सत्यमेव जयते

(Govt. of India)
(Ministry of Railways)

Hand book on Stainless Steel Welding

(For official use only)

IRCAMTECH/2012/M/SSW/1.0

January – 2012

Centre
for
Advanced
Maintenance
TECHnology

उच्च अनुरक्षण प्रौद्योगिकी केन्द्र

Excellence in Maintenance

MAHARAJPUR, GWALIOR -474005

महाराजपुर, ग्वालियर

FOREWORD

LHB coaches use a combination of Ferritic stainless steel, Austenitic stainless steel and corten steel for fabrication of various members of its body. New wagons are being used either partly or fully for fabrication under frame, side walls, end panels etc. Prototype aluminium wagons are also under manufacture.
Welding of stainless steel and aluminium requires more special care such as pre heating, proper use of flux and filler wire and proper training of welders. Therefore, it was felt that a handbook is required for guidelines to repair shops and sickliness to facilitate quality welding stainless steel and aluminium bodied coaches and wagons.

This hand book have covered all type of “Welding of Stainless Steel” with the purpose of disseminating the knowledge regarding Stainless steel welding on coaches and wagons .

I am sure that the handbook will be useful to the concerned staff to ensure trouble free service..

CAMTECH, Gwalior **P.Gupta**
Date: 20.01.2012 **Executive Director**

GO TO CONTENTS

PREFACE

Till few years back Indian Railways had been using only corten steel for fabrication of Railway carriages and mild steel/ carbon steel for fabrication of wagons. In October, 1995, Indian Railways entered into contract with M/S Linke Holfmann Busch (LHB) (Now ALSTOM LHB GmbH Germany) and Rail Coach Factory, Kapoorthala started manufacturing state of the Art high speed coaches under transfer of technology contract. These LHB coaches use a combination of Ferritic stainless steel, Austenitic stainless steel and corten steel for fabrication of various members of its body.

Indian Railways has also started manufacturing new types of wagons such as BOXNLW, BOXNHL, BCN LW, BCN HL in which stainless steel to specification IRS M-16 are being used either partly or fully for fabrication under frame, side walls, end panels etc. Prototype aluminium wagons are also under manufacture.

Traditional methods of Oxy-flame cutting and CO2 welding can not be used for cutting/ welding of stainless steel panels without causing deterioration in the structure strength. Special welding equipments, process and welding rods have to be used by properly trained welders to ensure quality welding. Welding of aluminium requires even more special care such as pre heating, proper use of flux and filler wire and proper training of welders. Therefore, it was felt that a handbook is required for guidelines to repair shops and sickliness to facilitate quality welding stainless steel/ aluminium bodied coaches and wagons.

Hence CAMTECH has prepared a Handbook on “Stainless Steel Welding” with the purpose of disseminating the knowledge regarding Stainless steel welding on coaches and wagons .

The suggestions are invited from the readers to improve and make the book more useful. Any such suggestion shall be included in next publication.

Date: - 20.01.2012 (K.P.Yadav)
CAMTECH, Gwalior **Director /Mechanical**

GO TO CONTENTS

CONTENTS

	Description	Page No.
	Foreword	i
	Preface	ii
	Contents	iii
	Correction slips	iv
1.0	Introduction	1
2.0	Type of Stainless Steel	1
3.0	Recent usage of Stainless Steel in Indian Railways	3
4.0	Physical Properties of Groups of Stainless Steel	4
5.0	Mech Properties of Groups of Stainless Steel	5
6.0	Weldability of Stainless Steel	9
7.0	Selection of Stainless Steel	20
8.0	Design of Stainless Steel	22
9.0	Selection of Filler Material	23
10.0	Selection of Welding Process	34
11.0	Procedure of Stainless Steel Welding	40

GO TO CONTENTS

CORRECTION SLIPS

The correction slips to be issued in future for this handbook will be numbered as follows:

CAMTECH/2012/Mech/ Stainless Welding/1.0/C.S. # XX date …
Where "XX" is the serial number of the concerned correction slip (Starting from 01 onwards)

CORRECTION SLIPS ISSUED

Sr.No. of C.Slip	Date of issue	Page No. and Item no. modified	Remarks

GO TO CONTENTS

STAINLESS STEEL WELDING

1.0 INTRODUCTION

Stainless steel is gradually penetrating Indian railways inventory replacing mild steel & Corton steel. Until recently, the use of stainless steel was limited to some specific components used in Diesel Locomotive for high temperature services such as exhaust manifold, turbo super charger, exhaust pipe, bellow etc. Now, with the introduction of LHB coaches, LHB coaches, BOXNCR wagons etc. use of stainless steel is increasing day by day. Panels of Coaches are on the anvil & prototype is under manufacture. Therefore an understanding of cutting & welding of stainless steel for manufacture of the above items as felt very necessary.

Traditional methods of Oxy-flame cutting and CO2 welding can not be used for cutting/ welding of stainless steel panels without causing deterioration in the structure strength. Special welding equipments, process and welding rods have to be used by properly trained welders to ensure quality welding. Welding of aluminum requires even more special care such as pre heating, proper use of flux and filler wire and proper training of welders. Therefore, it was felt that a handbook is required for guidelines to repair shops and sickliness to facilitate quality welding stainless steel/ aluminum bodied coaches and wagons

2.0 TYPES OF STAINLESS STEEL

There are five types of Stainless steels depending on the other alloying additions present.

Austenitic Stainless Steels : Addition of nickel makes the steel more ductile and resistant to acids and at the same time makes the steel autenitic at room temperature. Austenitic stainless steel includes the 200 and 300 series of which type 304 is the most common. The primary alloying additions are chromium and nickel. Austenitic stainless steels generally contain 18-30% chromimum which provide basic corrosion resistance and 5-20% nickel provides high temperature

strength and ductility. Carbon provides carbide former and strengener and nitrogen provide high temperature strength and ductility.

Ferritic Stainless Steel: Contains very low Carbon and about 11-30% chromium. As the name implies, the micro structure contains ferrite and hence magnetic. The steel posses good ductility and do not response to heat treatment as no change in phase takes place during heating or cooling. This very much prone to grain growth when heated above 950^{o} C. It has very good corrosion resistance property and suitable for low temperature use. Ferritic Stainless steels are non-hardenable Fe-Cr alloys. Types 405, 409, 430, 422 and 446 are representative of this group.

Chromium provides basic corrosion resistance, Molybdenum provides high temperature strength and increases corrosion resistance and Niobium (Columbium), titanium gives strong carbide formers.

Martensitic Stainless Steel : It contains 11-18% Chromium and comparatively higher amount of Carbon (Normally 0.2% but even 1.2% in some grades). These steels are hardened by heat treatment, contains martensite in the micro structure and find extensive usage because of their ability to resist wear, oxidation and corrosion. Types 403, 410,416 and 420 are representative of this group.

Duplex Stainless steels: are supplied with a microstructure of approximately equal amounts of ferrite & autenite. They contain roughly 24% chromium & 5% nickel. Their numbering system is not included in the 200,300 or 400 groups.

Precipitation hardening stainless steels : contains alloying additions such as aluminum which allow them to be hardened by a solutions and aging heat treatment. They are further classified into sub groups are martensitic, semiaustenitic and austenitic precipitation hardening stainless steels. They are classified as the 600 series of stainless steels (i.e 630,631,660).

3.0 RECENT USAGE OF STAINLESS STEEL IN RAILWAYS

SN	Class of Steel	Composition				Application
		C%	Cr%	Ni%	Others	
1.	301 (Austenitic)	0.15	16-18	6-8	-	Trough floor, inside paneling, vendor component deck sheet, drivers cabin etc of EMU
2.	304 (Austenitic)	0.08	18-20	8-12	-	Roof and Tough floor of LHB coach, trough floor, roof and side panel above window of all SS EMU, Break pipe of EMU
3.	409 M (Ferritic)	0.08	10.5-11.75	-	Ti6XC	Side wall & End wall of LHB Coach, side wall below window of EMU, Under-frame & side panel below window of SS EMU
4	M-44 (ferritic)	0.03	10.8-12.5	-	Ti-0.75 (max)	Side wall, extension, side sill and Centre Sill of BOXN CR wagon

4.0 PHYSICAL PROPERTIES OF STAINLESS STEEL

Average physical properties for each of the main groups of stainless steel are given in table. This includes elastic modulus, density, coefficient of thermal expansion, thermal conductivity, specific heat, electrical resistivity, magnetic permeability and melting range.

Property	**Austenitic type**	**Ferritic types**	**Martene-sitic types**	**Precipitation Hardening types**
Elastic modules 10^6 psi GPa	 28.3 195	 29.0 200	 29.0 200	 29.0 200
Density; lb/in^3 g/cm^3	 0.29 8.0	 0.28 7.8	 0.28 7.8	 0.28 7.8
Coffecient . of thermal Expansion: µ in/in °F µm/m°C	 9.2 16.6	 5.8 10.4	 5.7 10.3	 6.0 10.8
Thermal conductivity; BTU / hrft °F w/mk	 9.1 15.7	 14.5 25.1	 14.0 24.2	 12.9 22.3
Specific heat : Btu/ lb °F J/k°K	 0.12 500	 0.11 460	 0.11 460	 0.11 460
Electrical resistivity, µ Ω cm.	74	61	61	80
Magnetic permeability	1.02	600-1100	700-1000	95
Melting range °F °C	 2500-2650 1375-1450	 2600-2790 1425-1530	 2600-2790 1425-1530	 2560-2625 1400-1440

5.0 MECHANICAL PROPERTIES OF STAINLESS STEEL

5.1 Properties of Austenitic Stainless Steel

Type	Condition	Tensile Strength		0.2% Yield Strength		Elong.	RA	Hardness
		Ksi	MPa	Ksi	MPa	%	%	Rockwell
201	Anneal	115	793	55	379	55		B 90
201	Full Hard	185	1275	140	965	4		C 41
202	Anneal	105	724	55	379	55		B 90
301	Anneal	110	758	40	276	60		B 85
301	Full Hard	185	1275	140	965	8		C 41
302	Anneal	90	620	37	255	55	65	B 82
302 B	Anneal	95	655	40	276	50	65	B 85
303	Anneal	90	620	35	241	50	55	B 84
304	Anneal	85	586	35	241	55	65	B 80
304 L	Anneal	80	552	30	207	55	65	B 76
304 N	Anneal	85	586	35	241	30		
304 LN	Anneal	80	552	30	207			
305	Anneal	85	586	37	255	55	70	B 82
308	Anneal	85	586	35	241	55	65	B 80
308 L	Anneal	80	551	30	207	55	65	B 76
309	Anneal	90	620	40	276	45	65	B 85
310	Anneal	95	655	40	276	45	65	B 87
312	Anneal	95	655			20		
314	Anneal	100	689	50	345	45	60	B 87
316	Anneal	85	586	35	241	55	70	B 80
316 L	Anneal	78	538	30	207	55	65	B 76
316 F	Anneal	85	586	35	241	55	70	B 80
317	Anneal	90	620	40	276	50	55	B 85
317 L	Anneal	85	586	35	241	50	55	B 80
321	Anneal	87	599	35	241	55	65	B 80

347/348	Anneal	92	634	35	241	50	65	B 84
329	Anneal	105	724	80	552	25	50	B 98
330	Anneal	80	550	35	241	30		B 80
330 HC	Anneal	85	586	42	290	45	65	
332	Anneal	80	552	35	241	45	70	
384	Anneal	80	550					

5.2 Nominal Mechanical properties of Ferritic Stainless Steels

Type	**Condition**	**Tensile Strength**		**0.2% Yield Strength**		**Elong.**	**RA.**	**Hardness**
		Ksi	**MPa**	**Ksi**	**MPa**	**%**	**%**	**Rockwell**
405	Anneal	70	480	40	275	30	60	B 80
409	Anneal	65	450	35	240	25		B75 M
429	Anneal	71	490	45	310	30	65	B 88 M
430	Anneal	75	515	45	310	30	60	B 82
430 F	Anneal	80	550	55	380	25	60	B 86
430Ti	Anneal	75	515	45	310	30	65	
434	Anneal	77	530	53	365	23		B 83 M
436	Anneal	77	530	53	365	23		B 83 M
442	Anneal	80	550	45	310	25	50	B 85
444	Anneal	60	415	40	275	20		B 95 M
446	Anneal	80	550	50	345	23	50	B 86
26-1 EBrite	Anneal	65	450	40	275	22		B 90 M
26-1Ti	Anneal	68	470	45	310	20		B 95 M
29-4	Anneal	80	550	60	415	20		B 98 M
29-4-2	Anneal	80	550	60	415	20		B 98 M
18 SR	Anneal	90	620	65	450	25		B 90
Monit	Anneal	94	650	80	550	20		B 100 M
Seacure / SC-1	Anneal	80	550	55	380	20		B 100 M

GO TO CONTENTS

5.3 Nominal Mechanical properties of Martensitic Stainless Steels

Type	Condition	Tensile Strength		0.2%Yield Strength		Elong	R.A	Hardness
		Ksi	MPa	Ksi	MPa	%	%	Rockwell
403	Anneal	75	517	40	276	30	65	B 82
403	*temp.800°F	195	1344	150	1034	17	55	C 41
410	Anneal	75	517	40	276	30	65	B 82
410	*temp.800°F	195	1344	150	1034	17	55	C 41
410 S	Anneal	60	414	30	207	22		B 95 m
410 Cb	Anneal	70	483	40	276	13	45	
410Cb	*temp(int.)	125	862	100	689	13	45	
414	Anneal	120	827	95	655	17	55	C 22
414	*temp.800°F	200	1379	150	1034	16	58	C 43
414 L	Anneal	115	793	80	552	20	60	
416 Plus X	Anneal	75	517	40	276	30	60	
420	Anneal	95	655	50	345	25	55	B 92
420	*temp.600°F	230	1586	195	1344	08	25	C 50
422	*temp int.	140	965	110	758	13	30	
431	Anneal	125	862	95	655	20	60	C 24
431	*temp.800°F	205	1413	155	1069	15	60	C 43
440 A	Anneal	105	724	60	414	20	45	B 95
440 A	*temp.600°F	260	1793	240	1655	05	20	C 51
440 B	Anneal	107	738	62	427	18	35	B 96
440 B	*temp.600°F	280	1931	270	1862	03	15	C 55
440 C	Anneal	110	758	65	448	13	25	B 97
440 C	*temp.600°F	285	1965	275	1896	02	10	C 57

5.4 Nominal Mechanical Properties of Precipitation hardening and duplex Stainless Steels

Type	Condition	Tensile Strength		0.2% yield Strength		Elog.	RA	Hard ness
		Ksi	MPa	Ksi	MPa	%	%	Rockwell
Precipitation Hardening Types								
Ph13-8Mo	H950	220	1517	205	1413	8	4545	C45
15-5PH	H900	190	1310	170	1172	10	3535	C44
15-5PH	H1150	135	931	105	724	16	5050	C32
17-4PH	Sol. Ann.	150	1034	110	758	10	45	C33
17-4PH	H900	200	1379	178	1227	12	48	C44
17-7PH	Sol. Ann.	130	896	40	276	35		C85
17-7PH	RH950	235	1620	220	1517	6		C48
PH15-7 Mo	Sol.Ann.	130	896	55	379	35		B88
PH15-7 Mo	RH950	240	1655	225	1551	6	25	C48
17-10P	Sol. Ann.	89	613	37	255	70	76	B82
17-10P	H1300	143	986	98	676	20	32	C32
A286	H1350	130	896	85	586	15		
AM350	Sol. Ann.	160	1103	55	379	40		B95
AM350	DA	195	1344	155	1069	10.5		C41
AM355	Sol. Ann.	175	1207	65	448	30		B95
AM355	DA	195	1344	155	1069	10		C41
Custom 450	Anneal	125	862	95	655	10	40	C30
Custom 450	H900	180	1241	170	1172	10	40	C40
Custom 455	H900	235	1620	220	1517	8	30	C47
Stainless W	Sol. Ann.	120	827	75	517	7		C30
Stainless W	H950	195	1344	180	1241	7	25	C46
Duplex Types								
2205		120	827	65	448	25		
2304		110	758	60	414	25		
255		110	758	80	552	15		
2507		110	800	80	550	15		

6.0 WELDABILITY OF STAINLESS STEEL

Most of the stainless steels are considered to have good Weldability and may be welded by several welding processes including the arc welding processes, resistance welding, friction welding and brazing. For any of these processes, joint surfaces and any filler metal must be clean.

The thermal and Electrical Conductivity of stainless steel is much less than carbon steel and co-efficient of expansion is also higher. Low thermal conductivity tends to higher temperature rise in the vicinity of weld and that coupled with high coefficient of expansion leads to warpage and higher incidence of weld cracking under restrained condition.

Comparative Physical Properties of Stainless Steel and Carbon Steel

Property	Matrensitic	Ferritic	Austenitic	Carbon Steel
Thermal Conductivity Cal/Sec.cm^2 degree C/cm	0.059	0.049	0.033	0.104
Coefficient of Expansion $\mu m/m/^0C$	11.2	11.2	18.2	13.2
Electrical resistivity $\mu\Omega$ /cm	58	60	70	15
Melting range ^oC	1483-1532	1427-1510	1398-1454	1538

6.1 Weldability of Ferritic Stainless Steel

The Ferritic stainless steel contain 10.5% to 30% Cr, up to 0.20% C and some times ferrite promoters Al, Nb(Cb), Ti and Mo. They are Ferritic at all temperatures , do not transform to austenite and therefore, are not hardenable by heat treatment. This group includes the more common types 405, 409, 430, 442 and 446.

Nominal compositions of Ferritic stainless Steels

Type	UNS Number	Composition - Percent*							Other
		C	Mn	Si	Cr	Ni	P	S	
405	S40500	0.08	1.00	1.00	11.5-14.5		0.04	0.03	0.10-0.30Al
409	S40900	0.08	1.00	1.00	11.5-14.5		0.045	0.045	6x% c min. Ti
*430	S43000	0.12	1.00	1.00	16.0-18.0		0.04	0.03	
430F **	S43020	0.12	1.25	1.00	16.0-18.0		0.06	0.15 Min	0.06 Mo
430 FeSe **	S43023	0.12	1.25	1.00	16.0-18.0		0.06	0.06	).15min Se
430 Ti	S43036	0.10	1.00	1.00	16.0-18.0	0.75	0.04	0.03	5x%C-Ti min
446	S44600	0.20	1.50	1.00	23.0-27.0		0.04	0.03	0.25 N

To weld the Ferritic stainless steels, filler metals should be used which match or exceed the Cr. Level of the base alloy. Type 409 is available as metal cored wired and type 430 is available in all forms. Austenitic types 309 and 312 may be used for dissimilar joints. To minimize grain growth, weld heat input should be minimized,

preheat should be limited to 300-450^{o}F and used only for the higher carbon ferritic stainless steels (i.e 430, 434,442 and 446).

Ferritic stainless steel is less weldable than austenitic stainless steel. Following are the common problems encountered in welding Ferritic stainless steel

- Martensite formation
- Excessive grain growth
- Sigma phase formation
- 475 embrittlement
- Sensitization

In general, the most of the Ferritic grades have balanced chemistry to have ferrite structure at all temperature, but some grades with high carbon and low chromium composition, when heated above critical temperature from some austenite which transform to martensite on cooling resulting reduced toughness and ductility.

The steel has a tendency towards excessive grain growth when heated above 950^{o}C. This coarse gain coupled with small amount of martensite results in brittleness (HAZ).

When Ferritic stainless steel containing more than 20% chromium is subjected to slow heating/cooling in the range of 500-900^{o} C, there is formation of sigma phase, an Iron-Chromium inter-metallic compound which is hard and brittle.

It also suffers from '475 embitterment' on heating in the range of 400-540^{o} C due to formation of chromium rich zone along certain crystallographic plane.

When the Ferritic stainless steels are air cooled in the temperature range of 900^{o}C-700^{o}C, chromium rich carbide and nitride precipitates at grain boundaries from solid solution. Adjacent to the precipitate, the zone is called sensitized zone. This phenomenon when takes place welding because of heating and cooling cycle is known as weld decay or knife edge cracking.

Corrosion resistance of sensitized zone can be restored by annealing at 1050^{o}C followed by rapid cooling.

To minimize grain growth, heat input should be as low as possible. Inter pass temperature should not be more than 150^{o}C.

Gain Coarsening and sigma phase formation can be avoided by avoiding slow cooling. A post weld treatment at 790^{o}C i.e below the grain coarsening temperature, followed by furnace cooling to 650^{o}C, then rapid cooling to 400^{o} C is beneficial to avoid '475 embrittlement'.

Matching filler wire or fully austenitic filler wire (25/20 type) may be used. Smaller diameter electrode, low current and stringer beads are helpful.

However, for welding thin sheet using ductile Austenitic SS filler metal, preheating and post weld heat treatment is not generally required.

6.2 Weldability of Martensitic Stainless Steel :

Martensitic Stainless Steel contain 11 to 18% Cr, up to 1.20% C and small amounts of Mn and Ni and, sometimes, Mo. These steels will transform to autenite on heating and, therefore, can be hardened by formation of martensite on cooling. This group includes type 403,410,414,416,420,422,431 and 440.

Martensitic stainless steel is least weldable among all stainless steels because of hardened HAZ which is susceptible to crack formation. Preheating of 150-250^{o} C and post weld heat treatment at 750-800^{o} C, Furnace cooling to 590^{o} C then rapid cooling is beneficial. Matching filler wire (13Cr type) or austenitic filler wire (23/12, 25/20 type) may be used.

TABLE – Nominal Compositions of Martensitic Stainless Steels

Type	UNS Nos	Composition – Percent*							Other
		C	Mn	Si	Cr	Ni	P	S	
403	S40300	0.15	1.00	0.50	11.5-13.0		0.04	0.03	
410	S41000	0.15	1.00	1.00	11.5-13.0		0.04	0.03	
410Cb	S41040	0.18	1.00	1.00	11.5-13.0		0.04	0.03	0.05-0.3 Nb (Cb**)**
410S	S41008	0.08	1.00	1.00	11.5-13.0	0.6	0.04	0.03	
414	S41400	0.15	1.00	1.00	11.5-13.0	1.25-2.50	0.04	0.03	
414L		0.06	0.50	0.15	12.5-13.0	2.5-3.0	0.04	0.03	0.5Mo; 0.03 Al
416	S41600	0.15	1.25	1.00	12.0-14.0		0.04	0.03	0.6 Mo
416Se **	S41623	0.15	1.25	1.00	12.0-14.0		0.06	0.06	
416plus X**	S41610	0.15	1.5-2.5	1.00	12.0-14.0		0.06	0.15 min.	0.6 Mo
422	S42200	0.20-0.25	1.00	0.75	11.0-13.0	0.5-1.0	0.02 5	0.025	
431	S43100	0.20	1.00	1.00	15.0-17.0	1.25-2.50	0.04	0.03	
440A	S44002	0.60-0.75	1.00	1.00	16.0-18.0		0.04	0.03	0.75 Mo
440B	S44003	0.75-0.95	1.00	1.00	16.0-18.0		0.04	0.03	0.75 Mo
440C	S44004	0.95-1.20	1.00	1.00	16.0-18.0		0.04	0.03	0.75 Mo

6.3 Weldability of Austenitic Stainless Steel :

The austenitic stainless steels contain 16-26%Cr, 8-24%Ni + Mn, up to 0.40% C and small amounts of a few other elements such as Mo, Ti, Nb(Cb) and Ta. The balance between the Cr and Ni + Mn is normally adjusted to provide a microstructure of 90-100% austenite. These alloys are characterized by good strength and high toughness over a wide temperature range and oxidation resistance to over 1000^{o} F (538^{o} C). This group includes type 302,304,310,316,321 and 347.

TABLE – Nominal Compositions of Austenitic Stainless Steels

Type	UNS Nos	Composition – Percent*							Other
		C	Mn	Si	Cr	Ni	P	S	
201	S20100	0.15	5.5 - 7.5	1.0	16.80 -18.0	3.5-5.5	0.06	0.03	0.25N
202	S20200	0.15	7.5-10.0	1.0	17.0-19.0	4.0-6.0	0.06	0.03	0.25 N
205	S20500	0.12-0.25	14-15.5	1.0	16.5-18.0	1.0-1.75	0.06	0.03	0.32-0.40 N
216	S21600	0.08	7.5-9.0	1.0	17.5-22.0	5.0-7.0	0.045	0.03	2.0-3.0Mo; 0.25-0.5 N
301	S30100	0.15	2.0	1.0	16.80 -18.0	6.0-8.0	0.045	0.03	
302	S30200	0.15	2.0	1.0	17.0-19.0	8.0-10.0	0.045	0.03	
302B	S30215	0.15	2.0	2.0-3.0	17.0-19.0	8.0-10.0	0.045	0.03	
303**	S30300	0.15	2.0	1.0	17.0-19.0	8.0-10.0	0.20	0.15 min.	0.6 Mo
303Se **	S30323	0.15	2.0	1.0	17.0-19.0	8.0-10.0	0.20	0.06	0.15 min. Se
304	S30400	0.08	2.0	1.0	18.0-20.0	8.0-10.5	0.045	0.03	
304H	S30409	0.04-0.10	2.0	1.0	18.0-20.0	8.0-10.5	0.045	0.03	
304L	S30403	0.03	2.0	1.0	18.0-20.0	8.0-12.0	0.045	0.03	

GO TO CONTENTS

304LN	S30453	0.03	2.0	1.0	18.0-20.0	8.0-10.5	0.045	0.03	0.10-0.15 N
S30430	S30430	0.08	2.0	1.0	17.0-19.0	8.0-10.0	0.045	0.03	3.0-4.0 Cu
304N	S30451	0.08	2.0	1.0	18.0-20.0	8.0-10.5	0.045	0.03	0.10-0.16 N
304HN	S30452	0.04-0.10	2.0	1.0	18.0-20.0	8.0-10.5	0.045	0.03	0.10-0.16 N
305	S30500	0.12	2.0	1.0	17.0-19.0	10.5-13.0	0.045	0.03	
308	S30800	0.08	2.0	1.0	19.0-21.0	10.0-12.0	0.045	0.03	
308L		0.03	2.0	1.0	19.0-21.0	12.0-15.0	0.045	0.03	
309	S30900	0.20	2.0	1.0	22.0-24.0	12.0-15.0	0.045	0.03	
309S	S30908	0.08	2.0	1.0	22.0-24.0	12.0-15.0	0.045	0.03	
309 S Cb	S30940	0.08	2.0	1.0	22.0-24.0	12.0-15.0	0.045	0.03	8x%C-Nb (Cb)
309Cb +Ta		0.08	2.0	1.0	22.0-24.0	12.0-15.0	0.045	0.03	8x%C (Nb Cb) +Ta)
310	S31000	0.25	2.0	1.5	24.0-26.0	19.0-22.0	0.045	0.03	
310S	S31008	0.08	2.0	1.5	24.0-26.0	19.0-22.0	0.045	0.03	
312		0.15	2.0	1.0	30.0 nom.	9.0 nom.	0.045	0.03	
254S Mo	S31254	0.020	1.0	0.80	19.5-20.5	17.50-18.5	0.03	0.010	6.0-6.50 Mo; 0.18-0.22 N; cu=0.5-1.0
314	S31400	0.25	2.0	1.5-3.0	23.0-26.0	19.0-22.0	0.045	0.03	
316	S31600	0.08	2.0	1.0	16.0-	10.0-	0.04	0.03	2.0-3.0

					18.0	14.0	5		Mo
316F**	S31620	0.08	2.0	1.0	16.0-18.0	10.0-14.0	0.20	0.10 min.	1.75-2.5 Mo
316H	S31609	0.04-1.0	2.0	1.0	16.016.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo
316L	S31603	0.03	2.0	1.0	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo
316LN	S31653	0.03	2.0	1.0	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0Mo; .10-0.16 N
316N	S31651	0.08	2.0	1.0	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0Mo; 0.10-.16 N
317	S31700	0.08	2.0	1.0	18.0-20.0	11.0-15.0	0.045	0.03	3.0-4.0 Mo
317L	S31703	0.03	2.0	1.0	18.0-20.0	11.0-15.0	0.045	0.03	3.0-4.0 Mo
317M	S31725	0.03	2.0	1.0	18.0-20.0	12.0 –16.0	0.045	0.03	3.0-4.0 Mo
321	S32100	0.08	2.0	1.0	17.0-19.0	9.0-12.0	0.045	0.03	5x%C min. Ti
321H	S32109	0.04-0.10	2.0	1.0	17.0-19.0	9.0-12.0	0.045	0.03	5x%C min. Ti
329	S32900	0.10	2.0	1.0	25.0-30.0	3.0-6.0	0.045	0.03	1.0-2.0 Mo
330	N08330	0.08	2.0	0.75-1.5	17.0-20.0	34.0-37.0	0.04	0.03	
AL6-XN	N80367	0.030	2.0	1.0	20.0-22.0	23.5-25.5	0.03	0.03	6.0-7.0Mo; .18-0.25N; Cu=0.75
330HC		0.40	1.50	1.25	19.0 nom.	35.0 nom.			
332		0.04	1.0	0.50	21.5 nom.	32.0 nom	0.45	0.03	
347	S34700	0.08	2.0	1.0	17.0-19.0	9.0-13.0	0.45	0.03	10x % Cmin. Nb(Cb)+Ta(c)
347H	S34709	0.04-	2.0	1.0	17.0-	9.0-	0.45	0.03	10 x % Cmin.

		0.10			19.0	13.0			Nb(Cb)+Ta(c)
348	S34800	0.08	2.0	1.0	17.0-19.0	9.0-13.0	0.45	0.03	0.2 Cu;10x% Cmin.Nb(Cb) +Ta(c)
348H	S34809	0.04-0.10	2.0	1.0	17.0-19.0	9.0-13.0	0.45	0.03	0.2 Cu; 10x%C min. Nb 9Cb) +Ta
384	S38400	0.08	2.0	1.0	15.0-17.0	17.0-19.0	0.45	0.03	
Nitro-nic 32	S24100	0.10	1.0	0.5	18.0	1.6			0.35 N
Nitro-nic 33	S24000	0.06	13.0	0.5	18.0	3.0			0.30 N
Nitro-nic 40	S21900	0.08	8.0-10.0	1.0	18.0-20.0	5.0-7.0	0.06	0.03	0.15-0.40 N;
Nitro-nic 50	S20910	0.06	4.0-6.0	1.0	20.5-23.5	11.5-13.5	0.04	0.03	1.5-3.0 Mo; 0.2-0.4N; 0.1-0.3 Cb; 0.1-0.3 V
Nitro-nic 60	S21800	0.10	7.0-9.0	3.5-4.5	16.0-18.0	8.0-9.0	0.04	0.03	1.5-3.0 Mo; 0.2-0.4 N;

Filler metals for these alloys should generally match the base metal but for most alloys, provide a microstructure with some ferrite to avoid hot cracking. To achieve this type 308 is used for type 302 and 304 and type 347 for type 321. The others should be welded with matching filler. Type 347 can also be welded with type 308 H filler. These filler materials are available as coated electrodes, solid bare wire and cored wire. Type 321 is available on limited basis as solid and cored wire.

Two problems are associated with welds in the austenitic stainless steels :

1 Sensitization of the weld heat affected zone : sensitization leads to intergranular corrosion. Sensitization is caused by chromium carbide formation and precipitation at grain boundaries in the

heat affected zone when heated in the 800 to 1600° F (427 to 871°C) temperature range.Since most carbon is found near grain boudaries, chromium carbide formation removes some chromium from solution near the grain boundaries, thereby reducing the corrosion resistance of these local areas. This problem can be remedied by using low carbon base material and filler material to reduce the amount of carbon available to combine with chromium. Welds should be made without preheat and with minimum heat input to shorten the time in the sensitization temperature range.

2 ELC – Extra Low Carbon – Grades (304L, 308 L) : The 0.04% maximum carbon content of ELC grades helps eliminate damaging carbide precipitation caused by welding. These grades are most often used for weldmen which operates in severe corrosive conditions at temperatures under 800° F(427° C).
ELC steels are generally welded with the ELC electrode, AWS E308L-XX. Although the stabilized electrodes AWS E347-XX produce welds of equal resistance to carbide precipitation and similar mechanical properties, the ELC electrode welds tend to be less crack sensitive on heavy sections and have better low temperature notch toughness.

2. **Stabilized Grades (321,347,348) :** Stabilized grades contain small amounts of titanium (321), niobium (columbium) (347), or a combination of niobium and titanium (347, 348). These elements have a stronger affinity for carbon then does chromium.
   These grades are most often used in severe corrosive conditions when service temperatures reach the sensitizing range. They are welded with niobium stabilized electrodes, AWS E347-XX.

   Molybdenum Grades (316,316L317,317Ld319): Molybdenum in stainless steel increases the localized corrosion resistance to many chemicals.

HOT CRACKING : Hot cracking is caused by low melting materials such as metallic compounds of sulphur and phosphorous which tend to penetrate grain boundaries. When these compounds are present in the weld or heat affected zone, they will penetrate grain boundaries and cracks will appear as the weld cools and shrinking stresses developed.

Hot cracking can be prevented by adjusting the composition of the base material and filler material to obtain a microstructure with a small amount of ferrite in the austenite matrix. The ferrite provides ferrite-austenite grain boundaries which are able to control the sulfur and phosphorous compounds so they do not permit hot cracking. This problem can be avoided by reducing the sulfur and phosphorous to very low amounts, but this would increase significantly the cost of making the steel.

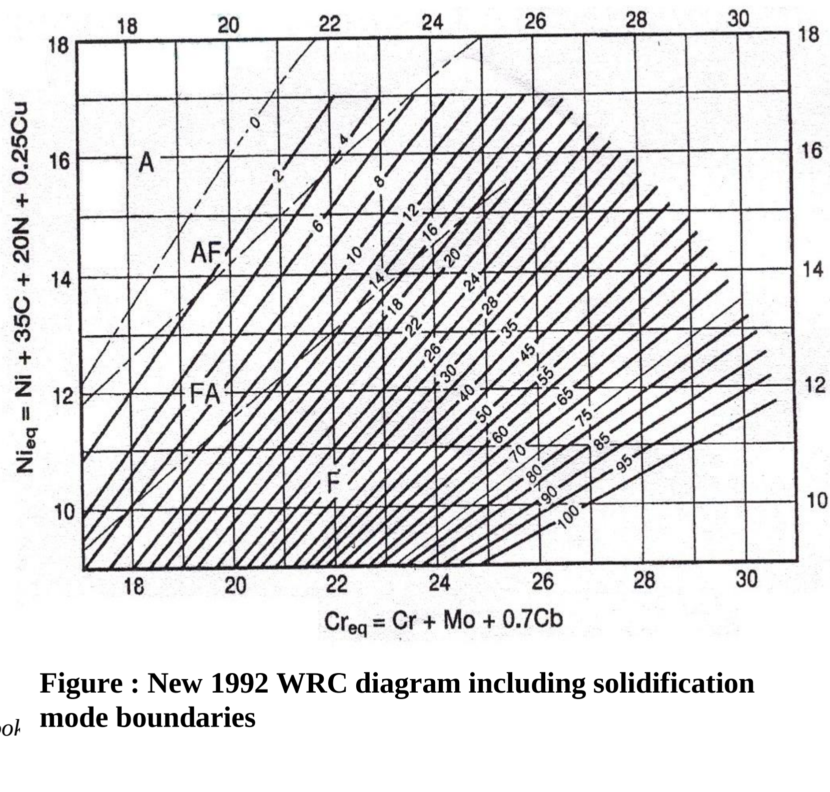


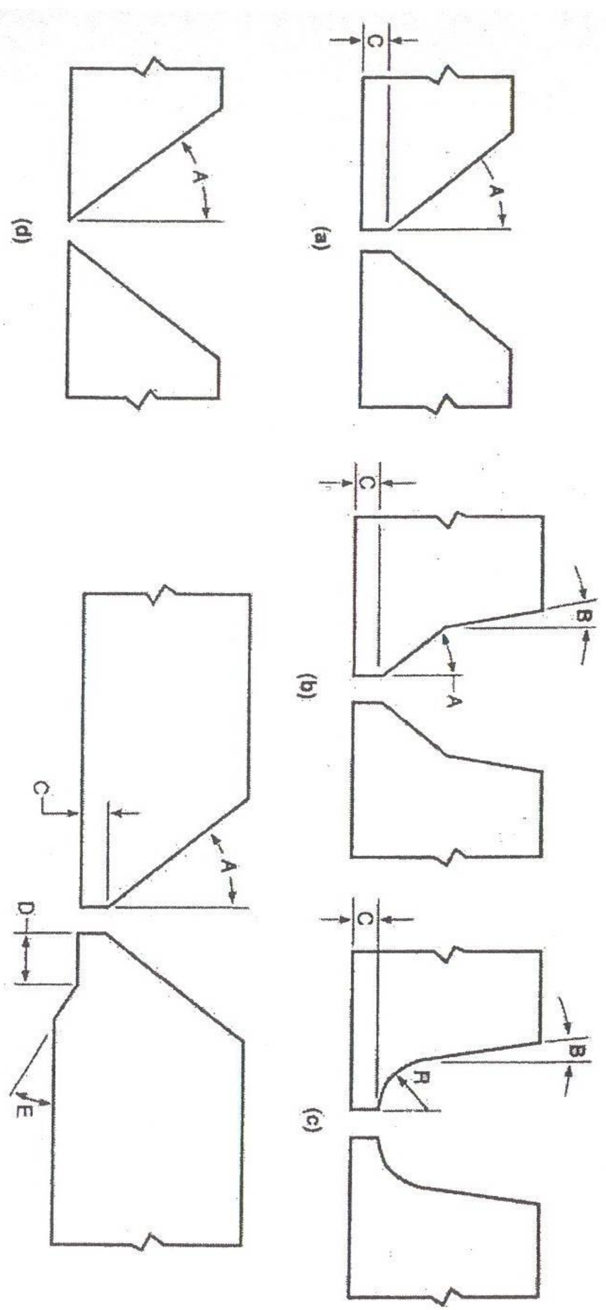
Figure : New 1992 WRC diagram including solidification mode boundaries

7.0 SELECTION OF A STAINLESS STEEL

The selection of a particular type stainless steel will depend on what is required by the application. In most cases the primary consideration is corrosion resistance, tarnish resistance or oxidation resistance at elevated temperature. In addition to these requirements, the selected stainless steel must have some minimum mechanical properties such as strength, toughness, ductility and fatigue strength. Several types and grades of stainless steel may provide the corrosion resistance and mechanical properties required. In this case the final selection should be made on the basis of the lowest cost available alloy which will fulfill the service requirements. Generally, selection of the type of stainless steel is made by the designer of the equipment or component based on his knowledge, experience and data on corrosion behavior of various alloys in the environment of interest. The sponsibility of the welding engineer normally does not include selection of the base alloy, only selection of the filler material, welding process and procedure.

Other factors which must be considered in selecting a stainless steel are resistance to pitting, crevice corrosion and intergranular attack. Intergranular attack is caused by carbide precipitation in weld heat affected zones and methods of preventing this problem were discussed previously. If the application involves service at elevated temperature, then elevated temperature mechanical properties such as creep strength, stress rupture strength and oxidation resistance must be considered.

With the corrosion and oxidation test data derived front the handbooks and other references, a stainless steel or other alloy may be selected for a particular application. Once the stainless steel is selected, it is the welding engineer's responsibility to design the joints, select the weld filler metal, welding process and welding procedure.



A = 37-1/2° ± 2-1/2°
B = 10° ± 1°
C = 1/16 in. ± 1/32 in. (1.6 mm ± 0.8 mm)
D = 2 times amount of offset
E = 30° max
R = 1/4 in. (6.4 mm)

FIGURE — Typical joint designs for welding austenitic stainless steel pipe.

8.0 DESIGN FOR STAINLESS STEELS

Since the coefficient of thermal expansion for austenitic stainless steels is relatively high, the control of distortion must be considered in designing weldments of these alloys. The volume of weld metal in joints must be limited to the smallest size which will provide the necessary properties.

Strong tooling and fixturing should be employed to hold parts in place and resist tendencies for components to move during welding. When any of the gas shielded processes are used, the tooling should also provide an inert gas backup to the root of the weld to prevent oxidation when the root pass is being made. This is particularly important when GTA welding pipe with insert rings to allow the weld metal to wet and flow together at the root of the joint.

In welding pipe, insert rings, Figure 4, of the same composition as the filler metal should be used for the root pass and be welded by the GTAW process. If copper chills are to be . used near a weld area, they should be nickel plated to prevent copper pickup. If copper is in contact with the high temperature region of the heat affected zone, it can melt and penetrate the grain boundaries of austenitic stainless steel causing cracking.

9.0 SELECTION OF FILLER METALS

Filler metals for welding stainless steels are produced as coated electrodes (AWS A5.4), solid and metal core wire (AWS AS.9) and flux core wire (AWS AS.22). The various electrodes, solid wires, metal cored wires and flux cored wires are contained in AWS "Filler Metal Comparison Charts", latest edition.

According to these charts, matching filler metal should be available for almost every type of austenitic stainless steel available, although many types may be produced in small quantities by only a few companies and may not be readily available. For example, E219-16 and E240-16 electrodes are produced by only two U.S. companies and no foreign companies. By contrast, the more popular electrodes, E308-16, E308L-16, E309-16, E310-16, E316-16, E316L-16 and E347-16 are produced by about 40 U.S. companies and 20 to 30 foreign companies. Most electrodes are available with a lime coating (-15) (for use with DC only), a titania coating (-16) (for use with AC or DC) or a sillca-titania coating (-17) (for use with AC or DC mainly in the downhand or horizontal positions) and in the standard or low carbon variety.

Most alloys which are available as coated electrodes are also available as either solid wire, metal cored wire or flux cored wire. A few are available only as coated electrodes. These are 310H, 310Cb, 310Mo and 330H. As was mentioned previously, filler metal for austenitic stainless steels should match or exceed the alloy content of the base metal. If a filler material of the correct match is not available, a filler with higher alloy content normally should be used. There are several austenitic stainless types for which no exact matching fillers are made. Examples are 201, 202, 205, 216, 301, 302, 304 and 305. The filler materials recommended for these base alloys are somewhat higher in Cr and Ni content. For example, 308 is used for 301, 302, 304 and 305 and may

be used for 201, 202, 205 and 216 if 209, 219 or 240 are not available. . The 6% molybdenum stainless steels 254SMo and AL6-XN are generally welded with higher molybdenum nickel-base alloys. The recommended filler materials in the form of coated electrodes, solid and metal core wire and flux core wire are listed in Tables XI, XII and XIII for austenitic, ferritic and martensitic stainless steels respectively. Note that a modification of a basic type should be welded with a filler material of that same modification, for example, Type 316L should be welded with E316L-XX, ER316L, ER316LS, or E316LT-X.

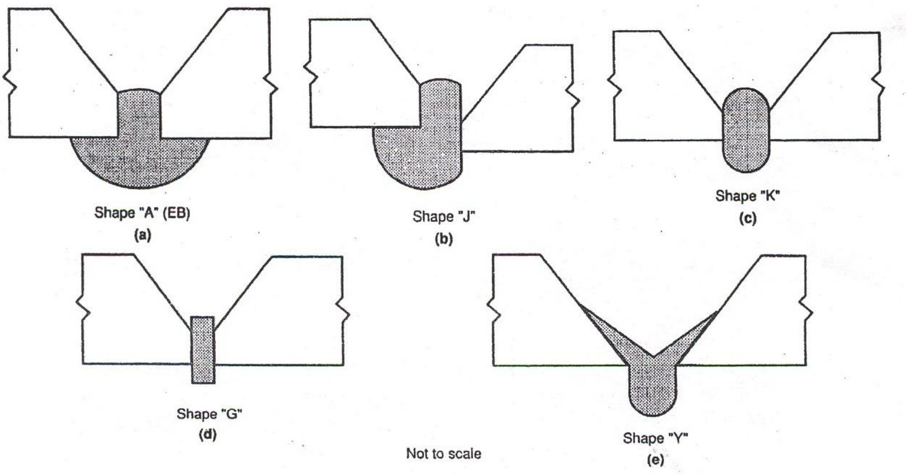


FIGURE — Standard consumable inserts.

Except for E630 electrodes and ER630 bare wires which match 17-4PH, matching filler materials for the precipitation hardening stainless are not listed in the AWS Filler Metals Comparison Charts, or in any of the AWS filler metal specifications. Matching filler metals are produced and available in, the form of coated electrodes and solid wire for

some of the precipitation hardening stainless steels and these are listed in Table XIV. Where no matching filler is available, standard austenitic or nickel base filler materials are recommended as indicated in Table XIV.

If maximum strength properties and corrosion resistance are required for the application, a filler metal of matching or similar composition to the base metal should be used. For martenisitic or semiaustenitic base alloys, the weldment should then be given the full solution and aging heat treatment if feasible. If not, the components should be solution treated before welding, then given a postweld aging treatment after welding. It is recommended that the austenitic precipitation hardening stainless steels not be heat treated after welding because of cracking problems. In fact, these alloys are difficult to weld for this reason and some are considered un weldable. Nickel base and conventional austenitic filler metals can be used.

TABLE – Filler Metals for Welding Austenitic Stainless Steels

Base Stain -less steels	Recommended Filler Metals			
Wrought	Cast	Coated electrode	Solid; Metal Core Wire	Flux Core wire
201		E209,E219,E308	Er209,er219,Er 308,ER308Si	E308TX-X
202		E209,E219,E308	Er209,er219,Er 308,ER308Si	E308TX-X
205		E240	Er240	
216		E209	ER209	E316TX-X
301		E308	ER308, ER308Si	E308TX-X
302	Cf-20	E308	ER308,ER308Si	E308TX-X
304	CF-8	E308, E309	ER308,ER308Si, Er309,ER309Si	E308TX-X, E309TX-X
304 H		E308H	ER308H	
304 L	CF-3	E308L,E347	ER308L,ER308 LSiER347	E308TX-X, E347TX-X
304LN		E308L, E347	ER308L,ER308 L,SiER347	E308TX-X, E347TX-X
304N		E308, E309	ER308,ER308Si, ER309,ER309Si	E308TX-X, ER309TX-X
304HN		E308H	ER308H	
305		E308, E309	ER308,ER308Si, ER309, ER309Si	E308TX-X, E309TX-X
308		E308, E309	ER308,ER308Si, ER309, ER309Si	E308TX-X,E309TX-X
308L		E308L,E347	ER308L,ER308 LSi, ER347	E308LTX-X,E347TX-X
309	CH-20	E309, E310	ER309,ER309Si, ER310	E309TX-X, ER310TX-X
309S	CH-10	E309L, E309 Cb	ER309L, Er309LSi	E309LTX-X, E309CbLTX-

309 SCb		E309Cb		E309CbLT X-X
309Cb Ta		E309Cb		E309CbLT X-X
310	CK-20	E310	Er310	E310TX-X
310S		E310Cb, E310	Er310	E310TX-X
312	CE-30	E312	ER312	E312T-3
314		E310	ER310	E310TX-X
316	CF-8M	E316, E308Mo	ER316,E308Mo	E316LTX-X, E308MoTX-X
316H	CF-12M	E316H,E16-8-2	E36H,Er16-8-2	E316TX-X, E308MoTX-X
316L	CF-3M	E316L,E308Mo L	ER316L,ER316 LSi, ER308MoL	E316LTX-X, E308MoTX -X
316LN		E316L	ER316L, Er316LSi	E316LTX-X
316N		E316	ER316	E316TX-X
317	CG-8M	E317,E317L	ER317	E317LTX-X
317L		E317L,E316l	ER317L	E317LTX-X
321		E308L,E316L	ER321	E308LX-X, E347TX-X
321H		E347	ER 321	E347TX-X
329		E312	ERE312	E321T-3
330	HT	E330	ER330	
330HC		E330H	ER330	
332		E330	ER330	
347	CF-8C	E347,E308L	ER347,ER347Si	E347TX-X, E308LTX-X
347H		E347	ER347,ER347Si	E347TX-X
348		E347	ER347,ER347Si	347TX-X
348H		E347	ER347,ER347Si	E347TX-X
Nitronic33		E240	ER340	
Nitronic40		E219	Er219	

Nitronic50		E209	Er209	
Nitronic60			Er218	
254 SMo		ENiCrMo-3	ERNiCrMo-3	
AL-6XN		ENiCrMo-10	ERNiCrMo-10	

for these alloys, especially if high strength weld metal is not required because the lower strength filler can stretch on cooling and minimize the stress on the crack sensitive heat affected zone of the base metal. Nickel base and conventional austenitic stainless steels can also be used to weld the other precipitation hardening stainless steels where full base material strength is not required.

Coated electrodes can be used for welding martensitic and semi austenitic stainless steels such as 17-4PH, AM350 and AM355 because these alloys do not contain titanium or aluminum which would be lost in the shielded metal arc. Welds can be made in all positions, with this process. Electrodes 'must " be dry and stored and handled in the same manner as used for other stainless steel and low hydrogen electrodes as described previously.

Type AMS 5827B (17-4PH) electrodes can be used to weld 17-7 PH steel, and reasonable heat treatment response can be obtained if the weld deposit is highly diluted with base metal.

Welding conditions suitable for conventional stainless steels are generally applicable .for joining the PH types. A short arc length should, be used to minimize oxidation, loss of chromium, and nitrogen pickup.

Lining

Mild steel process and storage equipment is sometimes lined with stainless steel for corrosion resistance. At least three different methods are used:

Large formed stainless steel sheets are plug welded at frequent intervals to join them closely to the shell.

TABLE – Filler Metals for Welding Ferritic Stainless Steels

Base stainless Steel		Recommended Filler Metal		
Wrought	Cast	Coated Electrode	Solid, Metal Core Wire	Flux Core wire
405		E410NiMo, E430	ER410NiMo, ER430	E410NiMoTX-X
409			ER409, AM 363, EC409	E409TX-X
429			ER409Cb	
430	CB-30	E430	ER430	E430TX-X
430F		E430	ER430	E430TX-X
430FSe		E430	ER430	E430TX-X
434			ER434	
442		E442,#446	ER442	
444		E316L	ER316L	
446	CC-50	E446	ER446	
26-1			ER26-1	

TABLE – Filler Metals for Welding Martenistic and Duplex Stainless Steels

Base Stainless Steel		Recommended Filler Metal		
Wrought Stainless	Cast	Coated Electrode	Solid, Metal Core wire	Flux Core wire
403		E410	ER410	ER410TX-X
410	CA-15	E410, E410NiMo	Er410, Er410NiMo	E410T, E410NiMoTX-X
410S		E410NiMo	ER410NiMo	E410NiMoTX-X
414		E410	ER410	E410TX-X
416		E410	ER312,ER410	
416Se			ER312	

416PlusX			ER312	
420	CA-90	E410, E430	ER420, ER410	ER410TX-X
420F			Er312	
431	CB-30	E410, E430	ER410	E410TX-X
440A		A		
440B		A		
440C		A		
	CA-6NM	E410NiMo	Er410NiMo	E410NiMoTX-X
	CA-15	E430	ER430	E430TX-X
2205		E2209	ER2209	
2304		E2209	ER2209	
255		E2553	ER2553	

TABLE – Filler Metals for Welding Precipitation Hardening Stainless Steels

Designation	UNS Nos	Covered Electrodes	Bare Welding Wire	Dissimilar PH Stainless Steels
Martensitic Types				
17-4PH And 15-5 PH	S17400 S15500	AMS 5827B, E630(17-4 PH) or E308	AMS 5826 (17-4 PH) or E308	E or ER 309, E or ER 309 Cb
Stainless W	S17600	E308 or EniMo-3[a]	AMS 58005 (A-286) or ERNiMo-3[b]	E or ERNiMo-3, E or ER309
Semi-austenitic Types				
17-7PH	S17700	AMS 5827B (17-4 PH), E308 or E309	AMS 5824[a] (17-7 PH)	E or ER 310, ENiCrFe-2, or ERNiCr-3
PH- 15-7 Mo	S15700	E308 or E309	AMS 5812C (PH 15-7 Mo)	E or ER 309, E or ER 310
AM 350	S35000	AMS 5775A (AM350)	AMS 5774B (AM350)	E or ER 308, E or ER 309

AM 355	S35500	AMS 5781 A (AM355)	AMS 5780 A (AM 355)	E or ER 308, E or ER 309
Austenitic types				
A-286	K66286	E309 or E310	ERNiCrFe-6 or ERNiMo-3	E or ER309, E or ER 310

1. Overlapping welds deposited on the steel surface.
2. Small strips are overlapped or placed side-by-side and welded to the shell. Sometimes this technique is referred to as "wallpapering" Clad steel consists of stainless steel sheet permanently bonded to mild steel plate. To join clad steel plates, first weld the mild steel with mild steel electrodes. Do not tie into the stainless cladding with the mild steel . electrodes. After gouging the backside of the first mild steel bead, weld from the stainless side using stainless steel electrodes.

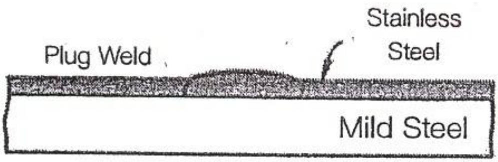
Base stainless Steel		Recommended Filler Metal		
Wrought	Cast	Coated Electrode	Solid, Metal Core Wire	Flux Core wire
405		E410NiMo, E430	ER410NiMo, ER430	E410NiMo TX-X
409			ER409, AM 363, EC409	E409TX-X
429			ER409Cb	
430	CB-30	E430	ER430	E430TX-X
430F		E430	ER430	E430TX-X
430FSe		E430	ER430	E430TX-X
434			ER434	
442		E442,#446	ER442	
444		E316L	ER316L	
446	CC-50	E446	ER446	
26-1			ER26-1	

Joining Manganese Steel

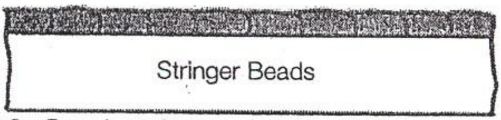
E308-X or E309-XX electrodes are used to weld manganese steel to carbon steel or to manganese steel. The stainless welds provide excellent joint strength and ductility but are difficult to flame cut. Therefore, when a manganese steel piece must be replaced periodically, such as dipper teeth, Wearshield Mangjet electrode can be recommended. Wearshield 15CrMn electrode has better crack resistance, but the deposit is difficult to flame cut.

Thick Harfacing Deposits

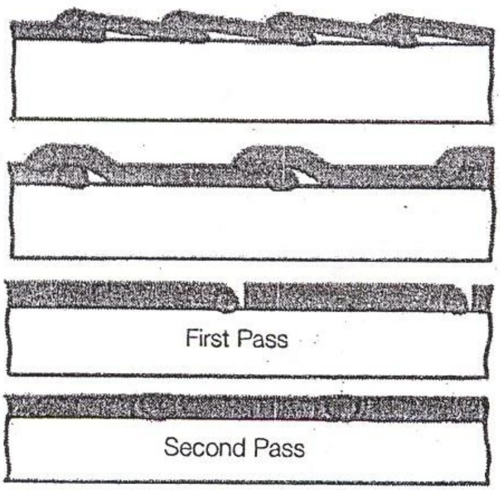
E308-X or E309-XX deposits increase the toughness of thick hard facing deposits. For best results, use one layer of stainless between each two layers of hard facing.



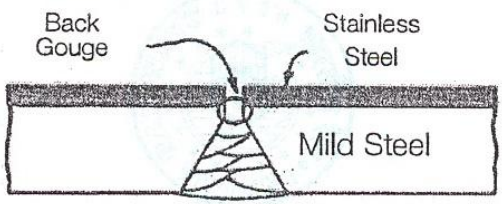
sheets are plug welded at frequent intervals to join them closely to the shell.



2. Overlapping welds deposited on the steel surface.



Welding Clad Steel



GO TO CONTENTS

10.0. SELECTION OF WELDING PROCESS

10.1 Joint Cleanliness

For high-quality welds, stainless steel joints must be clean. The choice of power brushing, degreasing, pickling, grinding or simply wiping depends upon the application and amount of dirt. Here are some specific hints:

1. Remove all moisture by blowing with dry air or heating with a torch. Beware of moisture in air lines, damp rags and humidity deposited overnight. .
2. Eliminate organic contaminants like oil, paints, anti-spatter compounds, grease, pencil marks, cutting compounds, adhesive from protective paper, soap used for leak testing, etc.
3. Stainless steels cannot be flame cut with a torch. Acceptable results are achieved with an arc plasma cutter.
4. Be particularly careful to avoid zinc contamination. Do not use brushes or tools previously used on galvanized steel.
5. Use only stainless steel wire brushes, and use these brushes only on stainless steel.

The decision on the form of filler metal to be used will depend upon several factors. These include the available forms of the filler material needed, the available welding equipment, the dimensions of the weldment and number of pieces to be welded.

TABLE – Standard Sizes for Stainless Electrodes

From	Diameter, in.	Diameter, mm
Electrode in coils, with or without support	0.045, /16, 5/64, 3/32/ 7/64 1/8,5/32,3/16,1/4	1.2,1.6,2.0,2.8,3.2, 4.0,4.8,6.4
Electrode wound on standard 12-in.O.D. sports	0.030,0.035,0.045,1/16,5/64,3/32,7/64	0.8,0.9,1.2,1.6 2.0,2.4,2.8
Electrodes wound on lightweight 1-1/2 & 2-1/2 lb., 4-in O.D. sports	0.020, 0.025, 0.030 0.035,0.045	0.5,0.6,.08 0.9,1.2
Coated Electrodes		
9 in. length (230 mm)	1/16, 5/64, 3/32	1.6, 2.0, 2.4
12 in. length (305 mm)	3/32	2.4
14 in. length (350 mm0	1/8, 5/32,3/16,1/4	3.2, 4.0, 4.8, 6.4

10.2 TYPES OF WELDING PROCEDURES

10.2.1 SHIELDED METAL ARC WELDING

Coated electrodes are available in most stainless compositions in a range of sizes and these can be used to weld joints in thicknesses from 0.05 inch to several inches. Slag from each pass must be completely removed before depositing the next pass to avoid porosity and slag entrapment. Welding equipment for stick electrode welding is the lowest cost but deposition rates are lowest of all the consumable electrode processes.

If it has been decided to perform the welding with stick electrodes, a further decision must be made. regarding the electrode coating. When lime (-15), titania (-16), and silica-titania - 17) type coatings are available for a particular type electrode, the decision

will be based mainly on the Position of welding. Lime-coated electrodes operate on DC only. They are recommended for:

1. Vertical and overhead welding and all position applications such as pipe. The light slag wets rapidly for good wash-in and no undercutting.
2. Root passes on heavy plate. The full throat section of the slightly convex beads help prevent. cracking.
3. Fully austenitic stainless steels such as types 330, 320.

Titania-coated electrodes operate on AC or DC, but always use DC when available. They are recommended for:

1. All applications when most of the welding is in the flat position.
2. Vertical up and overhead welding when lime-coated electrodes are not available.

Silica-titania coated electrodes operate also on AC or DC, but DC is usually preferred. They are recommended for:

1. Flat and horizontal position welding when minimum cleanup is desired.
2. Vertical up welding when a wide weave can be used.
3. Overhead welding.

Coated electrodes should be treated and stored as low hydrogen electrodes. They should not be exposed to damp air, and once a sealed container is opened, the electrodes should be used or stored in a holding oven at between 200 and 300°F (93 and 149°C). If the electrodes are exposed to moist air, they can be dried by baking as recommended by the manufacturer. This

baking temperature usually is between 500 and 600°F (260 and 316°C), but can be as high as 800°F (427°C). The electrode manufacturer should be consulted for specific recommendations.

The sizes and forms of coated electrodes and also solid and cored wire, which are normally available for welding stainless steels.

10.2.2 SUBMERGED ARC WELDING

Submerged arc welding (SAW) can be employed to join thick sections, usually greater than 0.5 inch, of most of the austenitic stainless steels. For austenitic stainless in which ferrite is not possible in the weld metal (types 310 or 330, for example), submerged arc welding is usually best avoided due to hot cracking problems. Welding is generally done using direct current, electrode positive. Alternating current is sometimes used for moderate penetration and good arc stability.

Since deposit composition, depends upon the filler wire composition, any alloy additions to the flux and chromium oxidation and loss to the slag, flux selection and welding conditions must be rigorously controlled. Voltage, current and travel speed variations will influence the amount of flux melted and the resulting weld deposit composition and ferrite content.

Conventional austenitic stainless steel electrodes such as ER308, ER309 and ER316 can be used with conventional stainless steel fluxes for welding most of the austenitic stainless steel except applications where Ferrite Number must be less than 4.

If base metal strength must be attained in martensitic or precipitation hardening stainless steels, special

procedures and fluxes must be used with the correct filler metal to provide a weld deposit which will respond to postweld heat treatment. If special fluxes are not used, the weld metal probably will not respond to heat treatment. This is particularly true for aluminum-bearing electrodes where aluminum is lost through metal-slag, reactions. The stainless flux manufacturers should be consulted for recommendation on fluxes and welding procedures.

10.2.3 GAS METAL ARC WELDING

If the production application involves long joints in relatively thick material or a large number of parts, the GMAW process with solid or metal cored wire may be the best choice.

Solid or metal cored wire will provide the fastest deposition rates with the GMAW process but wire feeding equipment, power supplies and the requirement for inert gas shielding add to the cost of using these fillers. However, there is little need to remove slag between passes. Solid and metal cored wire can be used in short circuiting, globular and spray modes of arc operation which gives a wide range of deposition rates and heat input levels. Solid and metal cored wire can therefore be used for welding a wide range of thicknesses.

Gas metal arc welding with spray transfer is used to join sections thicker than about 0.25 inch because deposition rates are higher than with other transfer modes. Welding procedures are similar for conventional austenitic and PH stainless steels.

The shielding gas is generally argon with 1 to 2 percent oxygen added for arc stability. Mixtures of argon and helium are employed if a hotter arc is desired. A small oxygen addition can be added to provide a stable arc, but some aluminum or titanium

can be lost from certain PH filler metals during transfer across the arc as a result of oxidation. Response of the weld metal to heat treatment might be less because of this action.

For flat position welding, spray transfer is usually preferred. For other welding positions. Short circuiting transfer is often used with helium-rich gas such as 90% He 7.5% A -2.5% CO_2 or pulsed spray transfer can be employed using argon or an argon-helium mixture with a small addition of oxygen or carbon dioxide.

10.2.4 FLUX CORED ARC WELDING

Flux cored wire uses basically the same wire feed equipment and power supply as solid and metal core wire. Wires can be designed for use with gas shielding (AWS Classes EXXXTX-1 or EXXXTX-4) or without gas shielding (AWS Classes EXXXTO-3). The "-1" indicates CO_2 shielding gas, while the "-4" indicates 75% Argon - 25% CO_2 shielding gas. Although carbon dioxide gas shielding is not recommended for gas metal arc welding, it is commonly used with flux cored arc welding because the slag protects the metal from carbon pickup. Use of EXXXTO-3 with gas will result in high ferrite. Use of EXXXTX-1 or EXXXTX-4 without gas will result in little or no ferrite and possibly porosity. Solid wire, metal core and flux core wire have an advantage over coated electrodes by their continuous nature in that it is not necessary to stop welding to change electrodes.

10.2.5 GAS TUNGSTEN ARC WELDING

Manual and automatic gas tungsten arc welding (GTAW) processes are frequently used for joining

conventional and PH stainless steels, particularly in thicknesses up to about 0.25 inch.

Normally direct current, electrode negative is used with a power supply having drooping volt-amperage characteristic. However, alternating current is sometimes used to weld those steels containing aluminum to take advantage of the arc cleaning action. '

11.0 PROCEDURES FOR WELDING STAINLESS STEELS

Once a joint design has been established and a welding process and filler material have been selected, a welding procedure may be developed. For any process, it is important that joint edges and filler material be clean and free of any oxide, organic material or other contamination. Thermal cut edges must be cleaned to remove oxide film. Rough machined surfaces on joint edge preparation should be avoided to prevent entrapment of contaminants.

Heat input for arc welding stainless steels should be minimized to minimize distortion and to minimize the possibility of sensitization of the heat affected zone. This is particularly important for standard, non stabilized austenitic stainless steels.

11.1 Welding With the Shielded Metal Arc Process

All stainless steel shielded metal arc electrode coverings must be protected from moisture pickup. Normally, electrodes packaged in hermetically sealed containers can be stored for several years without deteriorating. However, after the container is opened, the coating begins to absorb moisture and, depending on the ambient air condition, may need to be reconditioned after only four hours of exposure, otherwise porosity may result, especially at arc starts.

Usually, re-drying at 500 to 600°F (260 to 316°C) for 1 hour restores the electrode to its original condition,

and storing in a holding oven at 300°F (149°C) is satisfactory. Due to differences in materials and processing, the supplier should be consulted if large amounts of electrodes are involved.

DC electrodes (EXXX-15) operate on DC only, have good penetration, produce fillets with a slightly convex profile, and are recommended for:

- Vertical and overhead welding and all position applications such as pipe. The slag has a fast freeze characteristic.
- Root passes on heavy plate. The larger throat section of the convex bead helps prevent cracking.
- Austenitic stainless welds that cannot contain any ferrite.

AC-DC electrodes (EXXX-16 and 800(-17) are always used on DC when this type of power is available. The fillet profile is flat (EXXX-16) to slightly concave (EXXX-17), the weld surface is smoother and the penetration is less than with EXXX-15 (DC only) electrodes. The larger amount of slag requires more care to avoid slag inclusions. These electrodes are recommended for horizontal fillets and for all flat position welding.

EXXX-16 electrodes are also used in all positions by skilled welders. EXXX-17 electrodes can also be used in all positions, but a wider weave is generally necessary in the vertical-up position than is necessary for EXXX16 electrodes.

Cleaning

For high quality welds joints must be clean and dry. The choice of power brushing, degreasing, pickling. grinding or merely wiping depends upon the kind and amount of dirt. Some specific recommendations are:

1. Remove moisture by heating or by blowing with

dry air (beware of moisture in the air line). Moisture can collect on a weldmant overnight in high humidity conditions.

2. Eliminate organic contaminants such as paints, anti spatter compounds, grease pencil marks, cutting compounds. adhesive from protective paper and soap used for leak testing.
3. Flame beveling and machining may leave contaminants or oxide films that must be removed.
4. Avoid zinc contamination from brushes or tools that have been used on galvanized steel. Zinc contamination causes cracking. Use only stainless steel wire brushes that have been used only on stainless steel.
5. Avoid copper contamination from rubbing stainless over copper hold-down fixtures, etc. Copper contamination causes cracking.

Welding Techniques

Welding with stainless steel electrodes requires techniques similar to those used for mild steel low hydrogen electrodes. Use a short arc, but keep the coating from touching the puddle. Certain electrodes are designed to be dragged on the base metal in down hand and horizontal welding. Flat beads with good wash-in promote easy slag removal in deep grooves. Fill each crater before breaking the arc to avoid crater cracks. Clean the slag thoroughly from the finish of the bead before starting another electrode, and clean the complete weld before started the next pass. On deep groove butt joint, the root pass should penetrate only enough to fuse to both plates and seal the opening. More penetration may cause cracks.

For vertical and overhead positions never use an

electrode larger than 5/32". The DC electrodes, (EXXX-15) are preferred, but the AC-DC electrodes (EXXX-16), can be used for welding vertical up (using DC). On thick plate use the triangular weave or inverted Vee technique, welding vertical up. On thin plate, use small beads, vertical down.

The EXXX-17 AC-DC electrodes are more difficult to use vertical up than the EXXX-16 electrodes. A wider weave is generally necessary

Welding techniques can help control distortion. Weld with low current consistent with sufficient penetration to reduce the heat input to the work. Use stringer beads at a higher speed rather than wide beads at a slower speed. If weave beads must be made, limit the weave to 2-1/2 times the electrode diameter.

Other means to control distortion are:

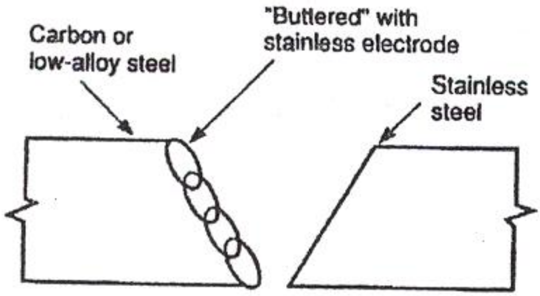
- Use rigid fixtures to hold parts in alignment.
- Use chill bars near the weld and backing bars under the weld. Rapid cooling of austenitic stainless steels is beneficial rather than harmful. If copper is used as the chill bar material, care must be exercised to prevent copper grain boundary penetration where the heat affected zone temperature exceeds the melting temperature of copper. This can be prevented by applying a thin nickel plate to the copper.
- Plan the sequence of welding; using the same techniques as with mi1d steel such as skip welding, and back step welding.

Joining Stainless and Other Steels

In some applications, stainless steel weld metal is applied to mild steel: for example, lining mild steel vessels or containers with stainless steel. For such applications, stainless electrodes with higher alloy

content are used so the admixture of the mild steel into the stainless weld deposit does not form an unsatisfactory alloy When stainless steel is joined to mild steel, the mild steel is often "buttered" with stainless steel. This technique consists of depositing a layer of stainless on the surface of the mild steel, then completing the joint with stainless electrode, as illustrated in Figure. The electrode commonly used for buttering is E309. This technique is also used for joining hard-to-weld or high carbon steels that cannot be preheated.

E308 electrode is used for joining austenitic manganese steel to carbon steel or to manganese steel. However, for the components that must be replaced periodically, such as dipper teeth, a manganese steel electrode is recommended because the stainless weld is more difficult to torch cut.



Buttering technique for joining mild steel to stainless steel.

Power Sources

The open circuit voltage of light duty AC transformer welders may not be high enough for larger diameters of EXXX-16 electrodes; otherwise, the same, power sources used with steel electrodes are satisfactory for

stainless electrodes.

Parameters and procedures for welding stainless steel in thicknesses from 18 gauge to 1/2 inch are given in Figures. These show joint designs and backup bars for butt, tee, lap and 90 degree edge joints.

11.2.1 WELDING WITH THE SUBMERGED ARC PROCESS

The submerged arc process is applicable to the welding of stainless steels where the higher heat input and slower solidification are tolerable. With submerged arc welding, depending upon the flux chosen, the silicon content may be much higher than with other processes, a factor that may promote hot shortness or fissuring when ferrite is less than 4FN.

The submerged arc process is not recommended where a weld deposit is needed that is fully austenitic or is controlled to a low ferrite content (below 4FN). However, high quality welds may be produced for applications in which more than 4FN in weld deposits is allowable. Figure shows the type of butt joint designs that can be used for submerged arc welding.

Good quality single pass welds up to 5/16 inch thick can be made using the square groove butt joint, Figure without root opening and with suitable backing. Two pass welds up to 5/8 inch thick are also made without root opening. It is essential on two pass welds, however, that the edges be closely butted since weld backing is not used. The advantage of this joint design is that it requires a minimum of edge preparation, yet produces welds of good quality having adequate penetration.

Single V-groove welds with a root face, Figure, are used with non fusible backing for single pass butt

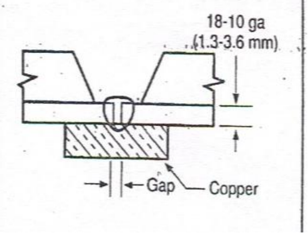
welds of 5/16 inch thickness or greater. For most industrial applications, the maximum thickness is of the order of 1-1/4 to 1-1/2 inch. Root face dimensions are 1/8 to 3/16 inch. This joint is also used for two pass welds without backing where plate thickness exceeds 5/8 inch. The first pass is made in the V of the joint, Figure. The work is then turned over and the first pass becomes the backing pass. In this position, the finishing pass is made on the flat side of the joint penetrating into the root of the first pass. The root face is approximately 3/8 inch for two pass welds.

The double V-groove butt, Figure is the basic joint design for submerged arc welding. A large root face is generally used with this design. Figure shows a typical double V-groove weld in 3/4 inch 304 plate and describes the welding sequence.

A single U-groove butt joint design, Figure , is also commonly used. A small manually produced backing weld is often made from the reverse side of the joint. It is usually desirable to fill the U-groove with 2 passes per layer as soon as possible after the root pass. Slag removal from a submerged arc weld pass toeing in to both sides of the groove can be very difficult.

For stainless steel welding, DC power is mostly used on thin sections. Either AC or DC may be used on heavier pieces but DC is preferred. Currents used are about 80% of those used for carbon steel. Single pass techniques usually result in dilution levels of 40% to 60%. This may be decreased by using multipass welds.

Welding Position: Flat
Weld Quality Level: Code
Steel Weldability: Good



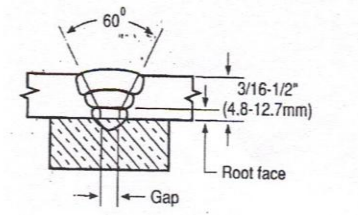


Plate Thickness in.	0.050 (18 ga)	0.078 (14 ga)	0.140 (10 ga)	3/16	1/4		3/8		1/2	
mm.	1.3	2.0	3.6	4.8	6.4		9.5		12.7	
Pass	1	1	1	1	1	2	1	2-3	1	2-5
Electrode Class	E3XX-16	E3XX-16	E3XX-16	E3XX-16	E3XX-16		E3XX-16		E3XX-16	
Size in.	5/64	3/32	1/8	5/32	5/32	3/16	5/32	3/16	5/32	3/16
mm.	2.0	2.4	3.2	4.0	4.0	4.8	4.0	4.8	4.0	4.8
Current (amp) DC (+)	40*	60	85	125	125	160	125	160	125	160
Arc Speed (in./min.)	14 -16	11.5 - 12.5	8.5 - 9.5	6.7 - 7.3	5.7-6.3	7.6-8.4	5.7-6.3	5.7-6.3	5.7-6.3	5.7-6.3
mm/sec	5.9 - 6.8	4.9 - 5.3	3.6 -4.0	2.8 - 3.1	2.4-2.7	3.2-3.6	2.4-2.7	2.4-2.7	2.4-2.7	2.4-2.7
Electrode Req'd (lb./ft.)	0.020	0.038	0.080	0.150	0.340		0.650		1.06	
kg/m	0.030	0.057	0.119	0.223	0.506		0.968		1.579	
Total Time (hr./ft. of weld)	0.0133	0.0167	0.0222	0.0286	0.0583		0.100		0.167	
hrs./m of weld	0.0436	0.0548	0.0728	0.0938	0.1913		0.3281		0.5479	
Gap (in.)	0	1/32	1/32	1/16	3/32		3/32		3/32	
mm	0	0.8	0.8	1.6	2.4		2.4		2.4	
Root Face (in.)	0	0	0	1/16	1/16		1/16		1/16	
mm	0	0	0	1.6	1.6		1.6		1.6	

*Use DC (–)

Note: AC can be used with 10% increase in current. E3XX-15 electrode can be used with a 10% decrease in current.

FIGURE — Suggested procedures for SMAW of butt joints in austenitic stainless steel from 18 (1.3 mm) gauge to 1/2 inch (12.7 mm) thickness in the flat position.

GO TO CONTENTS

Submerged arc welding creates a large volume of molten metal that remains fluid for appreciable time. It is essential that this molten metal be supported and contained until it has solidified. The two most common means of weld backing are non fusible backing and fusible backing.

Copper backing is the most frequently used non fusible backing in the welding of stainless steel. When copper is used as a chill bar, care must be taken to prevent copper grain boundary penetration. Recommended groove dimensions are shown in Figure. Ceramic backing tapes are also sometimes used.

With a fusible metallic backing, the weld penetrates into and fuses with the stainless backing, which either temporarily or permanently becomes an integral part of the assembly.

Most submerged arc welding is done in the flat position. This results in the best bead contour and ease of operation. Occasionally, welding is done on circumferential seams. Figure illustrates the effect of various inclinations.

Submerged arc fluxes are available as proprietary materials for welding stainless steel. Composition of materials fall into two categories - fused type and bonded type. The fused type is glasslike and is produced by melting the ingredients at high temperatures followed by crushing to granulate the flux. The bonded or agglomerated type is produced by mixing the ingredients with a suitable binder and baking' the mixture. Lincoln manufactures only bonded fluxes.

Welding Position: Vertical and Overhead
Weld Quality Level: Code
Steel Weldability: Good

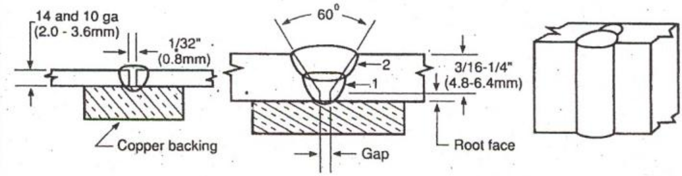
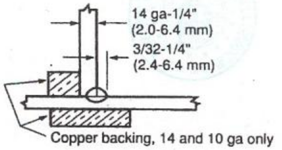


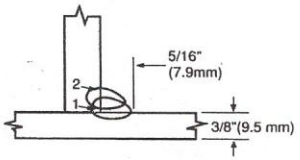
Plate Thickness (in.)	0.078 (14 ga)*	0.140 (10 ga)	3/16	1/4	
mm.	2.0	3.6	4.8	6.4	
Pass	1	1	1	1	2
Electrode Class	E3XX-15	E3XX-15	E3XX-15	E3XX-15	
Size in.	3/32	1/8	5/32	5/32	
mm.	2.4	3.2	4.0	4.0	
Current (amp) DC(+)	50	75	110	110	
Arc Speed (in./min.)	14 - 16	6.7 - 7.3	5.2 - 5.8	5.2 - 5.8	4.3 - 4.7
mm/sec.	5.9 - 6.8	2.8 - 3.1	2.2 - 2.5	2.2 - 2.5	1.8 - 2.0
Electrode Req'd (lb./ft.)	0.030	0.091	0.160	0.370	
kg/m.	0.045	0.136	0.238	0.551	
Total Time (hr./ft. of weld)	0.0133	0.0286	0.0364	0.0808	
hrs./m of weld	0.0436	0.0938	0.1194	0.2651	
Gap (in.)	0	0	1/16	3/32	
mm.	0	0	1.6	2.4	
Root face (in.)	0	0	1/16	1/16	
mm.	0	0	1.6	1.6	

*Vertical down, all others vertical up.

GO TO CONTENTS

Welding Position: Flat or Horizontal*
Weld Quality Level: Code
Steel Weldability: Good





Weld Size (in.)	3/32	1/8	3/16	1/4	5/16	
mm.	2.4	3.2	4.8	6.4	7.9	
Plate Thickness (in.)	0.078 (14 ga)	0.140 (10 ga)	3/16	1/4	3/8	
mm.	2.0	3.6	4.8	6.4	9.5	
Pass	1	1	1	1	1	2
Electrode Class	E3XX-16, E3XX-17	E3XX-16, E3XX-17	E3XX-16, E3XX-17	E3XX-16, E3XX-17	E3XX-16, E3XX-17	
Size in.	3/32	1/8	5/32	3/16	3/16	
mm.	2.4	3.2	4.0	4.8	4.8	
Current (amp) DC(+)	60	85	120	160	170	
Arc Speed (in./min.)	12.5 - 13.5	12.5 - 3.5	8.6 - 9.4	6.2 - 6.8	6.2 - 6.8	6.7 - 7.3
mm/sec.	5.3 - 5.7	5.3 - 5.7	3.6 - 4.0	2.6 - 2.9	2.6 - 2.9	2.8 - 3.1
Electrode Req'd (lb/ft)	0.036	0.056	0.120	0.220	0.430	
kg/m.	0.054	0.083	0.178	0.328	0.640	
Total Time (hr/ft of weld)	0.0154	0.0154	0.0222	0.0308	0.0594	
hrs/m of weld	0.051	0.051	0.073	0.101	0.195	

* For vertical and overhead use same procedures as for vertical and overhead butt welds.

Note: AC can be used with a 10% increase in current. E3XX-15 electrode can be used with a 10% decrease in current.

GO TO CONTENTS

Welding Position: Horizontal
Weld Quality Level: Code
Steel Weldability: Good

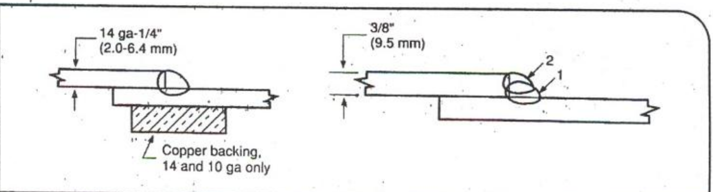


Plate Thickness (in.) / mm.	0.078 (14 ga) 2.0	0.140 (10 ga) 3.6	3/16 4.8	1/4 6.4	3/8 9.5	
Pass	1	1	1	1	1	2
Electrode Class	E3XX-16, E3XX-17	E3XX-16, E3XX-17	E3XX-16, E3XX-17	E3XX-16, E3XX-17	E3XX-16, E3XX-17	
Size in. / mm.	3/32 2.4	1/8 3.2	5/32 4.0	3/16 4.8	3/16 4.8	
Current (amp) DC(+)	60	90	125	170	175	
Arc Speed (in./min.) / mm/sec.	12.5 - 13.5 5.3 - 5.7	12.5 - 13.5 5.3 - 5.7	8.6 - 9.4 3.6 - 4.0	6.2 - 6.8 2.6 - 2.9	6.2 - 6.8 2.6 - 2.9	6.7 - 7.3 2.8 - 3.1
Electrode Req'd (lb/ft) / kg/m.	0.036 0.054	0.056 0.083	0.130 0.194	0.240 0.357	0.460 0.685	
Total Time (hr/ft of weld) / hrs/m of weld	0.0154 0.051	0.0154 0.051	0.0222 0.073	0.0308 0.101	0.0594 0.195	

The notes to fillet weld procedure also apply here.

Suggested procedures for SMAW of lap joints in austenitic stainless steel from 14 gauge (2.0mm) to 3/8 inch (9.5mm) thickness in the horizontal position.

Welding Position: Flat
Weld Quality Level: Code
Steel Weldability: Good

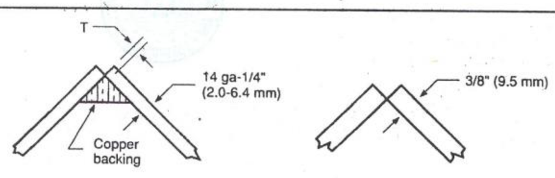
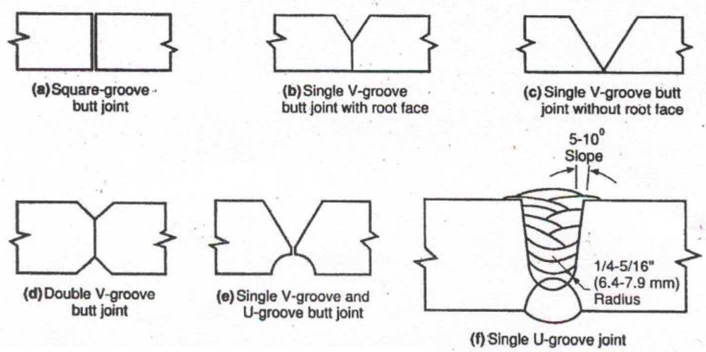


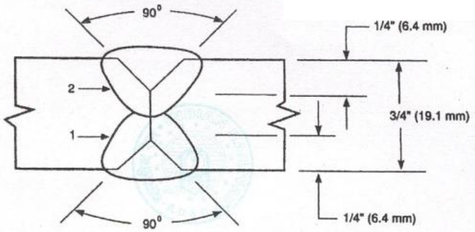
Plate Thickness (in.) / mm.	0.078 (14 ga) 2.0	0.140 (10 ga) 3.6	3/16 4.8	1/4 6.4	3/8 9.5	
Pass	1	1	1	1	1	2
Electrode Class	E3XX-16, E3XX-17	E3XX-16, E3XX-17	E3XX-16, E3XX-17	E3XX-16, E3XX-17	E3XX-16, E3XX-17	
Size in. / mm.	3/32 2.4	1/8 3.2	5/32 4.0	3/16 4.8	3/16 4.8	
Current (amp) DC(+)	60	85	125	160	160	175
Arc Speed (in./min.) / mm/sec.	14 - 16 5.9 -6.8	12.5 - 13.5 5.3 - 5.7	10.5 - 11.5 4.4 - 4.9	6.2 - 6.8 2.6 - 2.9	6.2 - 6.8 2.6 - 2.9	5.7 - 6.3 2.4 - 2.7
Electrode Req'd (lb/ft) / kg/m.	0.028 0.042	0.056 0.083	0.094 0.140	0.22 0.33	0.45 0.67	
Total Time (hr/ft of weld) / hrs/m of weld	0.0133 0.0436	0.0154 0.0505	0.0182 0.0597	0.0308 0.101	0.0641 0.210	
T (in.) / mm.	0.04 1.0	1/32 0.8	3/64 1.2	1/16 1.6	0 0	

AC can be used with a 10% increase in current. E3XX-15 electrode can be used with a 10% decrease in current.

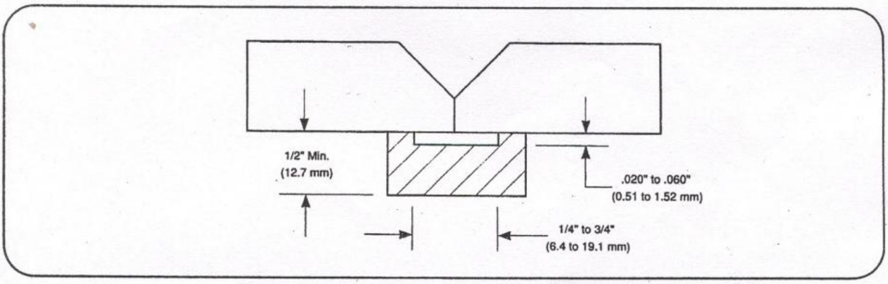
Suggested procedures for SMAW of corner joints in austenitic stainless steel from 14 gauge (2.0mm) to 3/8 inch (9.5mm) thickness in the flat position.



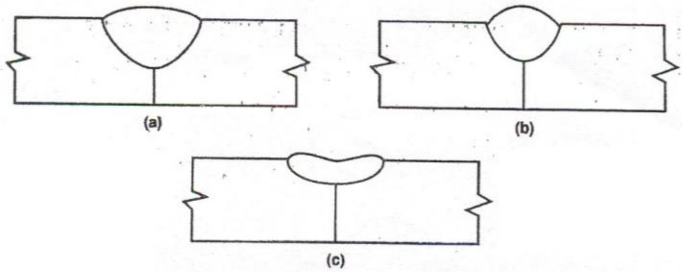
Butt joint designs for submerged-arc welding.



A typical double-V weld in Type 304 plate. Pass 1 was made at 700 amp, 33 volts, 16 ipm (6.8mm/sec); pass 2 at 950 amp, 35 volts, 12 ipm (5.1mm/sec). The power was DCRP; electrode 3/16-in. (4.8mm). Type 308; neutral flux.



Recommended groove dimensions for copper backing bars in the submerged arc welding of stainless steels.



(a) Contour of a weld bead in the flat position with the work horizontal; (b) welding slightly uphill; (c) welding slightly downhill.

Alloying elements can be added to the weld deposit through some bonded fluxes. These include chromium, nickel, molybdenum and niobium (columbium). If alloying additions to the flux are not made, the flux is called "neutral". The term neutral is only relative in that the alloy content of the weld is still altered by the flux. Lincoln flux ST-100 is an alloy flux for use with solid stainless steel electrodes. It contains chromium which helps compensate for chromium in the electrode that is oxidized in the arc and therefore not recovered in the weld deposit. Lincoln fluxes 801,802,880, 880M, 882, and Blue Max 2000 are neutral fluxes designed for welding with solid stainless steel electrodes. With Nb(Cb) - bearing stainless filler metal (such as ER347), slag removal is often best with Blue Max 2000 or 802 fluxes. Lincoln flux 860 is a neutral flux that can be used with 308L electrode for applications requiring a lower ferrite number. It should be noted that this combination will produce a tighter slag with surface slag sticking. Lincoln MIL – 800H flux can be used with ER308L filler metal to produce a 308H (0.04O.O8%C) deposit.

The composition ranges listed in AWS A5.9 are broad. Since com position profoundly affects weld quality and

GO TO CONTENTS

serviceability, the complete range of variations cannot always be tolerated in the deposit. To maintain control, the welding technique, alloy content of the flux or other appropriate changes should be made to compensate for variations in filler metal composition.

The several methods of starting the weld that are commonly in use include:

Scratch Start - In a scratch start, the wire is fed toward the work and the carriage travel is also started. When the wire touches the work, it will not fuse to the workpiece because of the relative motion of the carriage. This type *ot* starting is also called a "flying start."

Retract Starting - The wire is "inched" toward the work and covered with flux. When the weld is started, the wire retracts momentarily and then reverses to feed forward. This method is not recommended for light gauge stainless steel.

Once the arc is initiated, it is important to monitor the various parameters. Welding current is the most influential variable. Next in importance is welding voltage. Welding speed changes conform to a pattern; if the speed is increased, there is less weld reinforcement; if decreased, there is more weld reinforcement. In addition, weld speed can affect depth of penetration.

Cladding with Submerged Arc : SAW is normally a high dilution process, which is undesirable for cladding. A procedure that works well, however, is to change from the normal DC electrode positive polarity to DC electrode negative polarity, and to limit the wire feed speed to the low end of the normal range -e.g., 60 ipm wire feed for 1/8" electrode, or 80ipm for 3/32" electrode.

11.3 WELDING WITH THE GAS METAL ARC PROCESS

Stainless steels may be welded by the gas metal arc process, using either spray arc, short circuiting or pulsed arc transfer.

Copper backup strips are necessary for welding stainless steel sections up to 1/16 inch thick. Backup is also needed when welding 1/4 inch and thicker plate from one side only.

No air must be permitted to reach the underside of the weld while the weld puddle is solidifying.

Oxygen picked up by the molten metal may reduce the corrosion resistance and ductility of the stainless steel as it cools. To prevent this, the underside of the weld should be shielded by an inert gas such as argon. The shielding gas source can be built into the fixture Electrode diameters as large as 3/32 inch, but usually less than 1/16 inch, are used with relatively high currents to create the spray arc transfer. A current of approximately 300-350 amperes is required for a 1/16" electrode, depending on the shielding gas and type of stainless wire being used. The degree of spatter is dependent upon the composition and flow rate of the shielding gas, wire feed speed and the characteristics of the welding power supply. DCEP is used for most stainless steel GMA welding and an argon 1 or 2%-oxygen gas mixture is recommended. Suggested procedures for GMA welding 200 and 300 series stainless steels in the spray transfer mode are given in Figure

On square butt welds, a backup strip should be used to prevent weld metal drop-through. When fit up is poor or copper backing cannot be used, drop-through may be minimized by short circuiting transfer welding the first pass.

When welding with the semiautomatic gun, forehand ("pushing") techniques are beneficial. Although the operator's hand is exposed to more radiated heat, better visibility is obtained. .

For welding plate 1/4 inch and thicker, the gun should be moved back and forth in the direction of the joint and at the

same time moved. Slightly from side to side. On thinner metal, however, only back and forth motion along the joint is used. The more economical short circuiting transfer process for thinner material should be employed in the overhead and horizontal position for at least the root and first passes. Although some operators use a short digging spray arc to control the puddle, the weld may be abnormally porous.

Power supply units with slope, voltage and inductance controls are recommended for the welding of stainless steel with short circuiting transfer. Inductance, in particular, plays an important part in obtaining proper puddle fluidity.

Gas-Argon + 1% Oxygen.
Gas flow 35 cfh.
(16.5L/min.)

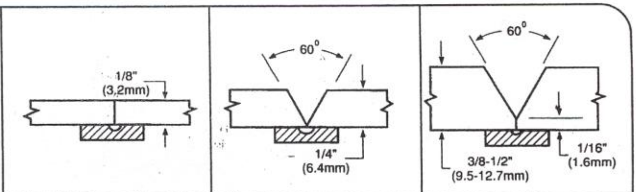


Plate Thickness (in.) mm.	1/8 3.2	1/4 6.4	3/8 9.5	1/2 12.7
Electrode Size in. mm.	1/16 1.6	1/16 1.6	1/16 1.6	3/32 2.4
Pass	1	2	2	4
Current DC(+)	225	275	300	325
Wire Feed Speed (ipm) mm/sec.	140 60	175 74	200 85	225 95
Arc Speed (ipm) mm/sec.	19 - 21 8.0 - 8.9	19 - 21 8.0 - 8.9	15 - 17 6.3 - 7.2	15 - 17 6.3 - 7.2
Electrode Required (lb/ft) kg./m	0.075 0.112	0.189 0.282	0.272 0.405	0.495 0.737
Total Time (hr/ft of weld) hr/m of weld.	0.010 0.033	0.020 0.066	0.025 0.082	0.050 0.164

Suggested procedures for GMAW of butt joints in 200 and 300 series stainless steels using the spray arc transfer mode.

The shielding gas often recommended for short circuiting welding of stainless steel contains 90% helium, 7.5% argon and 2.5% carbon dioxide. The gas gives the most desirable bead contour while keeping the CO2 level low enough so that is does not influence the corrosion resistance of the metal. High inductance in the power supply output is beneficial when using this gas mixture.

Single pass welds may also be made using argon-oxygen and argon-CO2 gas mixes. However, arc voltage for steady short circuiting transfer may be as much as 6 volts lower than for

the helium based gas. The colder arc may lead to lack of fusion defects. The CO2 in the shielding gas will affect the corrosion resistance of multipass welds made with short circuiting transfer due to carbon pickup.

Gasflow 15 to 20 cfh
(7.1 - 9.4 L/min.)
Helium, + 7-1/2% Argon,
+2-1/2% CO_2
Electrode 0.030 in. (0.8mm) dia.

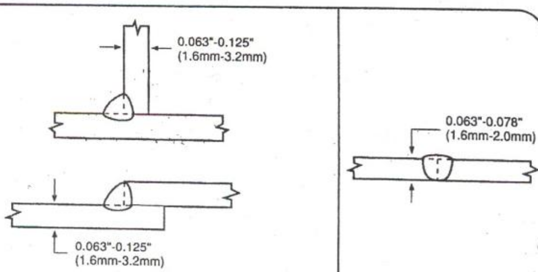
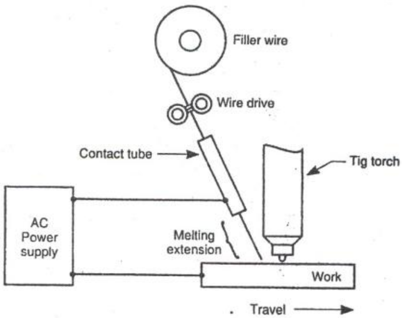


Plate Thickness (in.)	0.063	0.078	0.093	0.125	0.063	0.078*
mm.	1.6	2.0	2.4	3.2	1.6	2.0
Electrode Size in.	0.030	0.030	0.030	0.030	0.030	0.030
mm.	0.8	0.8	0.8	0.8	0.8	0.8
Current DC(+)	85	90	105	125	85	90
Voltage*	21 - 22	21 - 22	21 - 22	21 - 22	21 - 22	21 - 22
Wire Feed Speed (ipm)	184	192	232	280	184	192
mm/sec.	78	81	98	119	78	81
Welding Speed (ipm)	17 -19	13 - 15	14 - 16	14 - 16	19 - 21	11.5 - 12.5
mm/sec.	7.2 - 8.0	5.5 - 6.3	5.9 - 6.8	5.9 - 6.8	8.0 - 8.9	4.9 - 5.3
Electrode Required (lb/ft)	0.025	0.034	0.039	0.046	0.023	0.039
kg/m	0.037	0.051	0.058	0.069	0.034	0.058
Total Time (hr/ft of weld)	0.0111	0.0143	0.0133	0.0133	0.0100	0.0167
hr/m of weld	0.0364	0.0469	0.0436	0.0436	0.0328	0.0548

Suggested procedures for GMAW of butt joints and lap joints in 200 and 300 series stainless steels using the short circuiting transfer mode.



Schematic of the hot-wire system for the automatic TIG welding of stainless steels.

GO TO CONTENTS

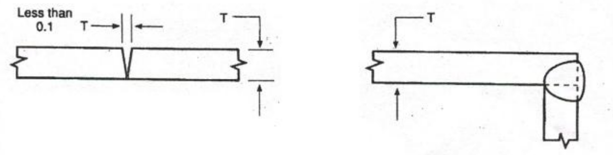


Plate Thickness (in.) mm.	1/16 1.6	3/32 2.4	1/8 3.2	3/16 4.8	1/4 6.4	1/2 12.7
Current DC(–)	80 - 100	100 - 120	120 - 140	200 - 250	200 - 350	225 - 375
Electrode Diameter (in.) mm.	1/16 1.6	1/16 1.6	1/16 1.6	3/32 2.4	1/8 3.2	1/8 3.2
Gas Flow, Argon (cfh) L/min..	10 4.7	10 4.7	10 4.7	15 7.1	20 9.4	25 11.8
Filler-Rod Diameter (in.) mm.	1/16 1.6	1/16 1.6	3/32 2.4	1/8 3.2	1/8 3.2	1/8 3.2
Arc Speed (ipm) mm/sec	12 5.1	12 5.1	12 5.1	10 4.2	8 3.4	8 3.4
Total Time (hr/ft of weld) hr/m. of weld	0.0167 0.0548	0.0167 0.0548	0.0167 0.0548	0.0200 0.0656	0.0250 0.0820	0.0250 0.0820

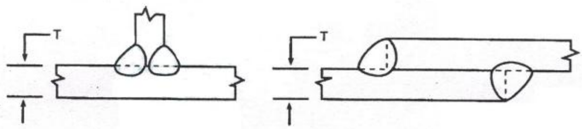


Plate Thickness, T (in.) mm.	1/16 1.6	3/32 2.4	1/8 3.2	3/16 4.8	1/4 6.4	1/2 12.7
Current DC(–)	90 - 110	110 - 130	130 - 150	225 - 275	225 - 350	225 - 375
Electrode Diameter (in.) mm.	1/16 1.6	1/16 1.6	1/16 1.6	3/32 2.4	1/8 3.2	1/8 3.2
Gas Flow, Argon (cfh) L/min..	10 4.7	10 4.7	10 4.7	15 7.1	20 9.4	25 11.8
Filler-Rod Diameter (in.) mm.	1/16 1.6	1/16 1.6	3/32 2.4	1/8 3.2	1/8 3.2	1/8 3.2
Arc Speed (ipm) mm/sec	10 4.2	10 4.2	10 4.2	8 3.4	8 3.4	8 3.4
Total Time (hr/ft of weld) hr/m. of weld	0.0200 0.0656	0.0200 0.0656	0.0200 0.0656	0.0250 0.0820	0.0250 0.0820	0.0250 0.0820

For vertical-up and overhead, decrease current 10 to 20%.

Suggested procedures for GTAW of butt, corner, tee and lap joints in stainless steels.

Wire extension or stick out should be kept as short as possible. Backhand welding is usually easier on fillet wire is kept centered over the non beveled edge of the joint.

Typical Travel Speeds and Deposition Rates with GTAW-Hot Wire

Wire Size: 1.2mm (0.045 in.)
Shielding Gas: 75% He, 25% A
Electrode: 4.0-4.8mm (5/32-3/16 in.) 2% Th

Arc Current Amps	Arc Voltage Volts	Travel Speed		Wire Speed Feed		Deposition Rate	
		mm/Sec	In/Min.	mm/Sec	In/Min.	Kg/Hr	Lbs/Hr
300	10 - 12	1.7 - 4.2	4 - 10	46 - 157	110 - 370	1.4 - 4.5	3 - 10
400	11 - 13	2.5 - 5.9	6 - 14	78 - 188	185 - 445	2.3 - 5.4	5 - 12
500	12 - 15	3.4 - 8.5	8 - 20	125 - 282	295 - 665	3.6 - 8.2	8 - 18

Parameters and procedures for welding 200 and 300 series stainless steels by the GMAW spray arc mode are given in Figures gives parameters and procedures for welding the 200 and 300 series stainless steels by the GMAW short circuiting mode.

11.4 WELDING WITH THE GAS TUNGSTEN ARC PROCESS

All stainless steel alloys that are considered weldable can be welded readily with the gas tungsten arc process (GTAW).

The preferred electrodes are thoriated, ceriated, or lanthanated tungsten as specified in AWS A5.12. The advantage of these electrodes is that they have a more stable arc and can be used with higher currents than pure tungsten electrodes.

The shielding gas is usually argon, but helium or mixtures of argon and helium are used on heavy sections. The advantages of argon are that flow rates can be lower, the arc is more stable and the arc voltage is somewhat less than with helium. The lower voltage makes it possible to weld thin sheet without burn through.

Filler materials for use with the gas tungsten arc process are in the form of solid wire available in coils for automatic welding or straight lengths for manual welding. These are specified in AWS A5.9 which also applies to filler material for Gas Metal Arc and Submerged Arc welding. Consumable

inserts, specified in AWS A5.30, are useful for root passes with gas tungsten arc.

The DC power source for gas tungsten arc welding must be a constant current type, and it is recommended that a high frequency voltage be superimposed on the welding circuit. The high frequency need be on only to start the arc. As the electrode is brought close to the work, the high frequency jumps the gap from the, tungsten to the work, and ignites the welding arc. Since the tungsten electrode does not, actually touch the work, the possibility of contaminating the stainless steel with tungsten is greatly reduced. Straight polarity (DC-) should be used - which produces a deep, penetrating weld.

A “scratch" start may be used in lieu of a high frequency start, although there is some possibility of tungsten pickup. The arc should not be struck on a carbon block because of the likelihood of carbon contamination.

Stainless steels are readily welded with automatic GTAW. Arc voltage is proportional to. arc length - thus a reliable signal can be generated to operate automatic arc voltage control equipment. Filler metal may be used, or light gauge material may be joined by simple fusion of the joint edges. When .cold" filler metal is used, it is always added to the front of the puddle.

The so called "hot wire" method of welding gives greatly increased deposition rates and welding speeds. The wire - which trails the torch, as illustrated in Figure 17 - is resistance heated by a separate AC power supply. It is fed through a contact tube and extends beyond the tube. The extension is resistance heated so that it approaches or reaches the melting point before it contacts the weld puddle. Thus; the tungsten electrode furnishes the heat to melt the base metal and the AC power supply furnishes a large portion of the energy needed to resistance melt the filler wire. The hot wire method is, in effect, an adaptation of the long , stick out principle used in submerged arc and self-shielded flux cored

GO TO CONTENTS

arc welding. The wire used for hot wire TIG welding is usually 0.045 inch diameter. Since the wire is melted or very nearly melted by its own power source, the deposition rate can be controlled almost independently of the arc.

Using the GTA hot wire method, deposition rates up to 18 Ib/hr can be achieved when welding at 400 to 500 amp DCEN (Table XVII). Still greater deposition rates can be obtained using an automatic oscillated welding technique. - Voltage control is essential to achieve control of the large puddle when welding at high deposition rates. For this reason, T1G hot wire welding requires the use of voltage control-equipment.

By using closely spaced multiple tungsten electrodes, the welding speed can also be increased substantially when GTA welding stainless steel tubing or sheet. Multiple electrodes practically eliminate the problem of undercutting at high speeds.

Procedures and parameters for GTA welding of stainless steel in thicknesses from 1/16 inch to 1/2 inch (1.6 to 12.7 mm) are given in Figure. These include butt, corner, tee and lap type joints.

Distortion Control in Austenitic, Precipitation Hardening, and Duplex Fenitic-Austenitic Stainless Steels

Austenitic Stainless steels have a 50% greater coefficient of expansion and 30% lower heat conductivity than mild steel. Duplex stainless steels are only slightly better. Allowance must be made for the greater expansion and contraction when designing austenitic stainless steel structures. More care is required to control the greater distortion tendencies. Here are some specific distortion control hints:

Rigid jigs and fixtures hold parts to be welded in proper alignment. Distortion is minimized by allowing the weld to cool in the fixture.

Copper chill bars placed close to the weld zone help remove

heat and prevent distortion caused by expansion. Back-up chill bars under welds and will result in a neater weld. Forehand welding should be used for butt welds. Outside corner welds may be made with a straight motion.

A slight backward and forward motion along the axis of the joint should be used. Figure summarizes the welding procedures normally used for the short circuiting transfer welding of stainless steel.

Short circuiting transfer welds on stainless steel made with a-shielding gas of 90% He, 7-1/2% A, 2-1/2% CO2 show good corrosion resistance and coalescence. Butt, lap and single fillet welds in material ranging from 0.060 inch to 0.125 inch in 304. 310,316,321,347,410 and similar stainless steels can be made successfully.

The pulsed arc process, as normally used, is a spray transfer process wherein one small drop of molten metal is transferred across the arc for each high current pulse of weld current. The high current pulse must be of sufficient magnitude and duration to cause at least one small drop of molten metal to form and be propelled by the pinch effect from the end of the wire to the weld puddle. During the low current portion of the weld cycle, the arc is maintained and the wire is heated, but the heat developed is not adequate to transfer any metal. For this reason, the time duration at the low current value must be limited otherwise metal would be transferred in the globular mode.

Wire diameters of 0.045 and 0.035 inch are most commonly used with this process. Gases for pulsed arc welding, such as argon plus 1 % oxygen are popular, the same as used for spray arc welding. These and other wire sizes can be welded in the spray transfer mode at a lower average current with pulsed current than with continuous weld current. The advantage of this is that thin material can be welded in the spray transfer mode which produces a smooth weld with less spatter than the short circuiting transfer mode. Another

advantage is that for a given average current, spray transfer can be obtained with a larger diameter" wire than could be obtained with continuous currents. Larger diameter wires are less costly than smaller sizes, and the lower ratio of surface to volume reduces the amount of deposit contamination.

The electrode diameters for gas metal arc welding are generally between 0.030 and 3/32 inch. For each electrode diameter, there is a certain minimum welding current that must be exceeded to achieve spray transfer. For example, when welding stainless steel in an argon-oxygen atmosphere with 0.045 inch diameter stainless steel electrode, spray transfer will be obtained at a welding current of about 220 amp DCRP. It must be kept in mind that, along with the minimum current, a minimum arc voltage must also be obtained. This is generally between 22 and 30 volts.

Electrodes come on spools varying in weight between 2 and 60 lb. Also available are electrodes for welding the straight chromium stainless steels and austenitic electrodes that contain more than the usual amount of silicon. The latter have particularly good wetting characteristics when used with the short circuiting transfer process.

Some stainless steel weld metals during welding have a tendency toward hot shortness or tearing when they contain little or no ferrite - Type 347, for example. When welding these, more welding passes than indicated in the procedures may be needed. Stringer bead techniques are also recommended rather than weaving or oscillating from side to side. Hot cracking maybe eliminated by stringer bead techniques since there is a reduction in contraction stresses, hence cooling is more rapid through the hot short temperature range. A procedure that tends to produce a more convex bead than normal can be very helpful, and care should be taken to fill craters.

Weld metal hot cracking may be reduced by short circuiting transfer welding, because of the lower dilution from the base

metal. Excessive dilution may produce a completely austenitic weld metal having strong cracking characteristics.

When welding magnetic stainless steels (ferritic and martensitic types) to the relatively nonmagnetic types (austenitic types), it is desirable to:

1. Use a single bevel joint to obtain minimum joint reinforcement.
2. Use low heat input short circuiting transfer to minimize the arc deflection encountered when welding magnetic to nonmagnetic steels.
3. For uniform fusion, be sure the wire is kept over the nonbeveled edge of joint.

Parameter and procedures for welding 200 and 300 series stainless steels by the GMAW spray arc mode are given in Figures gives parameter and procedures for welding the 200 and 300 series stainless steels by the GMAW short circuiting mode

OUR OBJECTIVE

To Upgrade Maintenance Technologies and Methodologies and achieve Improvement in Productivity and Performance of all Railway Assets and Manpower which Interalia would cover Reliability, Availability, Utilisation and Efficiency.

If you have any suggestions and any specific comments, please write to us :

Contact Person	**:**	**Director (Mech)**
Postal Address	**:**	Indian Railways , Centre for Advanced Maintenance Technology, Maharajpur,Gwalior.
Pin Code	**:**	474005
Phone	**:**	**0751-2470803, 2470890**
Fax	**:**	**0751-2470841**

GO TO CONTENTS