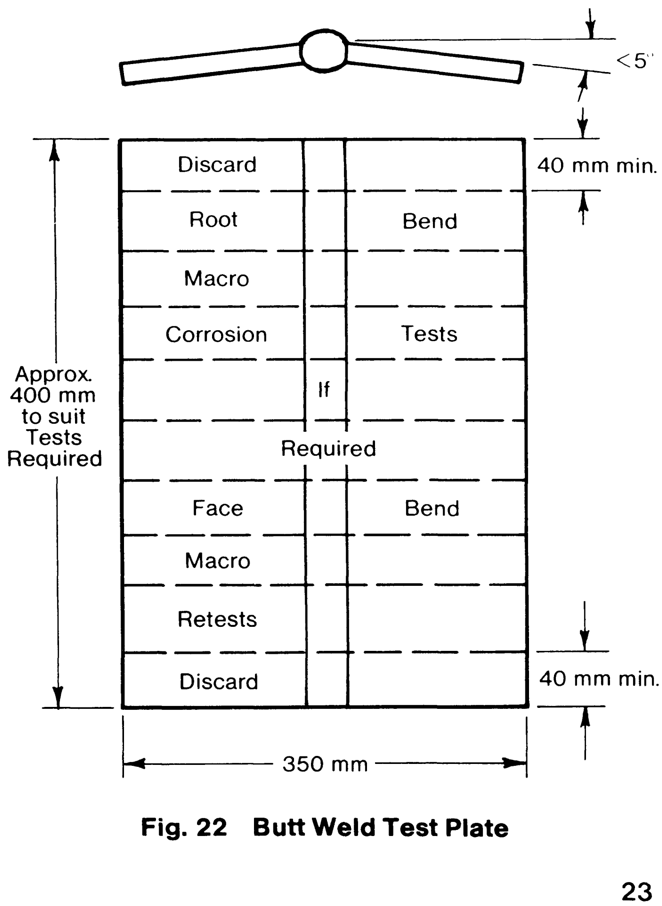


Fig. 22 Butt Weld Test Plate

Table 9 Filler Metals and Suppliers' Designations (Wire and Rod)

AWS	CIG	ESAB	Bohler	Sandvik	Avesta	Liquid Air	Lincoln Electric	WIA	Wright & Co
308			AS2-IG	308	308/MV			Austmig 308L	
308L	Autocraft 308L	Tigrod 16.10	EAS2-IG	308L	308L/MVR	308L Stainless	Lincolnweld 308L	Austmig 308L	308L
	Comweld 308L	Autrod 16.12							
308MoL				308MoL					
309	Autocraft 309	Autrod 16.52	FF-IG	309		309 Stainless		Austmig 309	309
309L	Comweld 309	Autrod 16.53	CN23/12IG	309L	309L				
309Mo			A9-M	309Mo					309Mo
309MoL			CN23/12MO-A	309MoL	P5				
310	Autocraft 310	Autrod 16.70	FFB-IG	310	254 EM	310 Stainless			310
310L				310L					
312		Autrod 16.75	CN29/9-IG	312	P7				312
316				316	316/SK				
316L	Autocraft 316L	Tigrod 16.30	EAS4M-IG	316L	316L/SKR	316L Stainless	Lincolnweld 316L	Austmig 316L	316L
	Comweld 316L	Autrod 16.32							
317L		Tigrod 16.34		317L	SLR				
		Autrod 16.34							
318		Tigrod 16.31	SAS4-IG	318	318/SKNb				
			A7-IG						
329				329					
347	Autocraft 347	Tigrod 16.11	SAS2-IG	347	347/MVNb	347 Stainless		Austmig 347	
	Comweld 347		AS4-IG		316/SK				
410			KW10-IG						
430			SKWA-IG	17Ti					
420			SKWAM-IG	13HC					
NiCr-3			NiCr70Nb-IG	Sanicro 72	P10				Inconel 82
NiCrFe-6				Sanicro 74					Inconel 92
				Sanicro 41X					Incoloy 65
NiCrMo-3				Sanicro 60X7	P12				Inconel 625
S30815*				253MA	253MA				
S31803*				SAF 2205	223FAL				
N08904*				2RK65	254SLX				
N08028*				Sanicro 28	928				
S32550*									Ferralium 255

* UNS Designation

Notes

1. This table lists the main wires and rods – others may be available on request.
2. Tables 7 and 8 in this Technical Note refer to high silicon grades which while not separately listed above are available in selected grades.

Table 10 Electrodes and Suppliers' Designations

AWS	CIG	ESAB	Bohler	Sandvik	Avesta	Liquid Air	Lincoln Electric	WIA	Wright & Co
308	Staincraft 308-16	OK61.53(16)	FoxAS2-A(16)	Sandvik E308					
			FoxAS2 (15)						
308L	Satincrome 308L-16	OK61.30(16)	FoxEAS2-A(16)	Sandvik E308L	MVR AC/DC (16)	Liquidarc 308L	Stainweld 308L-16	Staincord 308ELC	E308L
		OK61.41(15)	FoxEAS2 (15)		MVR (15)				
					MVR-VDX				
309		OK67-62(16)	FoxFF-A(16)	Sandvik E309	309S-H		Stainweld 309-16		E309
		OK67-75(15)	FoxFF (15)						
309L			FoxCN 23/12-A	Sandvik E309L	309L				E309L
309Mo	Staincraft 309Mo-16	OK67-70(16)		Sandvik E309Mo	P5 AC/DC (16)	Liquidarc 309Mo		Staincord 309M0-16	E309Mo
					P5 (15)				
309MoL			FoxCN 23/12Mo-A	Sandvik E309MoL					
316		OK63.53(16)	FoxAS4-A(16)	Sandvik E316	SK AC/DC (16)				
		OK63.35(15)	FoxAS4 (15)		SK (15)				
316L	Satincrome 316L-16	OK63.41(15)	FoxEAS4M-A(16)	Sandvik E316L	SKR AC/DC (16)	Liquidarc 316L	Stainweld 316L-16	Staincord 316ELC	E316L
		OK63.30(16)	FoxEAS4M- (15)		SKR DC (15)	Liquidarc 316V			
					SKR-VDX				
317L				Sandvik E317L	SNR-PW				
318	Staincraft 318-16	OK63.80(16)	FoxSAS4-A(16)	Sandvik E318	SKNb AC/DC(16)	Liquidarc 318		Staincord 318	
			FoxSAS4 (15)		SKNb (15)				
347	Satincrome 347-16	OK61.81(16)	FoxSAS2-A(16)	Sandvik E347	MVNb AC/DC(16)	Liquidarc 347		Staincord 347	
			FoxSAS2 (15)		MVNb (15)				
310	Heatcraft 310-15	OK67.15(15)	FoxFFB-A(16)	Sandvik E310	310 AC/DC (16)	Liquidarc 310-16	Stainweld 310-16		E310
		OK67.13(16)	FoxFFB (15)		310 (15) 310L				
312	Weldall	OK68.81(16)	FoxCN 29/9	Sandvik E312	P7	Liquidarc 312		Unicord 312	E312
320			FoxSAS20 (15)						
330			FoxFFB 400						
22.12.HT*				Sandvik E 253MA	253MA				
20.25.5.LCu*				Sandvik E 2RK65	254SLX				E904L
27.31.4.LCu*				Sandvik E Sanicro 28	928				
NiCrFe-3				Sandvik E 72	P10				
22.9.3.L*				Sandvik E SAF2205	223FAL				
NiCrMo-3				Sandvik E 625	P12				
NiCrFe-2									Incoweld A

* ISO Designation

Notes

1. Grades with rutile or basic coatings are available. Electrodes may also be available from suppliers in modified forms to give specific properties, ie. HP = high purity, HD = high deposition, HT = high temperature, LF = low ferrite, HF = high ferrite and VD = vertical down.
2. This table lists the main electrodes supplied. Others may be available on request.

Table 11 Acid Descaling and Cleaning Techniques for Stainless Steel

Alloy	Condition	Solution Volume, %	Temperature °C	Time, Min
Acid Descaling (Pickling) Solutions				
200, 300 and 400 series; Precipitation hardening, and maraging, except free machining	Fully annealed	H_2SO_4, 8 to 11	65	5 to 45
200 and 300 series; 400 series (>16%Cr), precipitation hardening except free machining	Fully annealed	HNO_3, 15 to 25 and HF, 1 to 4	20 to 60	5 to 30
Free machining and 400 series (<16%Cr)	Fully annealed	HNO_3, 10 to 15, and HF, ½ to 1½	20 (up to 60 with caution)	5 to 30
Nitric-Hydrofluoric Acid Cleaning Solutions Removes residual scale particles and smut; produces a uniform white pickled finish.				
200 and 300 series, 400 series (>16%Cr), and precipitation hardening	Fully annealed	HNO_3, 6 to 15, and HF, ½ to 1½	20 to 60	10
Free machining, maraging, and 400 series, (<16%Cr)	Fully annealed	HNO_3, 10, and HF ½ to 1½	20 (up to 60 with caution)	1 to 2
Nitric Acid Cleaning Solutions Removes soluble salts, corrosion products, free iron, and other metallic contaminants.				
200, 300 and 400 series, precipitation hardening, and maraging (>16%Cr) except free machining	Annealed, cold rolled, or work hardened (dull finish)	HNO_3, 20 to 40	50 to 70 20 to 40	20 to 30 60
200, 300 and 400 series precipitation hardening, and maraging (>16%Cr) except free machining	Annealed, cold rolled, or work hardened (bright finish)	HNO_3, 20 to 40, and $Na_2Cr_2O_7$, $2H_2O$, 2 to 6 mass	45 to 55 20 to 40	20 to 30 60
400 series, maraging, precipitation hardening (<16%Cr), and high carbon, straight chromium, except free machining	Annealed or hardened (dull finish)	HNO_3, 20 to 50	45 to 55 20 to 40	20 to 30 60
400 series, maraging, precipitation hardening (<16%Cr), and high carbon, straight chromium, except free machining	Annealed or hardened (bright finish)	HNO_3, 20 to 50, and $Na_2Cr_2O_7$, $2H_2O$ 2 to 6 mass	45 to 55 20 to 40	20 to 30 60
200, 300 and 400 series, free machining alloys	Annealed or hardened (bright finish)	HNO_3, 20 to 50, and $Na_2Cr_2O_7$, $2H_2O$ 2 to 6 mass	45 to 55 20 to 40	20 to 30 60
200, 300 and 400 series, free machining alloys	Annealed or hardened (bright finish)	HNO_3, 1 to 2, and $Na_2Cr_2O_7$, $2H_2O$ 1 to 5 mass	50 to 60	10
200, 300 and 400 series, free machining alloys	Annealed or hardened (bright finish)	HNO_3, 12, and $CuSO_4$, $5H_2O$ 4 mass	50 to 60	10
Special free machining 400 grades (>1.25% Mn or >0.40%S)	Annealed or hardened (bright finish)	HNO_3, 40 to 60, and $Na_2Cr_2O_7$, $2H_2O$ 2 to 6 mass	50 to 70	20 to 30
Other Acid Cleaning Solutions Used for general applications				
200, 300 and 400 series, (except free machining), precipitation hardening, and maraging	Fully annealed	Citric acid, 1 mass and $NaNO_3$, 1 mass	20	60

Table 11 (continued)

Alloy	Condition	Solution Volume, %	Temperature °C	Time, Min
Other Acid Cleaning Solutions (cont)				
200, 300 and 400 series, (except free machining), precipitation hardening and maraging	Fully annealed	Ammonium citrate 5 to 10 mass	50 to 70	10 to 60
Assemblies of stainless and carbon steel	Sensitized	Inhibited solution hydroyacetic acid, 2 mass, and formic acid, 1 mass	95	6 Hr
Assemblies of stainless and carbon steel	Sensitized	Inhibited ammonia neutralized solution EDTA. Hot water rinse Dip in solution 10 ppm NH_4OH, and 100 ppm hydrazine	Up to 120	6 Hr

5.7.3 Requirements of Procedure Qualification Tests

5.7.3.1 Macro Tests

The macro should be prepared in accordance with AS 2205.5.1 and is judged against the level of permissible imperfections given in Table 12. In the case of austenitic welding procedures, the delta ferrite content of the joint may be determined from the macro test either metallographically or by means of magnetic instruments.

5.7.3.2 Bend Tests

Bend tests should be carried out in accordance with AS 2205.3.1 employing a 3T former and rollers at 5.2T spacing. The requirement is that the bend should pass through 180° without exhibiting cracks or other defects in the weld or HAZ greater than 3mm measured in any direction at the outer surface of the test specimen.

5.7.3.3 Corrosion Testing

If required, corrosion tests should be carried out in accordance with AS2205.10 and AS2038.

5.7.3.4 Records of Procedures

Records should be kept of the procedures which have been qualified and it is also desirable that a macro specimen or a photograph of it also be retained.

5.7.3.5 Procedure Variations

Minor variations in procedures can be requalified by a macro test. Details of variations that are considered minor are given in Table 13. More fundamental changes require a full requalification. Table 14 lists the variations that fall within that category.

5.7.3.6 Permissible Levels of Weld Imperfections

Permissible levels of weld imperfections, both external and internal, are listed in Table 12.

5.7.3.7 Non-Destructive Testing

Stainless steel fabrication is normally inspected by means of dye-penetrant testing, radiographic or ultrasonic techniques. Difficulties are sometimes encountered when using ultrasonic techniques, but these can usually be overcome by a suitable choice of testing procedure. Suggested levels of inspection are:

- visual — 100% of weld length, acceptance levels according to Table 12.
- dye-penetrant — a minimum of 50% of the weld length, acceptance criteria as above.
- x-ray or ultrasonic testing — a minimum of 50% of the weld length, acceptance criteria in accordance with Table 12.

Table 12 Permissible Levels of Weld Imperfections

Type of Imperfection	Surface	Internal
Cracks	Nil	Nil
Reinforcement Must be smoothly blended with plate surface.	2 mm	NA
Undercut Undercut greater than this value may be removed by smooth blending to plate and weld surface provided reduction of the plate thickness does not exceed 5%.	Depth - 0.5 mm Length - no limit	NA
Overlap	Nil	NA
Lack of fusion or penetration or slag inclusion.	Nil	Depth - 0.25T Length - see Note
Porosity Uniform	Nil	2% weld area $t \leqslant 50$ mm proportional for $t > 50$
Clustered	Nil	3 x uniform
Isolated max. size	Nil	$t/3 \ngtr 5$ mm
Wormhole	Nil	Max. Length 6 mm - 20 mm in any 300 mm

T = plate thickness

Note

The total loss of load bearing area due to undercut lack of fusion and incomplete penetration should not exceed 5% of the weld area excluding reinforcement. See Technical Note 11 for methods of estimating loss of area.

5.7.3.8 Testing For Freedom From Ferritic Contamination

Specifications sometimes require that stainless steel fabrications be tested to ensure that the surface is free from ferritic contamination. This can often be done at the same time as the passivation process if this is carried out using a 10% nitric acid solution. Any contaminated areas appear as clearly defined darkened regions. Alternatively, areas of contamination may be revealed by swabbing the structure with a solution of 10% copper sulphate which causes contaminated areas to rapidly take on a salmon-pink appearance. Care must be taken to protect personnel using these solutions.

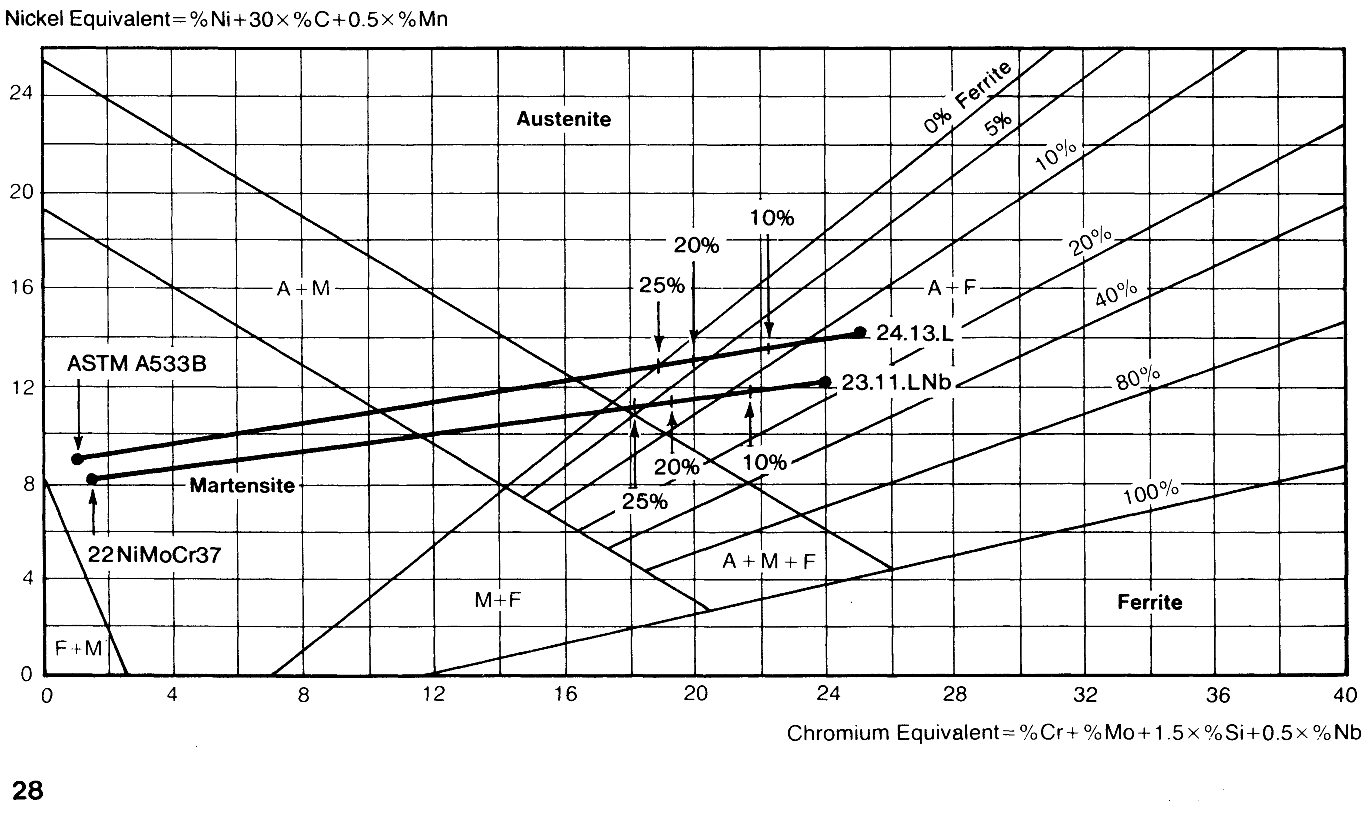
Table 13 Minor Changes in Essential Variables Requiring Requalification of Welding Procedures by Macro Test

Nature of Change
(a) An increase in the diameter of the electrode
(b) A change in the type of weld preparation, eg. change from V-shape to U-shape
(c) A change in the shape of any one type of weld preparation involving —
(i) a decrease in the included angle of the weld preparation
(ii) a decrease in the root gap of the weld preparation
(iii) an increase in the root face of the weld preparation
(iv) the omission or inclusion of backing material

Table 14 Changes in Essential Variables Requiring Requalification

Nature of Change
(a) A change from one process to another
(b) A change in electrode/flux/shielding gas combination
(c) A change from one gas or gas mixture to another gas or gas mixture
(d) A change of more than ± 7 percent of the specified mean arc voltage of the electrode used for automatic arc welding processes, or more than ± 15 percent for manual metal-arc welding
(e) A change of more than ± 10 percent of the specified mean welding current for the electrode used for automatic arc welding processes, or more than ± 15 percent for manual metal-arc welding
(f) A change of more than ± 15 percent of the specified mean speed of travel of the electrode
(g) A change of more than ± 25 percent in the specified number of runs. If the cross-sectional area of the preparation is increased, it is also permissible to increase the number of runs in proportion to the increased area
(h) An increase of 25 percent or more, or a decrease of 10 percent or more in flow rate of shielding gas
(i) A change in the position in which welding is done or a change in direction for a vertical weld
(j) A change in welding current from a.c. to d.c. or vice versa or a change in d.c. polarity or a change in metal transfer across the arc
(k) A change in material thickness outside the range 0.75 to 1.5 of test plate thickness
(l) A change in electrical stickout of more than 20 percent

Fig. 23 Schaeffler Diagram including two Parent Metals (left) and two Filler Metals (right)
The lines connecting them represent the structural change of the weld metal at different degress of dilution. eg. 10, 20 and 25%. The diagram was made assuming a nitrogen content of 0.060%.



5.8 Weld Metal Surfacing

When surfacing, a stainless steel layer is normally deposited by welding on a mild or low-alloy steel. Depending on the desired deposit composition, the dilution ratio and the required total thickness of the deposit, one or more layers have to be applied.

In most cases the required chemical composition, as far as elements such as Cr, Ni, Mo and Nb are concerned, can be obtained with single-layer deposits. Three main factors limit the use of single-layer deposits: the maximum permissible carbon content; the susceptibility to underbead cracking in the parent metal and the necessary build-up to compensate for distortion of the parent metal. Carbon contents in the range of 0.03-0.05% are commonly obtained in single-layer deposits. Depending on the abovementioned factors, two or more layers may be necessary.

When surfacing with nickel alloys, several layers are required to minimise the iron content in the upper layer in order to control a following welding operation, eg. tube-to-tube-sheet welding. The influence of dilution on the composition of the weld metal can be observed by plotting the compositions of the parent metal and filler metal on the Schaeffler diagram as shown in Figure 23. The desired composition and ferrite content of the weld metal sets the limits on permissible dilution. The degree of dilution depends on the welding method, but for the first layer, a highly alloyed filler metal should always be used to prevent a fully austenitic or a martensite containing austenitic weld metal being formed. This reduces the risk of hot cracking and eliminates weld metal brittleness. A correctly balanced austenitic weld metal should contain at least 5% ferrite in order to prevent hot cracking. The location of various stainless steel compositions on the Schaeffler diagram is shown in Figure 6.

The distribution of chromium and nickel by surfacing is shown in Figure 24. It shows that the alloying content rises very steeply from the fusion line in a zone about 50 μm thick and then remains constant up to the surface of the layer.

Because of the composition gradient, the transition zone between austenitic weld metal and parent metal is martensitic. Its hardness depends on the carbon content of the zone. In the as-welded condition the carbon content in the martensitic zone is relatively low and so is the hardness, see Figure 25. After heat treatment however, at about 600°C, carbon will diffuse into the weld metal, as shown in Figure 26. By reason of the metallurgical equilibria obtained in the martensitic fusion zone, its carbon content will be strongly increased, and will consequently have an increased hardness.

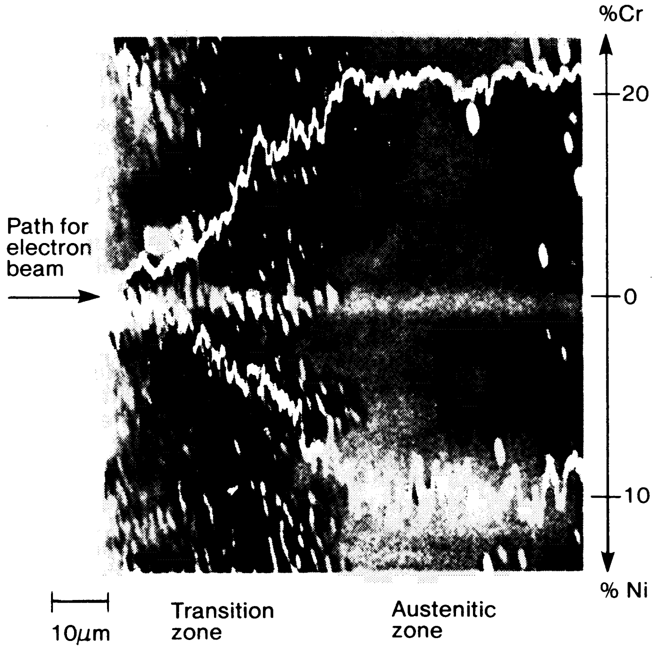


Fig. 24 Graph showing Cr and Ni Gradients in Electron Microprobe Investigation of Stainless Strip Surfaced Layer (right) on Carbon Steel (left)

The dark transition zone is martensitic and partially martensitic.

At normal heat treatment temperatures, ie. up to about 600°C, the hardness will not reach critical levels. But if the temperature is raised beyond that point, the result will be a steep increase in hardness, often evidenced by cracking in the area around the fusion line in bend tests, see Figure 27.

Surfaced components are usually stress relieved. The temperatures chosen are generally within the range 550-900°C in which harmful structural changes take place in the stainless weld metal, such as carbide precipitations and ferrite transformation. Other harmful, intermediate phases may also occur. They can usually be traced back to the weld metal chemistry.

x 250, reduced 30%

Fig. 25
Weld Metal and Parent Metal Before Heat Treatment

x 250, reduced 30%

Fig. 26
Weld Metal and Parent Metal After Heat Treatment at 610°C, 3h

x 6

Fig. 27
Microcrack Formation at the Fusion Line in a Side Bend Test

The delta ferrite in austenitic weld metals is transformed via various intermediate stages to sigma phases (CrFe) in the temperature range 550-900°C. The ability of an austenite Cr/Ni weld metal to undergo ferrite transformation depends on its ferrite content and its chemical composition. A high ferrite content promotes the transformation, and so do alloying elements that are ferrite-formers and carbide-formers. Examples of such alloying elements are chromium, molybdenum, and niobium. It is advisable to limit the ferrite content in weld metals to a max. 8-10% in order to prevent brittleness.

Figure 28 shows the influence on the microstructures of various heat treatment temperatures and weld metal compositions. It is evident from this series of figures that, in order to prevent sigma phase formation, both the ferrite content and the content of the two alloying elements chromium and niobium must be kept low.

The microstructure and properties of the heat-affected zone (HAZ) will depend on the parent metal used. Some parent metals are susceptible to grain growth during surfacing, and cracking in the form of grain boundary separations is liable to occur in the coarse grain zone, Figure 29. Applying a second layer gives a normalising effect on the coarse structure, and the risk of cracking is reduced, Figure 30.

5.9 Fabrication of Clad Plate

It is common practice to purchase carbon or low alloy steel plate clad with a thin layer of austenitic stainless steel. This may be produced either by specialised rolling techniques, explosion welding, or through the use of a special horizontal electroslag surfacing technique sometimes called maglay. In fabrication it is necessary to put joints in such plates in such a way as to maintain the integrity of both the corrosion-resistant stainless layer and the backing material which provides the strength. It will be evident from the above discussion that with the appropriate selection of filler metal it is possible to deposit the stainless steel weld metal upon carbon or low alloy steel. However, the opposite is very certainly not the case and therefore weld procedures must be developed for clad plate to avoid the necessity of depositing plain or low carbon steel weld metal upon stainless steel materials. Occasionally when access or geometry problems make this impossible, it may be necessary to deposit a very low carbon steel between the austenitic stainless steel layer and the carbon steel deposit. The techniques for undertaking these operations are described very fully in the IIW Document 317-69 which appears in Welding in the World, Volume 7(1), 1969.

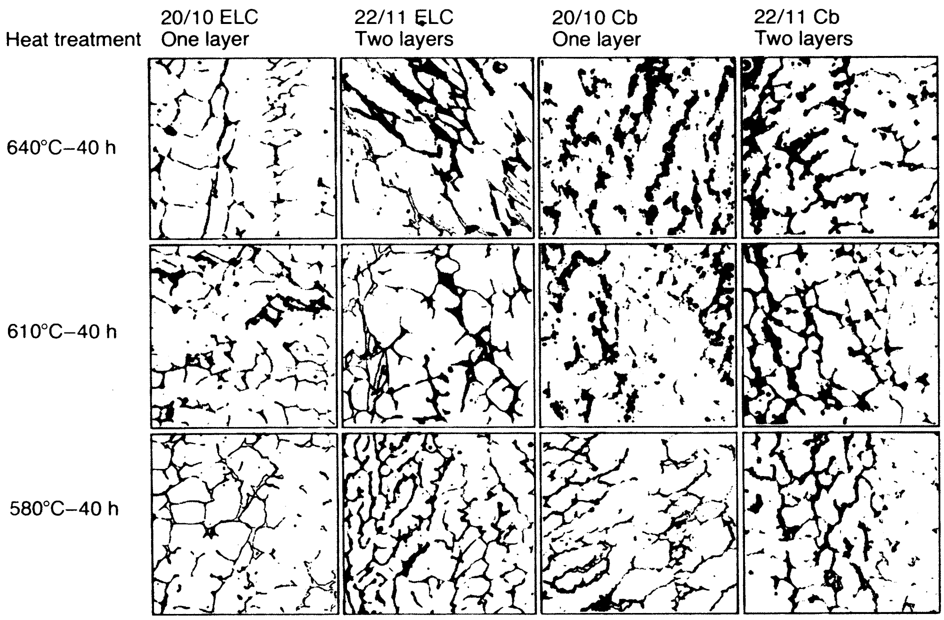


Fig. 28 Weld Metal Structure After Heat Treatments

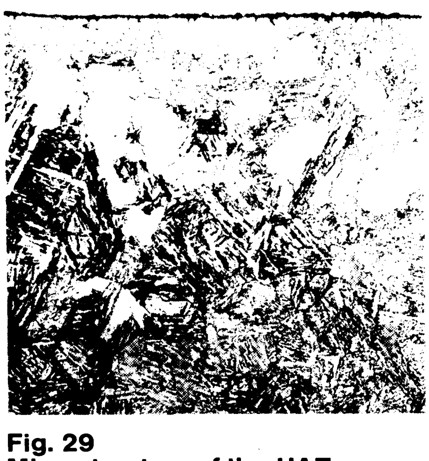


Fig. 29
Microstructure of the HAZ as-welded after the First Layer
Grain size ASTM 7. x 100, reduced 30%

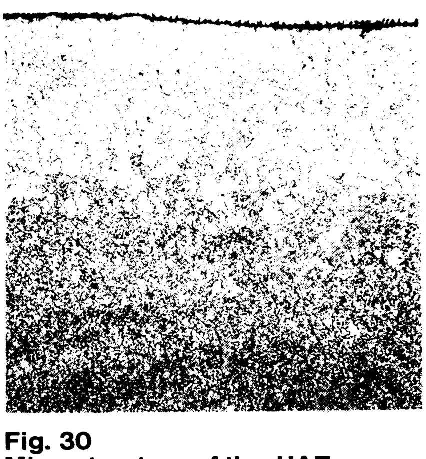


Fig. 30
Microstructure of the HAZ as-welded after the Second Layer
Grain size ASTM 10. x 100, reduced 30%

6 DISSIMILAR METAL JOINT WELDING

Welding metallurgists are very often faced with the problem of joining materials of different types, eg. high alloy stainless steel to mild or low alloy steel. The choice of filler metal is a decisive factor in determining acceptable results. Several filler metals which are very suitable for the welding of dissimilar joints have been developed (see Table 7). Their compositions are given in Table 8.

6.1 General

For joining different types of metals, the composition and properties of the weld metal are decided primarily by the filler metal and the dilution from the parent metals. Joint preparation and welding technique also play their part, which in turn infuences the choice of filler metal for a given combination of materials. It is also often necessary to make allowance for special requirements applying to the properties of the weld metal, eg. corrosion resistance, high-temperature suitability and thermal expansion

As a general rule the strength and corrosion resistance of the weld metal should be at least equal to that of the poorest parent metal. To obtain a sound serviceable joint it may be necessary to use a filler metal which contains considerably larger amounts of alloying elements than either of the pieces of parent metal being welded.

The primary requirement is that there must be no intermetallic or other phases to exert a negative influence on the properties of the weld metal. Furthermore, the weld structure must be crack-free. An austenitic structure containing 3-5% ferrite or more is desirable when at least one of the parts to be welded is highly alloyed. If a fully austenitic weld metal is desired, satisfactory resistance to cracking can be achieved by using a filler metal that is manganese-alloyed, or a nickel-base type.

The choice of filler metal also depends upon the thickness of the parent metal, since this factor determines the number of welding runs, the dilution ratio, (see Section 6.3) and the design of the joint.

When joining materials of heavy thickness, a common joining method involves "buttering" the ferritic side with an over-alloyed filler metal before welding the joint with a filler metal that suits the buttering and the other part of the joint. The buttering technique is illustrated in Figure 31.

For medium and thin stock sizes where buttering is not suitable or required, as well as for root runs in all types of joints, the filler metals mentioned in Table 7 are recommended.

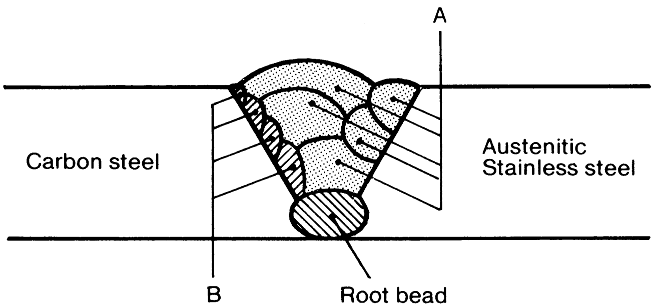


Fig. 31 A — Normal Filler Metal
B — Overalloyed Filler Metal

6.2 Special Problems

The usual cause of cracks in weld metal is that a crack-sensitive composition has been produced by the mixing of molten weld and parent metals. By appropriate choice of filler metal the composition can be adjusted so as to achieve a crack proof weld metal.

Porosity, lack of fusion, etc. can sometimes be related to the choice of filler metal as they may be caused by insufficient deoxidising elements and poor flow. The use of a filler metal with an increased silicon content such as 309, substantially decreases the occurrence of porosity and improves the flow. The risk of incomplete fusion and other similar defect is also reduced.

Ferritic steels and austenitic chromium-nickel steels are dissimilar in physical properties such as thermal expansion and thermal conductivity. This must be allowed for in design and in deciding filler metal and welding technique.

Carbon diffusion occurs in ferritic/austenitic joints at elevated temperatures. This can be substantially reduced by choosing a nickel-base filler metal such as ECrNiMo. Carbon diffusion can also be kept down by having a high carbon content in the filler metal.

High impurity contents can give rise to problems with cracking and low ductility. Due to its high ferrite content, 312 is notably insensitive to most of the impurities that occur in steel.

High-temperature oxidation resistance is sometimes required in joints between ferritic and austenitic high-temperature steels. 310 and 312, both which have a high chromium content, give good high-temperature properties.

6.3 Dilution

Dilution is defined as the proportion of fused parent metal in the weld metal and is a concept that must be considered in the selection of filler metal.

The dilution for any given process will nearly always be the same irrespective of the parent metals involved but may be influenced by preheating. It is assumed that in practice the parent metals each contribute with equal quantities. (see Figure 32).

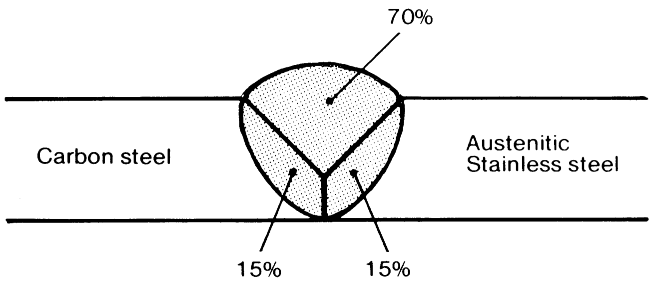


Fig. 32 Normal Dilution (30%) for a Butt Weld made by MIG Welding

The dilution can be calculated on the basis of the analysis according to the following formula. The usual practice is to base the calculations on the nickel content, since the transfer of nickel from the filler metal to the weld metal is virtually 100%.

$$X = \frac{F-W}{F-P} \times 100$$

where

X = dilution in %
F = percentage nickel in the filler metal
W = percentage nickel in the weld metal
P = percentage nickel in the parent metal

Dilution can also be approximately calculated by a purely geometrical approach involving the cross-section of the weld. The different areas of the weld are measured and the dilution calculated from that, refer to Figure 32.

The following values are a guide to the dilution expected in a butt weld.

Welding Method	Dilution %
Manual metal arc welding	20-30
MIG, TIG, and plasma-arc welding	20-40
Submerged-arc welding	30-40

The dilution in other types of joint may vary somewhat and if necessary actual tests should be carried out.

A suitable dilution for a specific combination of parent metals and filler metal can be determined graphically by using the Schaeffler diagram. Examples with nominated metal combinations are shown in Figures 33 and 34. The locations of various stainless steel compositions on the Schaeffler diagram is shown in Figure 6.

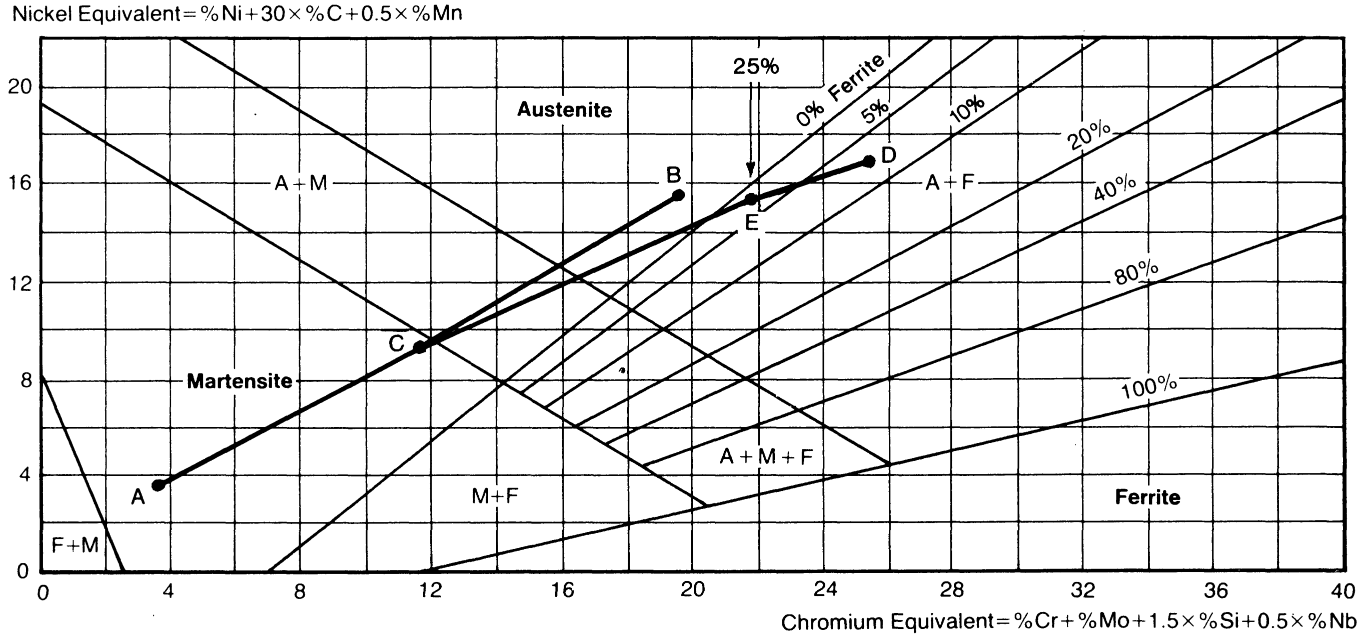


Fig. 33 Schaeffler Diagram showing the joining of a Ferritic-Bainitic Steel to a 316 Austenitic Stainless Steel using 309 as the Filler

This combination of materials is frequently used in heat exchangers. The materials are represented in the diagram by A, B and D respectively. Joining without filler metal would result in a highly martensitic weld metal structure, C, which is very susceptible to cold cracking. By using 309 as a filler metal it is possible to obtain a weld metal, E, which is hot and cold crack proof, ie. an austenitic structure with about 3-4% ferrite. E represents a structure with about 25% dilution. MIG is a suitable welding method in this case.

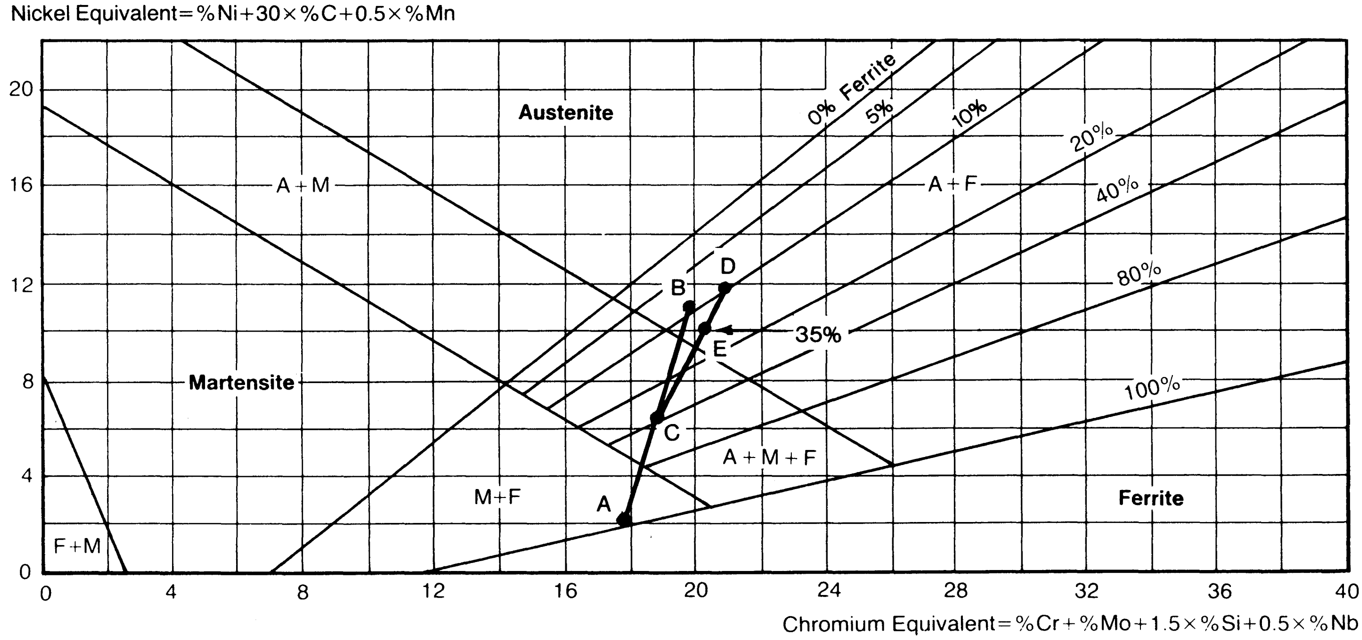


Fig. 34 Schaeffler Diagram showing the Joining of a Ferritic Chromium Steel, A, to a 304 Austenitic Stainless Steel, B, using 308 Filler Metal, D

This combination of materials is used in equipment involving exhaust gases. The example shows that even with as high a dilution as 35% the weld metal has only about 15% ferrite in the austenitic matrix and is free from martensite. Joining without filler metal would result in point C.

7 HEALTH AND SAFETY

Stainless Steel welding and its allied processes produce fume which is suspected of being carcinogenic, (i.e., cancer forming). This is the soluble chromium VI and possibly the nickel fume. Ventilation is important when welding stainless steel and consideration should be given to local extraction when welding in confined areas.

Protection from radiation is particularly important because of the highly reflective surface of stainless, and there is a need to cover the skin completely and provide for indirect eye/heat radiation hazards.

Guidance on safe practices in welding and allied processes for the prevention of injury and ill health to operators and persons working in the environs of welding are covered in Technical Note No 7.

Also covered in this note is information relating to the protection of property and equipment from fire and explosion.

The relative Australian Standards in this area are:

AS 1270	— Hearing Protection Devices
AS 1336	— Code of Practice for Industrial Eye Protection
AS 1337	— Industrial Eye Protectors
AS 1338	— Protective Filters against Optical Radiation in Welding and Allied Operations
AS 1558	— Protective Clothing for Welders
AS 1674	— Fire Precautions in Cutting, Heating and Welding
AS CC5	— Rules for the Prevention of Electric Shock to Arc Welders

Where welding is to be carried out in a confined area such as a vessel or container, State and Commonwealth Regulations apply. Some relative Acts for industry are given below.

- Dangerous Goods Act
- Poisons Act
- Factories, Shops & Industries Act

The relative Statutory Authorities should be approached prior to the commencement of such work.

A list of health authorities and industrial departments having regulations governing working conditions for the various Australian States is given in the AWRA Technical Note 7.

Disclaimer

List of Technical Notes

1. The Weldability of Steels (36 pages) **May 1982**
Gives guidance on the preheat and heat input conditions (run size, current, voltage) required for acceptable welds and to avoid cold cracking in a wide variety of steels used in Australia. The Note is applicable to a wide range of welding processes.

2. Welding Aluminium with the Inert Gas Processes (53 pages) **March 1985**
(A joint publication with AWI)
This Note covers the Inert Gas Welding Processes as they are used for the welding and repair of aluminium and its alloys. Information is given on process, equipment, consumables and techniques. It also provides information on the range of alloys available and briefly covers safety, costing, quality assurance, inspection and testing.

3. Care of Manual Arc Welding Steel Electrodes (13 pages) **September 1977**
Gives the basis and details for the correct care, storage and conditioning of electrodes to control hydrogen and to ensure high quality welding.

4. Hardfacing (32 pages) **July 1983**
Contains the main results of Australian experience and research on consumables, presented in a practical form. It gives guidance on the selection of hardfacing consumables and processes for a wide range of applications and introduces a useful classification system for hardfacing consumables.

5. Flame Cutting of Steels (37 pages) **July 1981**
Gives a wealth of practical guidance on flame cutting including detailed procedures for efficient cutting, selection of equipment and gases, practices for identifying and curing defective cutting, methods of maximising economy and other important guidance on the use of steels with flame cut surfaces.

Flame Cut Surface Replicas **December 1979**
These have been developed to complement Technical Note 5 by defining three qualities of flame cut surface. Each set of three is contained in a convenient holder with summary sheet of main flame cutting data.

6. Control of Lamellar Tearing (59 pages) **April 1976**
Describes the features and mechanisms of this important mode of failure and the means of controlling tearing through suitable design, material selection, fabrication and inspection. Acceptance standards, repair methods, specification requirements and methods of investigation are proposed. Four appendices give details on the mechanism, material factors, tests for susceptibility and the important question of restraint.

7. Health and Safety in Welding (68 pages) **July 1982**
(A joint publication with AWI)
Provides basic information on all aspects of health and safety in welding and cutting. Designed to provide this information in such a way that it is readily usable for instruction in the shop and to provide guidance to management. Recommendations are given for safe procedures to be adopted in a wide variety of situations found in welding fabrication.

8. Economic Design of Weldments (29 pages) **March 1979**
Principles and guidance are given on methods and procedures for optimising design of weldments and welded joints and connections to maximise economy in welding fabrication. Factors influencing the overall cost of weldments which need to be considered at the design stage are discussed.

9. Welding Rates in Arc Welding Processes: Part 1 MMAW (33 pages) **November 1979**
Gives practical guidance and information on the selection of welding conditions to improve productivity during manual metal arc welding (MMAW). Graphs are provided showing rates as a function of weld size. The graphs enable a direct comparison of different types of welding electrodes when used for butt and fillet welds in various welding positions.

10. Fracture Mechanics (48 pages) **June 1980**
Provides theory and gives practical guidance for the design and fabrication of structures, planning of maintenance and assessment of the likelihood of brittle or ductile failure initiation from flaws in ferrous and non-ferrous alloys. Engineering critical assessment case histories are discussed.

11. Commentary on Structural Steel Welding Code (53 pages) **June 1980**
(A joint publication with AWI and AISC)
The Note complements AS 1554 Parts 1 and 2 — 1980 by presenting background information which could not be included in the Standard. It discusses the requirements of the Standard, with particular emphasis on new or revised clauses from the 1974 Edition of the Standard. In explaining the application of the Standard to welding in steel construction, the Commentary emphasises the need to rely on the provisions of the Standard to achieve satisfactory weld quality.

12. Minimisation of Corrosion In Welded Steel Structures (15 pages) **October 1981**
Designed to provide practical guidance and information on corrosion problems associated with the welding of steel structures, together with possible solutions for minimising corrosion.

13. Stainless Steels for Corrosive Environments (21 pages) **July 1983**
Provides guidance on the selection of stainless steels for different environments. Austenitic, ferritic and martensitic stainless steels are described together with the various types of corrosive attack. Aspects of welding procedure, design, cleaning and maintenance to minimise corrosion are covered.

14. Design and Construction of Welded Steel Bins (48 pages) **December 1984**
Written because of the widely expressed need for guidance on the design and fabrication of welded steel bulk solids containers, this Technical Note gathers together relevant information on functional design, wall loads, stress analysis, design of welded joints and the fabrication, erection and inspection of steel bins. It also contains a very comprehensive reference list to assist in a further understanding of this very broad subject.

15. Quenched and Tempered Steels (17 pages) **March 1985**
Provides basic information on quenched and tempered steels available in Australia and gives guidance on welding processes, consumables and procedures and on the properties and performance of welded joints. Information is also provided on other important fabrication operations such as flame cutting, shearing and forming.

16. Welding Stainless Steels (33 pages) **December 1985**
This Technical Note complements Technical Note 13 by detailing valuable information on the welding of most types of stainless steels used in Australian industry.

Binder (holds ten of the above booklets)
These publications may be obtained from AWRA, 118 Alfred Street, Milsons Point, NSW, 2061, phone (02) 922 3711, or through the Australian Welding Institute.

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