KOBELCO WELDING TODAY

3rd Special Edition

KOBELCO WELDING CONSUMABLES

FOR

STAINLESS STEEL

KOBELCO

A Quick Guide to Suitable Welding Consumables for Stainless Steel

Steel type	Key notes for application	SMAW		FCAW	
		Brand name(1)	AWS class.	Brand name(1)	AWS class.
304	General	[P] **NC-38**	E308-16	[P] **DW-308** [P] **DW-308LP**	E308T0-1/-4 E308LT1-1/-4
304L	Cryogenic temperatures	[P] **NC-38LT**	E308L-16	[P] **DW-308LT** [P] **DW-308LTP**	E308LT0-1/-4 E308LT1-1/-4
	Low carbon (0.04% max.)	[P] **NC-38L**	E308L-16	[P] **DW-308L** [P] **DW-308LP**	E308LT0-1/-4 E308LT1-1/-4
	High temperatures, Solution treatment	[P] **NC-38L**	E308L-16	[P] **DW-308LH**	E308LT1-1/-4
304H	High temperatures	[P] **NC-38H**	E308H-16	[P] **DW-308H**	E308HT1-1/-4
304N2	General	-	-	[P] **DW-308N2**	-
Dissimilar metals	General	[P] **NC-39** [P] **NC-39L** [P] **NC-39MoL** [P] **NC-32**	E309-16 E309L-16 E309LMo-16 E312-16	[P] **DW-309** [P] **DW-309L** [P] **DW-309MoL** [P] **DW-309LP** [P] **DW-309MoLP** [P] **DW-312**	E309T0-1/-4 E309LT0-1/-4 E309LMoT0-1/-4 E309LT1-1/-4 E309LMoT1-1/-4 E312T0-1
	High temperatures, Solution treatment	-	-	[P] **DW-309LH**	E309LT1-1/-4
316	General	[P] **NC-36**	E316-16	[P] **DW-316** [P] **DW-316LP**	E316T0-1/-4 E316LT1-1/-4
316L	Cryogenic temperatures	[P] **NC-36LT**	E316L-16	[P] **DW-316LT**	E316LT1-1/-4
	Low carbon (0.04% max.)	[P] **NC-36L**	E316L-16	[P] **DW-316L** [P] **DW-316LP**	E316LT0-1/-4 E316LT1-1/-4
	High temperatures, Solution treatment	[P] **NC-36L**	E316L-16	[P] **DW-316LH**	E316LT1-1/-4
316H	High temperatures	-	-	[P] **DW-316H**	E316T1-1/-4
316L Mod.	Urea (Low ferrite content)	[P] **NC-316MF**	-	-	-
317L	Low carbon (0.04% max.)	[P] **NC-317L**	E317L-16	[P] **DW-317L**	E317LT0-1/-4
347	General	[P] **NC-37**	E347-16	[P] **DW-347**	E347T0-1/-4
	Low carbon	[P] **NC-37L**	E347-16	-	-
	High temperatures	[P] **NC-37**	E347-16	[P] **DW-347H**	E347T1-1/-4
321	General	[P] **NC-37**	E347-16	[P] **DW-347**	E347T0-1/-4
	High temperatures	[P] **NC-37**	E347-16	[P] **DW-347H**	E347T1-1/-4
310S	General	[P] **NC-30**	E310-16	[P] **DW-310**	E310T0-1/-4
Duplex stainless	General	[P] **NC-329M**	-	[P] **DW-329A** [P] **DW-329AP**	E2209T0-1/-4 E2209T1-1/-4
410	General	[P] **CR-40**	E410-16	-	-
405, 409	Overlaying in cladding	[P] **CR-40Cb**	-	[P] **DW-410Cb**	-
	Underlaying in cladding	[P] **CR-43Cb** [P] **CR-43CbS**	- -	[P] **DW-430CbS**	-
13Cr-Ni type	Low carbon	-	-	[P] **MX-A135N** [P] **MX-A410NM**	- -
409, 430, 436, 410L	Car exhaust system	-	-	[P] **MX-A430M**	-

(1) [P] designates **PREMIARC**™.

❑ Tips for Selecting Appropriate Welding Consumables

1. This guidance is to help users select appropriate welding consumables for a particular job. Users are requested to confirm whether the brand they selected can satisfy the chemical and mechanical requirements for the relevant job before use.

2. FCAW flux-cored wires designated with DW are of rutile-type and those denoted with MX are of metal-type. Each brand selects a CO_2 or Ar-CO_2 shielding gas according to its inherent characteristics or the application. DW wires with the suffix P are suitable for all position welding. GMAW solid wires symbolized with MG use 98%Ar-2%O_2 for shielding. GTAW solid wires designated with TG-S and flux-cored wires with TG-X use a pure argon gas for shielding.

GMAW		GTAW		SAW	
Brand name(1)	AWS class.	Brand name(1)	AWS class.	Brand name(1)	AWS class.(Wire)
[P] **MG-S308**	ER308	[P] **TG-S308**	ER308	[P] **PF-S1** / [P] **US-308**	ER308
-	-	[P] **TG-S308L**	ER308L	[P] **PF-S1** / [P] **US-308L**	ER308L
[P] **MG-S308LS**	ER308LSi	[P] **TG-S308L** [P] **TG-X308L**	ER308L R308LT1-5	[P] **PF-S1** / [P] **US-308L**	ER308L
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
[P] **MG-S309** [P] **MG-S309LS**	ER309 ER309LSi	[P] **TG-S309** [P] **TG-S309L** [P] **TG-X309L**	ER309 ER309L R309LT1-5	[P] **PF-S1** / [P] **US-309** [P] **PF-S1** / [P] **US-309L**	ER309 ER309L
-	-	-	-	-	-
-	-	[P] **TG-S316**	ER316	[P] **PF-S1M** / [P] **US-316** (Single pass) [P] **PF-S1** / [P] **US-316** (Multi-pass)	ER316 ER316
-	-	[P] **TG-S316L**	ER316L	-	-
[P] **MG-S316LS**	ER316LSi	[P] **TG-S316L** [P] **TG-X316L**	ER316L R316LT1-5	[P] **PF-S1M** / [P] **US-316L** (Single pass) [P] **PF-S1** / [P] **US-316L** (Multi-pass)	ER316L ER316L
-	-	-	-	-	-
-	-	-	-	-	-
-	-	[P] **NO4051** [P] **TG-S310MF**	- -	-	-
-	-	[P] **TG-S317L**	ER317L	[P] **PF-S1** / [P] **US-317L**	ER317L
[P] **MG-S347S**	ER347Si	[P] **TG-S347** [P] **TG-X347**	ER347 R347T1-5	[P] **PF-S1** / [P] **US-347**	ER347
[P] **MG-S347LS**	ER347Si	[P] **TG-S347L**	ER347	-	-
[P] **MG-S347S**	ER347Si	[P] **TG-S347**	ER347	-	-
[P] **MG-S347S**	ER347Si	[P] **TG-S347**	ER347	[P] **PF-S1** / [P] **US-347**	ER347
[P] **MG-S347S**	ER347Si	[P] **TG-S347**	ER347	-	-
-	-	[P] **TG-S310**	ER310	-	-
-	-	[P] **TG-S329M**	-	-	-
[P] **MG-S410**	ER410	[P] **TG-S410**	ER410	[P] **PF-S4M** / [P] **US-410**	-
-	-	[P] **TG-S410Cb**	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
[P] **MG-S430M**	-	-	-	-	-

3. PF designates bond-type SAW fluxes and US designates SAW solid wires.

4. For dissimilar metal joints between stainless steels and carbon or low-alloy steels, 309-, 309L, or 309LMo-type welding consumables are often used where the joint is subject to non-cyclical temperature services below 315°C. However, where either postweld heat treatment is required or the joint is subject to cyclical temperature services above 315°C, a Ni-based alloy welding consumable is recommended. For dissimilar metal joints between stainless steel castings and medium or high carbon steels, 312-type welding consumables containing high amounts of ferrite are better to prevent hot cracks in the weld.

5. For details of individual brands, refer to KOBELCO WELDING HANDBOOK.

PREMIARC™

DW-308L

AWS A5.22 E308LT0-1/-4

DW-308L represents a new generation of stainless flux cored wires by significantly reducing spatter and fumes over a wide range of welding parameters while featuring self-peeling slag removal and glossy bead appearance.

Basic characteristics of DW-308L

As shown in the AWS classification designations above, DW-308L is suited for flat and horizontal position welding with both CO_2 gas and 75-80%Ar + balanced CO_2 mixed gas shielding. DW-308L can be used in welding both 304L and 304 stainless steel.

What makes DW-308L a new generation wire?

Properly-controlled ferrite content (typically, 9% by Shaeffler Diagram) in DW-308L weld metal provides better resistibility to hot cracking. Additionally, low carbon content (typically, 0.027%) in DW-308L weld metal increases resistance to intergranular corrosion. The chemical composition of the weld metal provides superior mechanical properties and corrosion resistibility.

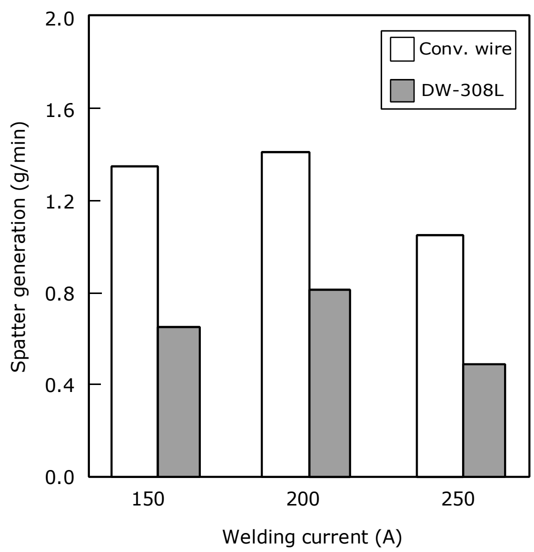


Figure 1: A comparison between DW-308L and conventional flux-cored wire in terms of spatter generation (Wire size: 1.2 mmØ; Shielding gas: 100%CO_2; Welding speed: 30cpm).

In addition to the sophisticated balance achieved in the chemical composition, DW-308L significantly lessens spatter and fumes. As shown in Figure 1, DW-308L reduces spatter by 40-50% over a range of welding parameters when compared to a conventional stainless flux cored wire. Materials savings can thus be realized in addition to savings in labor and material costs associated with postweld cleaning. As shown in Figure 2, DW-308L reduces fumes by 20-25% over a range of welding parameters when compared to a conventional stainless flux cored wire.

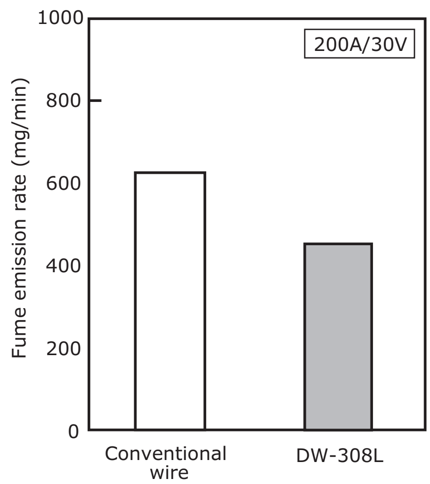


Figure 2: A comparison between DW-308L and conventional flux-cored wire in terms of fume emission rate (Wire size: 1.2 mmØ, Shielding has: 100%CO_2).

Convenient self-peeling slag removal and glossy bead appearance of DW-308L will leave you feeling very satisfied—Figures 3 and 4.

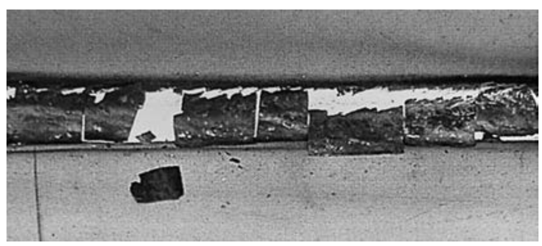


Figure 3: Excellent self-peeling slag removability of DW-308L.

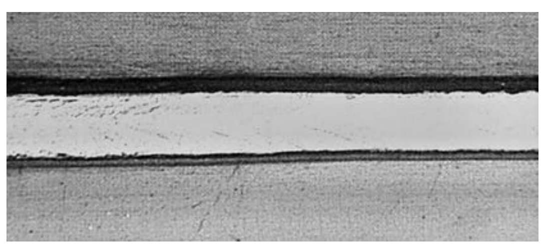


Figure 4: The glossy appearance of DW-308L fillet weld bead.

PREMIARC™
DW-308LP
AWS A5.22 E308LT1-1/-4

DW-308LP also represents a new generation of stainless flux cored wires, but in a different way than DW-308L. As easy to use as a mild-steel flux cored wire, DW-308LP can easily be used in all positions including vertical, horizontal, and overhead.

Basic characteristics of DW-308LP

As seen in the AWS classification designations shown above, DW-308LP is suitable for welding in all positions, with both CO_2 gas and 75-80%Ar + balanced CO_2 mixed gas shielding. DW-308LP can be used in welding both 304L and 304 stainless steel.

What makes DW-308LP a new generation wire?

Like DW-308L, the sophisticated chemical composition of DW-308LP weld metal provides superior mechanical properties and corrosion resistibility. In addition, DW-308LP offers unsurpassed welding performance in all positions and over a wide range of welding parameters.

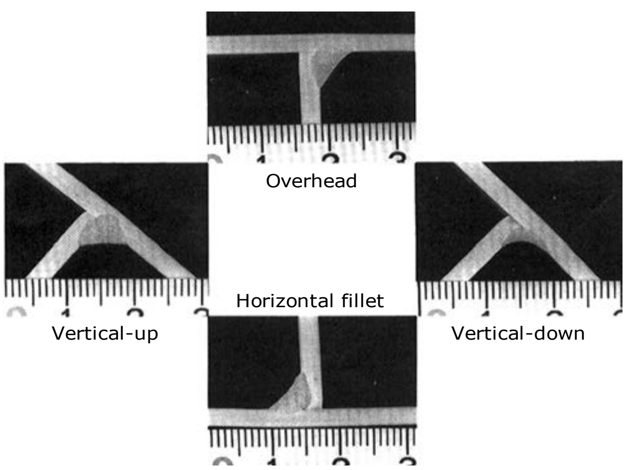


Figure 1: Cross-sectional weld profiles of DW-308LP (Wire size: 1.2 mmØ) with 304-type base metal (Plate thickness: 3 mm).

As shown in Figure 1, DW-308LP provides superior weld profiles with smooth fusion to the base metals and good penetration in such various welding positions as horizontal fillet, vertical-up, vertical-down and overhead.

It has generally been believed that welding stainless steel in vertical and overhead positions was more difficult than mild steel because molten metal was more likely to drop. This difficulty was assumed because of 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).

However, DW-308LP has jumped over these hurdles to become a superior flux cored wire suitable for welding in all positions. Figure 2 shows an application for DW-308LP: a curved, large-diameter water pipe that, because of the inherent difficulty in positioning the work, requires all-position welding. DW-308LP is suitable for welding fixed pipes, storage tanks and rolling stock, which are all difficult to position during welding.

Figure 2: A water pipe for the water gate equipment under fabrication by using DW-308LP in all positions.

Finally, DW-308LP offers very good re-arc-starting capability—almost no miss in re-arc-starting within 5, 10, and 30 seconds respectively after extinguishing the arc in 50-time re-arc-starting tests in the use of either inverter-type power sources or thyristor-type power sources. This excellent performance can be more beneficial in tack welding, automatic welding and robotic welding, eliminating the downtime for re-arc-starting.

PREMIARC™ DW-316L

AWS A5.22 E316LT0-1/-4

DW-316L is an advanced stainless flux cored wire that significantly reduces spatter and fumes over a wide range of welding parameters and features self-peeling slag removal and glossy bead appearance.

Basic characteristics of DW-316L

DW-316L is classified as AWS A5.22 E316LT0-1 and E316LT0-4, suitable for welding both 316L and 316 stainless steel in flat and horizontal positions. As for shielding, either CO_2 gas or 75-80%Ar + balanced CO_2 gas mixtures can be used.

What makes DW-316L an advanced wire?

Properly controlled ferrite content (typically 8% by Schaeffler Diagram) in DW-316L weld metal provides excellent resistibility to hot cracking. Low carbon content (typically 0.026%) in the weld metal provides superior resistance to intergranular corrosion. To verify resistance to intergranular corrosion, Strauss testing (Copper Sulfate Sulfuric Acid Test) per JIS G0575, equivalent to ASTM A262 Practice E, is generally employed. In this testing, DW-316L weld metal sensitized by the heat treatment (650°C×2h) exhibits no cracking in the bending test after corrosion testing. The sophisticated chemical composition of the weld metal provides outstanding mechanical properties and corrosion resistibility against diluted sulfuric acids in particular.

DW-316L significantly lessens spatter by 40-50% when compared with conventional stainless flux-cored wire. DW-316L features convenient self-peeling slag removal and glossy bead appearance. Because less postweld cleaning is required to remove spatter and slag, material and labor costs can be reduced. DW-316L also produces 20-25% less fumes compared with conventional stainless flux cored wire. This improves the work environment for welders.

DW-316L also provides higher deposition rates than solid wires and covered electrodes as shown in Figure 1. For instance, the deposition rate of DW stainless wires can be about two times that of covered electrodes at 150A and about 1.2 times that of solid wires at 250A. The use of 1.2-mmØ wire can produce higher deposition rates than 1.6 mmØ. This means that you can fill a particular welding groove faster with DW-316L, thereby increasing productivity while decreasing labor costs.

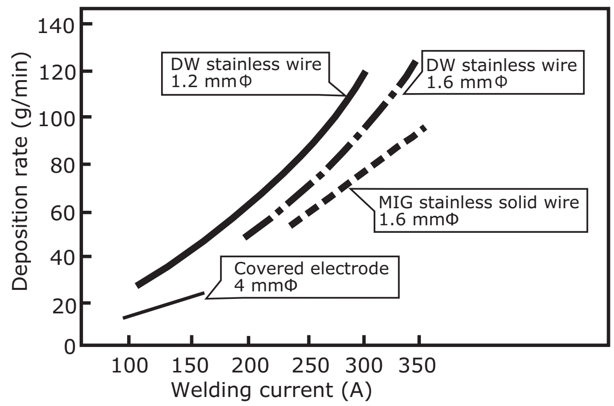


Figure 1: A comparison of deposition rates between flux-cored wire, MIG solid wire and covered electrode as a function of welding current.

Because of the superior corrosion resistibility, mechanical properties and usability, DW-316L is often used for welding 316L stainless solid and clad components of chemical tankers that require stricter corrosion resistance of the welds— Figure 2. In order to ensure the quality of the welds in the ship applications, DW-316L is approved by ship classes such as AB, LR, NV, BV, and NK.

Figure 2: An application of DW-316L for fillet welding of the pipe fittings and pipelines equipped on the bridge and in the cargo tanks of a chemical tanker.

PREMIARC™
DW-316LP
AWS A5.22 E316LT1-1/-4

DW-316LP is an advanced stainless flux cored wire that offers unsurpassed usability in all positions including flat, horizontal, vertical-up, vertical-down, and overhead.

Basic characteristics of DW-316LP

DW-316LP is classified as AWS A5.22 E316LT1-1 and E316LT1-4, suitable for welding in all positions with either CO_2 gas or 75-80%Ar + balanced CO_2 gas mixture shielding. DW-316LP can be used for welding both 316L and 316 stainless steel.

What makes DW-316LP an advanced wire?

Like DW-316L, the elaborate chemical composition of the DW-316LP weld metal containing a low amount of carbon (typically 0.028%) provides superior mechanical properties and corrosion resistibility particularly against diluted sulfuric acids. Its intergranular corrosion resistibility is proved to be excellent through Strauss testing.

DW-316LP also offers excellent welding performance in all positions and over a wide range of welding parameters. Figure 1 shows an example of proper welding parameters (welding current and arc voltage) in the vertical-up position. Once you adjust the welding current to 160-170A for example, you can properly weld a 6-mm-thick stainless plate in any of the flat, horizontal, vertical, and overhead positions without any current readjustment.

Because of the superior corrosion resistibility, mechanical properties and out-of-position welding usability, DW-316LP is often used for welding storage tanks of chemical tankers (Figure 2). Figure 3 shows an example of the welding procedures for the butt joints of a chemical tanker storage tank, which is one-sided welding procedure using a FB-B3 backing material for the root pass.

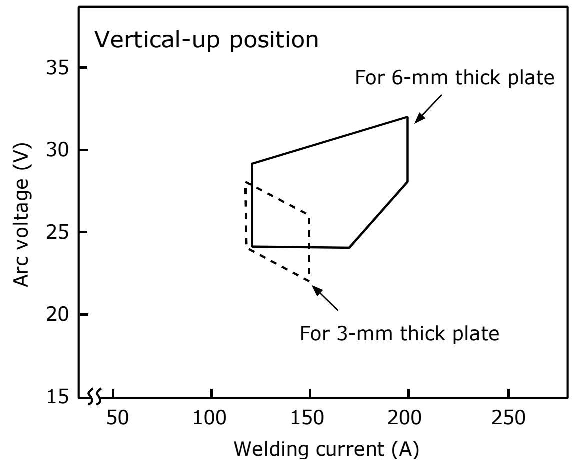


Figure 1: The proper range of welding currents and arc voltages in the vertical-up position using a 1.2-mmØ DW stainless wire for welding 6- and 3-mm thick stainless steel plates.

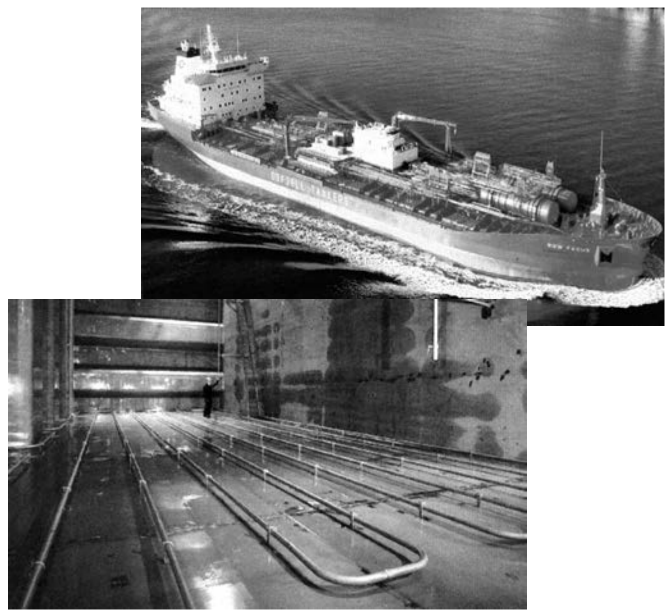


Figure 2: An application of DW-316LP: welding a storage tank (bottom) of a chemical tanker (top) with full penetration in all positions.

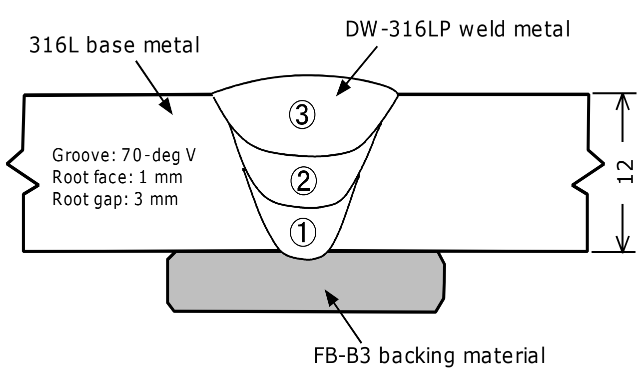


Figure 3: An example of the welding procedure with DW-316LP for the storage tank of a chemical tanker, a one-sided welding procedure using a FB-B3 refractory backing for the root pass in vertical-up position.

PREMIARC™

DW-309L

AWS A5.22 E309LT0-1/-4

Within the "DW stainless series," DW-309L is an exceptional flux-cored wire; it is an indispensable wire for welding dissimilar metal joints and the buffer layers for clad steel and overlaying.

Basic characteristics of DW-309L

The respective AWS classification designators, E309LT0-1 and E309LT0-4, will help you know the basic characteristics of DW-309L as follows.

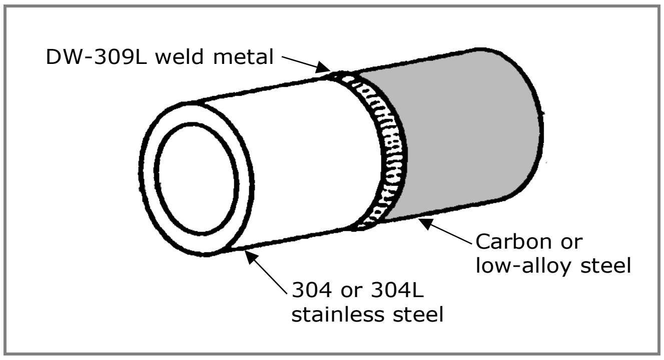
E: designates an electrode.
309: indicates 309 type deposited metal (22%Cr-12%Ni as minimum).
L: designates low-carbon type (C%= 0.04 max.).
T: designates a tubular wire or a flux-cored wire.
0: indicates the intended welding positions are flat and horizontal.
1: indicates the suitable shielding gas is CO_2.
4: indicates the suitable shielding gas is 75-80%Ar + balanced CO_2.

What welding applications need DW-309L

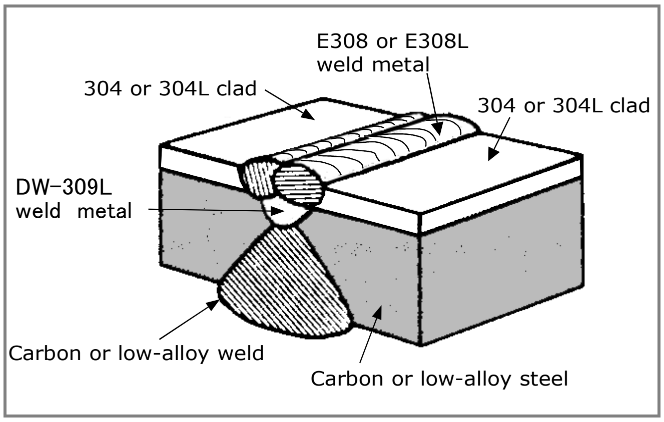
Most plant and equipment in oil refineries, chemical plants, power generation plants, chemical tankers, liquefied gas plants and carriers, and food processing plants consists, on any scale, of dissimilar metal joints and clad steel components. This is to minimize the material costs and, simultaneously,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

DW-309L is designed so that its weld metal can accommodate adverse effects caused by dilution by carbon or low-alloy base metals. The adverse effects include martensite (a brittle structure) formation and fully austenitic structure (non-ferrite-bearing austenite sensitive to hot cracking) formation in the weld metal. This feature makes DW-309L suitable for dissimilar metal joints which can contain various combinations of austenitic stainless steel and carbon or low alloy steels as shown in the following figures.

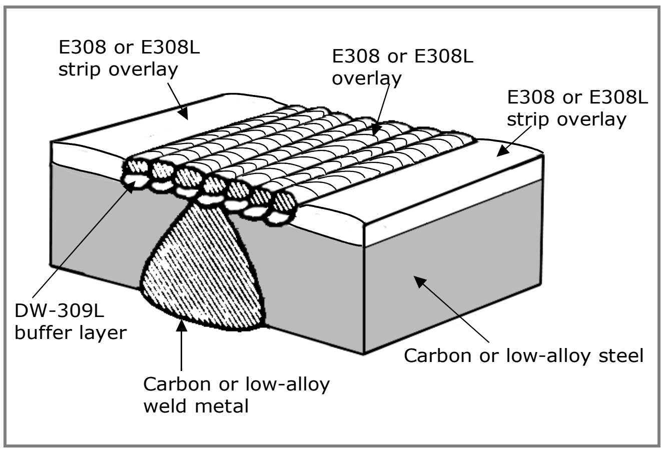
(1) Welding 304 or 304L stainless steel to carbon or low-alloy steel.



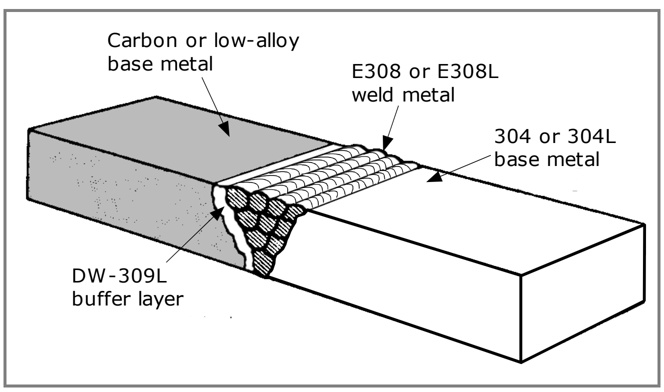
(2) Buffer layers in 304 or 304L clad steel welds.



(3) Buffer layers in E308 or E308L overlay welds.



(4) Buffer layers in welding 304 or 304L stainless steel to carbon or low-alloy steel.



PREMIARC™

DW-309LP

AWS A5.22 E309LT1-1/-4

DW-309LP: an advanced flux-cored wire offering superior usability in all positions including flat, horizontal, vertical-up, vertical-down, and overhead welding.

Basic characteristics of DW-309LP

The AWS classification of DW-309LP differs from that of DW-309L in only the seventh digit. The seventh digit, "1" indicates that out-of-position welding is intended. For other characteristics of DW-309LP, the reader may refer to the descriptions of the DW-309L classification.

In what kinds of joints DW-309LP shines

A typical application of DW-309LP is seen in chemical tankers (Figure 1). Chemical tankers are equipped with cargo tanks made of solid or clad austenitic stainless steels such as 304L, 316L, and 317L. Cargo tanks usually contain corrosive substances such as petroleum products, chemical products, acids, alkalis, molasses, animal oils, and vegetable oils. Therefore, cargo tanks and piping systems require corrosion-resistant stainless and stainless-clad steels.

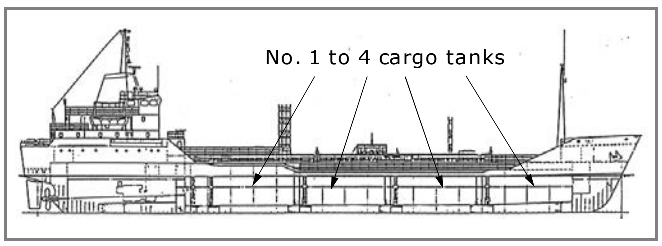


Figure 1: Cargo tanks of a chemical tanker.

Where 304L stainless-clad steel is used for the cargo tanks, DW-309LP is a suitable flux-cored wire for the buffer layer. DW-309LP provides excellent usability in all positions and is as easy to use as a mild-steel flux-cored wire. Figure 2 shows a cross sectional view of a cargo tank of a chemical tanker. Figures 3 and 4 show examples of DW-309LP buffer layers in butt welds of stainless-clad steel joints of a cargo tank.

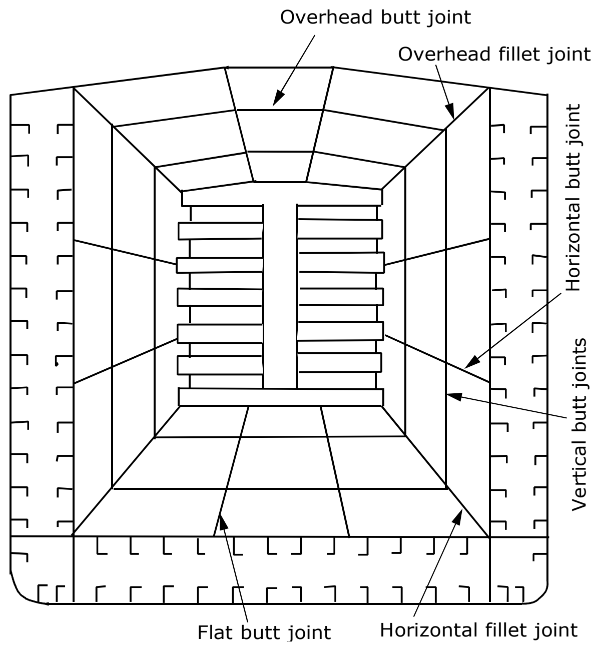


Figure 2: A cross sectional view of a cargo tank and a variety of welding joints in all positions.

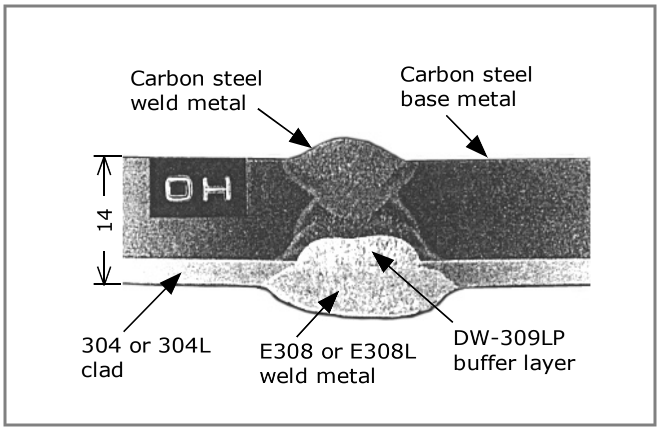


Figure 3: A DW-309LP buffer layer in an overhead joint weld of stainless-clad steel.

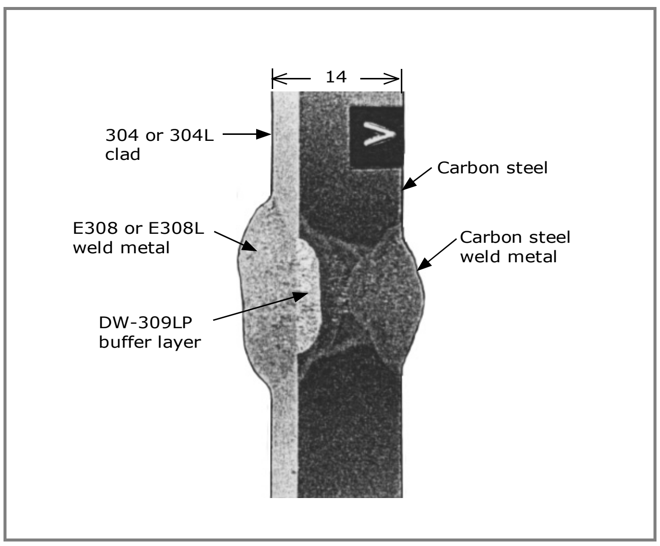


Figure 4: A DW-309LP buffer layer in a vertical joint weld of stainless-clad steel.

Photo courtesy of Hitachizosen Co., Ltd.

PREMIARC™

DW-309MoL & DW-309MoLP

The Indispensable FCWs for Dissimilar Metal Welding in Desalination Plants, Chemical Tankers and Paper Mills

Part of the DW stainless steel series, DW-309MoL and DW-309MoLP are special flux-cored wires. They are indispensable filler metals for welding dissimilar metal joints, such as in the buffer layer of clad steels, and the underlayer for overlaying. Mo-bearing austenitic stainless steel (316L and 317L), duplex stainless steel, carbon steel, and low-alloy steel usually constitute such dissimilar metal joints and clad steels. For the overlaying substrates, carbon steel and low-alloy steel are used. The demand for cost effective clad steels in particular, and thus for suitable filler metals, is expected to increase due to the brisk business in the relevant industries.

DW-309MoL and DW-309MoLP are classified as AWS A5.22 E309LMoT0-1/-4 and E309LMoT1-1/-4 respectively. As the AWS classifications indicate, the former is suitable for flat and horizontal fillet welding, whereas the latter is suitable for positional welding; both wires use either CO_2 gas or 75-80%Ar/20-25%CO_2 mixture shielding gas. The typical chemical and mechanical properties of these wires are shown in Table 1.

Table 1: Typical chemical and mechanical properties of DW-309MoL and DW-309MoLP deposited metals with CO_2 shielding gas

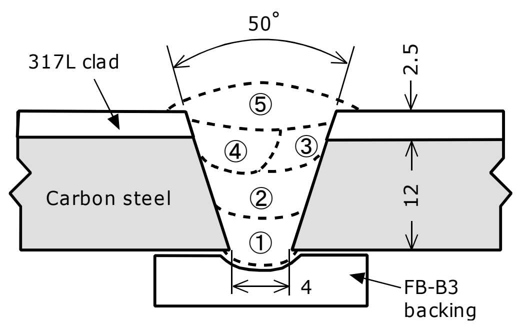
Trade designation	**DW-309MoL**	**DW-309MoLP**
C (%)	0.027	0.025
Si (%)	0.61	0.62
Mn (%)	1.18	0.81
P (%)	0.019	0.020
S (%)	0.009	0.010
Ni (%)	12.60	12.44
Cr (%)	23.20	22.60
Mo (%)	2.37	2.21
FNW(1)	28	25
0.2% PS (MPa)	540	540
TS (MPa)	720	699
El (%)	30	30

(1) Ferrite Number per WRC Diagram-1992.

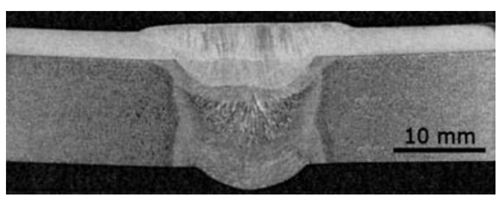
As DW-309MoL and DW-309MoLP weld metals contain sufficient amounts of ferrite, they can accommodate the detrimental effects caused by dilution by the carbon or low-alloy base metal. These effects may include the formation of martensite (brittle structure) and a fully austenitic structure (sensitive to hot cracking) in the weld metal. Similar to mild-steel titanium-type flux-cored wires, these wires offer excellent usability with a stable arc, low spatter, self-peeling slag removal, regular bead shape, and glossy bead appearance. Table 2 shows an example of a welding procedure for 317L stainless clad steel.

Table 2: One-side welding of 317L stainless clad steel plate with DW-309MoL and a FB-B3 backing

Pass No.	Trade designation	Size (mm)	Welding position	Amp. (A)	Volt. (V)	Speed (cm/min)
1	DW-100	1.2Ø	Flat	200	24	15
2	DW-100	1.2Ø	Flat	280	30	25
3	**DW-309MoL**	1.2Ø	Flat	180	26	43
4	**DW-309MoL**	1.2Ø	Flat	180	26	30
5	DW-317L	1.2Ø	Flat	190	28	14



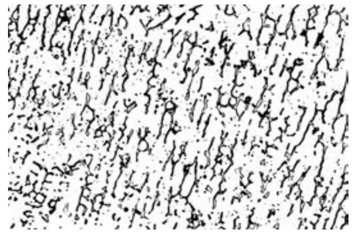
(a) Weld pass sequence



(b) Cross section macrostructure

The H-series DW stainless steel flux-cored wires shine in high-temperature applications

PREMIARC™ DW-308H / DW-308LH / DW-316H / DW-316LH / DW-347H / DW-309LH



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

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, the 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.

Table 1: Typical chemical and mechanical properties of H-series DW stainless steel flux-cored wires

Trade designation		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 composition of 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(1)		4	5	7	8	6	20
TS (MPa)		575	540	570	540	602	578
El. (%)		48	52	42	45	43	39

(1) Ferrite Number per WRC Diagram-1992.

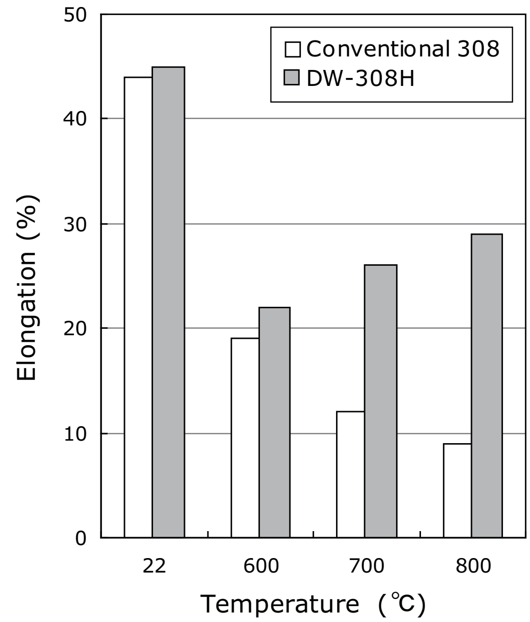


Figure 1: A comparison of high temperature elongation between DW-308H and conventional 308 FCW.

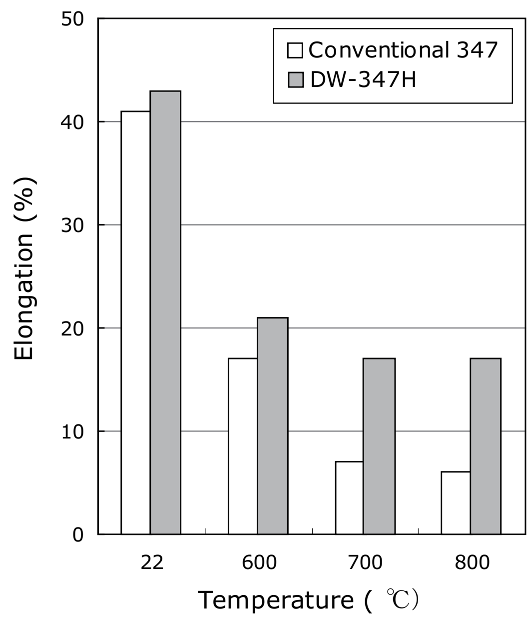


Figure 2: A comparison of high temperature elongation between DW-347H and conventional 347 FCW.

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

PREMIARC™ DW-329A — AWS A5.22 E2209T0-1/-4

PREMIARC™ DW-329AP — AWS A5.22 E2209T1-1/-4

Such technologically demanding welding applications as chemical tankers, pulp mills, and offshore structures are the typical fields where DW-329A and DW-329AP shine in flux-cored arc welding of duplex stainless steel.

What is duplex stainless steel?

Duplex stainless steel is known for combining the superior stress-corrosion crack resistance of ferritic stainless steel with the excellent ductility, toughness and weldability of austenitic stainless steel. To establish this sophisticated characteristic, duplex stainless steel features a binary microstructure consisting of approx. 50% ferrite and 50% austenite as shown in Figure 1 and a compositional balance of Cr, Ni, Mo and N. It also features yield strength that is two times higher than the 300-series austenitic stainless steels. Because duplex stainless steel has good weldability in terms of hot and cold crack resistance, users can follow almost the same welding procedure as that for austenitic stainless steels. Chemical plant machinery, oil and natural gas drilling pipes and pipelines, chemical tankers, and water gates are typical applications for duplex stainless steels.

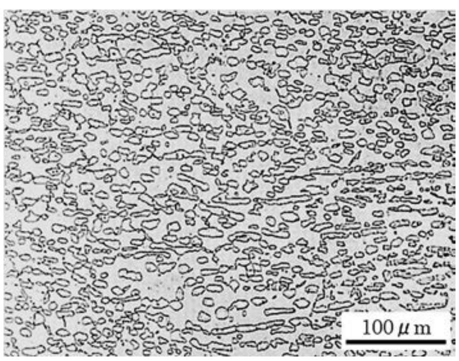


Figure 1: An example of duplex stainless steel microstructure which exhibits distributed austenite (brighter areas) in the ferrite matrix (darker areas).

The unsurpassed performance of KOBELCO duplex stainless flux-cored wires

Among several KOBELCO filler metals for duplex stainless steel, DW-329A and DW-329AP enjoy higher reputations worldwide due to excellent performance in usability, mechanical properties and corrosion resistibility. Both brands resemble each other in terms of type of flux (rutile-based flux), suitable shielding gases (CO_2 and Ar/CO_2 mixtures), mechanical properties and chemical composition. However, their applicable welding positions are different: DW-329A is suitable for flat and horizontal fillet welding only, while DW-329AP is excellent in out-of-position welding. DW-329AP features the chemical composition and mechanical properties listed in Table 1 and the microstructure in Figure 2.

Table 1: Typical chemical and mechanical properties of DW-329AP (1.2 mmØ) all-weld metal and AWS requirements(1)

Trade designation and AWS properties	DW-329AP	Requirements of AWS A5.22 E2209T1-4
C (%)	0.024	0.04 max
Si (%)	0.55	1.0 max
Mn (%)	0.89	0.5-2.0
P (%)	0.018	0.04 max
S (%)	0.005	0.03 max
Cu (%)	0.06	0.5 max
Ni (%)	9.68	7.5-10.0
Cr (%)	22.96	21.0-24.0
Mo (%)	3.28	2.5-4.0
N (%)	0.14	0.08-0.20
PRE(2)	36.0	-
FNW(3)	40.5	-
0.2% PS (MPa)	617	-
TS (MPa)	808	690 min
El. (%)	31	20 min
RA (%)	48	-

Note (1) Shielding gas: 80%Ar-20%CO_2.
(2) PRE = Cr% + 3.3Mo% + 16N%.
(3) FNW: Ferrite Number per WRC Diagram-1992.

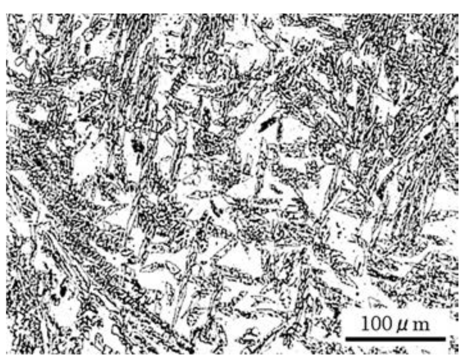


Figure 2: A typical austenite-ferrite binary microstructure of DW-329AP weld metal: the brighter areas show ferrite, and the darker areas show austenite.

PRE (Table 1) or Pitting Resistance Equivalent is used as the pitting index to evaluate the resistance to pitting corrosion. With a higher PRE value, the pitting corrosion resistance can be improved. The WRC chemistry-phase diagram (Figure 3) is commonly used for estimating the ferrite number related to the ferrite content of duplex stainless steel weld metals.

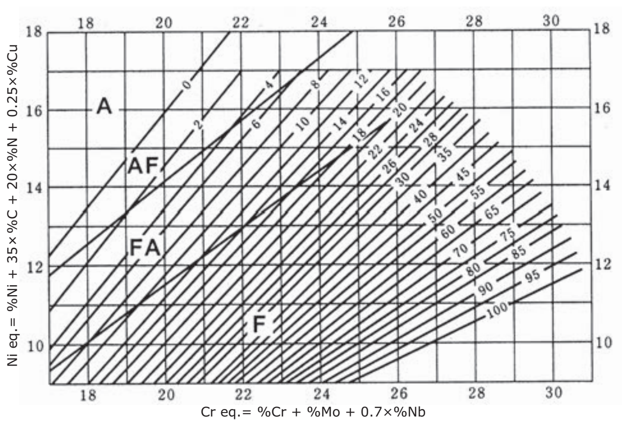


Figure 3: WRC chemistry-phase diagram (Solidification mode: A: austenite, γ ; F: ferrite, δ ; AF: $\gamma + \delta$; FA: $\delta + \gamma$).

DW-329AP weld metal possesses sufficient notch toughness or absorbed energies as shown in Figure 4. However, as the testing temperature decreases, the absorbed energy decreases. This is a noticeable disadvantage when compared with austenitic stainless steel weld metals. Therefore, duplex stainless steel weld metals are not suitable for cryogenic temperature applications.

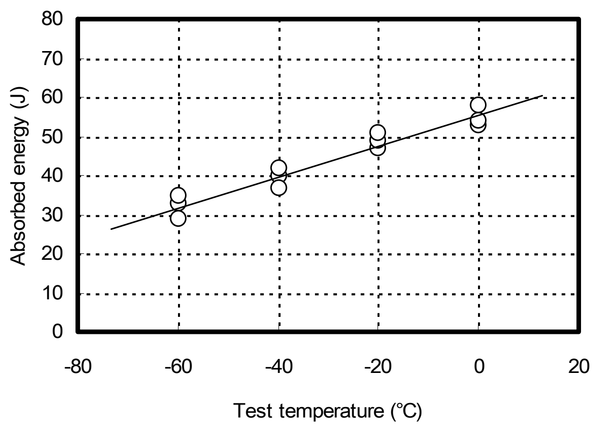


Figure 4: Charpy impact absorbed energies of DW-329AP (1.2 mmØ) weld metal at low temperatures with 80%Ar-20%CO_2 shielding.

Duplex stainless steel is superior in the resistance to pitting corrosion (defined as extremely localized corrosion, resulting in holes in the metal) in chloride-involved applications. DW-329AP weld metal features, as shown in Table 2, excellent resistance to pitting corrosion due to its elaborate chemistry design.

Table 2: Results of pitting corrosion testing of DW-329AP (1.2 mmØ) weld metal with 80%Ar-20%CO_2 shielding(1)

Testing condition	Corrosion loss (g/m^2-hr)	Judgement
20°C-24hr	0.005	No pitting
25°C-24hr	0.032	No pitting

Note (1) Testing method: ASTM G48 Practice A.
Specimen size: 10T x 15W x 35L (mm).

Figure 5 and Table 3 show the weld joint properties of DW-329AP with sound macrostructure, sufficient tensile strength and ductility. These test results were obtained in joint welding testing with a 20-mm thick duplex stainless steel base metal of UNS S31803 (0.025%C, 0.47%Si, 1.43%Mn, 5.51%Ni, 21.98%Cr, 2.96%Mo, 0.16%N).

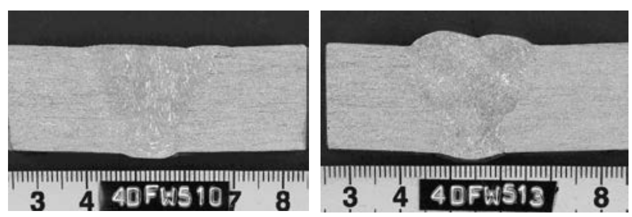
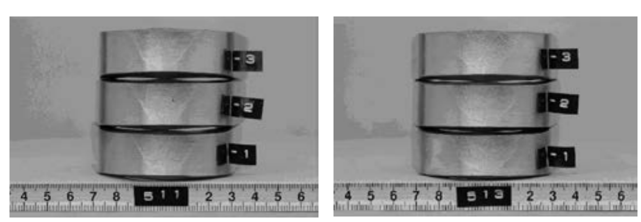


Figure 5: Macrostructure of DW-329AP one-sided weld joints in flat welding (left) and vertical-up welding (right) with ceramic backing and 80%Ar-20%CO_2 shielding.

Table 3: Results of tensile and bend testing of DW-329AP (1.2 mmØ weld joints with 80%Ar-20%CO_2 shielding

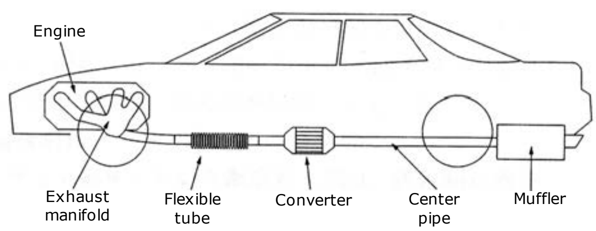
	Welding position	1G	3G
Tensile	Specimen size (mm)	20T x 25W	20T x 25W
	Tensile strength (MPa)	735	723
	Fracture location	Base metal	Base metal
Bend	Specimen size (mm)	9.5T x 20W	9.5T x 20W
	Bending radius	2TR-180 deg.	2TR-180 deg.
	Appearance(1)	Left below	Right below
	Judgement	Acceptable	Acceptable

Note (1) Appearance of specimens after testing by 2TR-180°.



1G position 3G position

PREMIARC™ MX-A430M is an Unsurpassed FCW for Cr Stainless Steel Welding



20-Year Track Records for Welding Automotive Exhaust Systems

The automotive industry worldwide has been promoting weight reduction of car bodies by using thinner, lighter materials to improve the fuel consumption efficiency, and improving the fuel combustion efficiency to reduce exhaust gases. In this trend, automotive exhaust systems have seen innovations in steel materials, and the increasing use of 17%Cr and 13%Cr ferritic stainless steel sheets and pipes for exhaust manifolds, converters, and mufflers. To respond to this trend, Kobe Steel developed MX-A430M metal-type flux-cored wire about 20 years ago. Since then this wire has earned a high reputation for the following advantages.

1. HIGHER BURN-THROUGH RESISTANCE: Automotive exhaust parts use sheet metals as thin as 0.8-2.0 mm. MX-A430M (1.2 mmØ) offers higher resistance to burn-through (excessive melt-through) as shown in Figure 1. This results from proper penetration and a wider weld pool.

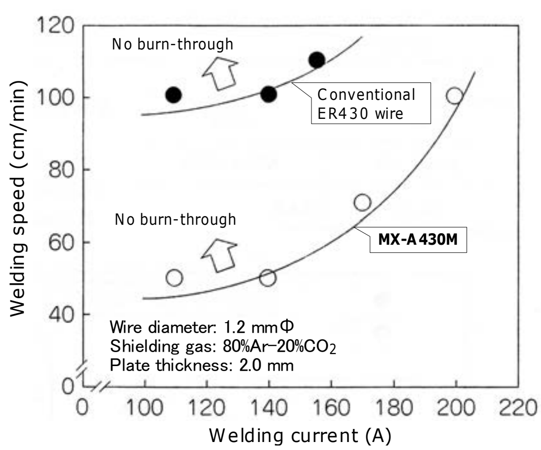
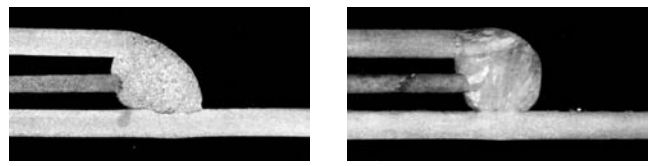


Figure 1: MX-A430M offers a wider current-speed range over conventional ER430 wire to prevent burn-through.

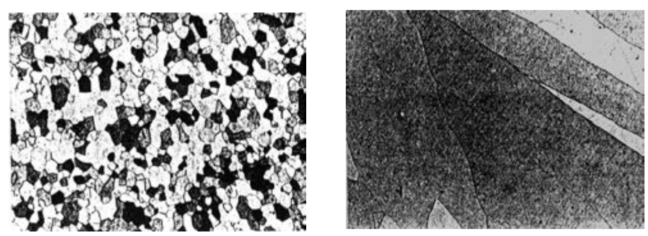
2. BETTER ROOT-GAP-BRIDGING ABILITY: Because the automotive exhaust parts are assemblages of thin pipes and press-formed shapes, the welding joints necessarily contain small or large gaps. If the weld pool cannot sufficiently bridges the gaps, incomplete fusion can occur. MX-A430M offers better root-gap-bridging ability over conventional ER430 wire to prevent incomplete fusion as shown in Figure 2.



MX-A430M Conventional ER430 wire

Figure 2: MX-A430M weld metal sufficiently bridges the gaps avoiding incomplete fusion in the 3-layer lapping joint that consists of a 1.5-mm stainless, 1.0-mm carbon, and 1.5-mm stainless steel assemblage with a root gap of 1.0 mm between sheet metals (130A, 17V, 45cm/min., 80%Ar-20%CO_2).

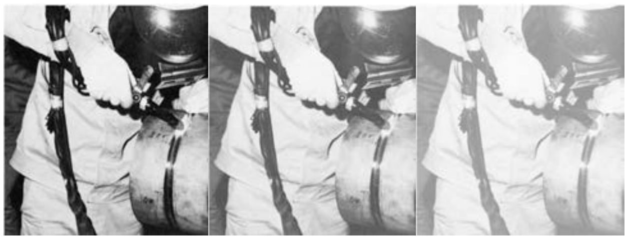
3. SUPERIOR CRACK RESISTANCE: The welding joints of auto parts are inevitably contaminated with machine oil caused by press-forming. Oil can be a source of carbon, sulfur and hydrogen, causing cracks in the weld. MX-A430M offers superior crack resistance, because of its finer microstructure over conventional ER430 wire (Figure 3).



MX-A430M Conventional ER430 wire

Figure 3: MX-A430M weld metal displays very fine microstructure to prevent cracks when compared with conventional ER430 wire.

4. EXCELLENT CORROSION AND OXIDATION RESISTANCE: The automotive exhaust parts are required to be resistible against corrosive condensed liquids and high-temperature oxidation as well as snow-melting agent. The fine microstructure and unique chemical composition (17%Cr-Nb) of MX-A430M weld metal offer higher resistance to intergranular and pitting corrosion and oxidation over conventional ER430 wire.



PREMIARC™ TG-X308L AWS A5.22 R308LT1-5
PREMIARC™ TG-X309L AWS A5.22 R309LT1-5
PREMIARC™ TG-X316L AWS A5.22 R316LT1-5
PREMIARC™ TG-X347 AWS A5.22 R347T1-5

The TG-X series of flux-cored stainless steel filler rods can eliminate gas purging for back shielding the root pass weld in one-side TIG pipe welding, cutting the costs for back shielding gases and gas purging downtime including the setting time for gas purging jigs. Process pipelines of Type 304, Type 316, Type 347 and dissimilar metals are typical applications for TG-X308L, TG-X316L, TG-X347 and TG-X309L, respectively.

How TG-X filler rods can eliminate back shielding

With a typical solid filler rod, back shielding is required in welding stainless steel pipes, or the root pass weld would not penetrate the backside of the joint properly. This can be attributed to significant oxidation of the root pass weld due to high chromium content of the weld. Therefore, back shielding with an inert gas is a must.

In contrast, unlike the typical solid wire, a TG-X filler rod contains a specific flux inside a tubular rod of stainless steel as shown in Figure 1. The flux can be fused by the arc heat to become molten slag. This molten slag can flow smoothly to the reverse side of the root to cover uniformly the penetration bead extruded inside the pipe. This molten slag protects the molten weld metal and red heated bead from the adverse effects of nitrogen and oxygen in the atmosphere.

When the weld cools down the slag solidifies to become thin, fragile slag, which can be removed easily by lightly hitting the face of the joint with a chipping hammer. Then a quality bead will appear on the face and reverse sides of the root with a smooth, uniform ripple without oxidation as shown in Figure 2. TG-X filler rods provide regular penetration through the entire part of the pipe in all positions as shown in Figure 3.

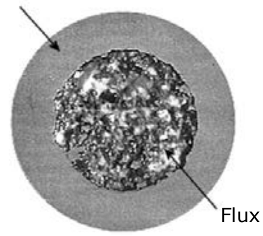


Figure 1: A cross sectional view of TG-X flux-cored filler rod.

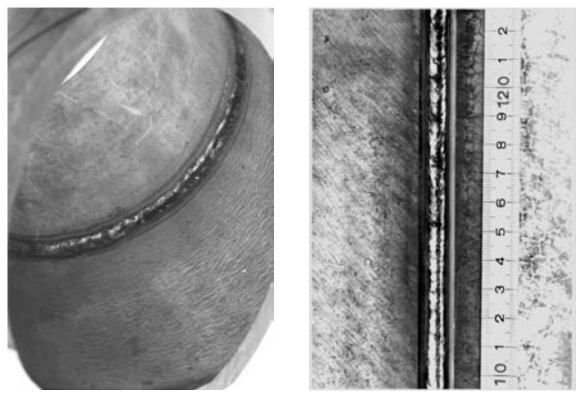


Figure 2: Glossy, regular bead appearance of the reverse (left) and face (right) surfaces of the root pass weld made by GTAW with a TG-X308L filler rod on a Type 304 pipe joint without back shielding.

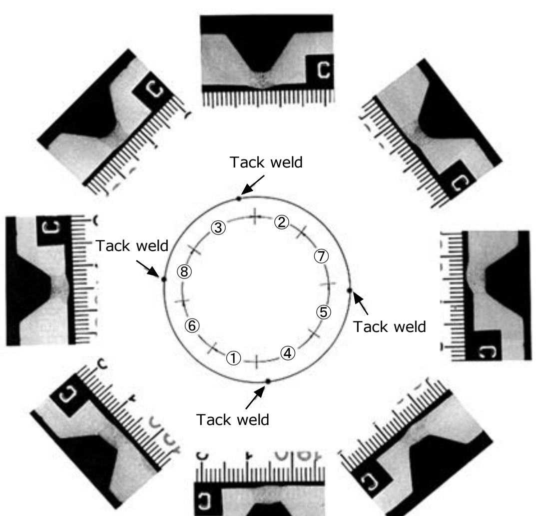
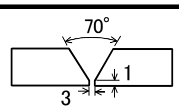
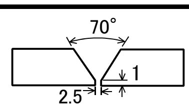


Figure 3: Macrostructures of TG-X308L welds made on a 304-type stainless steel pipe (12T×150mmØ) in 5G position.

How TG-X filler rods can cut costs for gas purging and back shielding

The use of a conventional solid filler rod needs back shielding with an inert gas: normally argon gas. Though the time and the amount of an inert gas needed for purging the inside of the pipe vary depending on the inside diameter and the length of the pipe to be purged, they affect markedly the total welding cost. Table 1 compares the uses of a usual solid filler rod and a TG-X filler rod on the factors affecting the welding costs in root pass welding on a pipe with an inside diameter of 305 mm. It is obvious that the use of a TG-X filler rod can noticeably reduce labor (man-hour) by 23-74% and the total argon gas consumption by 55-91% in a comparison with typical solid filler rods.

Table 1: A comparison between TG-X and solid filler rods on man-hour, argon gas consumption, filler rod consumption and power consumption in root pass welding of a pipe

Filler rod	TG-X	Solid	
Groove preparation			
Back shielding length of pipe	Without back shielding	300 mm for local shielding	6000 mm 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	120 g	100 g	100 g
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) The prepurging condition is per AWS D10.11-7X (Guide for Root Pass Welding and Gas Purging).
(2) Shielding gas flow rate for welding: 15 liter/min
Welding condition: 110 Amp./13 Volt.
(3) Shielding gas flow rate for back shielding: 8 liter/min.

On the other hand, with a TG-X filler rod, because of the flux-cored rod, the filler rod consumption increases a little and power consumption slightly increases because of a little lower deposition efficiency (approx. 90%) than with a solid filler rod. In addition, the unit price of TG-X filler rods is higher than that of solid filler rods. However, if you would calculate the total welding cost by multiplying the unit prices for each factor, you may notice that the TGX series can save a great deal in terms of total welding cost.

Chemical and microscopic properties of root pass welds

Chemical compositions of the root pass welds are shown in Table 2 for individual TG-X filler rods. As shown in this table, every TG-X filler rod exhibits low nitrogen in the bulk of root pass weld metal. Electron Probe Micro-Analysis (EPMA) of the vicinity of the reverse surface area has verified that no microscopic condensation of nitrogen can be observed. Still more, microstructure testing has revealed that the distribution of ferrite precipitation in the austenite matrix is uniform throughout the root pass weld. Low nitrogen content, together with the glossy bead appearance mentioned above, is evidence of the effectiveness of the shielding effect of the slag of TG-X filler rod.

Table 2: Typical properties of single-V groove one-sided root pass weld with TG-X filler rods

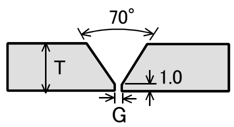
Filler rod for root pass(1)		**TG-X308L** (2.2mmØ)	**TG-X316L** (2.2mmØ)	**TG-X309L** (2.2mmØ)	**TG-X347** (2.2mmØ)
Type of base metal and thickness		304, 9 mm	316L, 9 mm	Mild steel / 316, 19 mm	321, 20 mm
Welding position		Flat	Flat	Flat	Flat
Welding current for root pass		DCEN 105A	DCEN 105A	DCEN 105A	DCEN 105A
Chemical composition and ferrite content of root pass weld metal (%)(2)	C	0.040	0.018	0.047	0.028
	Si	0.55	0.64	0.56	0.65
	Mn	1.11	1.48	1.36	1.78
	Ni	9.72	12.34	9.99	10.35
	Cr	18.89	18.93	19.47	18.67
	Mo	-	2.17	0.35	-
	Nb	-	-	-	0.44
	Ti	-	-	-	0.07
	N	0.044	0.041	0.038	0.044
	FS, FN	4.6-5.7	7.1-7.6	6.9-8.5	4.4-6.2
	SD, F%	7	7.5	7	6
	DD, FN	5.5	8	8	5

(1) Torch shielding gas: Ar (without back shielding).
(2) FS: Ferrite scope; SD: Schaeffler diagram; DD: DeLong diagram.

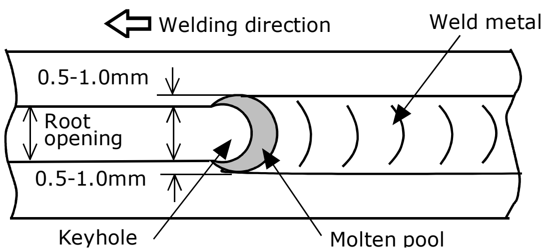
Tips for using TG-X filler rods

The following are the specific techniques for root pass welding with a TG-X filler rod.

(1) PROPER ROOT OPENING to assure a sound penetration bead:

Groove preparation			
Plate thickness (T)	4 mm	6 mm	10 mm min.
Root opening (G)	2.0 mm	2.5 mm	3.0 mm

(2) PROPER KEYHOLE TECHNIQUE to help the molten slag flow to the backside of the root:

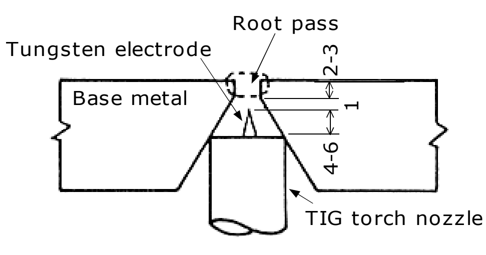


(3) HIGHER FEEDING PITCH with careful wire feeding than with a solid filler rod to ensure adequate fusion of the rod and a sound penetration bead and to compensate a slightly lower deposition efficiency of TG-X filler rods.

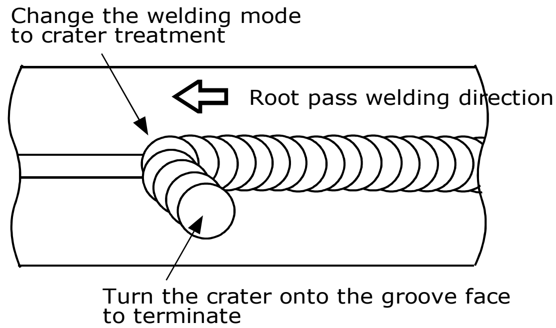
(4) PROPER WELDING CURRENT to ensure regular fusion and penetration:

Plate thickness	3-5 mm	6-9 mm	10 mm min
Amperage	80-90 A	90-105 A	90-110 A

(5) SHORT ARC LENGTH to ensure stable crater formation and regular slag flow by keeping the nozzle contact with the groove fusion faces, with a proper extension of tungsten electrode:

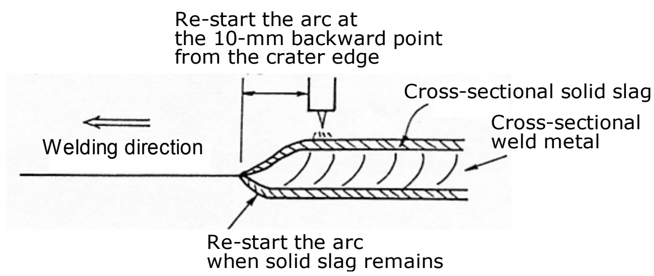


(6) PROPER CRATER TREATMENT by turning the crater onto the groove face to prevent crater cracking and shrinkage cavities in the crater:

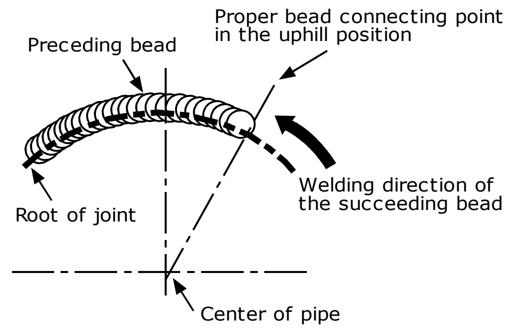


(7) PROPER BEAD CONNECTION to prevent oxidation in the penetration bead and to obtain normal penetration bead contour:

Maintain solid slag both on the crater and on the bead on the reverse side 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 approximately 10 mm as shown below.



In 5G position welding, the termination of the succeeding bead onto the crater of the preceding bead should be done in the uphill positions to control the molten slag and thereby to help create the keyhole:



(8) ONLY ROOT PASS welding is suitable. TG-X filler rods are designed so that enough slag can be generated to cover both the surfaces of the face and reverse sides of the root pass bead; therefore, if a TG-X filler rod is used in filler passes, all of the slag may cover the face side of the bead, thereby causing slag inclusions and lack of fusion.

PREMIARC

NC-38L

AWS A5.4 E308L-16

NC-38L is a versatile electrode for 304L and 304 stainless steel in all positions. Suitable for various applications at low and elevated temperatures.

Inception of NC-38L

NC-38L was developed around 1961. N is for Nickel, while C is for Chromium. These are major alloying elements in austenitic stainless steel. 38 was coined from the AWS classification of E308L. L is for low carbon in the weld metal.

Basic characteristics of NC-38L

NC-38L is a lime-titania type electrode, classified as AWS A5.4 E308L-16. NC-38L is suited for welding by both AC or DCEP (DC Electrode Positive) polarity. The deposited metal is of a low-carbon, 18%Cr-8%Ni type. As shown in Table 1, the composition of the weld metal offers a restricted amount of carbon, typically 0.034 percent. This low carbon content of the weld metal reduces the possibility of intergranular Cr-carbide precipitation and thereby increases the resistance to intergranular corrosion.

Table 1: Chemical composition of NC-38L all-weld metal (%)

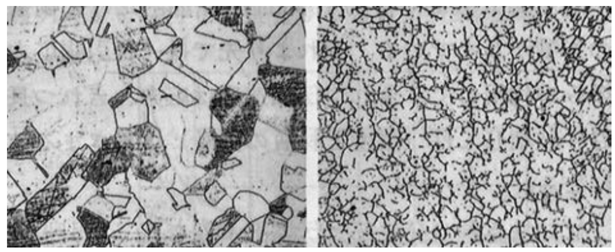
	C	Si	Mn	P	S	Ni	Cr
Typical	0.034	0.33	1.43	0.022	0.006	9.57	20.07
AWS req.	0.04 max.	0.90 max.	0.5-2.5	0.04 max.	0.03 max.	9.0-11.0	18.0-21.0

Outstanding features of NC-38L

Among all the competitive various brands classified as E308L, NC-38L has the following outstanding features.

(1) LESS SUSCEPTIBILITY TO hot cracking due to the properly controlled ferrite percentage:

Figure 1 shows the microstructure of NC-38L weld metal in comparison with that of 304L type base metal. It clearly shows how different the microstructures are. This is because, the base metal does not contain the ferrite to be a fully austenitic structure, while the weld metal contains a certain percentage of ferrite as indicated in Figure 2. This ferritic network structure in the austenitic matrix is effective at preventing the hot cracking that may occur during welding. On the other hand, an excessive ferrite content can cause sigma-phase embrittlement at elevated temperatures, so it must be properly controlled.



(A) 304L-type base metal (fully austenitic structure)
(B) NC-38L weld metal (austenite + ferrite)

Figure 1: Microscopic structures of 304L type base metal and NC-38L weld metal (100X).

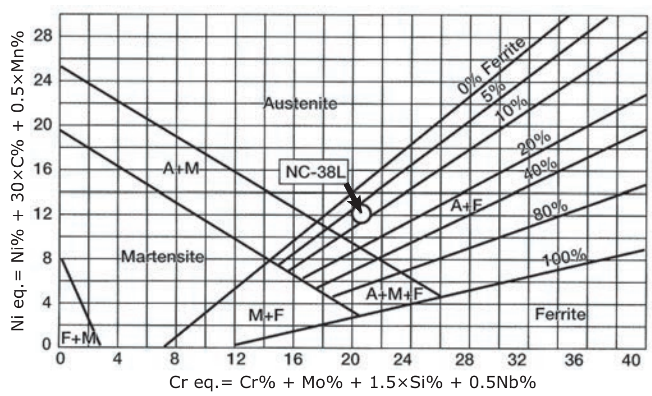


Figure 2: The typical ferrite percentage of NC-38L deposited metal indicated in a Schaeffler diagram.

(2) SUPERIOR CORROSION RESISTANCE due to sophisticated design of chemical compositions:
Table 2 shows corrosion test results of two different types. In the 65% nitric acid test (Huey test), the average weight loss of the test specimens is measured to know the intergranular corrosion resistance to the acids. The copper sulfate sulfuric acid test (Strauss test) checks the occurrence of cracking in bent specimens to know the intergranular corrosion resistance to the acids.

Table 2: Typical corrosion test results of NC-38L deposited metal to evaluate the intergranular corrosion resistance

65% nitric acid test (Huey test)	
As weld	0.00052 ipm
650°C x 2hr, AC	0.00069 ipm
1050°C x 30min, WQ	0.00047 ipm
Copper sulfate sulfuric acid test (Strauss test)	
650°C x 2hr, AC	No defect

(3) CONSISTENT MECHANICAL PROPERTIES (Table 3) of the weld metal due to properly controlled chemical compositions:

Table 3: Mechanical properties of NC-38L all-weld metal

	0.2%PS (MPa)	TS (MPa)	El. (%)	vE at 0°C (J)
Typical	410	580	48	78
AWS req.	-	520 min.	35 min.	-

(4) PROPERLY BALANCED USABILITY in out-of-position welding.

Highly reputed for nearly 40 years

Since it was launched, NC-38L has seen its features refined and its markets expanded. Kobe Steel pursues keen quality control in order to maintain the outstanding features of NC-38L produced in Japan and Thailand. This quality control is an important factor in the product's persistently high reputation, particularly for welding pressure vessels, tanks and pipes in such sophisticated equipment industries as oil refineries, chemical plants, and energy plants.

Figure 3: NC-38L is an indispensable electrode for construction of energy process plants.

Tips for better results with NC-38L

The choice of NC-38L can be the way to fulfill strict requirements for ferrite content, corrosion resistance and mechanical properties. The choice of NC-38L can also be the way to get sound welds in out-of-position welding by both AC and DCEP polarity. When you use NC-38L, however, the following tips should be noted in order to get better results.

(1) No preheating should be used when you weld 304L and 304 type stainless steel. Rather, the interpass temperature should be kept at 150°C or lower. This is to minimize the heat-affected zone, and thereby to minimize sensitization of the base metal that is caused by Cr-carbide precipitation at the grain boundaries of the heat-affected zone.

(2) Use proper welding currents. This is to prevent an electrode from the burning caused by Joule's heat. Note that a Cr-Ni stainless steel electrode has electrical resistance approximately 5 times that of a carbon steel electrode, and has low thermal conductivity approximately 1/3 that of a carbon steel electrode. This means the Joule's heat produced in a Cr-Ni stainless electrode tends to concentrate, which causes the electrode burn. In addition, the electrode burn adversely affects usability and mechanical properties.

(3) Re-dry NC-38L at 150-200°C for 30-60 minutes before use when it picks up moisture. If an electrode picks up moisture, the arc blow becomes stronger, which causes much spatter, irregular bead appearance and undercut.

(4) Keep the arc length shorter to create sufficient shielding for the weld pool, thereby preventing oxygen and nitrogen in the atmosphere from entering into the weld pool. The weaving width should be smaller than 2.5 times the electrode diameter to obtain adequate shielding for the weld pool.

(5) Wire brushing of the weld in order to remove welding slag and objectionable surface discoloration from welding should be done by stainless steel wire brushes that have not been used for any other purpose.

PREMIARC™
NC-36L
AWS A5.4 E316L-16

NC-36L is a matching electrode for welding 316L-type stainless steel. It can be used also for welding 316-type stainless steel, unless creep strength is a strict requirement at high temperature applications.

The birth of NC-36L

NC-36L is the first stainless electrode developed by Kobe Steel. It was developed in 1952 when many fabricators in Japan were still using imported stainless steel electrodes. The brand name, NC-36L, was chosen as follows. N was for Nickel, C was for Chromium, 36 was coined from the applicable 316L-type stainless steel, and L was for low carbon.

Basic characteristics of NC-36L

NC-36L is a lime-titania type, all-position electrode and is classified as AWS A5.4 E316L-16. The suffix 16 designates that NC-36L is suitable for welding by both AC and DC-EP (electrode positive) polarity. The deposited metal is of a low-carbon, 18%Cr-12%Ni-Mo type. As shown in Table 1, the chemical composition of the weld metal offers a restricted amount of carbon, typically 0.023 percent. This low carbon content of the weld metal reduces the possibility of intergranular Cr-carbide precipitation and thereby increases the resistance to intergranular corrosion.

Table 1 Chemical composition of NC-36L all-weld metal (%)

	C	Si	Mn	P	S	Ni	Cr	Mo
Typical	0.023	0.57	1.56	0.025	0.003	12.17	18.68	2.20
AWS req.	0.04 max.	0.90 max.	0.5-2.5	0.04 max.	0.03 max.	11.0-14.0	17.0-20.0	2.0-3.0

What NC-36L offers

Among all the competitive various brands classified as E316L, NC-36L offers the following unsurpassed performance.

(1) LOWER HOT-CRACK SUSCEPTIBILITY due to the proper amount of ferrite, and lower phosphorus and sulfur in the weld metal:

NC-36L is designed so that a proper amount of ferrite precipitates while the molten weld metal solidifies. Figure 1 shows the microstructure of a weld consisting of 316L-type base metal and NC-36L weld metal. It clearly shows the ferrite network structure precipitated in the austenite matrix of the weld metal. 316L-type base metal, however, does not contain ferrite to become a fully austenite structure. This ferrite network structure is effective at preventing hot cracks that may occur in weld metal.

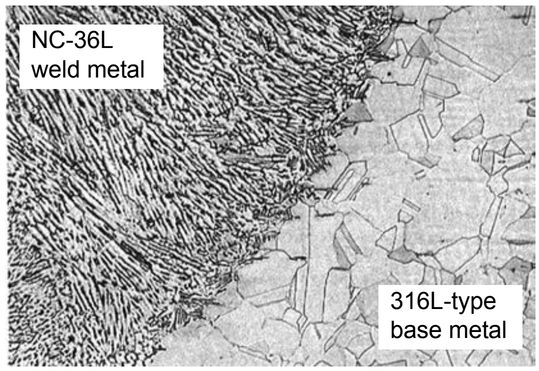


Figure 1: A microstructure of the weld consisting of 316L base metal and NC-36L weld metal (120X).

On the other hand, excessive ferrite content can cause sigma-phase embrittlement at elevated temperatures, so the ferrite content must be properly controlled. Figure 2 shows the typical amount of ferrite in the NC-36L deposited metal plotted in a DeLong diagram.

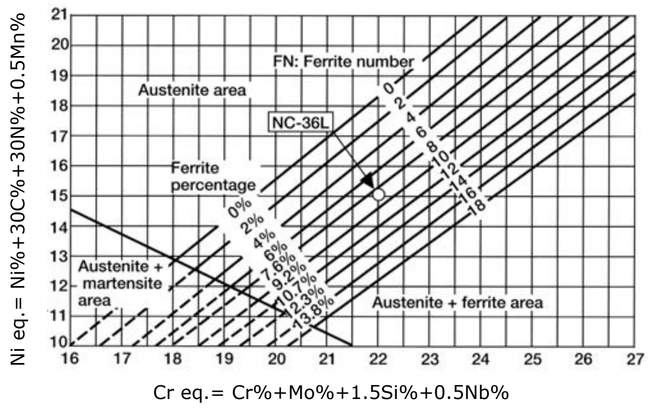


Figure 2: The typical ferrite number of NC-36L deposited metal indicated in a DeLong diagram.

(2) EXCELLENT RESISTANCE AGAINST general, intergranular, and pitting corrosion:

Because of the sophisticated design of its chemical composition NC-36L weld metal features excellent resistibility against general, intergranular, and pitting corrosion. Table 1 shows several corrosion test results of NC-36L deposited metal.

Table 1: Corrosion test results of NC-36L deposited metal in the as-welded (AW) and sensitizing treatment (SE) conditions

Type of corrosion and test method	Typical test results
General corrosion by 5% diluted sulfuric acid test (JIS G0591), AW	Corrosion loss: 5 $g/m^2/h$
Intergranular corrosion by 65% nitric acid test (ASTM A262-C), AW	Corrosion rate: 0.00138 ipm (inch per month)
Intergranular corrosion by copper sulfate sulfuric acid test (ASTM A262-E), SE(1)	Bending test after corrosion test: No cracking

(1) SE: 650°C×2h followed by air cooling.

(3) CONSISTENT MECHANICAL PROPERTIES (Table 2) of the weld metal due to the elaborately designed chemical composition:

Table 2: Mechanical properties of NC-36L all-weld metal

	0.2%PS (MPa)	TS (MPa)	El. (%)	vE at 0°C (J)
Typical	420	580	45	83
AWS req.	-	485 min.	30 min.	-

(4) POSITIONAL WELDING SUITABILITY in flat, horizontal, vertical, and overhead positions.

Figure 3: The cooling pipe equipment of the energy plants is one of the applications of NC-36L because of superior pitting corrosion resistibility against chloride ions.

Why NC-36L has lived so long

Since it was launched in the markets, NC-36L has seen its features refined and its markets expanded. Kobe Steel pursues continual quality control so as to maintain the outstanding features of NC-36L produced in Japan and Thailand. This quality control is a key factor in the product's persistently high reputation, particularly in such specialty fields as the chemical, oil refinery, paper, and nuclear-power industries. In construction of the equipment for these industries the quality control is one of the most important keys to the success.

Tips for better results with NC-36L

The choice of NC-36L can be the way to fulfill stricter requirements for ferrite content, corrosion resistibility, and mechanical properties. When you use NC-36L, however, the following tips should be noted in order to get better welding results.

(1) No preheating should be used when you weld 316L- and 316-type stainless steels. Rather the interpass temperature should be kept at 150°C or lower. This is to minimize the heat-affected zone, and thereby to minimize sensitization of the base metal that is caused by Cr-carbide precipitation at the grain boundaries of the heat-affect zone and can cause weld decay or localized corrosion at the areas adjacent to the grain boundaries in a corrosive environment.

(2) Use proper welding currents. This is to minimize the electrode-burn caused by Joule's heat. The electrode-burn adversely affects usability and mechanical properties of the weld metal.

(3) Re-dry NC-36L at 150-200°C for 30-60 minutes before use when it picks up moisture. If an electrode picks up moisture the arc blow becomes stronger, which causes much spatter, irregular bead appearance, and undercut.

(4) Keep the arc length shorter to create sufficient shielding for the weld pool, thereby preventing oxygen and nitrogen in the atmosphere from entering into the weld pool. The weaving width should be smaller than 2.5 times the electrode diameter to obtain adequate shielding for the weld pool.

PREMIARC™

NC-39L

AWS A5.4 E309L-16

Among KOBELCO stainless electrodes, NC-39L is unique. It is an indispensable electrode for welding dissimilar metal joints and the buffer layers for clad steel and overlaying.

Essential characteristics of NC-39L

The AWS classification shown above (E309L-16) will help you know the essential characteristics of NC-39L as follows.

- E: designates an electrode.
- 309: indicates 309 type deposited metal (22%Cr-12%Ni as minimum).
- L: designates low-carbon type (C% = 0.04 max.).
- 16: indicates suitable current polarity and welding position: DC-EP (direct current, electrode positive) and AC (alternating current) in all-position welding.

What features does NC-39L offer?

In addition to the essential characteristics stated above, NC-39L offers:

(1) SUPERIOR HOT-CRACK RESISTANCE due to a higher ferrite content in the austenitic weld metal (typical ferrite content: approximately 10% by means of a Schaeffler diagram), which can accommodate the dilution by the carbon and low-alloy steel base metal in dissimilar-metal joints.

(2) EXCELLENT CORROSION RESISTANCE and heat resistance due to the sophisticated design of the chemical composition with lower carbon content (typical C%: approximately 0.030):
The restricted percent carbon content of the weld metal reduces the possibility of intergranular Cr-carbide precipitation at grain boundaries and thereby increases the resistance to intergranular corrosion.

(3) STEADY TENSILE STRENGTH and impact toughness of the deposited metal due to strict quality control in production.

(4) CONSISTENT X-RAY SOUNDNESS in all position welding due to well-designed usability.

What kinds of joints need NC-39L

It can be said that almost all machinery and vessels are fabricated and constructed using various combinations of dissimilar metals on any scale. This is because sophisticated equipment, which must offer both efficient performance and competitive material and fabrication costs, is required for industrial advancement. Figure 1 shows various combinations of metals used for sophisticated equipment such as high-temperature high-pressure boilers, oil industry equipment, synthetic chemical equipment, and high-temperature high-pressure hydrotreating equipment.

In fabricating the boilers, for example, 18Cr-8Ni stainless steel must necessarily be joined to 2.25Cr-1Mo steel. In welding this type of dissimilar-metal joint, NC-39L is an appropriate electrode, provided the service temperature is below 800°F (427°C).

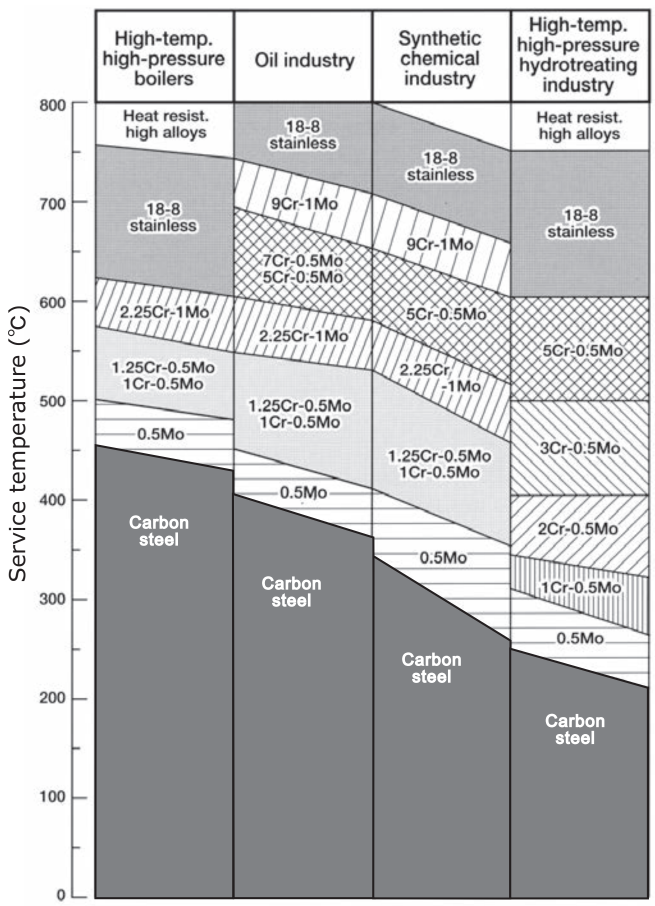


Figure 1: Various metals and their applications in high-temperature high-pressure equipment.

In fabricating pressure vessels for high-temperature high-pressure hydrotreating, the inner surface of the vessels is cladded by overlay welding with stainless steel welding consumables. Most of the inner surface is overlay welded by either submerged arc welding or electroslag welding. However, the inner surface at the butt joint area of the shell is overlay welded by shielded metal arc welding as shown in Figure 2.

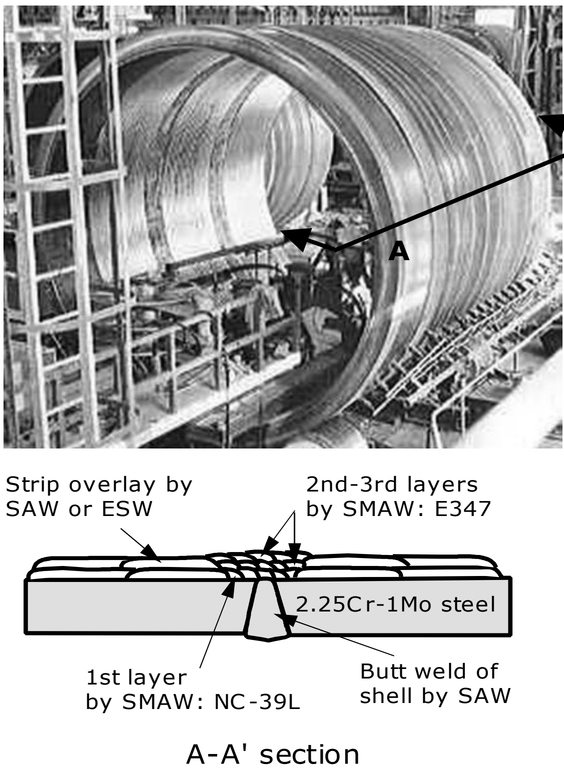
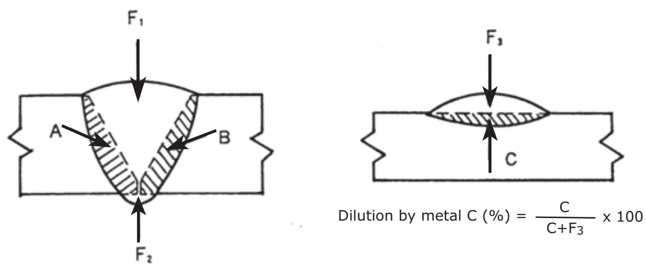


Figure 2: The application of NC-39L for the 1st layer (buffer layer) of overlaying the inner surface of high-temperature high-pressure hydrotreating reactor vessels.

NC-39L is also use for welding dissimilar metal joints of cryogenic-temperature-service piping for the production and storage of liquefied gases, provided the service temperature is higher than minus 100°C. These dissimilar metal joints include aluminum-killed steel-to-304 stainless steel joints in liquefied petroleum gas (LPG) equipment and 3.5Ni steel-to-304 stainless steel joints in liquefied ethylene gas (LEG) equipment.

Key points in dissimilar metal welding

In welding dissimilar metal joints and the buffer layers for clad steel and overlaying with NC-39L, the control of dilution is an important issue to obtain the proper chemical composition of the diluted weld metal, thereby ensuring the austenite + ferrite microstructure to prevent hot cracks in the weld metal. Dilution is defined as the change in chemical composition of a deposited metal caused by the admixture of the base metal or underlayer weld metal. It can be measured by the mass percentage of the base metal or underlayer weld metal that was fused in the weld metal as shown in Figure 3 for groove welds and bead-on-plate welds. Typical value of dilution for shielded metal arc welding is believed to be 25-40%.



$$\text{Dilution by metal C (\%)} = \frac{C}{C+F_3} \times 100$$

$$\text{Dilution by metal A (\%)} = \frac{A}{A+B+(F_1+F_2)} \times 100$$

$$\text{Dilution by metal B (\%)} = \frac{B}{A+B+(F_1+F_2)} \times 100$$

$$\text{Total dilution (\%)} = \frac{A+B}{A+B+(F_1+F_2)} \times 100$$

Figure 3: Determination of dilution ratios of welds.

Dilution is governed by welding currents. Figure 4 shows the relationship between dilution and welding current in bead-on-plate welds by shielded metal arc welding. It is obvious that the dilution increases in proportion to an increase of welding current. In addition to welding current, other factors affect dilution. A single pass weld will have a higher percentage of dilution than a multi-pass weld. There is always considerable dilution in the root pass. The greater the amount of weaving, the greater the dilution.

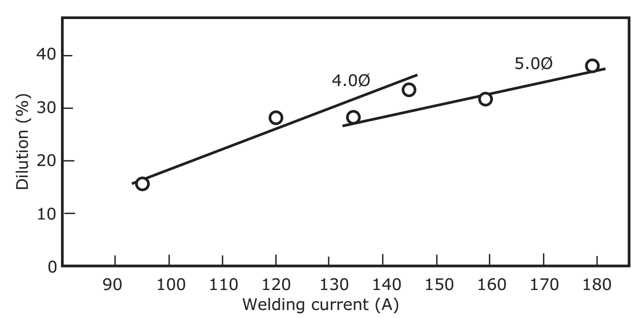


Figure 4: The relationship between welding current and dilution in bead-on-plate welds by shielded metal arc welding.

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