Essential Factors in Selecting Heat-Resistant Low Alloy Filler Metals for High-Temperature, High-Pressure Services in the Power Generation, Oil Refining, and Petrochemical Industries

Heat-Resistant Low Alloy Filler Metals Span Wide

Choosing an appropriate filler metal suitable for heat-resistant low alloy steels ranging from low Mo types such as 0.5Mo steel to high Cr types such as 9Cr-1Mo-V-Nb steel can be confusing. These low alloy steels are used for high-temperature, high-pressure equipment for the power generation, oil refining, petrochemical industries. Steam boilers, reactor vessels, heat exchangers, and process pipes are typical equipment for heat-resistant low alloy steel. As would be expected with such a wide scope of applications, numerous filler metals are available. **Table 1** serves as a quick selection guide to the filler metals for various types of heat-resistant low alloy steels.

How to Select Correct Filler Metals

To select the correct filler metal for welding a particular material (e.g., A335Gr.P11 pipe), you may follow this procedure.

(1) Confirm nominal amounts of Cr and Mo: 1.25Cr-0.5Mo type as per ASTM A335

(2) Confirm the minimum tensile strength: 415MPa as per ASTM A335

(3) Confirm candidates of filler metals: CMA-96, CMA-96MB, CMB-93, CMB-95, and CMB-98 for SMAW, and TGS-1CM and TGS-1CML for GTAW as indicated in Table 1.

Table 1. A selection guide to filler metals for heat-resistant low alloy steels

Steel type	ASTM (ASME) steel grade		KOBELCO filler metal				
	Plate	Pipe / Tube	SMAW	FCAW	GMAW	GTAW	SAW
Mn-Mo Mn-Mo-Ni	A302Gr.B,C,D A533Type A,B,C,D	–	BL-96 BL-106	–	MGS-56 MGS-63S	TGS-56	PF-200/US-56B PF-200/US-63S
0.5Mo	A204Gr.A,B,C	A209Gr.T1 A335Gr.P1	CMA-76	–	MGS-M MG-M	TGS-M	MF-38/US-40
0.5Mo-0.5Cr	A387Gr.2 Cl.1,2	A213Gr.T2 A335Gr.P2	CMB-83 CMB-86	–	MG-CM	TGS-CM	–
1Cr-0.5Mo 1.25Cr-0.5Mo	A387Gr.12 Cl.1,2 A387Gr.11 Cl.1,2	A213Gr.T11,12 A335Gr.P11,12	CMA-96 CMA-96MB CMB-93 CMB-95 CMB-98	DW-81B2	MGS-1CM MG-1CM	TGS-1CM TGS-1CML	PF-200/US-511N
2.25Cr-1Mo	A387Gr.22 Cl.1,2 A542Type B Cl.4	A213Gr.T22 A335Gr.P22	CMA-106 CMA-106N CMB-105 CMB-108	DW-91B3	MGS-2CM MGS-2CMS MG-2CM	TGS-2CM TGS-2CML	PF-200/US-521S
2.25Cr-1Mo-V	A542Type D,E Cl.4a A832Gr.22V	–	CMA-106H	–	–	TGS-2CMH	PF-500/US-521H
3Cr-1Mo-V	A542Type C Cl.4a A832Gr.21V	–	CM-3H	–	–	TGS-3CMH	PF-500/US-531H
5Cr-0.5Mo	A387Gr.5 Cl.1,2	A213Gr.T5 A335Gr.P5	CM-5	–	MGS-5CM	TGS-5CM	PF-200S/US-502
9Cr-1Mo	A387Gr.9 Cl.1,2	A213Gr.T9 A335Gr.P9	CM-9	–	MGS-9CM	TGS-9CM	PF-200S/US-505
9Cr-1Mo-V-Nb	A387Gr.91 Cl.2	A213Gr.T91 A335Gr.P91	CM-9Cb CM-96B9	–	MGS-9Cb	TGS-9Cb TGS-90B9	PF-200S/US-9Cb
Low C 2.25Cr-W-V-Nb	–	(SA213Gr.T23) (SA335Gr.P23)	CM-2CW	–	–	TGS-2CW	–

(4) Confirm the AWS classification where required: You can find out the AWS classification of filler metals as shown in **Table 2** by referring to the Kobelco Welding Handbook.

Because the combination of second and third digits (80 or 70) of the AWS classifications designates the minimum tensile strength of 80 or 70ksi (550 or 480MPa), you will know which filler metals have sufficient tensile strength over the minimum tensile strength of the pertinent pipe, in the testing conditions specified by the AWS standard (A5.5 and A5.18).

However, postweld heat treatment (PWHT) employed in welding fabrication may be stricter (higher temperature and longer soaking time) than the AWS standard. In this case, the minimum tensile strength guaranteed by Kobe Steel may be lower than that specified by AWS. Please contact the nearest Kobelco office or sales representative to confirm the permissible PWHT conditions (temperature and time) to ensure the minimum tensile strength of the pertinent base metal (Or refer to Kobelco Welding Today, Vol. 4, No.4, October 2001 for the PWHT dependence on the mechanical properties of 1.25Cr-0.5Mo weld metals).

(5) Confirm applications for and characteristics of filler metals: By referring to the Kobelco Welding Handbook, You may notice that recommended applications for and key characteristics of individual filler metals are not necessarily the same for the same AWS-class filler metals as summarized in **Table 2**,

Table 2. Applications for and key characteristics of filler metals for 1.25Cr-0.5Mo steel pipes

Filler metal	AWS classification	Applications and key characteristic
CMA-96	E8016-B2	▪General application
CMA-96MB	E8016-B2	▪Lower hardness ▪Higher impact value
CMB-93	E8013-G	▪Sheet metal ▪Surface-dressing
CMB-95	E7015-B2L	▪Low carbon ▪DC power source only
CMB-98	E8018-B2	▪Higher deposition rate
TGS-1CM	ER80S-G	▪General application
TGS-1CML	ER80S-G	▪Low carbon

When no specific requirement is imposed, you may choose CMA-96 for SMAW and TGS-1CM for GTAW for welding the aforementioned pipe. A typical application for CMB-93 (high-titania type electrode) is to dress fillet welds made by using low hydrogen type electrodes to make the fillet toe smooth for better fatigue strength—**Fig. 1**.

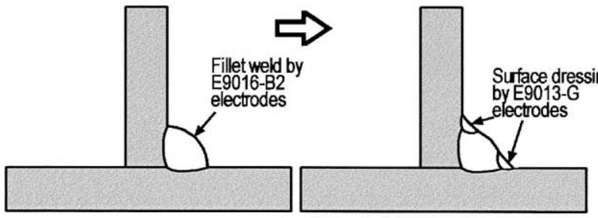


Figure 1. Surface dressing with E9013-G electrodes on an E9016-B2 fillet weld to improve fatigue strength

As for 1Cr-0.5Mo steel, the same matching filler metal for 1.25Cr-0.5Mo steel can be used in general because the required Cr ranges of both steels overlap: 0.85-1.25%Cr for 1Cr-0.5Mo steel; 1.00-1.50%Cr for 1.25Cr-0.5Mo steel, and filler metal standards (e.g., AWS) specify no specific classification for 1Cr-0.5Mo formula.

However, the tensile strengths of both types of plates specify different requirements as shown in **Table 3**. That is, the nominal tensile strength of 1Cr-0.5Mo plates can be lower than that of 1.25Cr-0.5Mo plates even when the steel class is the same. On the other hand, the matching filler metal should have generally the same or a little higher tensile strength relative to the base metal from the standpoint of the strength balance of the weld joint. Therefore, where the nominal tensile strength (650MPa / room temp. / 690℃×1h) of CMA-96 is deemed excessive relative to 1Cr-0.5Mo steel, CMA-96MB is recommended because its nominal tensile strength (590MPa / room temp. / 690℃×1h) is lower. For the same reason, TGS-1CML, rather than TGS-1CM, is more suitable for 1Cr-0.5Mo steel in terms of the strength balance.

Table 3. A comparison of tensile strength requirements of 1Cr-0.5Mo and 1.25Cr-0.5Mo steel plates

Steel type	Steel grade	Tensile strength (MPa)	
		Class 1	Class 2
1Cr-0.5Mo	A387Gr.12	380-550	450-585
1.25Cr-0.5Mo	A387Gr.11	415-585	515-690

Where the gas metal arc welding process (GMAW) is used, there are two choices for welding 0.5Mo, 1.25Cr-0.5Mo and 2.25Cr-1Mo steel depending on the type of shielding gas: MG-XXX wires use CO_2, MGS-XXX wires use Ar-CO_2 admixture (e.g., 80%Ar-20%CO_2).

CO_2 is more economical but causes much more spatter than the other. In contrast, Ar-CO_2 admixture causes low spatter but is more expensive than the other. In addition, the type of shielding gas affects the quality of the weld metal. **Figure 2** shows the effect of shielding gas composition on Charpy impact absorbed energy of weld metals. It is obvious in this figure that the impact energy decreases as the percentage of CO_2 in the shielding gas increases. This is because, as shown in **Fig. 3**, the chemical composition of weld metal is affected by the decomposition of CO_2 ($CO_2 \rightarrow CO + O$) at high temperatures in the arc atmosphere. This is why the GMAW filler metal should be selected, taking into account the type of shielding gas to be used and weld quality requirements.

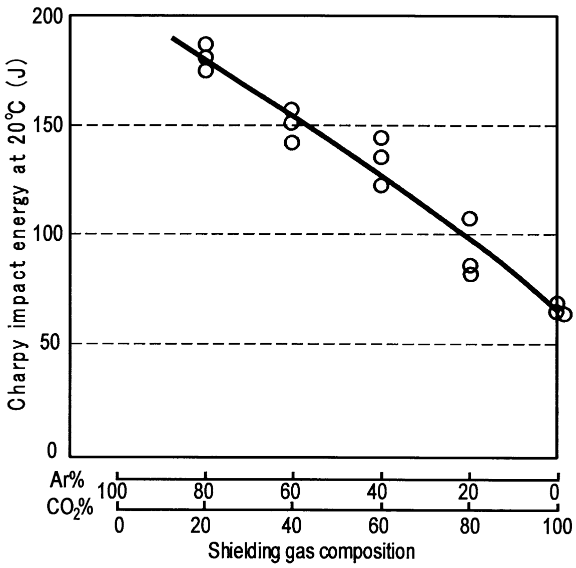


Figure 2. The effect of shielding gas composition on Charpy impact absorbed energy of 1.25Cr-0.5Mo weld metals (PWHT: 690℃×1hr)

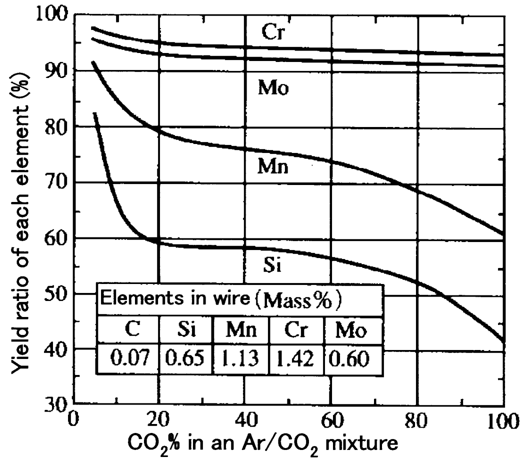


Figure 3. Yield ratios of chemical elements of a 1.25Cr-0.5Mo weld metal as a function of CO_2% in an Ar-CO_2 mixture

In contrast to GMAW with solid wires, flux-cored arc welding (FCAW) with Kobelco Cr-Mo flux-cored wires (FCW), DW-81B2 (AWS A 5.29 E81T1-B2) for 1.25Cr-0.5Mo steel and DW-91B3 (AWS A5.29 E91T1-B3) for 2.25Cr-1Mo steel, releases you from the annoyances of selecting an appropriate shield gas because both wires use either 75-80%Ar/bal.CO_2 admixture or CO_2. These FCWs offer spray transfer, low spatter loss, flat to slightly convex bead profile, and a moderate volume of slag that completely covers the weld bead and exhibits self-peeling removal, in out-of-position welding. The mechanical properties and microstructure of the weld metal after PWHT are consistent. The superior usability of DW-81B2 and DW-91B3 can facilitate smoother bead appearance on pipe branches and nozzle-to-vessel joints where the welding torch must be manipulated three-dimensionally to control the molten pool.

Joining Dissimilar Metals is Unavoidable in Welding High-Temperature High-Pressure Equipment

Almost all machinery, vessels and process pipes are fabricated using a variety of materials—thus dissimilar-metal joints are a necessity when efficient performance with competitive materials at lower fabrication costs are the goals. For instance, power generation boilers (**Fig. 4**) are fabricated by using different types of steels depending on, primarily, the service temperature as shown in **Table 4**, although other factors such as steam pressure and corrosives should also be taken into account.

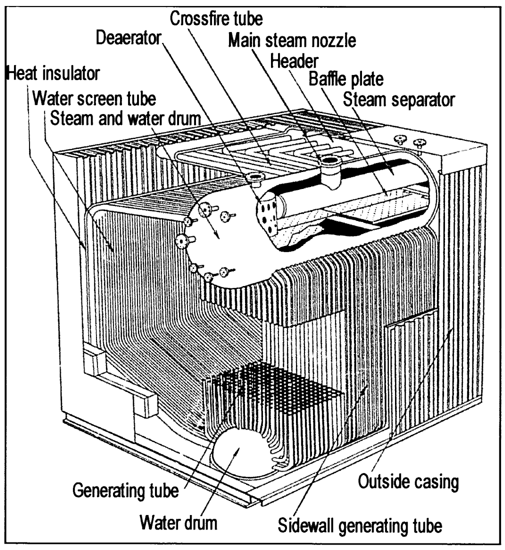


Figure 4. Schematic view of a water tube boiler fabricated with sophisticated structure components of various types of steels (Source: K.Nagumo, Basic Knowledge of Boiler, Ohmsha, 2002)

Table 4. Service temperature ranges for fire power boiler component materials

Steel type	Typical JIS (Karyoku) grade	Typical ASTM (ASME) grade	Service temperature (°C) [1]
carbon steel	STPT	A106	350-400
0.5Mo	STPA 12	A335Gr.P1	400-475
1Cr-0.5Mo	STPA 22	A335Gr.P12	450-550
1.25Cr-0.5Mo	STPA 23	A335Gr.P11	500-550
2.25Cr-1Mo	STPA 24	A335Gr.P22	520-600
Low C 2.25Cr-W-V-Nb	(KA-STPA 24J1)	(SA335 Gr.P23)	525-600
5Cr-0.5Mo	STPA 25	A335Gr.P5	550-600
9Cr-1Mo	STPA 26	A335Gr.P9	600-650
9Cr-1Mo-V-Nb	(KA-STPA 28)	A335Gr.P91	525-600
stainless steel	SUS 304HTP	A312Gr.304H	650-850

Note (1) Data source: Ka-ryoku Genshi-ryoku Hatsuden (Fire and Nuclear Power Generation), Vol.51, No.1, January 2000

As mentioned above, the structural components of a power generation boiler use several types of steels; therefore, joining dissimilar steels is unavoidable at the interface of different service condition areas. When joining carbon steels and Cr-Mo steels, or when joining dissimilar Cr-Mo steels, a filler metal with a composition similar to the lower-alloy steel or to an intermediate composition is commonly used for butt joints. This is because, the weld metal need not be stronger or more resistant to creep or corrosion than the lower alloy base metal in normal applications.

For instance, carbon steel can readily be joined to 2.25Cr-1Mo steel by using either a carbon steel or 1.25Cr-0.5Mo steel filler metal; however, carbon steel filler metals are usually selected except where carbon migration (the diffusion of carbon from lower-Cr metal to higher-Cr metal during PWHT and service at high temperatures) must be decreased. Likewise, 2.25Cr-1Mo steel can be joined to 9Cr-1Mo-V-Nb steel by using a 2.25Cr-1Mo filler metal. In contrast, Cr-Mo steel and austenitic stainless steel are joined with a high Cr-Ni stainless (e.g., E309) or, where carbon migration and thermal stress are important factors, nickel alloy (e.g., ENiCrFe-1) filler metal. For a quick guide to recommended Kobelco brands for joining dissimilar metals, refer to **Table 5**.

Tips for Pipe Welding

Process piping (**Fig. 5**) conveys fluids such as steam and hydrocarbon between the boilers, reactors, heat exchangers and distillation towers of a plant. It also connects one process unit with another. Such process piping is subject to elevated temperature and high pressure.

Table 5. A quick guide to proper filler metals for welding dissimilar-metal butt joints for general applications [1][2]

Base metal	Mild steel	0.5Mo	1.25Cr-0.5Mo	2.25Cr-1Mo	5Cr-0.5Mo	9Cr-1Mo 9Cr-1Mo-V-Nb
Type 304 stainless steel	•NC-39 (E309), NC-39L (E309L), TGS-309 (ER309), TGS-309L (ER309L) •NIC-703D (ENiCrFe-3), NIC-70A (ENiCrFe-1), TGS-70NCb (ERNiCr-3)					
9Cr-1Mo 9Cr-1Mo-V-Nb	LB-52 (E7016) TGS-50 (ER70S-G)	CMA-76 (E7016-A1) TGS-M (ER80S-G)	CMA-96 (E8016-B2) TGS-1CM (ER80S-G)	CMA-106 (E9016-B3) TGS-2CM (ER90S-G)	CM-5 (E8016-B6) TGS-5CM (ER80S-B6)	
5Cr-0.5Mo	LB-52 (E7016) TGS-50 (ER70S-G)	CMA-76 (E7016-A1) TGS-M (ER80S-G)	CMA-96 (E8016-B2) TGS-1CM (ER80S-G)	CMA-106 (E9016-B3) TGS-2CM (ER90S-G)		
2.25Cr-1Mo	LB-52 (E7016) TGS-50 (ER70S-G)	CMA-76 (E7016-A1) TGS-M (ER80S-G)	CMA-96 (E8016-B2) TGS-1CM (ER80S-G)			
1.25Cr-0.5Mo	LB-52 (E7016) TGS-50 (ER70S-G)	CMA-76 (E7016-A1) TGS-M (ER80S-G)				
0.5Mo	LB-52 (E7016) TGS-50 (ER70S-G)					

Note: (1) This table guides to recommended filler metals matching the lower-alloy steels in various dissimilar metal joints, excepting for Type 304 steel. Other types of filler metals may be needed where a specific requirement is imposed.

Note: (2) Preheating and postweld heat treatment for dissimilar Cr-Mo steels should be sufficient to the higher-alloy steel; however, the PWHT temperature should be lower to avoid damage to the lower-alloy steel and minimize the carbon migration. Type 304 stainless steel should not be preheated or postweld heat-treated to avoid sensitization.

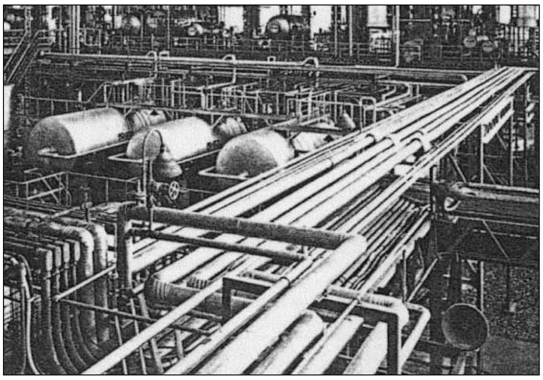
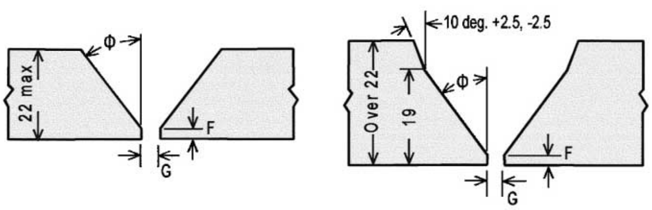


Figure 5. Cr-Mo filler metals are indispensable to construct the process piping of refineries and chemical plants

In welding pipes, it is essential to control the quality of the root pass weld in order to ensure the quality of the entire pipe weld. More importantly, correct groove preparation is a key technique to assure the soundness of the root pass weld. **Table 6** illustrates the standard, recommended targets and tolerances of groove preparation and acceptable misalignment in particular welding procedures.

Table 6. Proper groove preparation and recommended dimension control to ensure the root pass quality



		Bevel angle Φ(deg)	Root face F(mm)	Root gap [2] G (mm)	Misalignment (mm)
ANSI B31.3 [1]		37.5 +2.5 −2.5	1.6 +0.8 −0.8	−	−
Upward SMAW with low hydrogen electrodes	Target	Per ANSI	Per ANSI	2.0-3.2 (2.0-2.6)	1.6 max
	Tolerance	Per ANSI	Per ANSI	1.6-3.6	2.0 max
Upward GTAW	Target	Per ANSI	Per ANSI	2.0-3.2 (2.0-2.6)	1.2 (0.8) max
	Tolerance	Per ANSI	Per ANSI	1.6-3.6	1.6 max

Note (1) ANSI B31.3: American National Standard Institute, Chemical Plant and Petroleum Refinery Piping
(2) Targets in the parentheses are for thin tubes ($t \leq 7$)

In GTAW, the need for back shielding argon gas is an important factor because it affects the quality of the root pass weld and fabrication costs. 0.5Mo and 1.25Cr-0.5Mo filler metals can be used without back shielding except where the backside bead appearance has to be controlled strictly. 2.25Cr-1Mo or higher Cr filler metals need back shielding. Without back shielding, the root pass weld cannot properly be formed. Even if the appearance seems good, porosity may be formed inside the weld.

Even when the welding is perfectly conducted, the weld quality cannot finally be assured unless PWHT is appropriate because PWHT affects the mechanical properties of welds in addition to relieving residual stresses. Excessive PWHT may cause too low tensile strength and notch toughness to satisfy the requirements. In contrast, insufficient PWHT may result in too much hardness—thus too low ductility—and inadequate impact toughness. **Table 7** shows PWHT temperature and holding time for Cr-Mo pipe welds, employed in construction of process piping.

Table 7. Postweld heat treatment temperature and holding time for Cr-Mo steel welds (Source: ANSI B31.3-90)

Steel type	Heating temperatures (℃)	Holding time (h)
0.5%Mo	593-718	1h for each 25.4 mm of plate thickness, but min. 1h
1.25%Cr-0.5%Mo	704-746	1h for each 25.4 mm of plate thickness, but min. 2h
2.25%Cr-1%Mo 5%Cr-0.5%Mo 9%Cr-1%Mo	704-760	

In the fabrication of spools of pipes, PWHT is usually carried out in a furnace, where the entire pipework is placed inside. However, field pipe joints are frequently given a local heat treatment using, for instance, electric resistance heating tools suitable for pipe welds—**Fig. 6**. In local PWHT, temperature control is an essential factor to maintain the temperature gradient within the limits set by the relevant code. To assure this requirement, the temperature distribution is measured with thermocouples attached at the twelve, three and six o'clock positions of a weld.

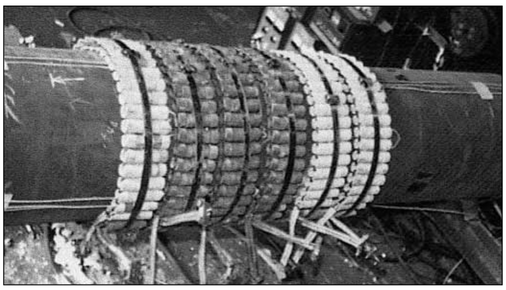


Figure 6. Preparation of local postweld heat treatment with electric resistance heating tools and thermocouples (Source: Jemix, Japan)