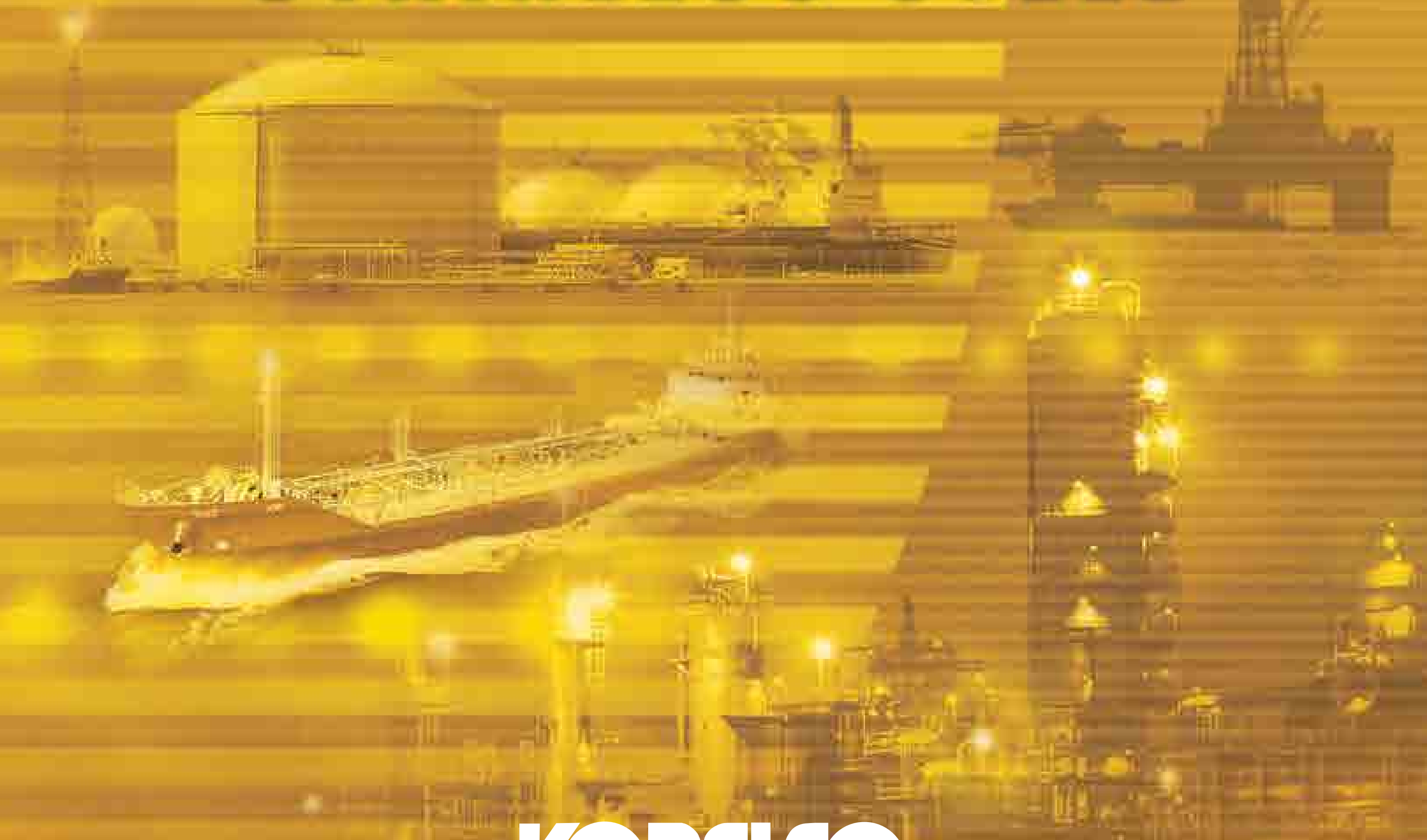
KOBELCO WELDING TODAY

2016 Special Edition

KOBELCO WELDING CONSUMABLES FOR
STAINLESS STEEL



KOBELCO

A Quick Guide to Suitable Stainless Steel and Nickel Alloy Welding Consumables

Steel alloy type	Key notes for application	FCAW		SMAW	
		Product name	AWS class.	Product name	AWS class.
304	General	**[P] DW-308** **[P] DW-308P**	E308T0-1/-4 E308T1-1/-4	**[P] NC-38**	E308-16
304H	High temperature operation	**[P] DW-308H**	E308HT1-1/-4 (Bi-free)	**[P] NC-38H**	E308H-16
304, 304L	Low carbon (0.04% max.); General	**[P] DW-308L** **[P] DW-308LP** **[P] DW-308LH**	E308LT0-1/-4 E308LT1-1/-4 E308LT1-1/-4 (Bi-free)	**[P] NC-38L**	E308L-16
	304, 304L Gauge plate	**[P] DW-T308L**	E308LT0-1/-4	---	---
	Low Cr(VI) in fume	**[P] DW-308L-XR** **[P] DW-308LP-XR**	E308LT0-1/-4 E308LT1-1/-4	---	---
	Cryogenic temperature (27J min./−196°C)	**[P] DW-308LTP** **[P] DW-308LT**	E308LT1-1/-4 E308LT0-1/-4	**[P] NC-38LT**	E308L-16
	TIG rod for root pass welding without back purging gas	---	---	---	---
316, 316L	General	**[P] DW-316L** **[P] DW-316LP** **[P] DW-316H**	E316LT0-1/-4 E316LT1-1/-4 E316LT1-1/-4 (Bi-free)	**[P] NC-36** **[P] NC-36L**	E316-16 E316L-16
	Gauge plate	**[P] DW-T316L**	E316LT0-1/-4	---	---
	Low Cr(VI) in fume	**[P] DW-316L-XR** **[P] DW-316LP-XR**	E316LT0-1/-4 E316LT1-1/-4	---	---
	High temperature operation	**[P] DW-316H**	E316T1-1/-4 (Bi-free)	---	---
	Cryogenic temperature (27J min./−196°C)(316L)	**[P] DW-316LT**	E316LT1-1/-4	**[P] NC-36LT**	E316L-16
	316L Mod.; Urea (low ferrite content)	---	---	**[P] NC-316MF**	---
	TIG rod for root pass welding without back purging gas	---	---	---	---
Dissimilar metal and overlay welding	General	**[P] DW-309L** **[P] DW-309LP** **[P] DW-309LH**	E309LT0-1/-4 E309LT1-1/-4 E309LT1-1/-4 (Bi-free)	**[P] NC-39** **[P] NC-39L**	E309-16 E309L-16
	Gauge plate	**[P] DW-T309L**	E309LT0-1/-4	---	
	Low Cr(VI) in fume	**[P] DW-309L-XR** **[P] DW-309LP-XR**	E309LT0-1/-4 E309LT1-1/-4	---	
	TIG rod for root pass welding without back purging gas	---	---	---	---
	General	**[P] DW-309MoL** **[P] DW-309MoLP**	E309LMoT0-1/-4 E309LMoT1-1/-4	**[P] NC-39MoL**	E309LMo-16
	High ferrite content	**[P] DW-312**	E312T0-1/-4	**[P] NC-32**	E312-16
310, 310S	General	**[P] DW-310**	E310T0-1/-4	**[P] NC-30**	E310-16
321, 347	General	**[P] DW-347**	E347T0-1/-4	**[P] NC-37**	E347-16
	High temperature operation	**[P] DW-347H**	E347T1-1/-4 (Bi-free)	---	---
	Low carbon	**[P] DW-347LH**	E347T1-1/-4 (Bi-free)	**[P] NC-37L**	E347L-16
	TIG rod for root pass welding without back purging gas	---	---	---	---
317L	General	**[P] DW-317L** **[P] DW-317LP** **[P] DW-317LH**	E317LT0-1/-4 E317LT1-1/-4 E317LT1-1/-4 (Bi-free)	**[P] NC-317L**	E317L-16
Duplex stainless steel	Lean duplex (ASTM S32101, S32304)	**[P] DW-2307**	E2307T1-1/-4	---	---
	Standard duplex (ASTM S31803, S32205)	**[P] DW-2209** **[P] DW-329AP**	E2209T1-1/-4 E2209T1-1/-4	**[P] NC-2209**	E2209-16
	TIG rod for root pass welding without back purging gas	**[P] TG-X2209**	---	---	---
	Super duplex (ASTM S32750, S32760)	**[P] DW-2594**	E2594T1-1/-4	**[P] NC-2594**	E2594-16
410	General	---	---	**[P] CR-40**	E410-16
13Cr-4Ni	Martensitic stainless steel for hydro turbine	**[P] DW-410NiMo** **[P] MX-A410NiMo**	E410NiMoT1-1/-4 EC410NiMo	**[P] CR-410NM**	E410NiMo-16
405, 409	Ferritic 13Cr-Nb	**[P] DW-410Cb**	E409NbT0-1	**[P] CR-40Cb**	E409Nb-16
	Buffer layer for 13Cr overlay welding	**[P] DW-430CbS**	E430NbT0-1	**[P] CR-43Cb** **[P] CR-43CbS**	E430Nb-16 ---
430	17Cr-Nb for car exhaust system	**[P] MX-A430M**	---	---	---
Ni alloy	Alloy 625 and 825; Overlay welding; dissimilar joint	**[P] DW-N625**	ENiCrMo3T1-1/-4	**[P] NI-C625**	---
	Cladding and girth welding of clad pipe (5G, 6G)	**[P] DW-N625P**	ENiCrMo3T1-1/-4	**[P] NI-C625**	---
	Alloy 600 and 800; Dissimilar joint	**[P] DW-N82**	ENiCr3T0-4	**[P] NI-C70A**	ENiCrFe-1
	Alloy C276	**[P] DW-NC276**	ENiCrMo4T1-4	---	---
9% Ni	LNG storage tank	**[P] DW-N70S** **[P] DW-N709SP** **[P] DW-N625**	--- ENiMo13T1-4/T0-1 ENiCrMo3T1-1/-4	**[P] NI-C70S** **[P] NI-C1S**	ENiCrFe-9 ENiMo-8

(1) [P] designates PREMIARC™

GTAW	
Product name	AWS class.
[P] TG-S308	ER308
–––	–––
[P] TG-S308L	ER308L
–––	–––
–––	–––
[P] TG-S308L	ER308L
[P] TG-X308L	R308LT1-5
[P] TG-S316	ER316
[P] TG-S316L	ER316L
–––	–––
–––	–––
–––	–––
[P] TG-S316L	ER316L
[P] NO4051	–––
[P] TG-S310MF	–––
[P] TG-X316L	R316LT1-5
[P] TG-S309	ER309
[P] TG-S309L	ER309L
–––	–––
–––	–––
[P] TG-X309L	R309LT1-5
–––	–––
–––	–––
[P] TG-S310	ER310
[P] TG-S347	ER347
–––	–––
[P] TG-S347L	ER347L
[P] TG-X347	R347T1-5
[P] TG-S317L	ER317L
–––	–––
[P] TG-S2209	ER2209
[P] TG-X2209	–––
[P] TG-S2594	ER2594
[P] TG-S410	ER410
–––	–––
[P] TG-S410Cb	–––
–––	–––
–––	–––
[P] TG-S625	ERNiCrMo-3
–––	–––
[P] TG-S70NCb	ERNiCr-3
–––	–––
[P] TG-S709S	ERNiMo-8

Steel alloy type	Key notes for application	GMAW		SAW	
		Product name	AWS class	Product name	AWS class (wire)
304	General	**[P] MG-S308**	ER308	**[P] PF-S1 / [P] US-308**	ER308
304L	General	**[P] MG-S308LS**	ER308LSi	**[P] PF-S1 / [P] US-308L**	ER308L
316, 316L	General	**[P] MG-S316LS**	ER316LS	**[P] PF-S1M / [P] US-316** (Single pass) **[P] PF-S1 / [P] US-316** (Multi pass) **[P] PF-S1M / [P] US-316L** (Single pass) **[P] PF-S1 / [P] US-316L** (Multi pass)	ER316 ER316 ER316L ER316L
Dissimilar metal and overlay welding	General	**[P] MG-S309**	ER309	**–––**	–––
321, 347	General	**[P] MG-S347S**	ER347Si	**[P] PF-S1 / [P] US-347**	ER347
317L	General	**–––**	–––	**[P] PF-S1 / [P] US-317L**	ER317L
Duplex stainless steel	Standard duplex (ASTM S31803, S32205)	**–––**	–––	**[P] PF-S1D / [P] US-2209**	ER2209
410	General	**[P] MG-S410**	ER410	**–––**	–––
9% Ni	LNG storage tank	**–––**	–––	**[P] PF-N4 / [P] US-709S** (Horizontal position) **[P] PF-N3 / [P] US-709S** (Flat position)	ERNiMo-8 ERNiMo-8

1. The ferrite numbers or percentage indicated by FN, FNW or FS in this brochure are:
   FN: ferrite number by DeLong Diagram
   FNW: ferrite number by WRC (Welding Research Council) Diagram-1992
   FS: ferrite percentage by Schaeffler Diagram
2. Inconel is the trademark of Special Metals Corporation, Hastelloy, the trademark of Haynes International, Inc. and SUPER304H, the trademark of Nippon Steel & Sumitomo Metal Corporation, respectively.
3. Abbreviations and marks
   (1) AWS: American Welding Society
   (2) Welding positions
      F: flat
      HF: horizontal fillet
      VU: vertical upward or vertical uphill
   (3) Welding procedures
      FCAW: Flux Cored Arc Welding
      SMAW: Shielded Metal Arc Welding
      GTAW: Gas Tungsten Arc Welding
      GMAW: Gas Metal Arc Welding
      SAW: Submerged Arc Welding
      ESW: Electroslag Welding
   (4) FCW: Flux Cored Wire

Austenitic stainless steel welding consumables for general use (Types 308L, 316L and 309L)

1. General

The austenitic stainless steel welding consumables are typically of the 308 L, 316 L and 309 L types. Type 308L is used for welding 304 or 304L stainless steels. Type 316L is for welding 316L stainless steel, while type 309 L is for welding dissimilar metals, under-laying on ferritic steels or buffer-laying on clad steels (Table 1).

Table 1: Austenitic stainless steel welding consumables

Base metal	Type	FCAW (AWS A5.22)	SMAW (AWS A5.4)	GTAW (AWS A5.9)
304, 304L	308L (20Cr-10Ni)	**DW-308L** **DW-308LP** (E308LT)	**NC-38L** (E308L-16)	**TG-S308L** (ER308L)
316, 316L	316L (18Cr-12Ni-2.5Mo)	**DW-316L** **DW-316LP** (E316LT)	**NC-36L** (E316L-16)	**TG-S316L** (ER316L)
Carbon steel / 304L (Carbon steel / 304)	309L (24Cr-12Ni)	**DW-309L** **DW-309LP** (E309LT)	**NC-39L** (E309L-16)	**TG-S309L** (ER309L)

Austenitic stainless steels have a single phase austenitic structure due to heat treatment during the steelmaking process, while austenitic stainless steel welding consumables contain 5 to 15% ferrite to prevent hot cracking during welding. Typical microstructures of both 304L stainless steel base metal and NC-38L weld metal are shown in Figures 1 and 2, respectively.

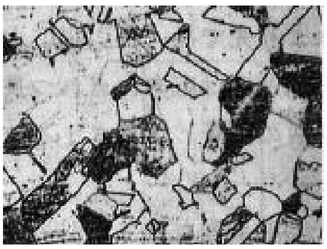


Figure 1: Microstructure of 304L type base metal (fully austenitic structure)

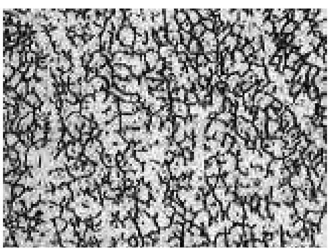


Figure 2: Microstructure of 308L weld metal (austenite +ferrite)

The ferrite content in weld metal can be calculated from the chemical composition of weld metal by using Schaeffler, De Long or WRC-1992 diagrams. All three diagrams plot the Nickel equivalent, made up of austenite forming elements such as C, Mn, Ni and N, against the Chromium equivalent, which represents the ferrite forming elements such as Cr, Mo, Si and Mn, in the weld metal.

The Schaeffler diagram (Figure 3) classifies microstructures with Ni and Cr equivalents in a wide range. Therefore, it can estimate ferrite content as well as weldability and crack resistance prior to performing dissimilar welding between stainless and carbon steel. However, in the case of weld metals with a high ferrite microstructure, such as E309L, the Schaeffler diagram will tend to show a larger deviation than a Feritscope, as shown in Figure 4.

The DeLong diagram (Figure 5) enables a more precise calculation of ferrite content by using a Ferrite Number (FN) in the range of 0 to 18, though the applicable chemical composition range is narrower than that of the Schaeffler diagram.

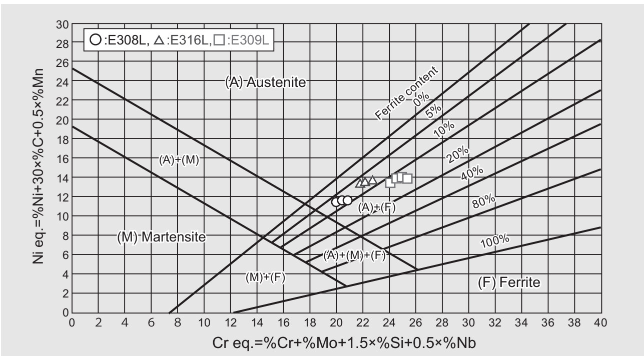


Figure 3: Schaeffler diagram

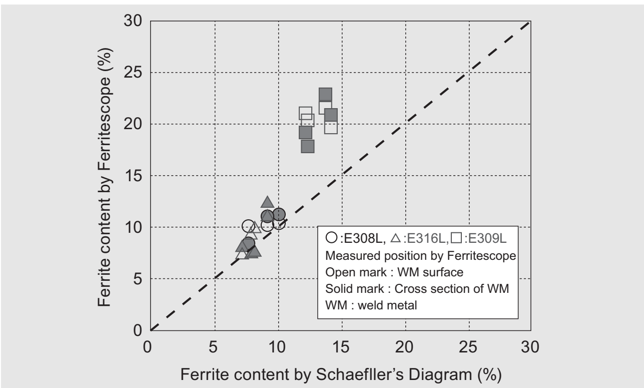


Figure 4: Comparison of ferrite content between Schaeffler diagram and Feritscope

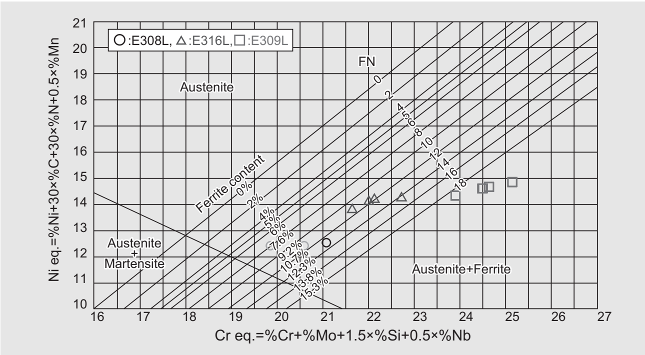


Figure 5: DeLong diagram

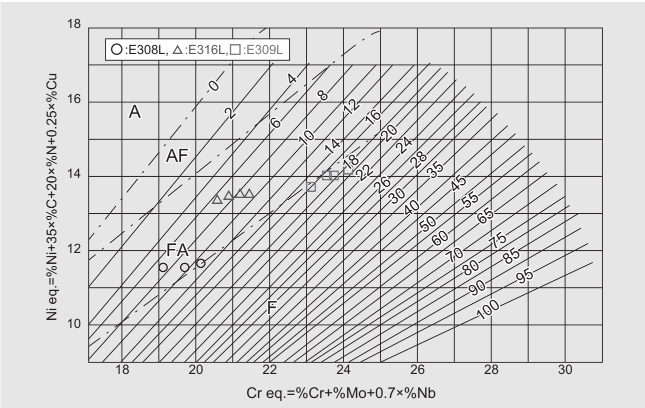


Figure 6: WRC-1992 diagram

The WRC-1992 diagram (Figure 6) allows one to estimate the ferrite content in the weld metals of E309L as well as duplex stainless steel, which is quite high in ferrite content.

Table 2 shows Huey corrosion test results (65% nitric acid test) of all weld metals with 308 and 316 type stainless steel welding consumables. In the Huey test, specimens are boiled in a 65% nitric acid solution, and the intergranular corrosion susceptibility resulting from precipitation of chromium (Cr) carbides and σ phase is evaluated.

Type 308 or 316 stainless steel weld metals, which contain higher Cr content, have better corrosion resistance against such oxidizing acids as nitric acid. On the other hand, they also experience reduced intergranular corrosion resistance when kept at the temperature range between 600 and 800°C for extended periods because C in the weld metal combines with Cr to form Cr carbides. This is known as sensitization. AWS and other bodies specify low carbon welding consumables in order to raise intergranular corrosion resistance.

Sensitized weld metals can have corrosion resistance restored through quenching, which dissolves the Cr carbides by first heating the weld metal to about 1050°C and then cooling it rapidly.

Table 2: Huey corrosion test results of all weld metal (65% nitric acid test)

Product name	Chemical composition (mass %)						ipm (inch/month)		
	C	Si	Mn	Ni	Cr	Mo	As-welded	650°C×2hrs AC*1	1050°C×30min WQ*2
NC-38	0.05	0.41	1.5	9.3	19.8	−	0.00056	0.00095	0.00044
NC-38L	0.03	0.37	1.5	9.5	19.8	−	0.00052	0.00069	0.00047
NC-36	0.06	0.4	1.5	12.2	19.2	2.2	0.00171	−	−
NC-36L	0.03	0.4	1.5	12.0	19.2	2.1	0.00138	−	−

*1: Air-cooling
*2: Water quenching

Table 3: General corrosion test results of NC-36L all weld metal by 5% diluted sulfuric acid (JIS G0591)

PWHT	Corrosion weight loss (g/m2・h)
As-welded	5
650°C×2hrs; AC*1	9
1050°C×30min; WQ*1	6

*1: Air-Cooling
*2: Water Quenching

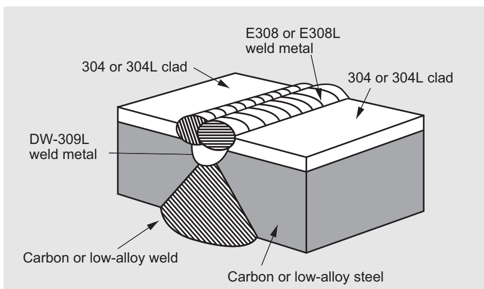
On the other hand for such reducing acids as hydrochloric or sulfuric acids, the addition of Ni, Mo and/or Cu increases corrosion resistance, and this has led to the development of 316 type stainless steels.

2. 309L type welding consumables

Most structures and equipment in oil refineries, chemical plants, power generation plants, chemical tankers, liquefied gas plants and carriers, and food processing plants consist of dissimilar metal joints and clad steel components on different scale. This is to minimize the material costs and maximize performance.

Type 309L stainless steel welding consumables are designed so that the weld metals can accommodate the adverse effects caused by dilution of carbon or low-alloy base metals. These adversities include the formation of martensite (a brittle structure) as well as austenitic structure, which, as non-ferrite-bearing austenite, is sensitive to hot cracking. Type 309L stainless steel welding consumables are thus suitable for dissimilar metal joints, which can contain various combinations of austenitic stainless steel and carbon or low alloy steels as shown in Figures 7 and 8.

Figure 7: Under-laying on ferritic steel part of clad steel



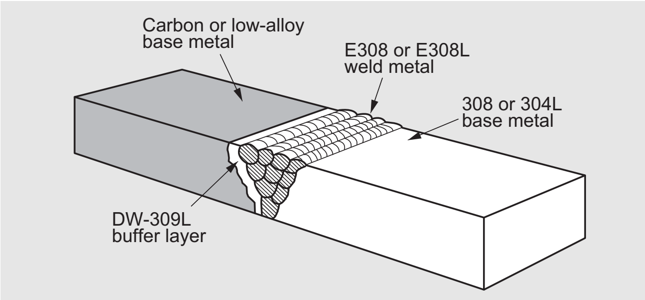


Figure 8: Buffer-laying of dissimilar metal joint

3. Welding processes

In addition to securing the required quality, welding procedures must be performed within a specified time and budget. One way to select an appropriate welding process is to compare the deposition rates of GTAW, SMAW, FCAW, SAW as well as the respective advantages and disadvantages of each process. Figure 9 shows the deposition rate of each welding process as a function of welding current and Figure 10, the optimum range of their welding parameters.

Kobe Steel provides two types of FCWs for stainless steels: one for flat and horizontal fillet welding and the other for all-position welding including vertical, horizontal and overhead positions. FCWs for flat and horizontal fillet welding can provide the beautiful bead appearance particular to stainless steel because they allow bead surfaces to be covered with uniform slag as shown in Figure 11. All-position welding by DW-308LP is shown in Figures 12.

In addition, Kobelco FCWs provide stable arc due to that their smooth wire feeding minimizes the arc length fluctuation as well as little spatter and fume generation. The spatter generation comparison and the fume emission rate comparison between DW-308L and the same 308L type FCWs from other supplier are shown in Figures 13 and 14, respectively.

Welding stainless steel in vertical and overhead positions is considered to be more difficult than mild steel because its molten metal was more likely to drop. This is due to the differences in the physical properties of stainless steel: it has a lower melting point (1400-1427°C) than mild steel (1500-1527°C), and less thermal conductivity (0.04 cal/cm/sec/°C in the 0-100°C range as opposed to 0.11 cal/cm/sec/°C in the 0-100°C range).

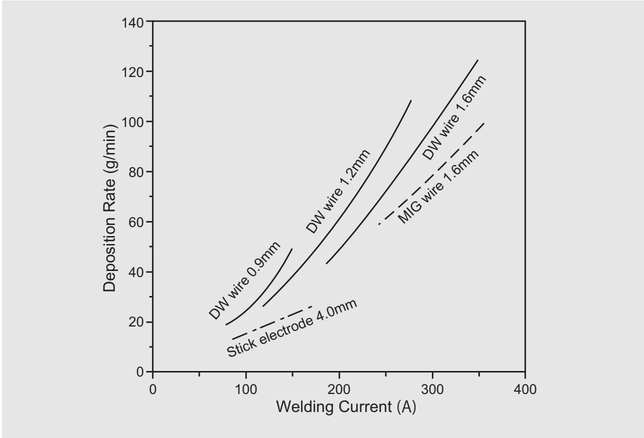


Figure 9: Deposition rate as a function of welding current

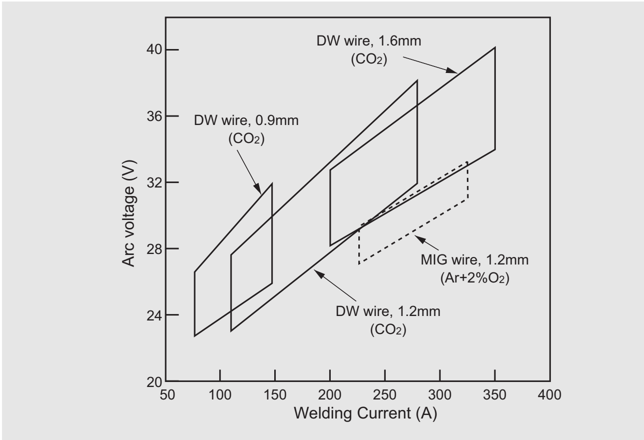


Figure 10: Optimum ranges of welding current and arc voltage

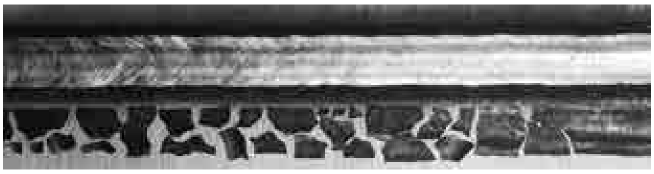


Figure 11: Bead appearance of DW-308L horizontal fillet welding by DW-308L

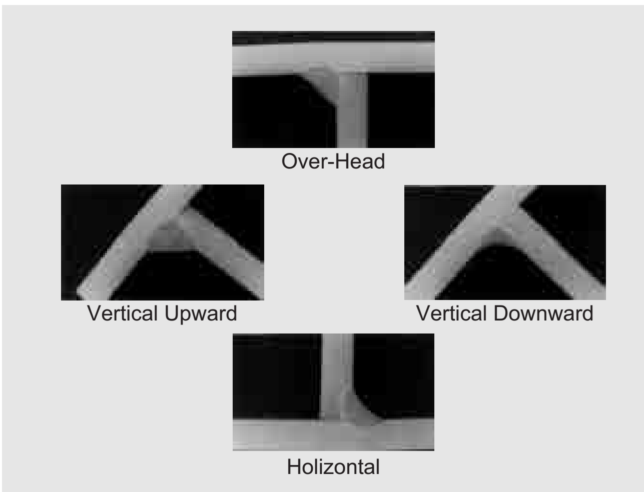


Figure 12: Cross-section of macrostructure of DW-308LP fillet weld (304L base plate of 3 mm thick)

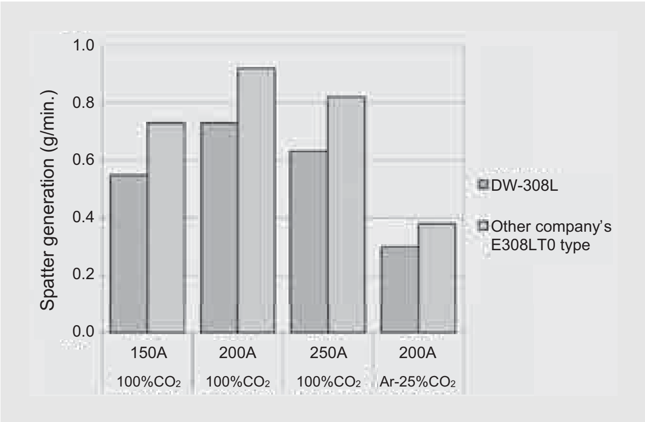


Figure 13: Spatter generation comparison

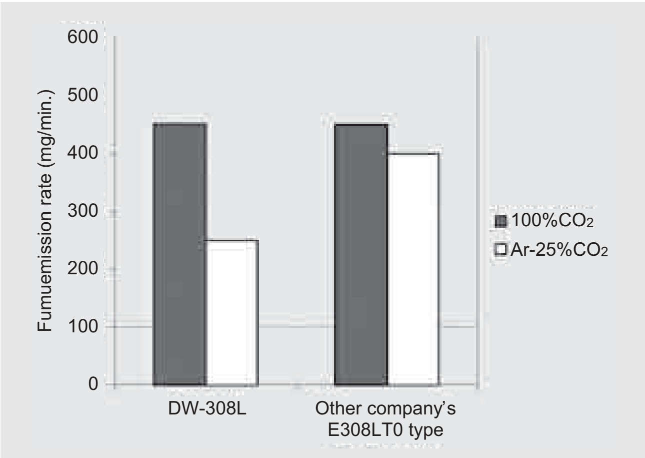


Figure 14: Fume emission rate comparison

4. General applications of FCAW

4.1 Butt joint welding

Applicable plate thicknesses are 2mm or more with a 1.2mm dia. wire and 5mm or more with a 1.6mm dia. wire in flat position. P-series FCWs enable welding of thin plates with 3-4mm thickness in vertical position.

One-side welding can be applied to a single V-shape groove with a 3-4 mm root opening in flat, horizontal and vertical positions by using a backing material of FBB-3 (T size).

4.2 Horizontal fillet welding

A welding speed of approximately 30-70 cm/min is recommended to obtain smooth bead appearance and sufficient penetration in horizontal fillet welding. With a type 309 FCW, dissimilar-metal welding of stainless steel against carbon steel can be performed with the same welding conditions as used for stainless steel welding. In order to secure the optimum ferrite content, however, the welding current should be 200A or less and the welding speed, 40 cm/min or slower with a 1.2 mm dia. FCW.

4-3 Overlay and clad-steel welding

The first layer of overlay welding onto a carbon steel base metal should be welded with a 309 (or 309MoL) FCW by the half lapping method. If dilution by the base metal is excessive, the ferrite content of the weld metal decreases and hot cracking may occur. Therefore, it is important to use appropriate welding conditions to control dilution, particularly, on the first layer. In order to obtain the proper dilution ratio, welding currents should be 200A or lower and welding speed, 20-40 cm/min with a 1.2 mm dia. FCW. With a 1.6 mm dia. FCW, use welding currents in the 200-250 A range and welding speeds, in the 20-30 cm/min range (see Figures 15 and 16).

Figure 15: Dilution ratio as a function of welding current (1.2mm dia.)

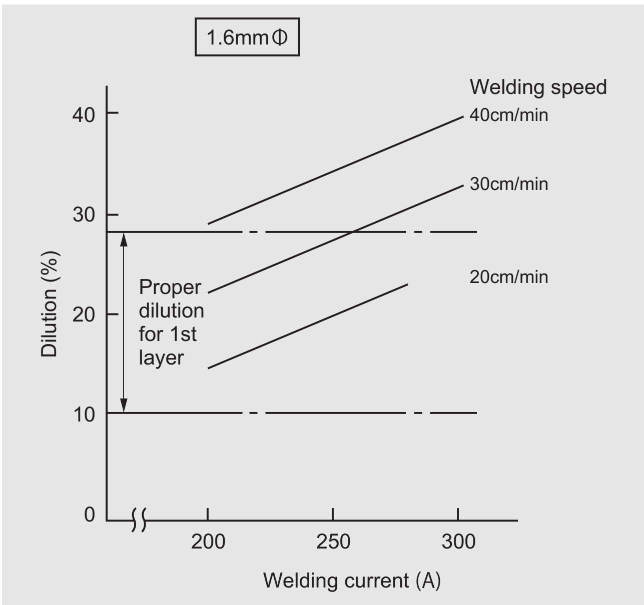


Figure 16: Dilution ratio as a function of welding current (1.6mm dia.)

Consumables for overlay welding of pressure vessels (Types 347 and 317L stainless steels)

1. Preface

Pressure vessels such as nuclear reactors and oil refining reactors (for desulfurization) are generally comprised of less expensive, high strength low alloy steels. In order to ensure appropriate corrosion resistance, however, the insides of these pressure vessels are overlay-welded with austenitic stainless steel welding consumables.

When a facility like a desulfurization reactor that handles hydrogen sulfide under high temperature and pressure is out of operation, polythionic acid is often generated and may cause stress corrosion cracks (SSC). Therefore, on an internal structure or an overlay weld, type 347 stainless steel is commonly used, instead of conventional austenitic stainless steel. Type 347 steel is able to prevent intergranular corrosion because it includes niobium (Nb) in its composition.

Type 317L stainless steel can also be used for reactors handling oil rich in sulfur (S).

2. Overlay welding procedure

A number of welding methods are applied in the internal welding of desulfurization reactors as shown in Figure 1. Strip overlay welding is an efficient process for such large-sized reactors, while automatic GTAW is used for the insides of small-diameter nozzles. FCAW/SMAW is applied for overlay welding of butt joint parts and also for assembling internal equipment.

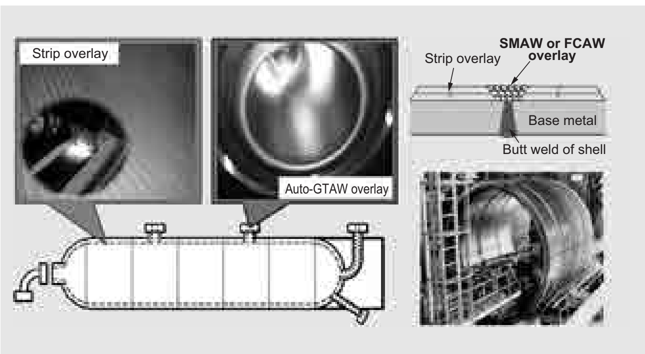
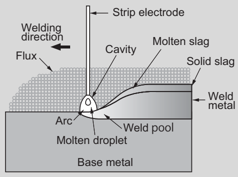
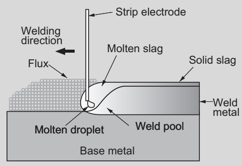
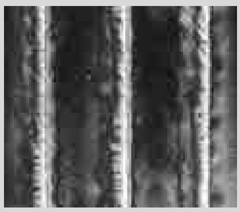
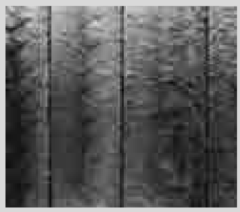


Figure 1: Schematic view of pressure vessel and overlay welding

Table 1: Concepts of overlay welding processes (SAW and ESW) with strip electrodes

Process	SAW	ESW
Schematic view		
Arc generation	Yes	No
Electrode melted by	Arc heat	Heat of molten slag resistance
Dilution ratio	15-20%	5-10%
Magnetic control	Not possible	Possible
Bead appearance		
Cross-sectional macrostructure (Overlapped connection part)		

SAW and ESW are two methods for carrying out strip overlay welding, the process that accounts for the largest consumption of welding consumables. Among the differences between the two methods (see Table 1), the most significant is that SAW generates an arc that melts the strip, while ESW melts the strip via the electric resistance of molten slag. SAW requires less heat input than ESW, resulting in low susceptibility to hydrogen-induced disbonding. On the other hand, with ESW, a low base metal dilution ratio produces low carbon weld metal with superb corrosion resistance. It also provides a smooth overlapped connection, especially when magnetic control is applied.

3. Properties of Kobelco overlay welding consumables

Pressure vessels usually require post-weld heat treatment (PWHT) during fabrication for stress relief (SR) of low alloy base metals and quality improvement of the materials. However, the applied PWHT temperature can produce harmful intermetallic compounds or precipitates in the weld metals, leading to embrittlement and reduced corrosion resistance. It is therefore necessary to control both welding consumables and welding procedures in order to obtain optimum chemical compositions and ferrite content on the overlay weld metal.

Table 2 shows all weld metal chemical compositions of type 347 welding consumables, Table 3, austenitic stainless steel welding consumables for strip overlay welding and Table 4, chemical compositions of type 347 welding consumables for strip overlay welding.

As all of Kobelco welding consumables are optimized in terms of chemical compositions and ferrite content, they perform well against cracking and embrittlement during PWHT. While it is well known that Nb in type 347 stainless steel has an adverse effect on slag removal, Kobelco's type 347 consumables are designed for superb slag removability as shown in Table 1.

Table 2: All weld metal chemical compositions of type 347 stainless steel welding consumables

Process		GTAW		SMAW		FCAW
Product name		**TG-S347**	**TG-S347L**	**NC-37**	**NC-37L**	**DW-347**
AWS class.		A5.9 ER347	A5.9 ER347L	A5.4 E347-16	A5.4 E347L-16	A5.22 E347T0-1/4
Polarity		DCEN		AC or DCEP		DCEP
Shielding gas		100%Ar		–	–	CO_2 or $Ar+CO_2$
Chemical compositions of all weld metal (mass %)	C	0.05	0.03	0.06	0.04	0.02
	Si	0.40	0.39	0.55	0.58	0.37
	Mn	2.1	1.5	1.5	2.3	1.2
	Ni	10.0	9.4	10.1	9.7	10.3
	Cr	19.3	18.9	19.6	19.1	18.3
	Mo	0.07	0.11	0.04	0.03	0.06
	Nb	0.60	0.66	0.67	0.59	0.60
FN		6	10	8	8	5
FNW		7	10	6	8	5

SMAW and FCAW: All weld metal of AC and 100%CO_2, respectively.

Table 3: Welding consumables for strip overlay welding

Application \ Process		SAW		ESW	
		Strip *2	Flux	Strip *2	Flux
Type 308L	Single layer	–	–	**US-B309L**	**PF-B7FK**
	Double layer *1	**US-B308L**	**PF-B1**	**US-B308L**	**PF-B7FK**
Type 316L	Double layer *1	–	–	**US-B316EL**	**PF-B7FK**
Type 317L	Double layer *1	–	–	**US-B317L**	**PF-B7FK**
Type 347	Single layer	**US-B347LP**	**PF-B1FP**	**US-B309LCb**	**PF-B7FK**
				US-B24.13LNb	**PF-B7HM**
	Double layer *1	**US-B347LD**	**PF-B1FK**	**US-B347LD**	**PF-B7FK**
Buffer layer		**US-B309L**	**PF-B1**	**US-B309L**	**PF-B7FK**

*1 Double layer: The first layer of the double layer requires buffer layer welding with a type 309L stainless steel welding consumable.
*2 Strip size: 0.4mm thick × 25, 50 and 75 mm wide or 0.5mm thick × 30, 60 and 90 mm wide

Table 4: Chemical compositions of type 347 stainless steel welding consumables for strip overlay welding

Process		SAW		ESW		
Application		Single layer	Double layer	Single layer		Double layer
Product name		**US-B347LP /PF-B1FP**	**US-B347LD /PF-B1FK**	**US-B309LCb /PF-B7FK**	**US-B24.13LNb /PF-B7HM**	**US-B347LD /PF-B7FK**
Base metal or buffer layer		ASTM A387 Gr 22	**US-B309L /PF-B1**	ASTM A387 Gr 22		**US-B309L /PF-B7FK**
Chemical compositions of cladding weld metal (mass %)	C	0.05	0.04	0.03	0.04	0.03
	Si	0.58	0.50	0.60	0.49	0.42
	Mn	1.4	1.3	1.8	1.4	1.8
	Ni	10.0	10.4	10.7	9.6	10.1
	Cr	19.4	19.4	19.2	18.7	18.5
	Mo	0.19	0.04	0.12	0.28	0.03
	Nb	0.53	0.53	0.50	0.56	0.53
FN		9	8	8	8	5
FNW		7	7	7	8	6

4. Special care for overlay welding

When overlay welding is conducted on carbon or low alloy steels, the base metal dilution ratio may fluctuate depending on the welding parameters used at the first layer, causing changes in chemical compositions from what is required in the weld metal. Figure 2 shows the influence of welding speed on weld thickness and dilution ratio in strip overlay welding. It can be seen that the base metal dilution ratio varies greatly according to changes in welding speed. It is, therefore, necessary to confirm the welding conditions in advance such as welding current, and strip stick-out length.

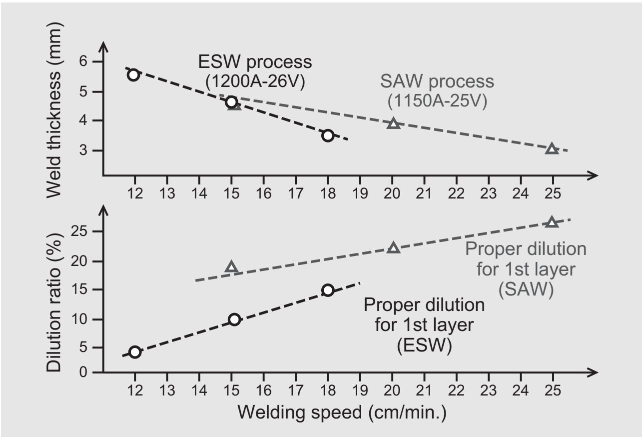


Figure 2: Influence of welding speed (Strip electrode width: 75mm)

Welding standard, super and lean duplex stainless steels: AWS E(R)2209, E(R)2594 and E2307

1. Preface

Duplex stainless steel, which has a dual-phase microstructure consisting of ferritic and austenitic grains, as shown in Photo 1, overcomes the weaknesses associated with two types of steel by offering higher resistance to stress corrosion cracking than austenitic stainless steel and better notch toughness than ferritic stainless steel. Duplex stainless steel plays an important role in such diverse applications as petro-chemical plants, chemical carriers, offshore structures and bridges as shown in Photos 2 and 3. This article will discuss the features of duplex stainless steels as well as their most suitable welding consumables.

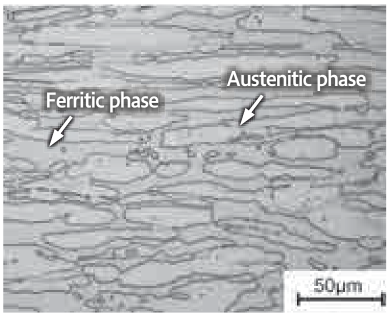


Photo 1: Microstructure of duplex stainless steel


Photo 2:
Chemical Tanker Bulkhead


Photo 3:
Stonecutters Bridge main tower, rising over 175 m above sea level (Hong Kong)

2. Features of duplex stainless steels

The microstructure of duplex stainless steel shows that the austenitic grains have precipitated on a completely ferritic phase with a phase balance of approximately 50% ferrite and 50% austenite. As this condition is the most stable of microstructures, the features of duplex stainless steel can be highlighted.

In comparison with austenitic stainless steel, duplex stainless steel offers the following advantages:

· smaller thermal expansion coefficient and larger thermal conductivity,
· higher room temperature strength,
· excellent resistance against pitting corrosion and stress corrosion cracking;

but also some disadvantages:
· higher nitrogen (N) content
· larger microstructure transformation caused by heat treatment and easier property deterioration including corrosion resistance

The effects of microstructure transformation are particularly noticeable at the heat affected zone (HAZ) and will be discussed later.

Duplex stainless steel is produced mainly in three grades in relation to chemical compositions: standard, super and lean.

A. Standard duplex stainless steel: Composed of 22% Cr-5% Ni-3% Mo-0.15% Ni, it is literally the standard.
B. Super duplex stainless steel: Amounts of Mo and N are added to the standard in order to increase room temperature strength and pitting corrosion resistance.
C. Lean duplex stainless steel: Amounts of Ni and Mo are reduced from the standard in order to lower the cost.

Table 1 shows the typical chemical compositions of the three grades of duplex stainless steels. Figure 1 shows a relative comparison between tensile strength and the pitting corrosion resistance index [PREW=Cr+3.3(Mo+0.5W)+16N] of various stainless steels. A larger PREW means better pitting corrosion resistance.

Table 1: Typical chemical compositions of duplex stainless steels (mass%)

Grade	UNS	C	Si	Mn	P	S	Cu	Cr	Ni	Mo	W	N	PREW
Standard	S31803	0.02	0.5	1.5	0.02	0.001	0.4	22.1	6.0	3.0	−	0.12	33.9
	S32205	0.02	0.4	1.4	0.03	0.001	0.3	22.1	5.6	3.1	−	0.18	35.2
Super	S32750	0.02	0.4	0.7	0.02	0.001	0.1	25.6	7.0	3.8	0.1	0.28	42.8
	S32760	0.03	0.3	0.7	0.02	0.001	0.6	25.4	7.0	3.5	0.6	0.21	41.3
Lean	S32101	0.03	0.7	4.9	0.03	0.001	0.2	21.6	1.5	0.2	−	0.22	25.8
	S32304	0.02	0.5	1.5	0.02	0.001	0.2	22.7	4.7	0.3	−	0.10	25.3

PREW=Cr+3.3(Mo+0.5W)+16N

3. Features of the welded zone of duplex stainless steel

3.1 HAZ of duplex stainless steel

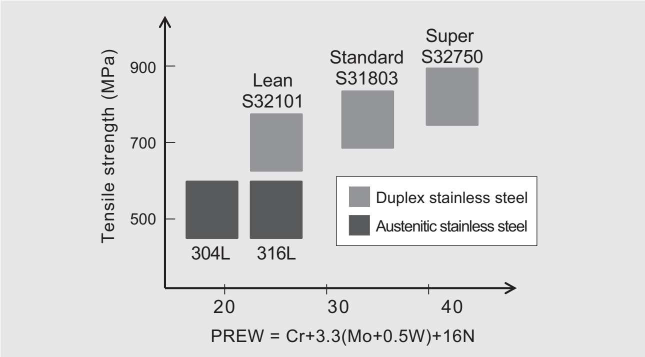


Figure 1: Relative comparison between tensile strength and pitting corrosion resistance index (PREW) of various stainless steels

In duplex stainless steel, the dual phases of austenitic and ferritic grains are balanced in the heat treatment process. By contrast, at the HAZ of duplex stainless steel, pitting corrosion resistance and mechanical properties can deteriorate occasionally, because the phase balance and chemical compositions of the dual phases change in accordance with the cooling rate, which is influenced by welding heat input or plate thickness.

To be more precise, at the high temperature HAZ (HT-HAZ) close to the weld interface, the austenitic grains dissolve into the ferritic phase first and then precipitate as austenitic grains during the cooling process and create the dual microstructures at the end. However, when a high cooling rate occurs due to excessively low heat input, austenitic grain re-precipitation is delayed, and Cr carbides and/or Cr nitrides precipitate into the ferritic grains. As a result, a Cr-depleted layer will form around the HAZ, leading to a deterioration in corrosion resistance.

On the other hand, at the low temperature HAZ (LT-HAZ), away from the weld interface, a low cooling rate due to high heat input can cause ferritic grain coarsening and precipitation of the σ (sigma) phase, Cr-carbides, and Cr-nitrides, thereby decreasing corrosion resistance and notch toughness.

To conclude, the HT-HAZ requires relatively slow cooling so as to enable the austenitic grains to precipitate sufficiently, while the LT-HAZ needs much faster cooling so as to suppress the harmful precipitates from precipitating. Accordingly it is necessary to control the cooling rate to satisfy the requirements of both the HT-HAZ and LT-HAZ through appropriate weld heat input, pre-heating and interpass temperatures.

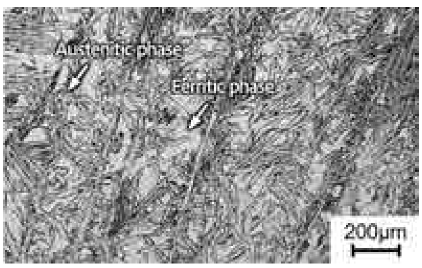


Photo 4: Microstructure of duplex stainless steel weld metal

3.2 Weld metal of duplex stainless steel

The weld metal of duplex stainless steel is adjusted to obtain the required properties in the as-welded condition as shown in Photo 4; in contrast to the stable distribution of the ferritic and austenitic phases in duplex stainless steel, in weld metal they are distributed much more haphazardly.

Figures 2 and 3 show the correlations between the ferrite number (FN), i.e. the ferrite content, and tensile strength/proof stress, and between the FN and notch toughness on the weld metal by the AWS E2594 type FCW, respectively.

It can be seen in both figures that when the FN increases, room temperature strength improves while notch toughness declines. As the FN also influences pitting corrosion resistance, good mechanical properties as well as pitting corrosion resistance can be obtained by selecting the most suitable welding consumables and controlling welding procedures,

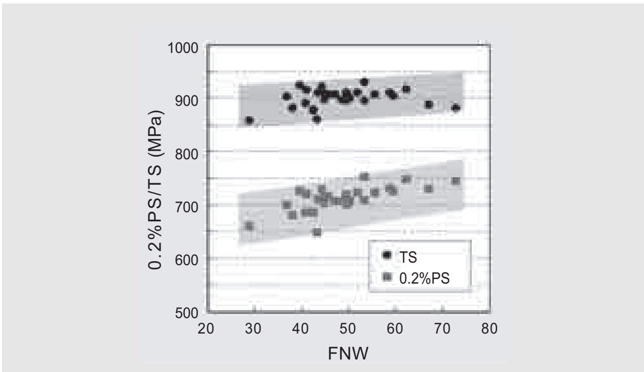


Figure 2: Correlation between FN and tensile strength/0.2% proof stress of E2594 type FCW weld metal

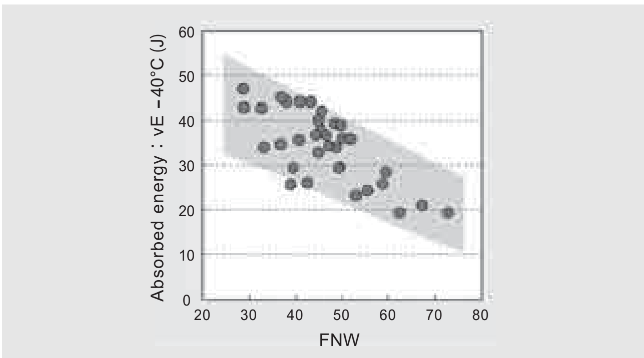


Figure 3: Correlation between FN and notch toughness of E2594 type FCW weld metal

Table 2: Kobelco's welding consumables for duplex stainless steel, their chemical compositions and mechanical properties of all weld metal

Grade	Welding process	Product name	AWS classification	Chemical compositions (mass%)									Mechanical properties				Remarks
				C	Si	Mn	Ni	Cr	Mo	N	PREW*1	FNW	0.2%PS (MPa)	TS (MPa)	El (%)	vE 0°C (J)	
Standard duplex stainless steel	GTAW	**TG-S2209**	A5.9/A5.9M ER2209	0.008	0.39	1.67	8.7	22.7	3.10	0.16	35.5	51	598	773	39	270	DCEN, 100% Ar
	SMAW	**NC-2209**	A5.4/A5.4M E2209-16	0.028	0.54	1.14	8.8	23.1	3.34	0.15	36.5	51	667	845	30	97	DCEP
	FCAW	**DW-329AP**	A5.22/A5.22M E2209T1-1/-4	0.023	0.57	0.66	9.4	23.0	3.40	0.14	36.4	49	605	823	30	55	DCEP, 100% CO_2
	FCAW	**DW-2209**	A5.22/A5.22M E2209T1-1/-4	0.028	0.61	0.74	9.1	22.7	3.30	0.13	35.6	46	639	820	28	73	DCEP, 80% Ar+20% CO_2
	SAW	**US-2209 / PF-S1D**	A5.9/A5.9M ER2209 (Wire)	0.021	0.31	1.56	8.9	23.0	3.28	0.15	35.9	57	618	798	29	69	DCEP
Super duplex stainless steel	GTAW	**TG-S2594**	A5.9/A5.9M ER2594	0.019	0.44	0.57	9.3	25.0	3.82	0.28	42.0	42	721	870	31	286	DCEN, 98% Ar+2% N_2
	SMAW	**NC-2594**	A5.4/A5.4M E2594-16	0.035	0.55	0.66	9.8	26.6	3.86	0.25	43.3	50	750	935	28	55	DCEP
	FCAW	**DW-2594**	A5.22/A5.22M E2594T1-1/-4	0.026	0.50	1.18	9.6	25.7	3.79	0.24	42.0	49	712	905	27	55	DCEP, 80% Ar+20% CO_2
Lean duplex stainless steel	FCAW	**DW-2307**	A5.22/A5.22M E2307T1-1/-4	0.026	0.45	1.26	7.9	24.6	0.03	0.15	27.1	41	571	750	29	58	DCEP, 80% Ar+20% CO_2

*1: PREW=Cr+3.3 (Mo+0.5W) +16N

including base metal dilution and/or the cooling rate, to put the weld metal FN within a range from 30 to 65. In addition, because the weld metal is less corrosion resistant than the base metal, which is produced through a process of thermal refining, it is designed to hold slightly higher amounts of alloying elements (higher PREW) than the base metal. The Ni content of the weld metal is also designed to be higher than that of the base metal in order to optimize the ratio of austenitic and ferritic grains under as-welded conditions in many cases.

Because the weld metal FN influences mechanical properties as well as pitting corrosion resistance, it is important to check and control it. (To learn how FN is measured, please see the appendix.)

4. Kobelco's duplex stainless steel welding consumables

Kobelco's duplex stainless steel welding consumables are available for all grades of duplex stainless steel and are listed in Table 2 together with their chemical compositions and mechanical properties.

A key factor in the design of welding consumables for duplex stainless steel is how to control for the relatively high amount of nitrogen (N), which frequently causes porosity problems such as blowholes, pits and elongated porosity as well as poor slag removal. It can also cause the radiographic property (X-ray property) in flux cored arc welding (FCAW) or shielded metal arc welding (SMAW) to fail in the horizontal or overhead positions. In order to counter the porosity problems, Kobelco's welding consumables are designed to increase N solubility by adjusting the weld metal chemical compositions and to optimize the slag solidification temperature and viscosity. Improving slag removability is necessary since N in the weld metal makes that difficult even though the slag generated from the slag forming components in the coating flux (on SMAW) or in the flux (on FCAW or SAW) covers the weld metal during welding. Poor slag removal may cause slag to remain here and there on the bead surface and may prevent smooth welding and/or cause slag inclusions. Kobelco welding consumables are therefore designed to

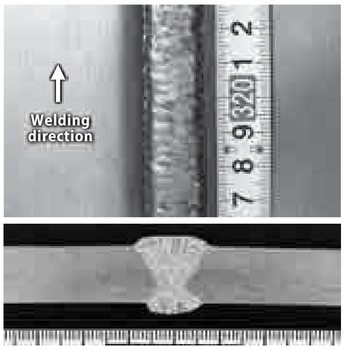


Photo 5: Bead appearance and macro-structure of DW-2594 butt joint

Note: 1. Welding position: Vertical upward (3G)
2: Welding parameters: 160A-26V-15cm/min
3: Shielding gas & polarity: 80%Ar-20%CO_2; DCEP
4: Pass sequence: 2 passes/1st layer; 1 pass/2nd layer
5: Wire size: 1.2 mm dia.

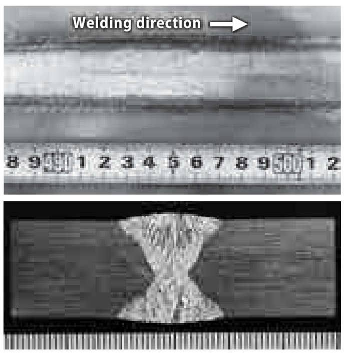


Photo 6: Bead appearance and macro-structure of US-2209 / PF-S1D butt joint

Note: 1. Welding position: Flat (1G)
2: Welding parameters: 450A-32V-35cm/min
3: Polarity: DCEP
4: Pass sequence: 1 pass each and 2 layers
5: Wire size: 3.2 mm dia.

optimize the slag forming components in the coating of covered electrodes and in the flux of FCWs and SAW fluxes for easy slag removal.

Photo 5 shows the bead appearance and macro-structures of a butt joint welded by DW-2594 and Photo 6, the same by SAW with US-2209 wire / PF-S1D flux.

Kobelco duplex stainless steel welding consumables provide excellent mechanical properties (see Table 2), high pitting corrosion and porosity resistance as well as superb slag removability.

5. Selection of welding consumables

When welding duplex stainless steels, it is recommended to select the welding consumables of the same grade or higher, depending on the situation. For example, when welding standard duplex stainless steel, a welding consumable equivalent to AWS E2209 or E2594 (a higher grade) can be chosen. The selection guide is shown in Table 3.

In cases of dissimilar welding between carbon steel or austenitic stainless steel and duplex stainless steel, 309 L or 309 MoL welding consumables or those for duplex stainless steels are applicable. The selection guide is shown in Table 4.

Table 3: Selection of duplex stainless steel welding consumables

	Welding consumable grade		2307 type	2209 type	2594 type
Duplex stainless steel grade	Product name / Base metal	GTAW	–	**TG-S2209**	**TG-S2594**
		SMAW		**NC-2209**	**NC-2594**
		FCAW	**DW-2307**	**DW-329AP** **DW-2209**	**DW-2594**
		SAW		**US-2209/PF-S1D**	
Lean	UNS S32101 UNS S32304		◎	○	○
Standard	UNS S31803 UNS S32205		×	◎	○
Super	UNS S32750 UNS S32760		×	×	◎

◎: Applicable welding consumables of similar composition metals
○: Applicable welding consumables
×: Not applicable

Table 4: Selection of dissimilar welding consumables

Duplex stainless steel grade	Carbon steel/Low alloy steel	Austenitic stainless steel	
		304L type	316L type
Lean	Types of 309L, 309MoL, 2307	Types of 309L, 309MoL, 2307	Types of 309MoL, 2307
Standard	Types of 309L, 309MoL, 2209	Types of 309L, 309MoL, 2209	Types of 309MoL, 2209
Super	Types of 309L, 309MoL, 2594	Types of 309L, 309MoL, 2594	Types of 309MoL, 2594

6. Notes on usage

The welding procedures for duplex stainless steels are similar to those of austenitic stainless steels in general but special care should be paid in order to maximize their strengths.

6.1 Heat input limitation

The heat input limitation is common in all welding processes. However, duplex stainless steel contains higher amounts of Cr and Mo than usual. If weld metal cools down extremely slowly due to excessive heat input and remains in a temperature range of 700-800°C for a long time, it forms the σ (sigma) phase, which deteriorates notch toughness. On the other hand, when the cooling rate of the weld metal is too high due to extremely low heat input, Cr nitride precipitates at the HAZ close to the weld interface and, as a result, forms a Cr-depleted layer. This will cause corrosion resistance to deteriorate. Because the cooling rate also influences the amount of weld metal FN, it is necessary to avoid heat input that is too high or too low. The American Petroleum Institute (API) recommends heat input of 5 to 25 kJ / cm as its guideline.

6.2 Shielding gas composition on GTAW

TIG welding usually adopts 100% Ar as the shielding gas for circumferential root pass welding of stainless steel pipes. However, if 100% Ar shielding gas is used for TIG welding with a solid filler rod for duplex stainless steel, the amount of N in the weld metal may be less than that in the TIG filler rod. This results when the N in the TIG filler rod does not completely transfer to the weld metal; instead, some of the N is discharged as N_2 gas from the molten pool inside.

This will cause excessive ferrite in the weld metal and/or a PREW drop, resulting in the possible deterioration of notch toughness and pitting corrosion resistance. In order to avoid such problems, it is recommended to add about 2% N_2 gas into the shielding gas, depending on the N content in the weld metal and/or base metal.

6.3 Prevention of hot crack on SAW

It should also be noted that duplex stainless steel welding consumables are more susceptible to hot cracks than standard austenitic stainless steel welding consumables except for fully austenitic stainless steel welding consumables. In this sense, there is a high risk of hot cracks with SAW, which applies high heat input in general. As the susceptibility to hot cracks is influenced by bead shapes as well, it is recommended to avoid narrow gap welding, large welding currents and high welding speeds. Such welding conditions must be confirmed thoroughly before actual welding takes place.

Welding of chemical tankers

Chemical tankers carry many corrosive liquids such as petroleum and chemical products, acids, alkalis, even molasses, animal oils, and vegetable oils. Therefore, while chemical tanker hulls may be made of low-cost carbon steel, their cargo tanks and piping systems require corrosion-resistant stainless and stainless-clad steels. Because of the use of special steel materials, the welding procedures used during the manufacturing of chemical tankers also need special consideration.

1. Several stainless steel types are used

The stainless steel grades used in cargo tanks and piping systems are mainly austenitic 316L, 316LN and 317 L which provide excellent pitting corrosion resistance in chloride-rich environments. Nitrogen-bearing 316 LN offers higher tensile strength and stronger resistance to pitting corrosion. In recent years, the use of duplex stainless steel: UNS S31803 has also increased due to its superior resistance to stress corrosion cracking and its higher tensile strength. Table 1 shows the typical chemical and mechanical requirements for these grades of stainless steel.

These stainless steel materials are used for monometallic components and stainless-clad steel components for the cargo tanks and piping systems. During welding, several combinations of materials have to be joined in all positions as shown Figures 1 and 2. When welding these monometallic and dissimilar metal joints, careful consideration is required in selecting filler metals in order to obtain sound welds.

Table 1: Chemical and mechanical requirements for austenitic and duplex stainless steel wrought products (1)

Properties		Type of stainless steel			
		316L	316LN	317L	S31803
Chemical compositions (mass %)	C	≦0.030	≦0.030	≦0.030	≦0.030
	Si	≦1.00	≦1.00	≦1.00	≦1.00
	Mn	≦2.00	≦2.00	≦2.00	≦2.00
	Cr	16.00-18.00	16.00-18.00	18.00-20.00	21.0-23.0
	Ni	10.00-14.00	10.00-14.00	11.00-15.00	4.50-6.50
	Mo	2.00-3.00	2.00-3.00	3.00-4.00	2.50-3.50
	N	−	0.10-0.16	−	0.08-0.20
0.2%PS (MPa)		≧170	≧205	≧205	≧450
TS (MPa)		≧485	≧515	≧515	≧620
El (%)		≧40.0	≧40.0	≧40.0	≧25.0

(1) In accordance with ASTM A204

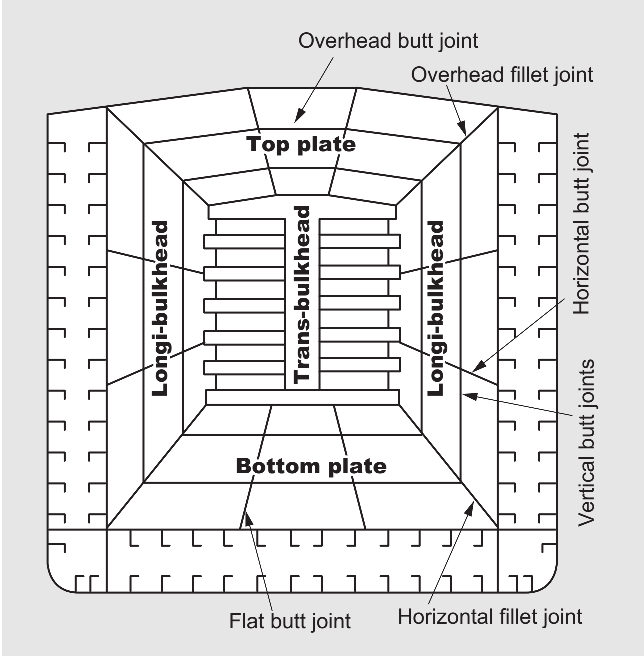


Figure 1: Cross sectional view of cargo tank

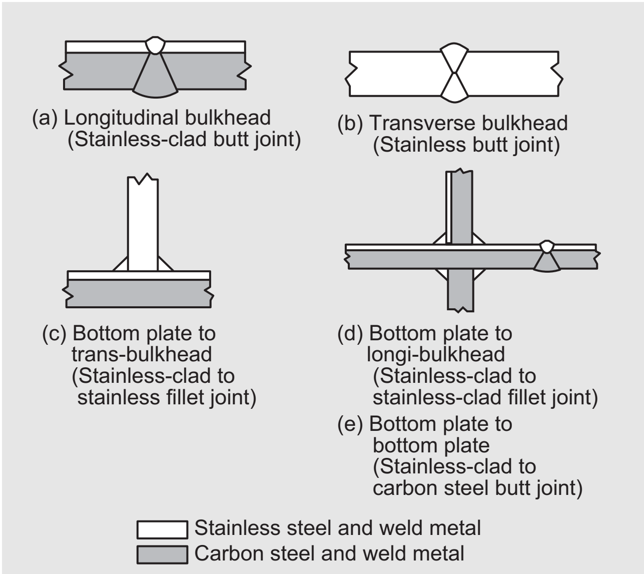


Figure 2: Varieties of weld joints in cargo tanks

2. Welding consumables for similar joints of stainless steels

Table 2 shows suitable welding consumables for austenitic and duplex stainless steels. 316L and 317L stainless steels commonly use matching filler metals,

Table 2: Welding consumables for austenitic and duplex stainless steels

Type of stainless steel	Welding process			
	SMAW	FCAW (1)	GTAW	SAW
316L	**NC-36L**	**DW-316LP**	**TG-S316L/ TG-X316L**	**PF-S1M/US-316L**
316LN	**NC-317L**	**DW-317L**	**TG-S317L**	**PF-S1/US-317L**
317L	**NC-317L**	**DW-317L**	**TG-S317L**	**PF-S1/US-317L**
S31803	**NC-2209**	**DW-329AP**	**TG-S2209**	**PF-S1D/US-2209**

(1) Shielding gas: 100%CO_2 or Ar-CO_2 mixture
(2) TG-X316L for root pass welding with no purging gas

but 316LN stainless steel requires filler metals with higher amounts of Cr and Ni (317L-type filler metals) to provide the weld metal with pitting corrosion resistance equivalent or superior to the base metal. For UNS S31803 duplex stainless steels, the specific filler metals shown in Table 2 are recommended.

3. Excellent performance of FCAW leads to wide applications

In welding stainless steel and stainless-clad steel assemblies, SMAW, FCAW, GTAW and SAW are commonly used. SMAW is so versatile that it is used for such assemblies as plate-to-plate joints and pipe-to-pipe joints in all positions. FCAW with CO_2 or Ar-CO_2 mixture shielding offers higher efficiency, smoother bead appearance, better slag removal, and lower spatter, thereby cutting welding costs. For cargo tanks that consist of out-of-position joints as shown in Figure 1, all-position type FCWs are particularly versatile. In addition, when compared with GMAW using solid wires, FCAW leaves the weld metal with less carbon and, thus, superior resistance to intergranular corrosion. Because of these advantages, FCAW is widely used in fillet and butt joints.

4. Butt joints and fillet joints of stainless-clad steels

Austenitic stainless steel is often used for the cladding metal bonded with the carbon steel base metal to produce stainless-clad steel. For welding stainless-clad steel joints, a filler metal with higher amounts of Ni-Cr is needed in addition to those requirements discussed above to prevent hot cracks in the buffer layer of the weld metal. Table 3 shows common combinations of filler metals for FCAW of stainless-clad steel butt joints.

DW-309MoL is also used for stainless-clad steel fillet joints as well as stainless-clad steel to carbon steel butt joints as shown in Figure 3. It shows a typical selection of filler metals for stainless-clad steel fillet joints.

Table 3: FCWs for stainless-clad steel butt joint

Type of stainless-clad steel	FCAW	
	Buffer layer (④ pass)	Final layer (⑤ pass)
316L	**DW-309MoL**	**DW-316LP**
316LN	**DW-309MoL**	**DW-317L**
317L	**DW-309MoL**	**DW-317L**

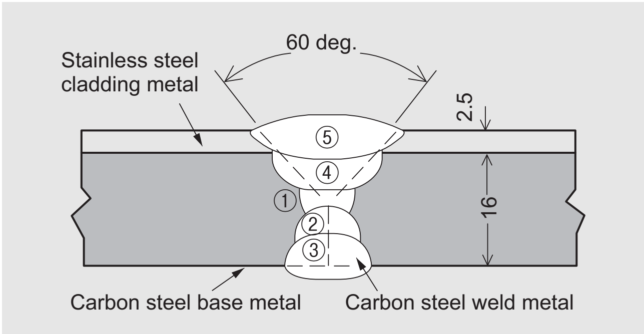


Figure 3: Typical pass sequence of a cladding butt joint

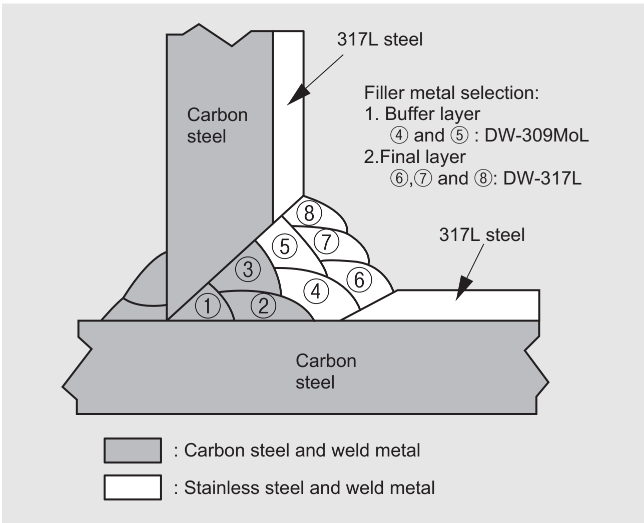


Figure 4: Typical pass sequence and FCWs of horizontal fillet welding of 317L cladding metal

SAW is not suitable for welding in the groove of the stainless-clad side because its penetration is deeper, which increases dilution of the base metal and may cause hot cracking. GTAW is better at minimizing base metal dilution due to shallower penetration, but its welding efficiency is lower. SMAW and FCAW are widely used for welding stainless-clad steel joints, however, FCAW is more widespread because it is 3 to 4 times higher in deposition rate and about 2 times higher in deposition efficiency than SMAW.

Typical pass sequences and FCWs for stainless-clad steel butt joint are shown in Figure 3 and Table 3, respectively. Typical pass sequences and FCWs for stainless-clad steel horizontal fillet joint are shown in Figure 4. ①, ② and ③ welding are for carbon steel

Table 4: Chemical compositions and mechanical properties of all weld metals of FCWs

Product name		DW-316LP	DW-317L	DW-309MoL	DW-329AP
AWS class.		E316LT	E317LT	E309LMoT	E2209T
Chemical compositions of all weld metal (mass %)	C	0.028	0.025	0.025	0.027
	Si	0.60	0.59	0.65	0.58
	Mn	1.50	1.10	0.78	0.78
	Ni	12.65	13.01	12.62	9.42
	Cr	18.35	19.81	22.67	23.34
	Mo	2.68	3.35	2.69	3.42
	N	–	–	–	0.14
	Cu	–	–	0.05	0.02
0.2%PS (MPa)		370	380	535	620
TS (MPa)		540	590	698	830
El (%)		43	37	30	29

joints, and ④ and ⑤ of a butt joint and ④-⑧ of a horizontal fillet joint are for dissimilar joints.

The chemical and mechanical properties of the recommended FCWs, which are tailored to contain a small amount of ferrite in the weld metal to improve their hot crack resistance, are shown in Figure 4.

5. Shipping approvals

Shipping approvals of Kobelco's welding consumables for duplex, 316 LN and 317 L stainless steels and dissimilar metals are shown in Table 5.

Table 5: Shipping approvals of FCWs for duplex, 316LN and 317L stainless steel and for dissimilar metals

Purpose		Duplex	316LN & 317L	Dissimilar		
Shipping Classification \ Product name		**DW-329AP** 100%CO_2 1.2mm	**DW-317L** 100%CO_2 1.2mm	**DW-309LP** 100%CO_2 1.2mm	**DW-309L** 100%CO_2 1.2mm	**DW-309MoL** 100%CO_2 1.2mm
NK	Grade	KW2209	MG	KW309LG(C)	KW309LG(C)	KW309MoLG(C)
	WP	FVH	F	FVOH	F	FVH
LR	Grade	S31803	MG (E317LT0-1)	Dup/CMn, SS/CMn	SS/CMn	SS/CMn
	WP	FVH	F	FVOH	F	FVH
DNV	Grade	Duplex	317L	309L	309L	309MoL
	WP	FVH	F	FVOH	F	FV
BV	Grade	2205	UP	309L	UP	UP
	WP	FVH	F	FVOH	F	FVH
CCS	Grade	2205	-	-	-	-
	WP	FVH	-	-	-	-

H-series stainless steel flux cored wires for high-temperature applications

1. Preface

Conventional stainless steel FCWs generally contain a minute amount of bismuth oxide (Bi_2O_3) in the flux to improve slag removal. The resulting weld metal, therefore, contains a very small amount of Bi. When this weld metal is exposed to temperatures over 600°C, the ductility (elongation) of the weld metal is reduced because of segregation of Bi at the grain boundaries, and cracks may occur.

2. Bismuth (Bi) free stainless steel FCWs

In contrast to this, the H-series DW stainless steel FCWs shown in Table 1 contain no bismuth oxide in the flux and, thus, no Bi in the weld metal. Consequently, elongation of the weld metal at high temperatures is higher than that of conventional FCWs as shown in Figures 1 and 2. This is why the Bi-free FCWs are suitable for high temperature applications, including high temperature equipment and postweld stabilization heat treatment. The H-series FCWs contain advanced flux compositions (without Bi_2O_3) that make slag removal comparable to conventional FCWs.

Where welds are subject to solid solution heat treatment as well as hot rolling, the H-series DW stainless steel FCWs should also be used to prevent reduced ductility.

Table 1: Typical chemical compositions and mechanical properties of H-series DW stainless steel FCW

Product name		DW-308H	DW-308LH	DW-316H	DW-316LH	DW-347H	DW-309LH
AWS class.		E308H T1-1/-4	E308L T1-1/-4	E316 T1-1/-4	E316L T1-1/-4	E347 T1-1/-4	E309L T1-1/-4
Chemical compositions of all weld metal (mass %)	C	0.052	0.026	0.050	0.023	0.027	0.028
	Si	0.42	0.41	0.38	0.45	0.38	0.47
	Mn	1.50	1.35	1.10	1.08	1.18	1.24
	Ni	9.62	10.20	11.60	11.94	10.20	12.58
	Cr	18.68	18.70	18.75	18.47	18.87	24.17
	Mo	−	−	2.40	2.45	−	−
	Nb	−	−	−	−	0.57	−
	Bi	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
FNW		4	5	7	8	6	20
TS (MPa)		575	540	570	540	602	578
El (%)		48	52	42	45	43	39

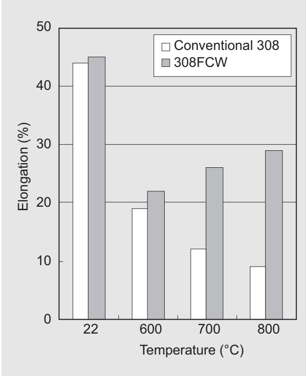


Figure 1:
Comparison of high temperature elongation between DW-308H and conventional 308 FCW

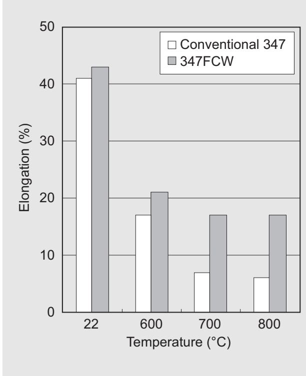


Figure 2:
Comparison of high temperature elongation between DW-347H and conventional 347 FCW

3. Bi content in the weld metal for high temperature service or PWHT is specified by AWS A5.22-2012

In the article A8.1.4 of AWS A5.22-2012, it is stated that stainless steel electrodes containing bismuth (Bi) additions should not be used for such high temperature service or postweld heat treatment above about 500°C. Welding consumable manufacturers are required to report Bi analysis results of all deposited metals if Bi is intentionally added in stainless steel FCWs or if it is known to be present at levels greater than 0.002% in all deposited metal.

It is, therefore, forecast that demand for Bi free FCWs will increase in accordance with growing demand for processing at elevated temperatures and energy-related equipment for high temperature operations.

Figure 3 shows the bead appearance of DW-316H weld metal in each layer of the butt joint.

Welding conditions:
Welding consumable and diameter: DW-316H & 1.2mm dia.
Welding parameters: 200A-30V
Shielding gas: 100%CO_2
Base metal & thickness: Type 316L plate & 15 mm thick
Joint type: Butt joint
Welding position: 1G

Figure 3: Bead appearance of DW-316LH weld metal

XR series: Low Cr(VI) stainless steel flux cored wires

1. Preface

As FCAW generates more welding fumes than other stainless steel welding methods, it presents a burdensome safety challenge. Welding fume is an oxide that forms when metal vapor, generated by the arc, cools and solidifies in the air. In addition, the welding fumes emitted by stainless steel FCAW contain 5-20% chromium (Cr) oxide in the form of Cr_2O_3 as shown in Figure 1, a part of which exists as highly toxic Cr^{6+}, noted as Cr(VI). Figure 1 shows the typical composition of fumes generated by the conventional 308 L-type FCW. These fumes were collected following ISO 15011-1: 2009 and the Cr(VI) in the fumes was analyzed according to ISO 16740: 2005.

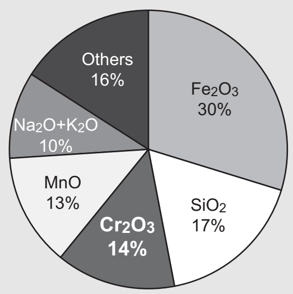


Figure 1: The typical chemical composition of welding fumes generated by a conventional 308L-type FCW

2. OSHA amendment

The toxicity of Cr(VI) has recently been re-evaluated in accordance with moves toward regulating it more strictly in the workplace. For example in 2010 the American Occupational Safety and Health Administration (OSHA) amended the existing standard of the permissible exposure limit (PEL), from 52 to 5 $\mu g/m^3$, cutting the amount of airborne Cr(VI) allowed in workplace by 90 %. It goes without saying that the most effective method of reducing Cr(VI) associated with stainless steel welding is to install more powerful ventilation systems to remove fumes. On the other hand, if welding fumes contained less Cr(VI) to begin with, the effort and expense for better ventilation could be reduced.

3. Development of XR series FCWs

Reducing Cr(VI) in welding fumes themselves is an effective alternative. Kobe Steel has developed a new FCW series, the "XR series," for flat position / horizontal fillet welding as well as for all position welding that drastically reduces the Cr(VI) content in the welding fume. The highly versatile XR series FCWs target three types of stainless steels, namely 308L, 316L and 309L. Table 1 shows a list of XR series FCWs.

Table 1: XR series FCWs

Welding position	Product name	AWS A5.22	Available size (mm)
Flat position and horizontal fillet welding	**DW-308L-XR**	E308LT0-1/-4	1.2
	DW-316L-XR	E316LT0-1/-4	1.2
	DW-309L-XR	E309LT0-1/-4	1.2
All position welding	**DW-308LP-XR**	E308LT1-1/-4	1.2
	DW-316LP-XR	E316LT1-1/-4	1.2
	DW-309LP-XR	E309LT1-1/-4	1.2

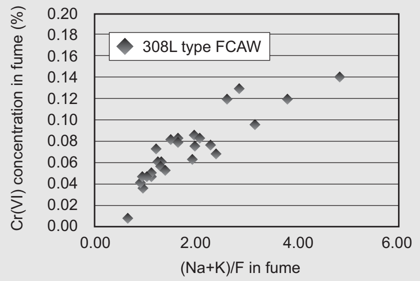


Figure 2: Relationship between flux components and Cr(VI) in welding fume

As shown in Figure 2, decreasing the amount of Na and K, added to flux as arc stabilizers, can reduce Cr(VI) in the welding fume. In order to maintain stable usability, however, the relative amounts of other additives, such as fluorides as well as Na and K, may have to be adjusted.

4. Cr(VI) emission rates of XR series

The Cr(VI) emission rates of XR series FCWs are greatly reduced to 1/5 or 1/10 the amount emitted by conventional stainless steel FCWs as seen in Figure 3.

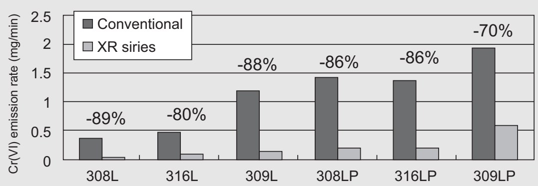


Figure 3: Comparison of Cr (VI) emission rates between conventional FCWs and XR series FCWs
: Welding condition: 100%CO_2; 200A-31V

The chemical compositions and mechanical properties of all weld metals deposited by XR series FCWs, shown in Table 2, are almost identical to those of the conventional FCWs for stainless steels.

5. Butt joint test results

Butt joints were welded in the flat (1G) and vertical upward (3G) positions with L-XR series and LP-XR series FCWs under the conditions listed in Tables 3 and 4, respectively. Figure 4 shows the bead appearance and macrostructure with DW-308 L-XR and Figure 5, with DW-308 LP-XR, respectively.

6. Special care for safety

Although use of the XR series FCWs will substantially reduce exposure to Cr(VI) in the workplace, it is also recommended to control exposure by using respiratory protection, ventilation equipment and protective work clothing to achieve a safer workplace environment.

Table 2: Typical chemical compositions and mechanical properties of XR series FCW

Product name			DW-308 L-XR	DW-308 LP-XR	DW-316 L-XR	DW-316 LP-XR	DW-309 L-XR	DW-309 LP-XR
100%CO_2	Chemical compositions of all weld metal (mass %)	C	0.026	0.023	0.020	0.023	0.031	0.030
		Si	0.66	0.74	0.67	0.70	0.72	0.57
		Mn	1.13	1.58	1.16	1.03	0.95	0.75
		P	0.016	0.018	0.016	0.018	0.018	0.015
		S	0.008	0.002	0.008	0.003	0.007	0.002
		Cu	0.015	0.05	0.025	0.06	0.028	0.02
		Ni	9.6	10.2	12.0	12.5	12.3	12.3
		Cr	18.8	18.9	18.5	18.5	23.3	23.4
		Mo	0.01	0.01	2.4	2.8	0.03	0.02
		Nb	0.01	0.01	0.01	0.01	0.01	0.02
		N	0.016	0.015	0.021	0.015	0.015	0.019
	FN		11	9	12	13	18	18
	FS		9	7	8	8	13	13
	FNW		8	7	8	8	17	18
	0.2%PS (MPa)		367	367	404	407	410	412
	TS (MPa)		550	540	542	545	543	545
	El (%)		44	43	36	43	38	36
Bal Ar-20~25%CO_2	Chemical compositions of all weld metal (mass %)	C	0.027	0.026	0.025	0.029	0.030	0.032
		Si	0.74	0.82	0.74	0.75	0.76	0.67
		Mn	1.29	1.79	1.28	1.19	1.10	0.95
		P	0.016	0.017	0.016	0.017	0.018	0.014
		S	0.008	0.002	0.008	0.003	0.007	0.002
		Cu	0.016	0.04	0.025	0.05	0.028	0.01
		Ni	9.5	10.4	12.0	12.5	12.4	12.3
		Cr	19.4	19.5	18.9	19.0	24.1	24.2
		Mo	0.01	0.02	2.4	2.8	0.03	0.02
		Nb	0.01	0.01	0.01	0.01	0.01	0.02
		N	0.016	0.014	0.022	0.014	0.015	0.017
	FN		14	12	14	14	18	18
	FS		11	8	9	8	15	15
	FNW		11	8	9	9	21	22
	0.2%PS (MPa)		396	386	400	429	454	430
	TS (MPa)		583	551	548	566	608	562
	El (%)		42	42	42	41	32	37

Table 3: Butt joint welding conditions of L-XR series in 1G position

Groove shape and pass sequence	Location	Welding current (A)	Arc voltage (V)	Interpass temperature (°C)
Plate thickness: 15mm Groove shape: Single V Groove angle: 70° Back side: 3 passes Final side: 2 pass	Back	200	29	<300
	Final	200	29	<300

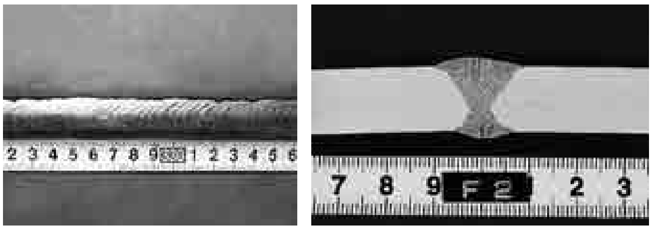


Figure 4: Bead appearance and macrostructure of DW-308L-XR butt joint weld metal (1G position)

Table 4: Butt joint welding conditions of LP-XR series in 3G position

Groove shape and pass sequence	Location	Welding current (A)	Arc voltage (V)	Interpass temperature (°C)
Plate thickness: 15mm Groove shape: Single V Groove angle: 60° Back side: 3 passes Final side: 1 pass	Back	160	28	<300
	Final	160	28	<300

Figure 5: Bead appearance and macrostructure of DW-308LP-XR butt joint weld metal (3G upward position)

T-series stainless steel flux cored wires for sheet metal

When it comes to welding sheet metals with thickness of around 2 mm, welders have been accustomed to using small diameter – and more expensive – solid wire or FCW (e.g. 0.9 mm dia.) at welding currents of 150 A or lower. More convenient and less expensive larger diameter wires (e.g. 1.2 mm dia.) were not suitable for welding sheet meals due to inferior arc stability at such a low welding current.

To accomplish the technically demanding challenge of using 1.2 mm dia. FCW with good arc stability at low welding current, the DW-T series of stainless steel FCWs (DW-T308L, DW-T316L and DW-T309L) has been developed by Kobe Steel as shown in Table 1.

Table 1: DW-T series FCWs

Product name	AWS A5.22	Available size (mm)
DW-T308L	E308LT0-1/-4	1.2
DW-T316L	E316LT0-1/-4	1.2
DW-T309L	E309LT0-1/-4	1.2

The DW-T series FCWs offers outstanding performance with shielding gases of 100%CO_2 and Bal-Ar-20~25%CO_2. When the welding current is lower than 130 A, 100%CO_2 is strongly recommended to achieve the best performance.

Conventional power sources with DC-constant voltage can be used in DCEP. Although both thyristor and inverter power supplies can also be utilized, it is recommended to apply the power source without pulse control even if pulse control is available. Some features that contribute to the excellent performance of the DW-T series FCWs are described below.

(1) Excellent arc stability with smooth molten droplet transfer generates little spatter and fumes in a wide range of welding parameters from 80-240 A. This covers the most common welding parameters for conventional 0.9 and 1.2 mm dia. FCWs (see Figure 1).

(2) Smaller fillet legs can be obtained by using higher welding speeds (Figure 2) due to excellent arc stability at low welding currents and arc voltages and higher deposition rates over conventional 1.2 mm FCWs. Figure 3 shows typical applications of DW-T308L for 304L 1.5-2.0 mm thick sheet metals.

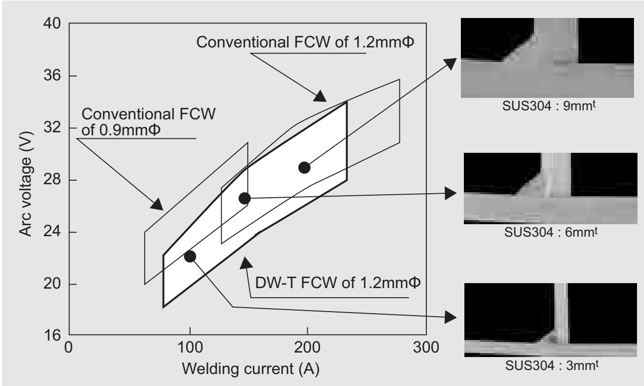


Figure 1: Optimum welding parameter ranges and fillet weld profiles

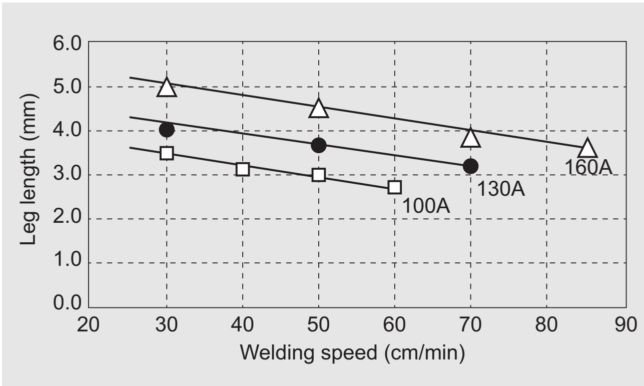
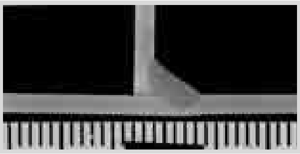
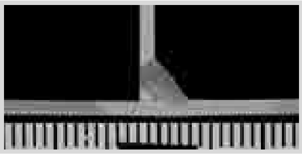


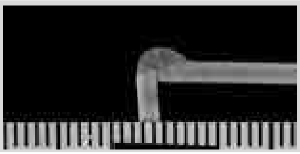
Figure 2: Leg length vs welding speed in 2F welding



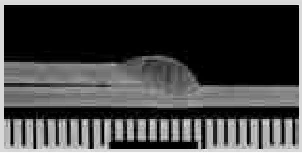
Horizontal fillet welding:
120A-22V-40cm/min
(100%CO_2)
SUS304L base metal (2mm^t)
DW-T308L (1.2mmΦ)



Horizontal fillet welding:
100A-19V-40cm/min
(100%CO_2)
SUS304L base metal (1.5mm^t)
DW-T308L (1.2mmΦ)



Comer joint welding:
120A-22V-40cm/min
(100%CO_2)
SUS304L base metal (2mm^t)
DW-T308L (1.2mmΦ)



Lap fillet welding:
120A-22V-30cm/min
(100%CO_2)
SUS304L base metal (2mm^t)
DW-T308L (1.2mmΦ)

Figure 3: Application of sheet metal welding (1.5 and 2 mm thickness)

(3) Failure-free arc restarting enables more efficient intermittent welding clipping off the wire end (see Figure 4). This is because the solidified molten droplet at the tip of the wire after arc stopping can be smaller and covered by conductive slag as shown in Figure 5.

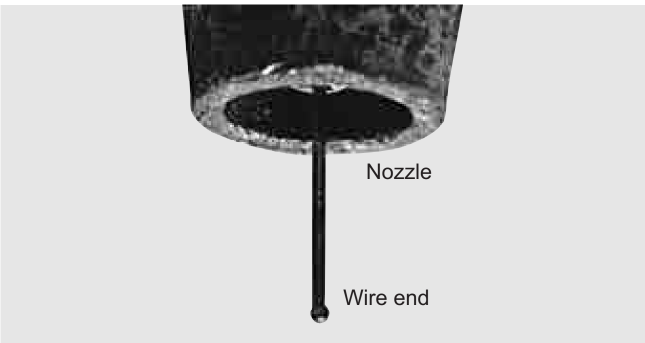


Figure 4: Wire end of DW-T series FCW

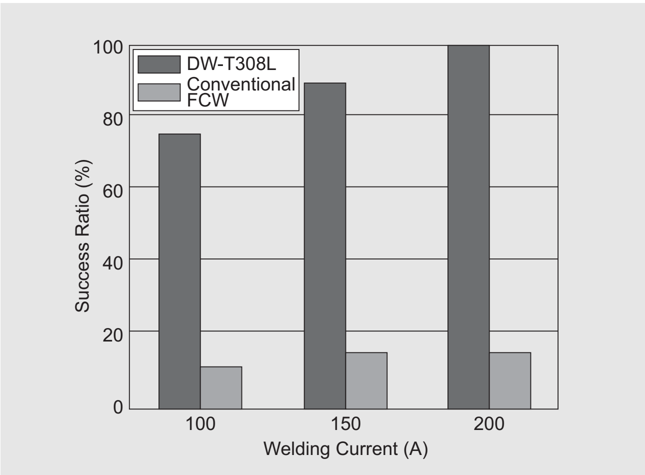


Figure 5: Arc restarting in DW-T308L vs conventional FCWs

(4) Higher deposition rate contributes to higher welding speed or, conversely, lower heat input for getting the same amount of deposited metal when compared with conventional FCWs as shown in Figure 7.

Applicable welding procedures are one-side welding with backing materials and both side welding in flat and horizontal fillet positions due to the excellent X-ray and mechanical properties of the DW-T series FCWs. See Tables 2 and 3 for an example of chemical compositions and mechanical properties of DW-T series FCWs with 100% CO_2 shielding.

Photo 1 shows on-site welding with DW-T series FCWs for a beer tank jacket used for water cooling.

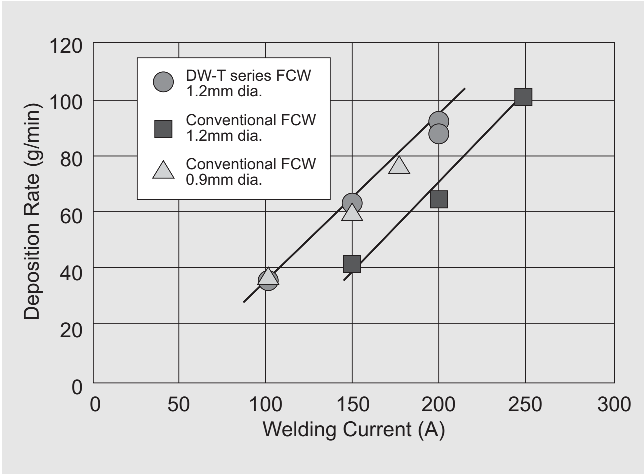


Figure 7: Comparison of deposition rates between DW-T series FCW (1.2mm) and conventional FCWs (1.2 and 0.9 mm)

Table 2: Chemical composition of all weld metal

Product name	Chemical composition (mass %)								Ferrite content	
	C	Si	Mn	P	S	Ni	Cr	Mo	FS	FNW
DW-T308L	0.03	0.62	1.25	0.03	0.02	9.7	19.3	-	9	10
DW-T309L	0.03	0.68	1.21	0.03	0.02	12.5	24.1	-	13	20
DW-T316L	0.03	0.61	1.24	0.03	0.02	12.2	18.6	2.3	7	7

Table 3: Mechanical properties of all weld metal

Product name	0.2%PS (MPa)	TS (MPa)	El (%)	vE 0°C (J)
DW-T308L	372	551	43	45
DW-T309L	448	572	37	35
DW-T316L	386	552	42	40

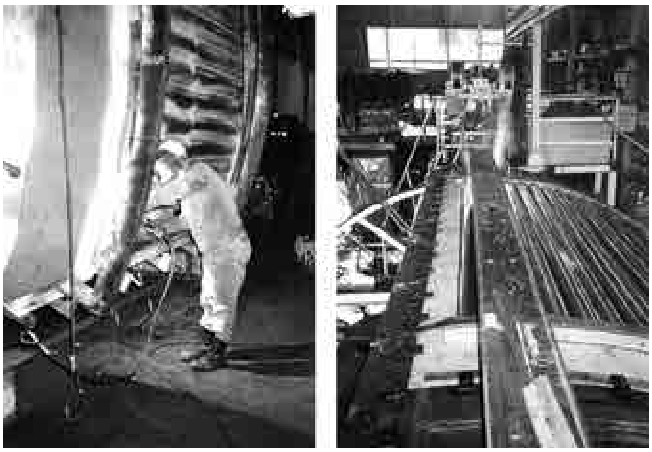


Photo 1: On-site welding with DW-T series FCW

Flux cored wires for Ni-based alloy

Table 1: Kobelco's typical FCWs for Ni-based alloys

Product Name		DW-N82	DW-N625	DW-N625P	DW-NC276
AWS A5.34		ENiCr3T0-4	ENiCrMo3T1-4		ENiCrMo4T1-4
Features		Suitable for welding Ni-based alloy : Inconel 600, and dissimilar metal joints of Ni-based alloy to low alloy steel, and of stainless steel to low alloy steel	Suitable for welding Ni-based alloy : Inconel 625, dissimilar metal joints, overlay and 9%Ni steel for LNG storage tanks	Suitable for clad welding as well as girth welding of clad-steel pipe (5G, 6G)	Suitable for welding Ni-based alloy: Hastelloy C276 and super austenitic stainless steel
Welding position		F, HF	F, HF, Vu	Pipe 5G, 6G	F, HF, Vu
Chemical composition and mechanical properties of all weld metal (Ar-20%CO_2 shielding gas)					
Chemical compositions (mass %)	C	0.038	0.029	0.031	0.018
	Si	0.23	0.36	0.21	0.16
	Mn	3.40	0.31	0.02	0.74
	P	0.002	0.005	0.007	0.009
	S	0.006	0.002	0.004	0.004
	Cu	<0.01	<0.01	0.01	0.06
	Ni	70.6	62.9	65.2	57.5
	Cr	21.2	21.9	21.3	15.5
	Mo	−	8.5	8.8	15.9
	Co	−	−	−	0.02
	V	−	−	−	0.02
	Ti	0.31	0.15	0.17	−
	Fe	1.5	2.1*1	2.0	6.2
	Nb+Ta	2.30	3.50	3.23	−
	W	−	−	−	3.6
0.2%PS (MPa)		383	475	479	459
TS (MPa)		649	752	765	720
El (%)		46	46	45	48
vE 0°C (J)		128	90	84	67
vE −100°C (J)		−	85	78	59
vE −196°C (J)		−	78	70	53

*1: According to AWS A5.34-2007 (that is identical with ASME 2013 SECTION II, PART C, SFA-5.34/SFA-5.34M), the iron (Fe) is 1.0 maximum (mass %), when specified by the purchaser, though it specifies the standard content as 5.0 maximum.

Demand is increasing for Ni-based alloy, which can serve as a heat-resistant super alloy with superior strength at high temperature or as a corrosion-resistant alloy in environments that reduce the durability of conventional stainless steel. This demand is particularly driven by chemical plants that, due to environmental concerns and new exhaust gas regulations, are required to run efficiently at higher temperatures and pressures and under conditions that induce increased corrosion.

In 2007, AWS A5.34 [Specification for Nickel-Alloy Electrodes for Flux Cored Arc Welding] was established under consideration that welding with

FCWs would enhance efficiency in this field. Table 1 shows Kobelco's FCWs for Ni-based alloy steels that meet AWS A5.34: DW-N82, DW-N625, DW-N625P and DW-NC276.

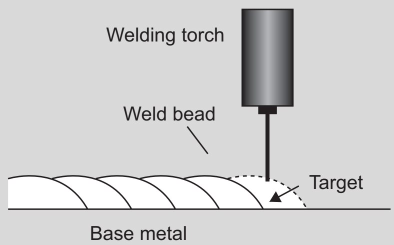
Lower welding currents and speeds are recommended for welding Ni-based alloy steels because they and their resulting weld metals have fully austenitic structures and are sensitive to hot cracking.

The FCWs shown in Table 1 feature a more stable arc in the low welding current range than conventional FCWs while retaining their excellent workability. DW-N82 is designed for flat position and horizontal fillet welding. DW-N625 and DW-NC276 are for all position welding, while DW-N625P is designed for welding 5G (horizontally fixed) or 6G (45-degree-fixed) positioned pipes.

A low Fe type of DW-N625 for welding Inconel 625 is available upon request. As specified in AWS A5.34-2007, its deposited metal is designed to fulfill the chemical container requirement of Fe equal to or less than 1.0%.

Three layers of the weld metal were overlay-welded on ASTM A36 steel under the conditions shown in Table 2. Figure 1 shows the macrostructure of the overlay

Table 2: Welding conditions of DW-N625 in overlay-welding

Polarity	DC-EP	Groove configuration
Welding Position	Flat (1G)	
Current-Voltage	180A-29V	
Running speed	30cm/min.	
Shielding Gas	Ar-20%CO_2 25L/min.	
Interpass-temp.	100~150°C	
Wire stick-out	18mm	
Pass sequence	3 layers, half-lap method	Base metal: ASTM A36

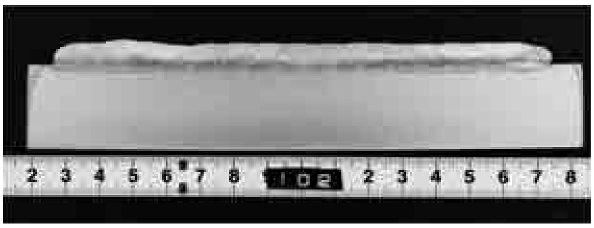


Figure 1: Macrostructure of DW-N625 overlay weld metal

Figure 2: Side-bend test results of DW-N625

Table 3: Chemical compositions of DW-N625 overlay weld metal (mass %)

Layer	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	Ti	Fe	Nb
3rd	0.028	0.42	0.34	0.005	0.003	0.06	63.1	21.6	8.6	0.18	2.1	3.4
2nd	0.031	0.42	0.37	0.006	0.003	0.08	62.4	21.4	8.5	0.18	2.9	3.4
1st	0.036	0.43	0.40	0.006	0.003	0.05	62.0	21.0	8.1	0.17	4.3	3.3
Base metal A36	0.14	0.42	1.33	0.012	0.001	0.22	0.18	0.02	0.05	–	–	–

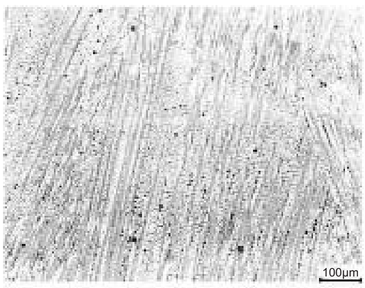


Figure 3: Microstructure of DW-NC276 all deposited metal in as-welded condition

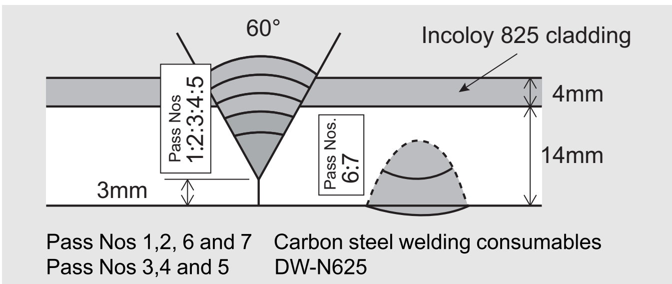
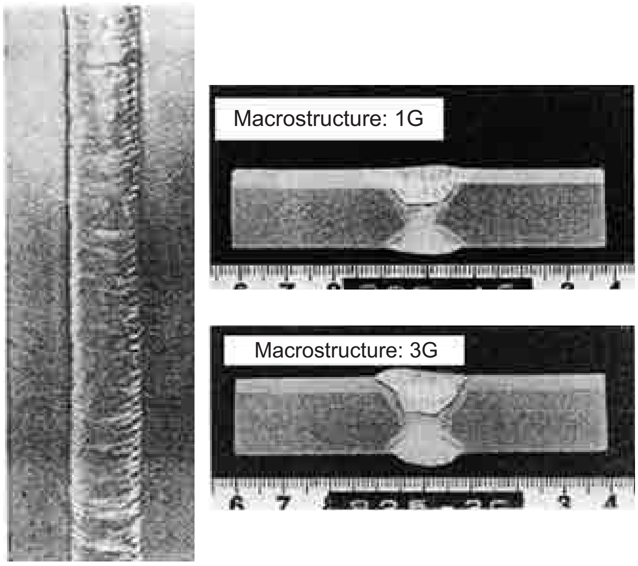


Figure 4: Schematic drawing of the pass sequence for welding clad steel by DW-N625

weld metal, Table 3, the chemical compositions analyzed in each layer, and Figure 2, the soundness of the weld examined by the side-bend test, respectively. No defect was found in either specimen and the sufficient soundness and ductility are confirmed.

The microstructure of DW-NC276 all deposited metal in the as-welded condition is shown in Figure 3. The metallographic structures of Ni-based alloy weld metals exhibit a single phase austenitic structure which remains stable from room temperature to elevated temperature. Therefore, welding consumables for Ni-based alloy steels can be applied in dissimilar welding between carbon or low alloy steels and stainless steels, or for super stainless steels like super austenitic or super duplex stainless steels.

Figures 4 and 5 show a schematic pass sequence and the welding results (bead appearance in 3G vertical-upward position and macro-structures in 1G and 3G vertical-upward positions) of clad steel welding with DW-N625, respectively.



Bead appearance: 3G

Figure 5: Bead appearance and macro-structure of DW-N625 on Inconel 825 clad steel

Figure 6 shows a pipe being girth-welded with a Magnatech machine with DW-N625P in the 5G position; Figure 7 shows the pipe welding machine supplied by CRC Evans.

GTAW and FCAW were used to conduct pipe welding according to the welding conditions listed in Table 4. GTAW was used for the root, hot and 3rd passes (3 passes) with TG-SN625 rod, and FCAW was used from the 4th pass to the cap pass (10th pass) with DW-N625P.

The bead appearances from 6 to 3 o'clock of the 4th pass and the cap pass are shown in Figures 9 and 10, respectively. The macrostructures of 6, 4 and 3 o'clock positions are shown in Figures 11, 12 and 13, respectively. Table 5 shows the impact test results of the 3 o'clock position at the different temperatures down to −196°C.

These tests show that in girth welding excellent bead appearance was obtained at the 6, 4 and 3 o'clock positions, the most difficult positions from which to achieve defect-free welds.

Figure 6: Welding of clad pipe by DW-N625P and Magnatech machine.
Photograph supplied, courtesy of Magnatech International B.V.

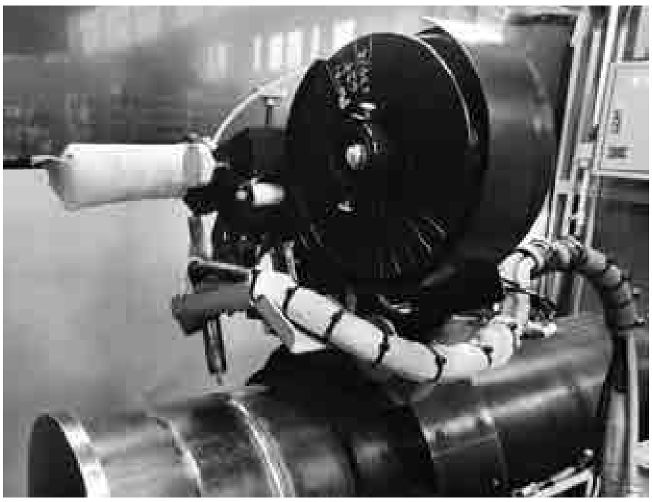
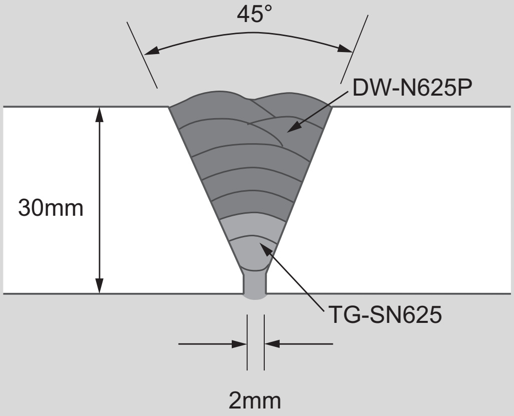


Figure 7: CRC Evans M300-C welding machine

Table 5: Impact test results of girth welding

Position	Tested temp. (°C)	Absorbed energy (J)
3 o'clock	0	Av. 96
	−30	Av. 93
	−100	Av. 87
	−196	Av. 82

Table 4: Welding conditions of girth welding

Welding position	5G (6→12 o'clock)	Pass sequence
Kind of steel	Carbon steel (for checking the usability of DW-N625P only)	
Pipe size	Wall thickness 30 mm Outer diameter 267 mm	
Welding process	1-3 passes: GTAW 4-10 passes: FCAW	
Wire	1-3 passes: TG-SN625 2.4 mm dia. (AWS A5.14 ERNiCrMo3) 4-10 passes: DW-N625P 1.2 mm dia.	
Shielding gas	1-3 passes: 100%Ar (Back purge: 100%Ar) 4-10 passes: 80%Ar-20%CO_2 (25 l/min)	
Wire stick-out	4-10 passes: 15 mm (160A)	
Torch angle	10° back-hand	
Interpass temp.	≦150°C	

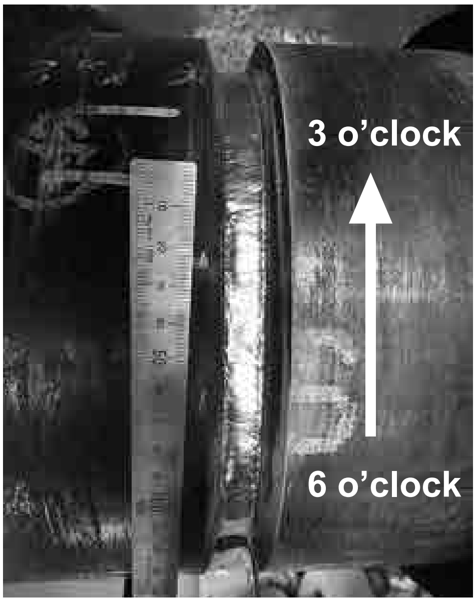


Figure 9: Fourth-pass bead appearance

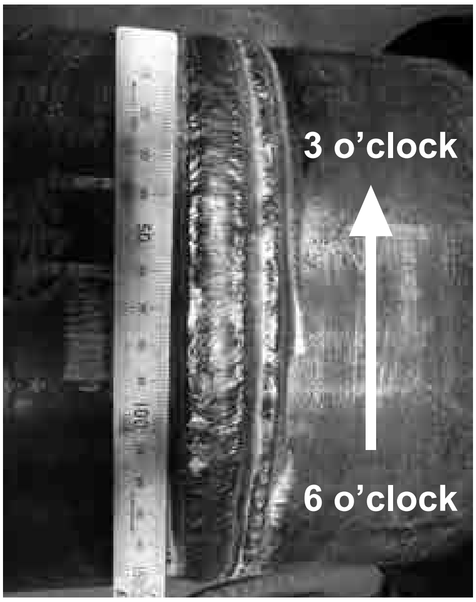


Figure 10: Cap-pass bead appearance

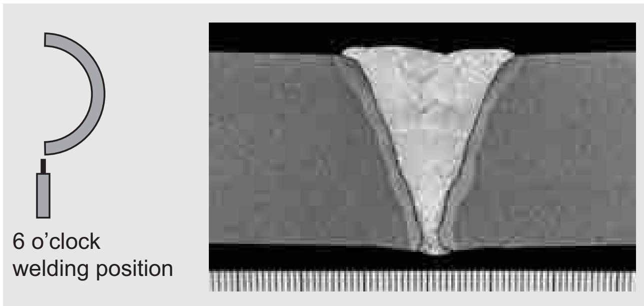


Figure 11: Macrostructure of the weld metal in the 6 o'clock position

Figure 12: Macrostructure of 4 o'clock position weld bead

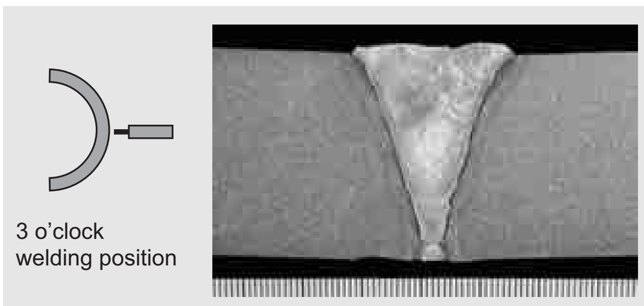


Figure 13: Macrostructure of 3 o'clock position weld bead

Flux cored wires for welding hydraulic turbine components

DW-410 NiMo and MX-A410 NiMo are FCWs designed to weld 410 NiMo stainless steels, in particular for the production of hydraulic turbine components, such as CA6NM (ASTM A352, A356, A 487 & A 743), a corrosion resistant stainless steel casting.


Model of hydraulic turbine runner (by Toshiba Corp.)

DW-410NiMo shows excellent usability with Bal Ar-20~25%CO_2 and even with 100% CO_2 shielding gas in all-position welding, while the metal type MX-A 410 NiMo features superb impact properties in flat position due to the low oxygen in the weld metal with 98%Ar-2%CO_2, 98%Ar-2%O_2 and Bal Ar-20~25%CO_2 shielding gas.

Table 1 shows the applicable codes and classifications of DW-410NiMo and MX-A410NiMo.

As 410 NiMo type weld metal is composed of a martensitic microstructure, it is sensitive to cold cracking; therefore, heat control (i. e. preheating, interpass temperature control during welding, and post heating right after welding) is indispensable. Applying post weld heat treatment (PWHT) after the weld metal cools down to an ambient temperature is also necessary to temper the weld metal as well as the heat affected zone (HAZ). The recommended heat control is shown in Table 2, and the typical chemical and mechanical properties of all weld metal of DW-410NiMo and MX-A410 NiMo are shown in Tables 3 and 4, respectively.

Table 1: Applicable code and classification

Applicable code	Classification	
	DW-410NiMo	MX-A410NiMo
AWS A5.22/A5.22M: 2012	E410NiMoT1-1/-4	EC410NiMo

Table 2: Recommended heat control

Heat control	Temperature (°C)	
	DW-410NiMo	MX-A410NiMo
Preheating	150-200	100-150
Interpass	100-200	100-200
Post-heating	200-300	200-300
PWHT	590-620	590-620

Because 410 NiMo weld metal is sensitive to cold cracking, special precautions are performed with regard to the packaging of DW-410NiMo wire. Figure 1 shows that the wire is wound on a basket spool and packaged in an aluminum foil pack, which protects the wire from humidity and prevents the spool from burning during the recommended redrying at 250°C for 2 hours.

The diffusible hydrogen contents of DW-410 NiMo (1.2mmΦ and 1.6mmΦ) in the as-opened and redried conditions, and MX-A410 NiMo in the as-opened condition were measured according to AWS A4.3. The DW-410NiMo test results are shown in Figures 2 and 3. Results for MX-A410NiMo are shown in Table 5.

Butt joint welding results are shown below for

Table 3: Chemical compositions of all weld metal (mass %)

	C	Cr	Ni	Mo	Mn	Si	P	S	Cu
DW-410NiMo	0.015	11.6	4.3	0.55	0.52	0.34	0.024	0.004	0.03
AWS A5.22 E410NiMoT	0.06	11.0-12.5	4.0-5.0	0.40-0.70	1.0	1.0	0.04	0.03	0.75
MX-A410NiMo	0.024	11.75	4.35	0.61	0.46	0.23	0.021	0.005	0.02
AWS A5.22 EC410NiMo	0.06	11.0-12.5	4.0-5.0	0.40-0.70	0.6	0.5	0.03	0.03	0.75

Table 4: Mechanical properties of all weld metal

Product name	PWHT	Tensile test			Absorbed energy (J)	
		0.2%PS (MPa)	TS (MPa)	El (%)	−20°C	0°C
DW-410NiMo	600°C×1 hr, AC*1	846	926	17	41	44
	600°C×25hrs, FC*2	699	855	20	51	52
MX-A410NiMo	595C×8 hrs, AC*1	813	888	19	58	67

*1: Air cooling
*2: Furnace cooling to ambient at 40°C/hr


Figure 1: Outer package and basket spool of DW-410NiMo

reference. Table 6 shows the welding conditions by DW-410NiMo and MX-A410NiMo. The pass sequence and welding parameters used with these two FCWs are shown in Tables 7 and 8, respectively.

The weld bead appearance, the macrostructure, hardness test as well as the impact test results of the DW-410NiMo butt joint weld metal are shown in Figures 4, 5 and 8 and Table 9. The microstructure, hardness test as well as the impact test results of the MX-A410NiMo butt joint weld metal are shown in Figures 6, 7 and 9 and Table 10.

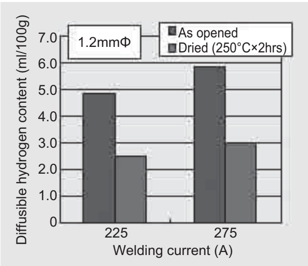


Figure 2:
Diffusible hydrogen content of DW-410NiMo all weld metal (1.2mm dia.)

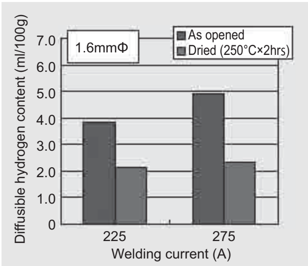


Figure 3:
Diffusible hydrogen content of DW-410NiMo all weld metal (1.6mm dia.)

Table 5: Diffusible hydrogen content of MX-A410NiMo all weld metal (cc/100g)

200A	280A
0.3, 0.3, 0.4 (Ave. 0.3)	0.7, 0.4, 0.6 (Ave. 0.6)

Table 6: Butt joint welding conditions by DW-410NiMo and MX-A410NiMo

Product name	**DW-410NiMo**	**MX-A410NiMo**
Wire diameter (mm)	1.2	
Base metal	ASTM A743 CA6NM	
Shielding gas	80%Ar-20%CO_2	
Post heating	250°C×2 hrs	
PWHT	600°C×1 hr (AC) 600°C×25 hrs (FC)	590°C×8 hrs (AC)

Table 7: Pass sequence and welding parameter by DW-410NiMo

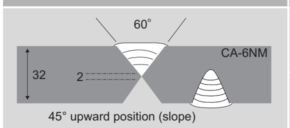
Groove shape, & welding position	Side	Layer/ pass	Welding current (A)	Arc voltage (V)	Interpass temp (°C)
	Face	4 layers/ 4 passes	240	31	150-200
	Back	6 layers/ 6 passes	240	31	150-200

Table 8: Pass sequence and welding parameter by MX-A410NiMo

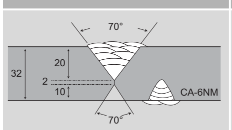
Groove preparation	Position	Side	Layers and passes	Welding current (A)	Arc voltage (V)	Inter-pass temp. (°C)
	Flat	Face	5 layers-10 passes	250	33	150-200
		Back	5 layers-6 passes	240	33	150-200

Figure 4:
Bead appearance of DW-410NiMo

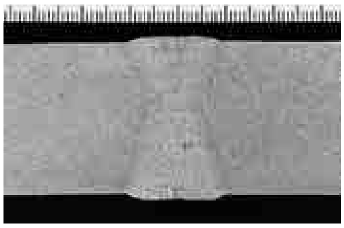


Figure 5:
Macrostructure of DW-410NiMo weld metal

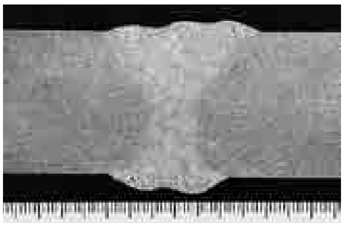


Figure 6:
Macrostructure of MX-A410NiMo weld metal

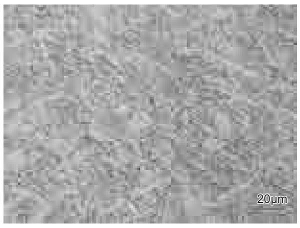


Figure 7:
Microstructure of MX-A410NiMo weld metal

Table 9: Impact test results of DW-410NiMo weld metal at 0°C

Side	600°C × 1 hr, AC (J)	600°C × 25 hrs, FC (J)
Face	39, 35, 36 (Avg 37)	51, 51, 53 (Avg 52)
Back	36, 36, 36 (Avg 36)	53, 53, 55 (Avg 53)

Table 10: Impact test result of MX-A410NiMo

Side	vE (−20°C)	vE (0°C)
Face	49, 56, 60 (Ave 55J)	69, 66, 69 (Ave 68J)
Back	49, 46, 49 (Ave 48J)	57, 57, 51 (Ave 55J)

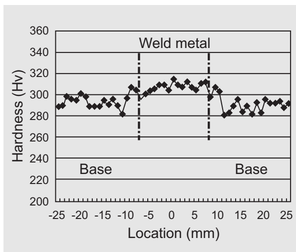


Figure 8:
Hardness test results of DW-410NiMo weld metal

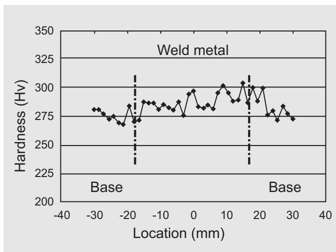


Figure 9:
Hardness test results of MX-A410NiMo weld metal

(Tested location: 3 mm below the face side surface)

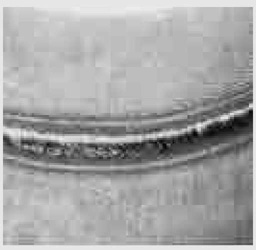
FCW filler rods for TIG root pass welding of pipes

1. Eliminating back shielding with TG-X - TIG filler rods

Welding stainless steel pipes with a typical TIG solid filler rod requires back shielding, or else the root pass weld cannot penetrate the backside of the joint properly. This can be attributed to significant oxidation of the root pass weld due to its high chromium (Cr) content. Therefore, back shielding with an inert (Ar) gas is a must. There are two common back shielding methods : whole pipe shielding and local zone shielding. However, with either method, the large amount of time and Ar gas required for shielding raises costs enormously.

Those costs can be cut with the TG-X series of FCW filler rods for TIG root pass welding. They eliminate the need for expensive back shielding and allow operators to work safely inside pipes without the danger of asphyxiation. Figure 1 shows pipe root pass welding on site by using TG-X filler rod.

Figure 1: Site welding by TG-X filler rod



Back bead of a pipe weld by TG-X filler rod

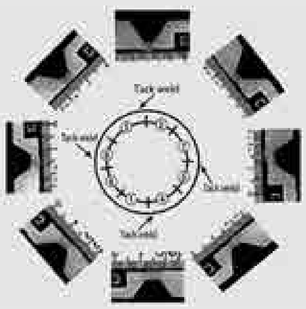


Figure 2: Macrostructures of TG-X308L welds on a pipe (12 mm thick×150 mm dia.) in 5G position

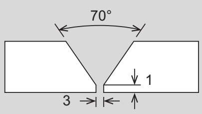
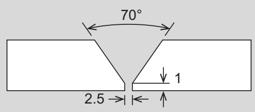
The flux inside the TG-X filler rod produces enough slag to completely cover both the back and surface sides of the bead, protecting them from exposure to air and preventing oxidation even without a back shield. The slag covering both sides of the bead is easily removed with a light tap and leaves a beautiful bead. The TG-X filler rod also provides smooth and uniform penetration through the pipe wall in all positions as shown in Figure 2.

2. Cutting costs with TG-X filler rods

Table 1 compares four cost factors associated with root pass welding with TG-X and solid filler rods on a pipe with an inside diameter of 305 mm.

It is clear that the use of TG-X filler rods can reduce labor costs by a remarkable 23-74% and Ar gas costs by 55-91%, both of which make up a large part of the total cost.

Table 1: Comparison of four cost factors between TG-X and solid filler rods in pipe root pass welding

Filler rod	TG-X	Solid	
Groove preparation			
Back shielding length of pipe	Without back shielding	300mm for local shielding	6000mm for entire shielding
Prepurging(1)	Not required	5.2 min.	104 min.
Setting jigs	Not required	10 min.	Not req.
Welding(2)	35 min.	30 min.	30 min.
Arc time rate	50%	50%	50%
Total man-hour	35 min.	45 min.	134 min.
Total filler rod consumption	120g	100g	100g
Prepurging(1)	Not required	122.2 liter	2444 liter
Welding(2)	263 liter	225 liter	225 liter
Back shield(3)	Not required	240 liter	240 liter
Total argon gas consumption	263 liter	587 liter	2909 liter
Total power consumption	0.405 kwh	0.358 kwh	0.358 kwh

(1) Prepurging is per AWS D10.11-7X (Guide for Root Pass Welding and Gas Purging).
(2) Welding parameters: 110 A/13 V
Shielding gas flow for welding: 15 liter/min
(3) Shielding gas flow for back shielding: 8 liter/min

3. Chemical and microscopic properties of root pass welds

Chemical compositions and ferrite content of the root pass welds with individual TG-X filler rods are shown in Table 2. The low nitrogen (N) content even in the reverse surface area as well as uniform distribution of ferrite precipitation in the austenite matrix was observed by Electron Probe Micro-Analysis (EPMA).

Table 2: Chemical compositions and ferrite content of all weld metals

Product name		TG-X308L	TG-X309L	TG-X316L	TG-X347	TG-X2209
AWS A5.22 Classification		R308LT1-5	R309LT1-5	R316LT1-5	R347T1-5	−
Chemical composition and ferrite content (mass %)	C	0.02	0.02	0.02	0.02	0.02
	Si	0.8	0.8	1.0	0.8	0.6
	Mn	1.8	1.9	1.9	1.9	0.9
	Ni	10.7	12.5	12.4	10.2	9.5
	Cr	20.1	24.8	19.5	19.1	23.1
	Mo	0.1	0.1	2.2	0.1	3.3
	Nb	0.1 max	0.1 max	0.1 max	0.7	0.1 max
	N	0.03	0.03	0.03	0.03	0.15
FN		12	24	14	11	−
FNW		10	25	10	9	47

(1) TG-X filler rod size and length: 2.2mm dia. × 1000mm long
(2) Welding current: DCEN 105A
(3) Torch shielding gas: Ar (without back shielding)

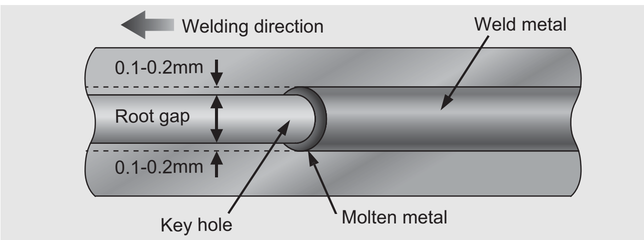
4. Tips for using TG-X filler rods

In order to secure a sound back bead with TG-X filler rod, it is essential to follow specific techniques.

(1) Proper root gap for sufficient penetration

Groove shape	Single V (70°) with 1.0mm shoulder		
Wall thickness (mm)	4	6	10 min.
Root gap (mm)	2.0	2.5	3.0

(2) Keyhole forming



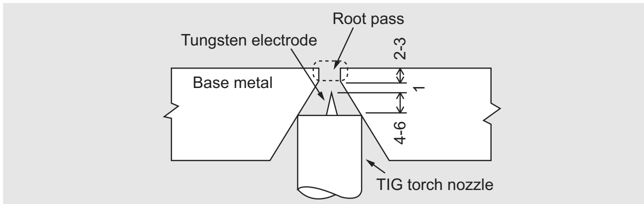
By forming a key hole during welding, a sufficient amount of molten slag will flow to the back side of the groove and cover the back side of the bead.

(3) Higher feeding speed of TG-X filler rod
The feeding speed of TG-X filler rod differs slightly from that of conventional solid TIG filler rod. It has to be fed at a high pace and little by little, with attention paid to not feeding too much at one time.

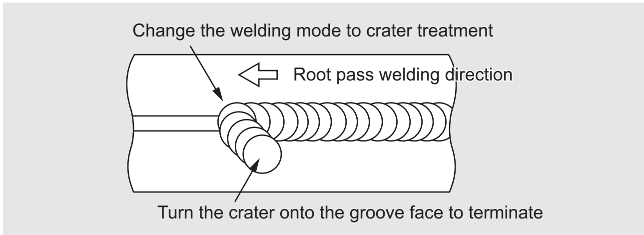
(4) Proper welding current and short arc length

Wall thickness (mm)	3-5	6-9	10 min.
Current (A)	80-90	90-105	90-110

It is recommended to keep the nozzle in contact with the groove fusion faces with an appropriate extension of the tungsten (W) electrode.



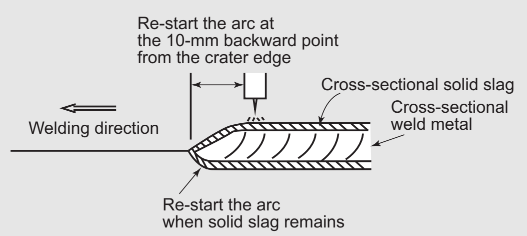
(5) Crater treatment to avoid crater cracking
Turn the crater onto the groove face to prevent crater cracking as well as shrinkage cavities in the crater.

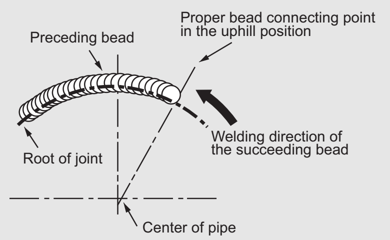


(6) Bead connection
It is also important to maintain the bead connection properly to prevent oxidation in the penetration bead and to obtain a normal penetration bead contour.

Maintain solid slag both on the crater and the back bead when re-starting an arc to join a preceding bead. The re-arcing point should be placed back from the edge of the crater by about 10 mm as shown below.

In 5G position welding, terminate the succeeding bead onto the crater of the preceding bead in the uphill position to control molten slag and thereby to help create the keyhole.





Austenitic stainless steel TIG wire for coal-fired steam boilers: TG-Super304H

In the field of power generation, ultra supercritical (USC) coal-fired boilers, in which the operational temperature is increased from the conventional 550°C to 650°C, are increasingly seen as a way of not only increasing efficiency but of helping to mitigate the issues of global energy consumption and CO_2 emissions.

In the 1990's, high-efficiency USC coal-fired boilers with a steam temperature level of 600°C were first put into practical use in Japan, while in recent years, the construction of such facilities has started in such Asian emerging economies as India and China.

Because of the high temperature requirements associated with USC coal-fired boilers, the stainless steels and relevant welding consumables for the heat exchanger tubes must be austenitic rather than ferritic.

TG-Super304H, developed for welding SUPER304H®, the heat exchanger tube for USC fossil-fired boilers, provides excellent creep rupture strength, hot crack resistance and weldability.

The chemical compositions of TG-Super304H are shown in Table 1 and the mechanical properties, in Table 2.

The microstructure of TG-Super304H all weld metal is shown in Figure 1.

Table 1: Chemical compositions (mass %)

C	Mn	Cu	Ni	Cr	Nb	W	N
0.1	3	3	16	20	0.5	2	0.2

Table 2: Mechanical properties of all weld metal

Tested temperature	Tensile test			
°C	0.2%PS (MPa)	TS (MPa)	El (%)	RA (%)
23	573	796	28	51
550	392	574	19	25
650	355	477	11	28
750	326	373	5	7

Welding parameters: 150A -12V-8cm/min
Wire feeding speed: 10 g/min
Heat input: 13.5 kJ/cm
Preheat temp: Room temp; Interpass temp: 100-150°C

Creep rupture test results of TG-Super304H all weld metal are shown in Table 3 and Figure 2. The typical creep rupture characteristics of SUPER304H® steel tubes are also shown in Figure 2 for reference.

A hot crack test was performed under the welding conditions as shown in Table 4, and the results were judged by a side bend test, as shown in Figure 3.

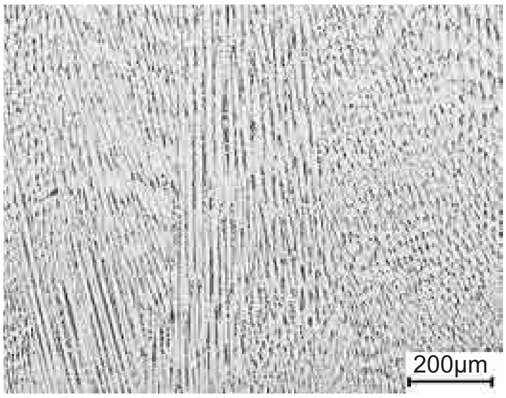


Figure 1: Microstructure of all weld metal

Table 3: Creep rupture test results of all weld metal

Test temperature (°C)	Creep rupture test	
	Stress (MPa)	Rupture time (hrs)
600	300	3172
600	200	>14400*
650	250	552
650	190	4239
650	140	>14400*
700	140	6502

*: under testing

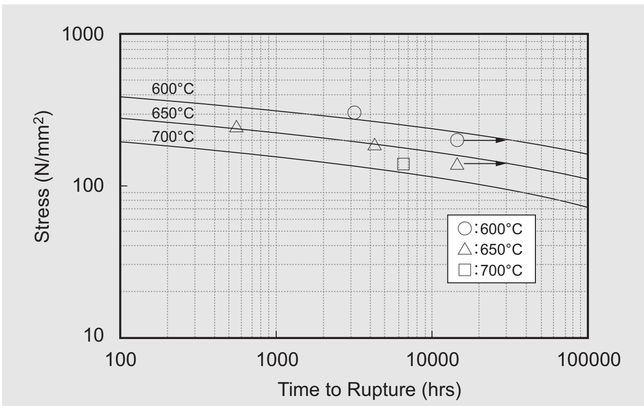


Figure 2: Creep rupture test results of all weld metal.
Note: Typical creep rupture characteristics of SUPER304H® steel tube are represented by the solid lines.

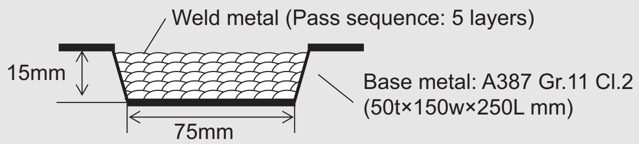
Butt joint welding was conducted with TG-Super304H wire and SUPER304H® steel tube (outer dia.: 51 mm) with 4mm and 11 mm wall thicknesses, respectively, according to the welding conditions listed in Table 5.

The tensile test results of the above-mentioned butt joints are shown in Tables 6 and 7, respectively, and the hardness distribution of the butt joint with an 11 mm wall-thickness is shown in Figure 4.

The excellent appearance of the outer bead and root pass bead, as shown in Figures 5 and 6, were obtained due to the excellent weldability of TG-Super304H.

Table 4: Welding conditions for hot crack test

Polarity	Welding position	Welding current (A)	Arc voltage (V)	Welding speed (cm/min)	Preheat temp. (°C)	Interpass temp. (°C)
DCEN	1G	150	11	10	RT	100-150



No	1	2	3	4	5
Indication of defect	<0.5mm×1	ND*1	ND*1	<0.5mm×1	<0.5mm×1
No	6	7	8	9	10
Indication of defect	ND*1	ND*1	ND*1	ND*1	ND*1

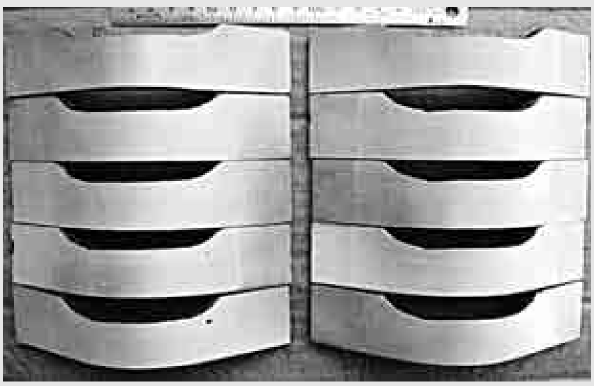


Figure 3: Hot crack test result by side bend test
*1 ND: No Defect

Table 5: Welding conditions of butt joint welding

Thickness (mm)	Polarity	Welding position	Welding current (A)	Arc voltage (V)	Welding speed (cm/min)	Preheat temp. (°C)	Interpass temp. (°C)
4	DCEN	1G	110	13	10	RT	Continuous
11	DCEN	1G	120	13	7-10	RT	Continuous

Table 6: Tensile test results of butt joint (4 mm wall-thickness)

Tested temperature (°C)	TS (MPa)	Fractured position
RT	665	Base metal
500	490	Base metal
550	479	Base metal
600	465	Base metal
650	413	Base metal

Table 7: Results of butt joint (11 mm wall-thickness) tensile tests

Tested temperature (°C)	TS (MPa)	El (%)	Fractured position
RT	649	72	Base metal
500	493	66	Base metal
550	472	66	Base metal
600	445	64	Base metal
650	395	64	Base metal

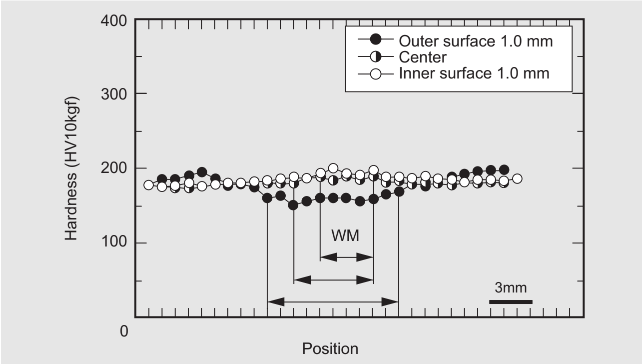


Figure 4: Hardness distribution of butt joint (11mm wall-thickness)

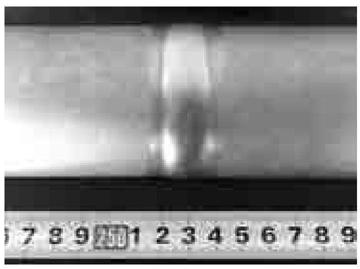


Figure 5: Butt joint outer appearance
Note: Tube outer dia.: 51mm

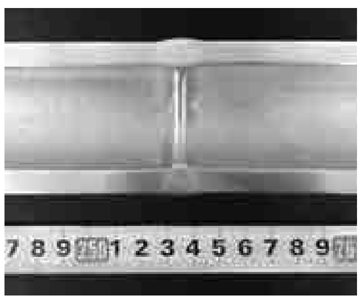


Figure 6: Root-pass bead appearance

7% and 9% Ni steel welding consumables for LNG storage tanks

For safe operations under cryogenic conditions, LNG storage tanks are generally made of 9% Ni steel plates. Recently, however, 7% Ni TMCP steel plate has been developed, which reduces the content of expensive Ni by nearly 20%. Table 1 shows the specifications of 9% Ni steel and 7% Ni TMCP steel.

The welding consumables that are generally used for welding 9% Ni steel are the high nickel alloy types such as the Inconel type (Ni-Cr) and the Hastelloy type (Ni-Mo) even though their chemical compositions are quite different from that of 9% Ni steel. While versatile high Ni alloy welding consumables such as Alloy 625 and Alloy C276 are widely used outside Japan, Kobe Steel has been supplying welding consumables exclusively developed for 9% Ni steels for over 30 years, and they have been highly reputed in Asia as well as the Middle East, North America and South America.

The welding consumables used for welding 9% Ni steels are also suitable for welding 7% Ni TMCP steels. Although the strength of high Ni alloy is lower than that of 9% Ni or 7% Ni TMCP steel, it does not cause brittle fractures, even at cryogenic temperatures, because of its full austenitic microstructure.

Table 1: JIS and ASTM specifications for 7% Ni TMCP and 9% Ni steels

Standard		ASTM			JIS G 3127	
		A553 Type I	A841 Gr G Cl.9	A841 Gr G Cl.10	SL9N 590	SL7N 590
Max. plate thick (mm)		50	50		100	50
Heat treatment		QT	TMCP		QT	TMCP
Chemical compositions (mass %)	C	≤0.13	≤0.13		≤0.12	
	Si	0.15-0.40	0.04-0.15		≤0.30	
	Mn	≤0.90	0.60-1.20		≤0.90	≤1.20
	P	≤0.035	≤0.015		≤0.015	
	S	≤0.035	≤0.015		≤0.015	
	Ni	8.50-9.50	6.00-7.50		8.50-9.50	6.00-7.50
0.2%PS (MPa)		≥585	≥585	≥620	≥590	
TS (MPa)		690-825	690-825	750-885	690-830	
El (%); Thick (mm)		≥20	≥20		≥21 (6 ≤ t ≤16) ≥25 (t > 16)	
vE −196°C (J)		≥34	≥34		≥41	
LE (mm) at −196°C *1		≥0.38	≥0.38 (6 ≤ t ≤32) ≥0.48 (t=50) *2		−	−

Note: *1: LE: Lateral Expansion
*2: LE value between the plate thickness 32 and 50 shall be determined by linear interpolation.

Table 2 lists Kobelco's typical welding consumables and their properties.

An important drawback of Alloy 625 type welding consumables is the formation of low-melting point compounds such as Ni_3Nb that cause hot cracks. DW-N625, an Alloy 625 type FCW, has been developed especially for welding 9% Ni and 7% Ni TMCP steels. It provides high hot crack resistance as well as excellent impact properties under cryogenic conditions through the optimization of chemical compositions of the deposited metals.

DW-N625 is recommended for 3G uphill position welding with the following welding parameters in order to prevent hot cracks: a welding current at 200A max. as well as a welding speed of 30 cm/min max.

Table 3 shows the welding conditions and Figure 1, the groove shape and the macrostructure of a butt joint on a 10 mm thick plate welded by DW-N709SP in the 3G position. Its mechanical properties are shown in Table 4.

Table 2: Typical Kobelco's welding consumables for 7% and 9% Ni steel

		SMAW		FCAW		SAW
Product name		**NI-C70S**	**NI-C1S**	**DW-N709SP**	**DW-N625**	**PF-N4** (flux) **/US-709S** (wire) *1
AWS		A5.11 ENiCrFe-9	A5.11 ENiMo-8	A5.34 ENiMo13T1-4/T0-1	A5.34 ENiCrMo3T1-4	A5.14 ERNiMo-8 (wire)
Features		·Inconel type ·Excellent in ead shape and slag removal ·Excellent in X-ray property in 4G	·Inconel type ·Used for repair welding of PF-N4 / US-709S	·Hastelloy type ·Ar-CO_2 gas for 3G position welding and CO_2 gas for 1G, 1F and 2F welding ·Excellent in hot-rack resistance and CTOD values	·Inconel type ·Suitable for 3G welding ·Excellent weldability	·Hastelloy type ·Suitable for 2G position welding ·Excellent in hot-crack resistance
Polarity		AC	AC	DCEP	DCEP	DCEP
Chemical compositions (mass %)	Ni	64.1	69.3	62.1	64.7	70.1
	Cr	16.3	1.9	6.9	21.4	1.9
	Mo	5.1	18.4	17.6	8.2	19.1
	W	0.6	2.8	2.4	−	3.0
	Nb+Ta	1.1	−	−	3.4	−
	Fe	12.0	6.5	7.7	1.3	5.6
0.2%PS (MPa)		475	463	450	475	435
TS (MPa)		716	731	710	752	716
El (%)		39	46	46	46	48
vE −196°C (J)		62	76	90	78	71

*1: Chemical compositions of US-709S wire

Table 3: Welding conditions of DW-N709SP

Polarity			DCEP
Shielding gas & gas flow rate			80%Ar-20%CO_2 & 25l/min
Welding position			3G
Interpass temperature			150°C
Welding parameters	Face side	1st layer	140A-24V-17cm/min
		2nd layer	160A-26V-16cm/min
	Back side	Final layer	160A-26V-15cm/min

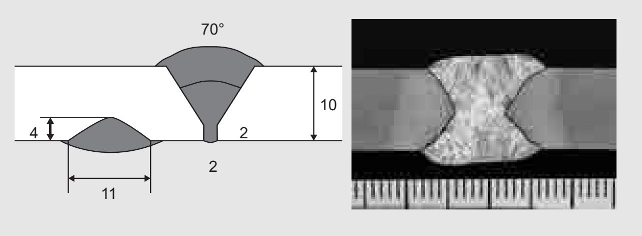


Figure 1: Groove configuration and macro-structure of DW-N709SP weld metal

Table 4: Welded joint (plate thickness: 10mm) properties by DW-N709SP

Properties	Measurements
TS (MPa)	759; 764 (Fractured at base metal)
Notch toughness (J) at −196°C	62, 65, 60 (Avg. 62) *1
Longitudinal bending, 180°	No defect

*1: Specimen size is 7.5mm × 10mm

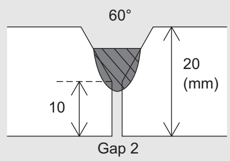
A FISCO test was conducted with DW- N625 and DW-N709SP following the test procedure shown in Figure 2. The results are shown in Figure 3.

Notes on usage

High Ni alloy welding consumables are hot crack sensitive in general, and LNG tanks typically require much dissimilar welding. The following special precautions against hot crack and base metal dilution have to be taken.

(1) Easy magnetization

Because 9% Ni and 7% Ni TMCP steels are easily magnetized, it is advised not to use magnet jigs or lifting tools together with these steels. Residual magnetism in them will cause magnetic arc blow.



- Base metal: 9%Ni Steel
- Wire dia.: 1.2mm
- Welding length: 300mm
- Polarity: DCEP
- Shielding gas: 80%Ar-20%CO_2 (25 liter/min)
- Welding position: Flat
- Distance between contact tip and base metal: 20mm

Figure 2: Test procedure of FISCO test

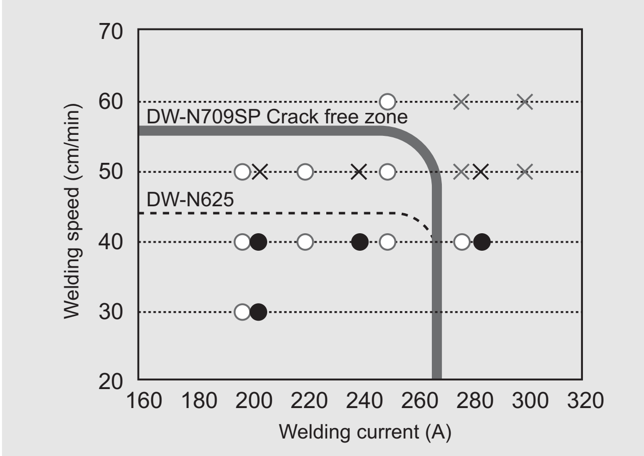


Figure 3: Result of FISCO test

(2) Crater crack

It is strongly recommended that users grind the crater down each time the arc stops, in order to avoid crater cracks.

(3) Dilution

Dilution of the base metal into the weld metal by the arc causes changes in the weld metal chemistry, resulting in the decrease of weld metal tensile strength. Users must ensure that the tensile strength and 0.2% proof strength fulfill the requirements in a procedure test in advance.

Table 5: List of shipping approvals

		SMAW		FCAW		SAW
Ship class.	Grade & welding position (WP)	**NI-C70S** /AC 3.2-5.0 mm dia.	**NI-C1S** /AC 3.2-5.0 mm dia.	**DW-N709SP** /Bal 80%Ar-20-25%CO_2, 1.2mm dia.	**DW-N625** /Bal 80%Ar-20-25%CO_2, 1.2mm dia.	**PF-N4 /US-709S** 1.6 & 2.4 mm dia.
ABS	Grade	MG (ENiCrFe-9)	−	MG (ISO 12153: T Ni 1013 P M21 2)	MG (ENiCrMo3T1-4)	MG (ERNiMo-8)
	WP	F, Vu, O, H	−	F, Vu, HF	F, Vu, HF	F, H
LR	Grade	5Ni, 9Ni	−	9Ni	−	9Ni
	WP	F, Vu, O, H	−	F, Vu, HF	−	F, (H)*1
DNV	Grade	NV9Ni	−	NV9Ni	−	NV9Ni
	WP	F, Vu, O, H	−	F, Vu, HF	−	F, H
BV	Grade	MG (ENiCrFe-9)	−	MG (ISO 12153: T Ni 1013 P M21 2)	MG (ENiCrMo3T1-4)	MG (ERNiMo-8)
	WP	F, Vu, O, H	−	F, Vu, HF	F, Vu, HF	F, H
Others		NK: KMWL91, CCS: 9Ni	NK: KMWL92	CCS: 9Ni	−	NK: KAWL92M

MG: Maker guarantee

*1: Although LR does not specify the H (horizontal) position welding, it is allowed to use it if the LR's approval of its welding procedure is obtained.

APPENDIX
1. About stainless steel

1. About stainless steel

Stainless steel is an iron-based material with a high level of corrosion resistance. With 11% or more chromium (Cr), the material forms a fine Cr oxide film (called passivated film) on the surface that functions as a barrier against corrosion. The corrosion resistance of stainless steel can be improved by adjusting the amount of such alloying elements as nickel (Ni), molybdenum (Mo) as well as Cr, or by decreasing the amount of carbon (C) depending on the nature of a particular corrosive environment. Stainless steel is a versatile structural material that can perform well at a range of temperatures depending on whether its properties are designed for high strength (for elevated temperatures) or toughness (for extremely low temperatures). It is, therefore, important how to choose a stainless steel that best suits the expected service temperature and/or corrosiveness in the environment.

The following four kinds of stainless steels are well known and used in many industries.
① Austenitic stainless steel
② Ferritic and martensitic stainless steels
③ Duplex (austenitic and ferritic) stainless steel

① Austenitic stainless steel features an austenitic microstructure containing Ni in addition to Cr and is nonmagnetic. It is the most widely applied stainless steel because of its ductility, workability and excellent corrosion resistance and usability. It is used in a wide range of temperatures from extremely low to very high.

Table 1 shows typical chemical compositions of austenitic stainless steels. In austenitic stainless steel, Cr carbide grain boundary precipitation occurs over time at elevated temperatures, resulting in an increase of intergranular corrosion susceptibility, also known as sensitization (Figure 1). As shown in Figure 2, the higher the C content in the stainless steel at 500-800 °C, the more easily it is sensitized. The L (low carbon) grades of stainless steel in Table 1, which contain 0.03% or less carbon, as well as types 347 or 321, which are stabilized by an addition of Nb or Ti, can prevent stabilization. Austenitic stainless steel is also susceptible to stress corrosion cracking (SCC); however, this susceptibility can be lessened with additions of Ni, which also reduces work hardening because it stabilizes the austenitic phase and helps restrain deformation-induced martensitic transformation.

Table 1: Chemical composition of austenitic stainless steels

	Type/ Grade	UNS No	Chemical composition (mass %)									
			C	Si	Mn	P	S	Cr	Ni	Mo	N	Others
Austenitic	201	S20100	0.15	1.00	5.5-7.5	0.06	0.03	16.0-18.0	3.5-5.5	--	0.25	---
	202	S20200	0.15	1.00	7.5-10.0	0.06	0.03	17.0-19.0	4.0-6.0	---	0.25	---
	301	S30100	0.15	1.00	2.0	0.045	0.03	16.0-18.0	6.0-8.0	---	---	---
	304	S30400	0.08	1.00	2.0	0.045	0.03	18.8-20.0	8.0-10.5	---	----	---
	304H	S30409	0.04-0.10	1.00	2.0	0.045	0.03	18.0-20.0	8.0-10.5	---	---	---
	304L	S30403	0.03	1.00	2.0	0.045	0.03	18.0-20.0	8.0-12.0	---	---	---
	304LN	S30453	0.03	1.00	2.0	0.045	0.3	18.0-20.0	8.0-12.0	---	0.10-0.16	---
	309	S30900	0.20	1.00	2.0	0.045	0.03	22.0-24.0	12.0-15.0	---	---	---
	309S	S30908	0.08	1.00	2.0	0.045	0.03	22.0-24.0	12.0-15.0	---	---	---
	310	S31000	0.25	1.50	2.0	0.045	0.03	24.0-26.0	19.0-22.0	---	---	---
	310S	S31008	0.08	1.50	2.0	0.045	0.03	24.0-26.0	19.0-22.0	---	---	---
	316	S31600	0.08	1.00	2.0	0.045	0.03	16.0-18.0	10.0-14.0	2.0-3.0	---	---
	316H	S31609	0.04-0.10	1.00	2.0	0.045	0.03	16.0-18.0	10.0-14.0	2.0-3.0	---	---
	316L	S31603	0.03	1.00	2.0	0.045	0.03	16.0-18.0	10.0-14.0	2.0-3.0	---	---
	316LN	S31653	0.03	1.00	2.0	0.045	0.03	16.0-18.0	10.0-14.0	2.0-3.0	0.10-0.16	---
	317	S31700	0.08	1.00	2.0	0.045	0.03	18.0-20.0	11.0-15.0	3.0-4.0	---	---
	317L	S31703	0.03	1.00	2.0	0.045	0.03	18.0-20.0	11.0-15.0	3.0-4.0	---	---
	321	S32100	0.08	1.00	2.0	0.045	0.03	17.0-19.0	9.0-12.0	---	---	Ti:5×C
	321H	S32109	0.04-0.10	1.00	2.0	0.045	0.03	17.0-19.0	9.0-12.0	---	---	Ti:5×C
	347	S34700	0.08	1.00	2.0	0.045	0.03	17.0-19.0	9.0-13.0	---	---	Nb: 10×C
	347H	S34709	0.04-0.10	1.00	2.0	0.045	0.03	17.0-19.0	9.0-12.0	---	---	Nb: 8×C-1.0
	254 SMO	S31254	0.20	0.80	1.00	0.030	0.010	19.50-20.50	17.50-18.50	6.00-6.50	0.180-0.220	Cu:0.50-1.00
	904L	N08904	0.02	1.00	2.00	0.045	0.035	19.0-23.0	23.0-28.0	4.0-5.0	---	Cu: 1.0-2.0

Note: Each single value of chemical compositions indicates maximum unless otherwise shown.

Figure 1: Cr carbide precipitations in stainless steel

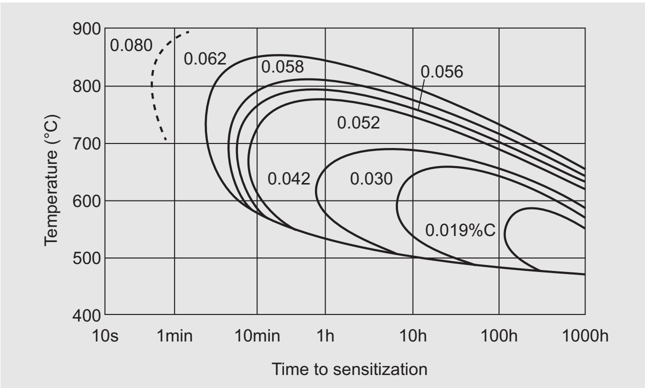


Figure 2: Effect of carbon content on carbide precipitation

② Ferritic and martensitic stainless steels obtain the same body-centered cubic (BCC) or body-centered tetragonal (BCT) microstructure as normal carbon steel and feature lower Ni than austenitic stainless steel or no Ni at all; thus, they are called Cr-type stainless steels. Low level of comparatively expensive Ni reduces the price of these steels.

Ferritic and martensitic stainless steels differ in relation to the effect that heat has on them. Ferritic stainless steel grows coarse crystal grains at high temperatures, as shown in Figure 4, and may form a martensitic phase during rapid cooling after welding. As a result, its mechanical properties deteriorate, lowering usability. Ferritic stainless steel is also sensitive to 475°C embrittlement because of the way Cr-rich α ferrite forms from Fe-rich ferrite. However, it can be recovered by heating the steel above 600°C. Ferritic stainless steel is also sensitive to sigma (σ) phase embrittlement due to the precipitation of Fe-Cr intermetallic compound.

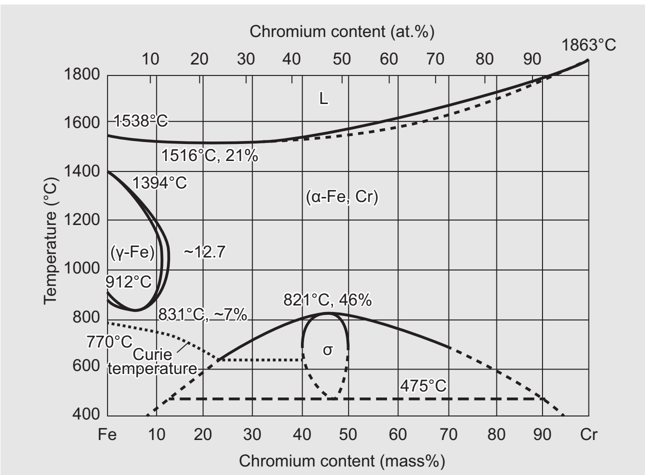


Figure 3: Binary iron-chromium equilibrium phase diagram

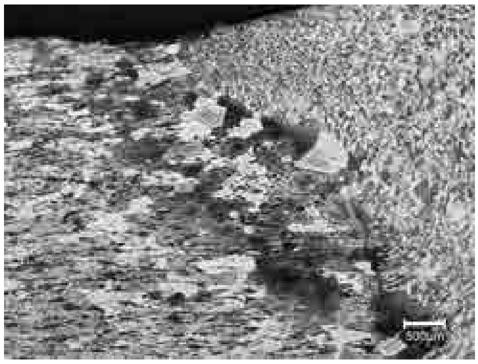


Figure 4: Grain growth in HAZ of ferritic stainless steel

During welding, heat input should be carefully controlled since, when the Cr content is higher, it is easy for crystal grains to coarsen or the sigma phase to form (Figure 3).

By contrast, martensitic stainless steel, which contains lower Cr and higher C to improve hardenability, performs well at room or high temperatures due to its high strength and solid properties. On the other hand, its corrosion resistance is poorer.

Table 2 shows typical chemical compositions of ferritic and martensitic stainless steels.

③ A Cr-Ni type of stainless steel, duplex stainless steel is composed of a dual phase microstructure of ferritic and austenitic grains. It features high N content, which provides higher strength than austenitic stainless steel and allows for thinner plate thicknesses.

As for corrosion resistance, duplex stainless steel is highly resistant to stress corrosion cracking (SCC), a weak point of austenitic stainless steel. Additionally, duplex stainless steel containing Mo shows superb pitting corrosion resistance (PCR), which is an important factor in environments containing chloride such as sea water. Figure 5 shows a typical example of pitting corrosion in an austenitic stainless steel (304) weld joint.

In addition to standard duplex stainless steels, the market now offers super duplex stainless steel, having a pitting resistance equivalent [PREW=Cr+

Table 2: Chemical composition of ferritic and martensitic stainless steels

Type/ Grade		UNS No	C	Si	Mn	P	S	Cr	Ni	Mo	N	Others
Ferritic	430	S43000	0.12	1.00	1.00	0.040	0.030	---	16.00-18.00	---	---	---
	436	S43600	0.12	1.00	1.00	0.040	0.030	---	16.00-18.00	0.75-1.25	---	Nb+Ta: 5×C -0.70
	405	S40500	0.08	1.00	1.00	0.040	0.030	11.5-14.5	---	---	---	Al: 0.10 -0.30
	409	S40900	0.08	1.00	1.00	0.045	0.045	10.50-11.75	0.50	---	---	Ti: 6×C -0.75
	439	S43035	0.030	1.00	1.00	0.040	0.030	17.00-19.00	0.50	---	0.030	Ti: 0.20+ 4(C+N) -1.10 Al: 0.15
	444	S44400	0.025	1.00	1.00	0.040	0.030	17.5-18.5	1.00	1.75-2.50	0.025	Nb+Ti: [0.20+4× (C+N)] -0.80
Martensitic	410	S41000	0.15	1.00	1.00	0.40	0.03	11.5-13.5	---	---	---	---
	420	S42000	0.15 min	1.00	1.00	0.04	0.03	12.0-14.0	---	---	---	---
	440	S44002	0.60-0.75	1.00	1.00	0.04	0.03	16.0-18.0	---	---	---	---
	410S	S41008	0.08	1.00	1.00	0.0400	0.030	11.5-13.5	0.60	---	---	---

Note: Each single value of chemical compositions indicates maximum unless otherwise shown.

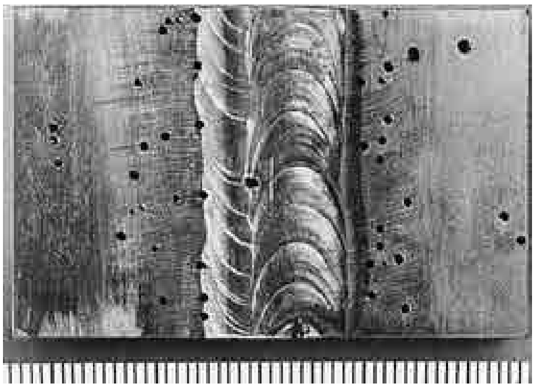


Figure 5: Pitting corrosion on a 304 weld joint

3.3(Mo+0.5W)+16N] equal to or more than 40, as well as lean duplex stainless steel, which reduces material costs by containing smaller amounts of expensive Mo and Ni.

Some drawbacks of duplex stainless steel include poor toughness at extremely low temperatures and sigma (σ) embrittlement at elevated temperatures. The steel, therefore, is applied in ambient environments in general.

Table 3 shows typical chemical compositions of duplex stainless steels.

The microstructures of austenitic (304), ferritic (409), martensitic (410S) and duplex (S32750) stainless steels are shown in Figure 6. Table 4 compares the properties of carbon and stainless steels.

Table 3: Chemical composition of duplex stainless steels

Type/ Grade	UNS No	Chemical composition (mass %)									
		C	Si	Mn	P	S	Cr	Ni	Mo	N	Others
Duplex	S31803	0.03	1.00	2.00	0.03	0.02	21.0-23.0	4.5-6.5	2.5-3.5	0.08-0.20	---
	S32304	0.03	1.0	2.5	0.04	0.04	21.5-24.5	3.0-5.5	0.05-0.20	0.05-0.20	Cu: 0.05 -0.60
	S32550	0.03	1.0	1.5	0.04	0.03	24.0-27.0	4.5-6.5	2.9-3.9	0.10-0.25	Cu: 1.5 -2.5
	S32750	0.03	1.0	1.2	0.035	0.02	24.0-26.0	6.0-8.0	3.0-5.0	0.24-0.32	Cu: 0.5
	S32760	0.03	1.0	1.0	0.03	0.01	24.0-26.0	6.0-8.0	3.0-4.0	0.30	Cu: 0.5 -1.0 W: 0.5 -1.0

Note: Each single value of chemical compositions indicates maximum unless otherwise shown.

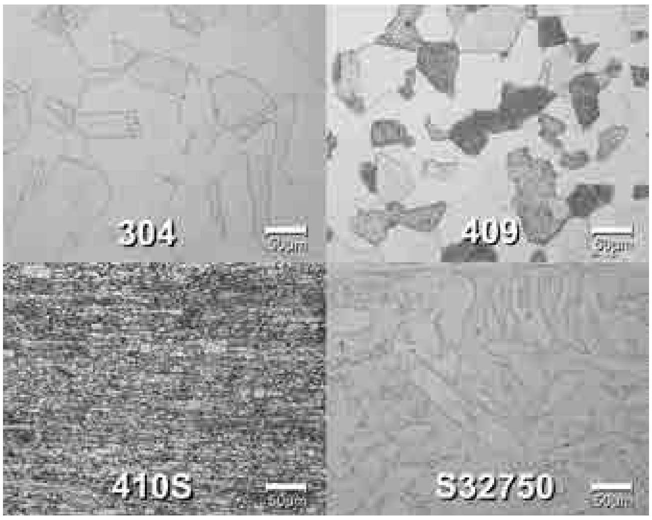


Figure 6: Microstructure of austenitic (304), ferritic (409), martensitic (410S) and duplex (S32750) stainless steels

Table 4: Properties of carbon steel and stainless steels

	Density	Specific electric resistance (μΩ·cm)	Magnetism	Specific heat (Cal/g/°C)	Linear expansion coefficient (10^{-4}/°C)	Thermal conductivity (10^{-2}cal/cm /sec°C)
Carbon steel (A36)	7.9	15	Yes	0.12	11.5	11.2
Austenitic type (304)	7.9	72	No	0.12	17.3	3.9
Ferritic type (430)	7.7	60	Yes	0.11	10.4	6.2
Martensitic type (410)	7.8	57	Yes	0.11	9.9	6.0
Duplex type	7.8	89	Yes	0.12	10.6	5.0

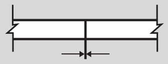
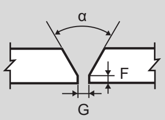
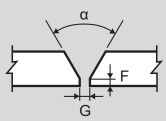
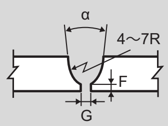
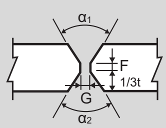
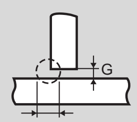
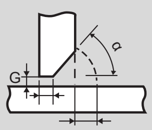
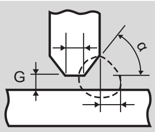
APPENDIX
2. Welding of stainless steels

2. Stainless steel welding

2-1 Groove, pass sequence and electrode manipulation

Edge preparation is an important task before starting to weld. Selecting the optimum groove configuration, with regard to joint type, base metal plate thickness, welding method, welding consumable diameter and welding position is essential for getting sound, defect-free weld metal efficiently. Typical groove shapes are shown in Table 1.

Table 1: Typical groove shapes

Type of joint	Groove shape	t, G, f and α *1	Note
I-joint		t: 0-5 mm G: 0-1/2t	Both side or one side welding
V-joint		t: 3-30 mm G: 0 F: 0-3 mm α: 45-90°	Both side welding Gouging from back side and welding
V-joint		t: ≥3 mm G: 2-3 mm F: 0-2 mm α: 45-90°	One side welding Root pass welding by TGX filler rod or with Cu or ceramic backing
U-joint		t: ≥3 mm G: 2-3 mm F: 0-2 mm α: 20-60°	Welding of small diameter pipe Root pass welding by TGX filler rod
X-joint		t: ≥10 mm G: 0-2 mm F: 0-2 mm α: 45-90°	Both side welding Gouging from back side and welding
T-joint		t: ≥3 mm G: 0-2 mm	Horizontal fillet welding
T-joint		t: ≥5 mm G: 0-2 mm α: 45-60°	One side welding or Gouging from back side and welding
T-joint		t: ≥10 mm G: 0-2 mm α: 45-60°	Both side welding

*1 t, G, F and α: plate thickness (mm), root gap (mm), root face (mm) and groove angle (°), respectively

Edge preparation is performed either by thermal cutting with plasma or lasers or by machining, which provides a fine finish. Thermal cutting requires grinding to remove oxide film from the cut surface. If an organic oil such as machine oil, grease or paint adheres to the groove surface, it has to be cleaned (e.g. with acetone) to prevent the oil from being decomposed by the arc and generating gas that creates porosity.

2-2 Welding processes

Stainless steel welding is generally carried out with GTAW, SMAW, GMAW and SAW. Additionally, when overlay welding is applied to provide the corrosion resistant surface on carbon steels, SAW or electro-slag welding (ESW) with wide strip electrodes is used. Table 2 shows the typical welding defects and types of corrosion that may occur in a stainless steel weld joint.

Table 2: Types of defects and corrosion in stainless steel weld joints

Defect/Corrosion	Type	Cause
Welding defect	Lack of penetration slag inclusion	Welding parameter
	Poor bead shape (undercut, etc)	Welding parameter
	Porosity	Water, nitrogen, chemical composition
	Surface oxidation	Lack of (back) shielding
	Hot rack (solidification crack)	Impurity, ferrite content, restraint
Corrosion	Sensitization	Carbide precipitation
	Stress corrosion crack	Corrosive environment, stress
	High temperature corrosion	Oxidation, carburization, sulfidation at high temperature
	Pitting corrosion, crevice corrosion	Chlorine
	Galvanic corrosion	Electric potential difference between dissimilar materials
Embrittlement	Sigma embrittlement	PWHT condition, ferrite content

2-2-1 GTAW

In GTAW, a filler rod is inserted in the arc generated between a tungsten (W) electrode, connected in direct current-electrode negative polarity (DCEN), and a base metal. An inert gas, such as Argon (Ar) or Helium (He), is applied as a shielding gas. Ar gas containing 1-

3% N_2 may be used when welding duplex stainless steel containing a high amount of N. While GTAW provides highly pure, slag-free weld metals, the deposition rate is low, resulting in low efficiency because a cut filler rod has to be fed manually into the arc. On the other hand, its low heat input makes it suitable for thin plate or pipe welding. In case of root pass welding (or one-side welding), the bottom of the groove has to be filled with Ar gas as a back shield to protect the weld and HAZ from oxidization. The filler rod is specified in AWS A5.9/A5.9M.

2-2-2 SMAW

Electrodes for SMAW are composed of a core rod and coated flux. An excessively high welding current has to be avoided to prevent electrode burn-out, which can occur when an alloying electrode is overheated through its electric resistance.

Drying electrodes in an oven before welding, as shown in Figure 1, is also essential to prevent porosities, which are caused by absorbed moisture in the coated flux (See Figure 2). Following the recommended drying conditions is necessary, particularly for ferritic and martensitic stainless steel electrodes because of the need to reduce hydrogen through a higher drying temperature. The stainless steel electrode is specified in AWS A5.4/A5.4M.

Figure 1: Oven for redrying electrodes

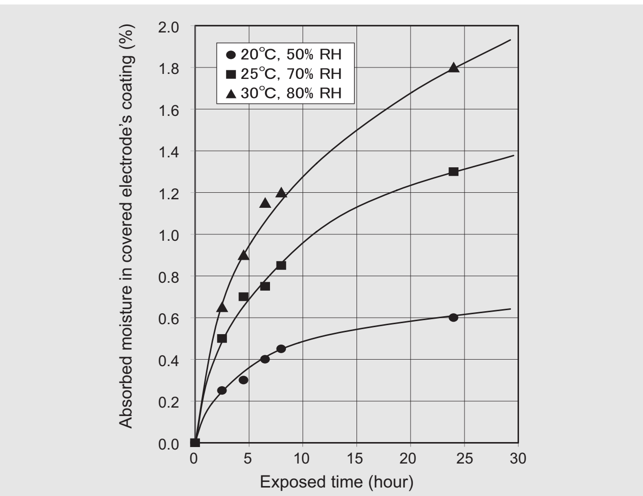


Figure 2: Moisture absorption of covered electrodes

2-2-3 GMAW and SAW

GMAW with solid wire is mainly used in single pass and high speed welding for thin plates like automobile exhaust system components. When it is used in multi-pass welding for thick plate groove joints, the solid Cr oxide scale that forms on the bead surface may cause slag inclusions or lack of penetration as the number of passes increases. High silicon solid wire, classified as AWS A5.9/ A5.9M, contains 0.65 to 1.00% Si whereas standard grade contains 0.30 to 0.65%. It provides better wetting and is suited to multi-groove GMAW welding. FCAW is frequently used instead of GMAW for multi-pass welding.

SAW is applied less on stainless steel than on normal carbon steels. Stainless steel plate is usually thinner than that of carbon steel. Additionally, the thermal expansion coefficient for austenitic stainless steel is large while thermal conductivity is low (see Table 4, Appendix 1). These factors can lead to distortion under the high level of heat generated by SAW.

2-2-4 FCAW

FCAW for stainless steel is essentially a form of gas-shielded welding that uses 100%CO_2 or Bal Ar-20~25% CO_2. 100% CO_2 provides deep and stable penetration while Ar-CO_2 mixed gas offers excellent all-position welding while generating low amounts of spatter and fume (see Table 3). Low heat input is advised in welding austenitic stainless steel in order to minimize distortion and maintain corrosion resistance in the heat affected zone (HAZ). A short stick out length of 15 to 20 mm is recommended so as to maintain a stable arc in spite of the high Joule heat

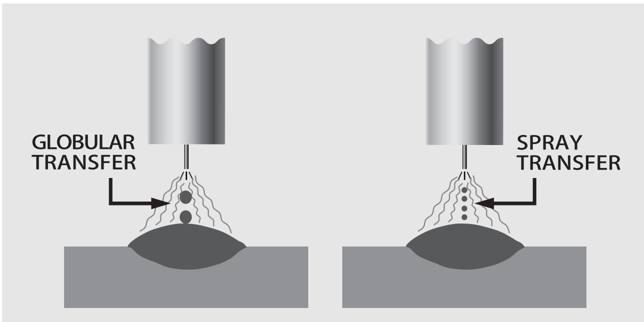


Figure 3: Modes of molten droplet transfer

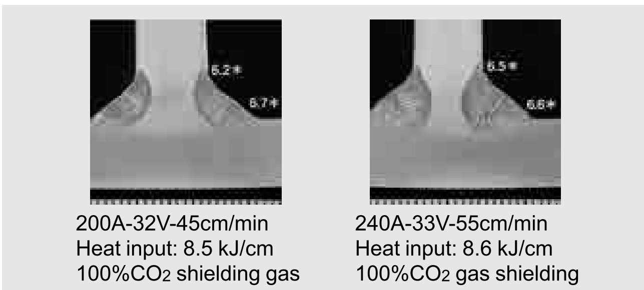


Figure 4: Effects of welding parameters on penetration (*: leg length)

Table 3: Features of shielding gas compositions

	100%CO_2	Bal Ar-20~25%CO_2
Mode of molten droplet transfer	Globular transfer (large droplets)	Spray transfer (small droplets)
Merit	·Deep penetration ·Smooth wettability ·Low gas costs	·Little spatter and fume ·Easy vertical upward welding

generated through its high electric resistance.

Figure 4 shows how welding conditions can influence root penetration in horizontal fillet welding. Increasing welding current and speed even while maintaining heat input and leg length will provide greater root penetration. Excessive welding current and speed, however, may cause hot cracking.

2-3 Welding of austenitic stainless steels

Selecting "matching filler metals" for austenitic stainless steel welding is key in providing weld metals with the same level of corrosion resistance as the base metals. Avoiding hot cracks is another important consideration. As its name suggests, a hot crack occurs on or even inside the weld metal surface during the cooling that follows the solidification of the hot weld metal.

The solidification of weld metal can be understood as involving different solidification modes. The F mode is when solidification is completed in a single ferritic phase. The A mode is when it is completed in a single austenitic phase, while in FA mode, solidification is completed in a single austenitic phase after the ferrite crystallizes out of the liquid phase.

It is also well known that the formation of the ferritic phase in the solidification process reduces hot cracking susceptibility. This phenomenon has been applied in the design of welding consumables that develop a small amount of ferritic microstructure in the weld metal to counter hot cracking. Figures 5 and 6 show

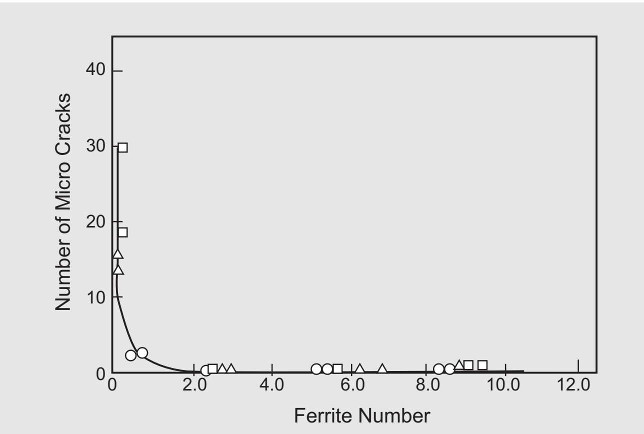


Figure 5: Relationship between number of micro cracks and Ferrite Number in type 308 weld metal

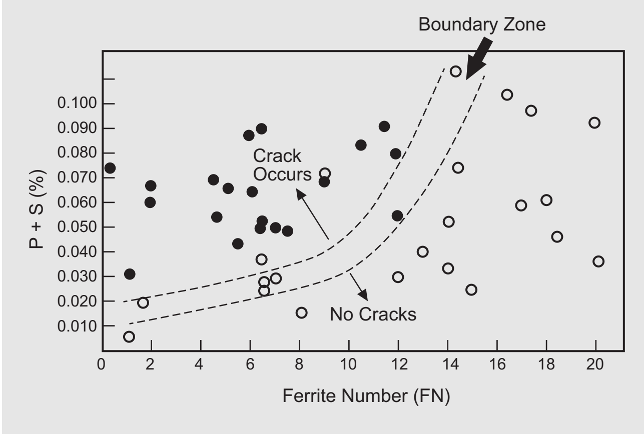


Figure 6: Effect of (P+S) and Ferrite Number on hot cracking susceptibility in type 309 weld metal

how effectively the ferrite content in type 308 or 309 weld metal prevents micro cracks.

Figure 7: Ferrite Scope

The ferrite content in the weld metal is quantified as a ferrite number (FN). The Ferrite Scope shown in Figure 7 is a convenient and portable device that measures ferrite content in the ferritic phase (that obtains magnetism) by probing the weld metal surface in a work shop. The other method of measuring FN is to use a diagram after calculating the Cr equivalent and Ni equivalent from the chemical composition of the weld metal. Schaeffler, DeLong and WRC-1992 diagrams are widely used for this purpose.

For welding type 6Mo stainless steel (S31254), which offers superior pitting as well as crevice corrosion resistance in chloride environments, the matching filler metal cannot secure corrosion resistance equivalent to that of the base metal; therefore, a Ni-base alloy such as E(R)NiCrMo-3 or E(R)NiCrMo-4 is used instead.

Not preheating and keeping the interpass temperature at 150°C or below are also basic to austenitic stainless steel welding. The temperature of a welded portion is usually measured with a thermocouple or a contact thermometer. High interpass temperatures are not recommended on austenitic stainless steel weld metal with high ferrite content because the cooling ratio of the HAZ will slow down, leading to sensitization across a wider area of the welded zone. PWHT is generally not necessary, but if required for stress relief at the 600°C region that corresponds to the sensitizing temperature, short time PWHT is recommended. Solid-solution heat treatment requires rapid cooling with water as well.

2-4 Welding of ferritic and martensitic stainless steel

Because ferritic and martensitic stainless steels develop a BCC / BCT microstructure with low hydrogen solubility and a high hydrogen diffusion rate, preventing delayed cracks caused by hydrogen is important. Covered electrodes require redrying before welding to discharge absorbed moisture, a source of hydrogen. A drying temperature of 300-350°C for about one hour in general is recommended.

Preheating and maintaining higher interpass temperatures are needed in order to remove the diffusible hydrogen that may cause delayed cracking. Specific preheating and interpass temperature ranges depend on the type of stainless steel as well as plate thickness. While 100-200°C is optimum for ferritic stainless steel, 200-350°C as well as immediate post heating is necessary for martensitic stainless steel because it has higher strength; the risk of delayed cracking is also higher in thicker plates.

PWHT on the weld metal and HAZ of martensitic and ferritic stainless steels is performed in order to recover ductility and toughness. However, PWHT is not recommended with austenitic stainless steel welding consumables like type 309L as PWHT can lead to embrittlement of weld metal. Ferritic stainless steel with 15% or higher Cr is particularly susceptible to a form known as "475°C embrittlement" when exposed to temperatures of 350-550°C for a long time. It is, therefore, necessary to pass through this temperature range quickly during the cooling process by ensuring that preheating as well as interpass temperatures are not kept too high.

While matching filler metals are available for ferritic and martensitic stainless steels, austenitic consumables such as 309 and 309L can be used to restrain hydrogen diffusion from the weld metal to the HAZ and, thereby, prevent delayed cracking. However, choosing to apply austenitic consumables requires consideration of the operating environment as well as whether or not to apply PWHT, because the difference in the thermal expansion coefficient between the base and weld metal may cause thermal stress against joints, and because PWHT may cause embrittlement in the weld metal.

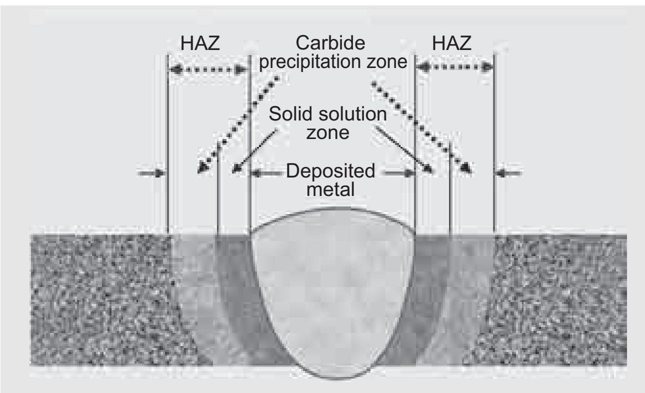


Figure 8: Schematic drawing of the HAZ

2-5 The HAZ and corrosion resistance

Figure 8 shows a schematic drawing of the HAZ.

After being heated to a melting point of 1500°C by the welding arc, the base material in contact with the weld interface, cools down rapidly as soon as welding stops. The area a little further from the weld interface that is heated to below 1000°C cools less rapidly, resulting in longer exposure to temperatures between 500 and 800°C. This can cause sensitization – or precipitation of Cr carbides – and corrosion resistance drops as a result. In the sensitized area, intergranular corrosion as well as stress corrosion crack (SCC) easily occurs. Therefore, special care in selecting welding consumables and welding procedures is essential when the welded structure is to be used in a highly corrosive environment.

There are several methods that can prevent sensitization. One is to apply a low carbon stainless steel, such as 304L or 316L, or a stabilized stainless steel, such as 321 (with Ti) or 347 (with Nb), either of which can form carbides more easily than Cr, thus preventing Cr carbide precipitation. Low carbon grade with C content equal to or less than 0.03% largely reduces the risk of intergranular corrosion, because the heating and cooling cycles used in conventional welding are too short for the HAZ to be sensitized.

Another method that prevents sensitization is a quick pass through the 500-800°C temperature range that is associated with sensitization by minimizing heat input and maintaining the lowest possible interpass temperature in order to speed up the cooling rate at the HAZ. As the Cr carbides dissolve, reheating to over 1000°C with solid solution heat treatment will then restore corrosion resistance.

2-6 Dissimilar welding

Dissimilar welding in this section is the term for joining stainless steel to a carbon or low alloy steel by welding. In order to select the best-suited welding consumables, one must take into consideration that chemical compositions from two different base metals will dilute in the weld metal. It is basically recommended to select a welding consumable that provides the weld metal with higher properties than the base metal that is lower in strength and corrosion resistance. If PWHT is to be conducted or if the dissimilar joint is to be located in a high temperature environment, the risk of embrittlement must also be considered when selecting the welding consumables.

For a dissimilar joint between an austenitic stainless steel and a carbon or low alloy steel, a welding consumable that is high in ferrite and that is designed to provide the weld metal with high Cr and/or Ni like type 309 should be used in general. This selection has the advantage of not generating a martensitic phase in the weld metal, even if Cr and/or Ni in the weld metal decreases due to carbon steel dilution. An alternative would be to apply a fully austenitic consumable, such as type 310, or a Ni-base alloy that contains no ferritic phase; however, welding would have to proceed with care because hot cracking can be an issue.

Yet another solution is to butter the groove face of the carbon steel side with a type 309 consumable and then weld the joint with a consumable that matches the stainless steel (see Figure 9). This technique will minimize the difference in chemical compositions between the two steels. If a consumable high in ferrite, like type 309, is selected for a dissimilar joint and PWHT is applied or the joint is to be located in a high temperature environment over 315°C, sigma (σ) embrittlement may occur at the location of high ferrite in the weld metal. To counter this problem, buttering or applying a Ni-base alloy welding consumable that is less susceptible to embrittlement is recommended.

Figures 10 and 11 show the effect of the welding consumable on sigma (σ) embrittlement. Both figures show the macrostructure and side bend test results of a dissimilar joint with type 304 stainless steel (left side) and heat resistant (Cr-Mo) steel (right side). In Figure 10, the joint was welded by a Ni-base consumable (ENiCr3) with PWHT (690°C × 4 hours) while Figure 11 shows a similar joint by a type 309 consumable with the same PWHT. All side bend test specimens welded with the type 309 consumable failed due to loss of ductility in the weld metal, whereas the Ni-base weld metal maintained ductility even after PWHT.

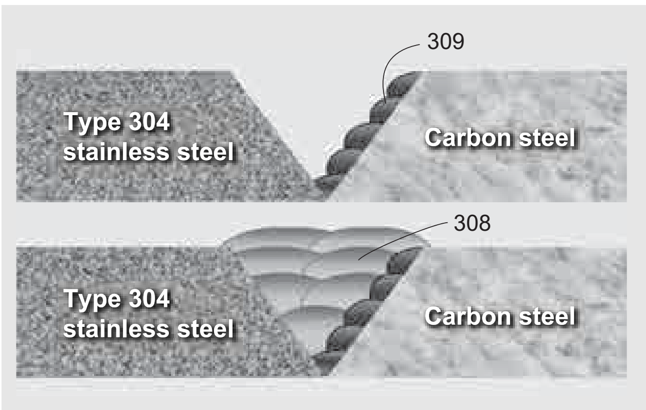


Figure 9: Dissimilar metal joint

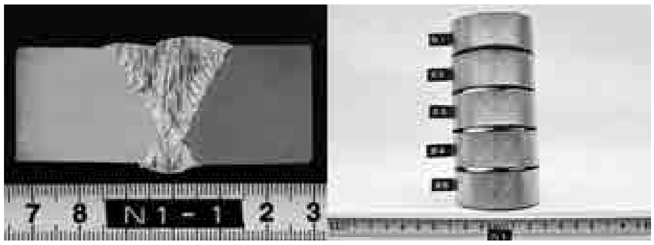


Figure 10: Macrostructure and side bend test results of a dissimilar joint welded by Ni-base alloy (ENiCr3)

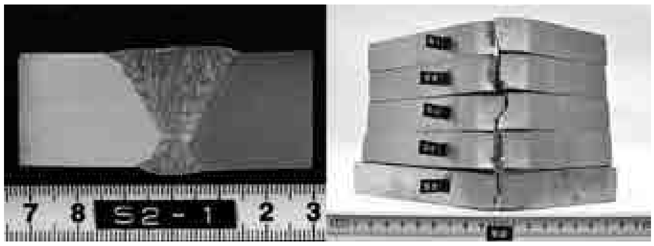


Figure 11: Macrostructure and side bend test results of a dissimilar joint welded by type 309

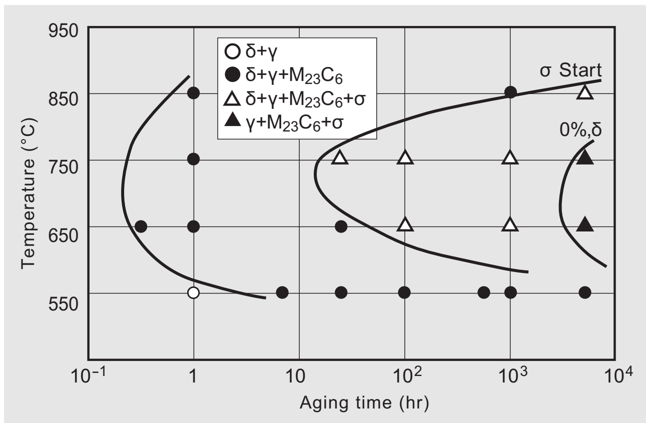


Figure 14: Sigma (σ) phase formation diagram of 308L weld metal

Ni-base alloy is also effective at reducing thermal fatigue. Because its thermal expansion coefficient is between that of carbon and austenitic stainless steel, it experiences less thermal stress in operations involving repeated heating and cooling.

When ferritic or martensitic stainless steel is welded to carbon, low alloy or austenitic stainless steel, the application of a type 309 welding consumable is the least risky because it can prevent hot or cold cracking. In these cases, PWHT temperature should be reduced to around 620°C or less, in order to avoid embrittlement caused by PWHT. However, when a Ni-base consumable is used, a higher PWHT temperature

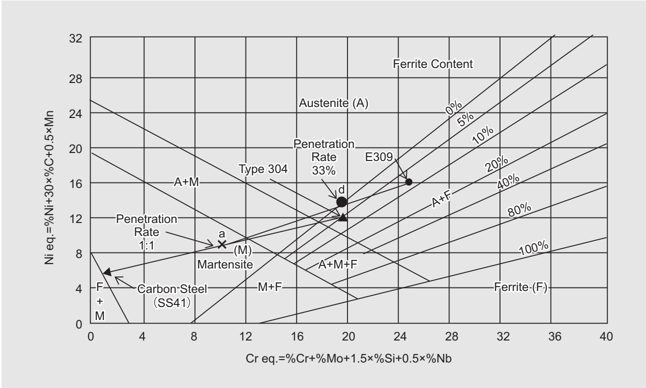


Figure 12: Schaeffler diagram for estimating ferrite content of weld metal obtained by dissimilar welding

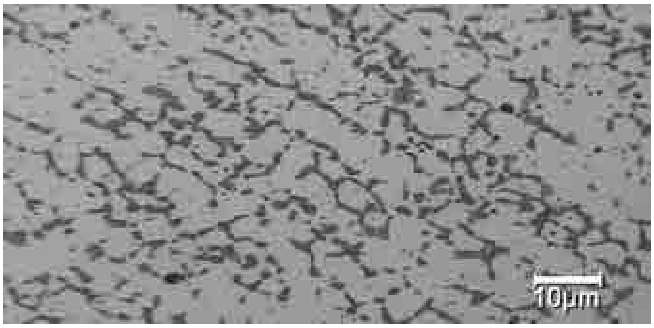


Figure 13: Sigma phase precipitation

can be applied.

In dissimilar welding between stainless steel and carbon or low alloy steel, it is important to control the dilution ratio of the carbon or low alloy steel. In short, this is equal to controlling the ferrite content in the weld metal. One of the methods of controlling ferrite content is to use a constituent diagram such as Schaeffler, DeLong or WRC-1992. As an example, Figure 12 shows the Schaeffler diagram used with base metals of type 304 stainless and carbon steel. Using their Cr equivalents (Creq) and Ni equivalents (Nieq), the two base metals are plotted first on the diagram. As the base metals are supposed to melt at the same rate during welding, the fusion of the two weld metals would be represented by the chemical composition located at Point (a). Therefore, the chemical composition of the weld metal welded by type 309 welding consumable (plotted as Point E309) exists on a straight line between Points (a) and E309, and its location changes according to the dilution ratio. As a certain amount of ferrite content is needed in the weld metal in order to prevent hot cracking, it is necessary to ensure that the ferrite content is above 0% (Point d); in other words, the penetration ratio should be equal to or lower than 33%. However, if it is too low, the chemical composition of the weld metal will be too close to that of type 309 stainless steel, and the weld metal may easily experience sigma embrittlement after PWHT. Figure 13 shows an example of a sigma phase generated in 309LMo weld metal after long-time operation at 800°C.

Figure 14 is a Time-Temperature-Transformation diagram showing the aging of 308L weld metal. It shows that the sigma phase forms in 20 hours at 730°C following $M_{23}C_6$ type Cr carbide precipitation at an earlier time of aging. The tendency for sigma formation increases as Cr, Mo and Si increase or Ni, C and N decrease.

In the case of welding a base metal with high carbon content and a Nieq like that of cast iron, a type 309 welding consumable is not ideal selection because the weld metal often consists of an austenitic single phase (A region in Figure 12). Instead, type 309LMo or 312 welding consumables with higher ferrite content are more appropriate so as to put the weld metal into the A+F region.

In a dissimilar joint between stainless and low alloy steel, PWHT is an important tempering procedure that improves the mechanical properties of the HAZ of the low alloy side, which is hardened by welding heat. When a joint of steels with different amounts of Cr is heated to a high temperature, the carbon diffuses from the low Cr-steel to the high Cr-steel, resulting in a decarburized layer forming in the low Cr-steel (i.e. carbon steel) and a carburized layer in the high Cr-steel (i.e. stainless steel). Figure 15 shows decarburized and carburized layers after PWHT (710°C × 32 hours). Figure 16 shows the hardness distribution of a dissimilar joint. It can be seen that while the decarburized layer is softened, the carburized layer is hardened.

The carburized layer consists of carbide precipitated by carbon movement and has Vickers hardness of 300 or more. In the interface between the decarburized and

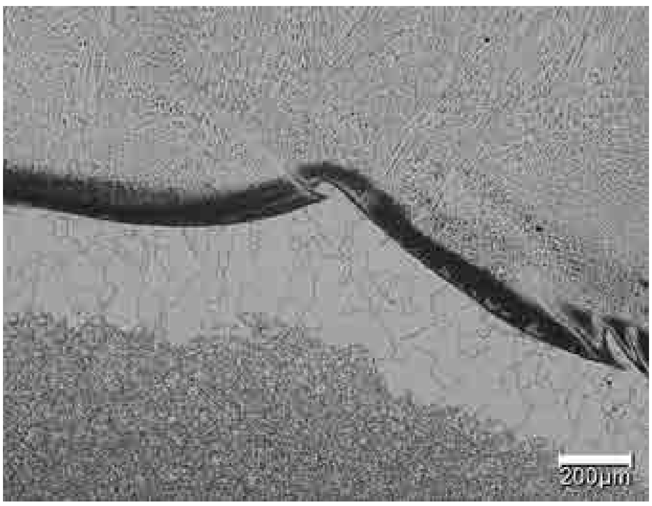


Figure 15: Decarburized and carburized layers after PWHT (710°C × 32 hrs)
(Upper side: 309L weld metal; Bottom side: Base metal of 2.25Cr-1Mo steel)

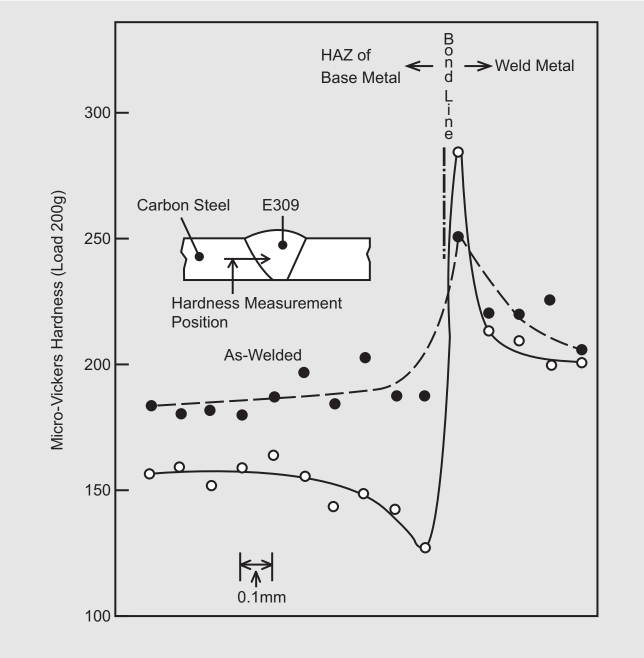


Figure 16: Hardness distribution of dissimilar joint
(PWHT: 625°C×30hrs)

carburized layers, microcracks may occur in a bend test. In general, because the carbon movement is influenced more by temperature than time during PWHT, lowering the PWHT temperature will decrease the hardness of decarburized layer. Applying a Ni-base alloy, which has a slow carbon diffusion rate, will also help avoid the formation of a decarburized or carburized layer.

2-7 Overlay welding

Overlay welding on a carbon steel surface with a stainless steel welding consumable can provide corrosion resistance only to a particular area. Although selecting an appropriate welding consumable for overlay welding is nearly the same as that for dissimilar welding, particular care has to be paid in regards to the dilution of the base metal during welding.

It is also advisable to utilize a constituent diagram, in overlay welding on carbon steel by a type 309 welding consumable. Controlling the base metal (carbon steel) dilution is particularly important, for if the base metal dilution is high, the ferrite content will drop, resulting in hot cracking. If it increases further, the martensitic phase will form in the weld metal, leading to deteriorated ductility and toughness. And extreme dilution of the base metal will cause poor corrosion resistance due to excessive drops in the amounts of Cr and Ni in the weld metal.

The base metal dilution rate varies depending on welding conditions (welding process, welding current, arc voltage and shielding gas) as well as pass sequence (amount of overlapping in each pass and number of layers). It is, therefore, recommended to study the above-mentioned in a preliminary test, set up an appropriate welding procedure specification (WPS) and execute the overlay welding according to the WPS.

2-8 Clad steel welding

In the welding of clad steel composed of carbon and stainless steel base metals, the same concept as those for dissimilar or overlay welding can apply. In other words, the welding consumable can be selected by understanding that the welding that melts both carbon and clad stainless steel is a form of dissimilar welding while welding on the carbon steel side only is overlay welding.

Table 4 shows how to choose welding consumables, depending on the types of clad stainless steels and Figure 17, welding sequence of clad steel.

Table 4: Selection of welding consumables

Type of clad stainless steel	No. of layer	Welding consumable (AWS Exxx)	
304	1st (Buffer layer)	309 or 309L	
	2nd onward	308 or 308L	
304L	1st (Buffer layer)	309L	
	2nd onward	308L	
316L	1st (Buffer layer)	309L or 309LMo	
	2nd onward	316L	
321, 347	1st (Buffer layer)	309L or 309LNb	
	2nd onward	347	
405	1st (Buffer layer)	430Nb	309(L)
	2nd onward	410Nb	309(L)

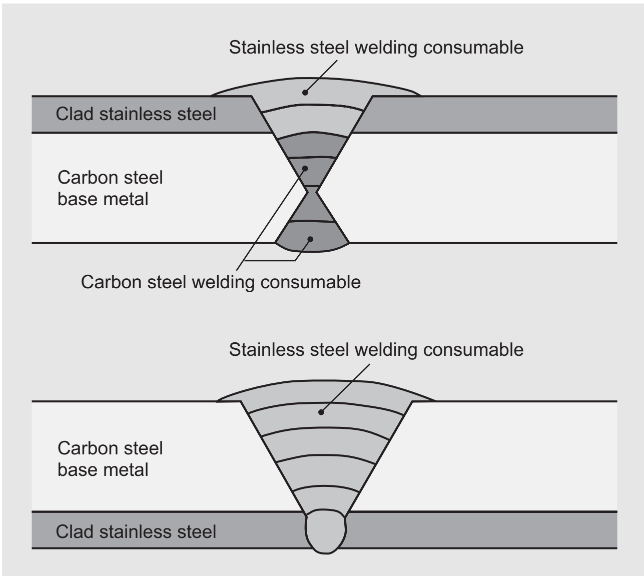


Figure 17: Welding sequence of clad steel

Reference: *ASM Specialty Handbook "STAINLESS STEELS"*, ASM International

KOBELCO

GLOBAL MANUFACTURING AND SALES BASES

ASIA

JAPAN:
KOBE STEEL, LTD., Welding Business
Marketing Dept., International Sales & Marketing Sec.
Tel. (81) 3 5739 6331 Fax. (81) 3 5739 6960

KOREA:
KOBE WELDING OF KOREA CO., LTD.
Tel. (82) 55 292 6886 Fax. (82) 55 292 7786

KOBELCO WELDING MARKETING OF KOREA CO., LTD.
Tel. (82) 51 329 8950 to 8952 Fax. (82) 51 329 8949

CHINA:
KOBE WELDING OF SHANGHAI CO., LTD.
Tel. (86) 21 6191 7850 Fax. (86) 21 6191 7851

KOBE WELDING OF TANGSHAN CO., LTD.
Tel. (86) 315 385 2806 Fax. (86) 315 385 2829

KOBE WELDING OF QINGDAO CO., LTD.
Tel. (86) 532 8098 5005 Fax. (86) 532 8098 5008

SINGAPORE:
KOBELCO WELDING ASIA PACIFIC PTE. LTD.
Tel. (65) 6268 2711 Fax. (65) 6264 1751

THAILAND:
THAI-KOBE WELDING CO., LTD.
Tel. (66) 2 636 8650 to 8652 Fax. (66) 2 636 8653

KOBE MIG WIRE (THAILAND) CO., LTD.
Tel. (66) 2 324 0588 to 0591 Fax. (66) 2 324 0797

MALAYSIA:
KOBE WELDING (MALAYSIA) SDN. BHD.
Tel. (60) 4 3905792 Fax. (60) 4 3905827

INDONESIA:
P.T. INTAN PERTIWI INDUSTRI
(Technically Collaborated Company)
Tel. (62) 21 639 2608 Fax. (62) 21 649 6081

INDIA:
KOBELCO WELDING INDIA PVT. LTD.
Tel. (91) 124 4010063 Fax. (91) 124 4010068

EUROPE

NETHERLANDS:
KOBELCO WELDING OF EUROPE B.V.
Tel. (31) 45 547 1111 Fax. (31) 45 547 1100

AMERICA

USA:
KOBELCO WELDING OF AMERICA INC.
Tel. (1) 281 240 5600 Fax. (1) 281 240 5625

2016.7.2000F