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>
<thead>
<tr>
<th>Material</th>
<th>CMA-96</th>
<th>CMA-96MB</th>
<th>CMB-93</th>
<th>CMB-95</th>
<th>CMB-98</th>
<th>TGS-1CM</th>
<th>TGS-1CML</th>
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<tbody>
<tr>
<td>A335Gr.P11</td>
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(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.

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.

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. / 690º 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. / 690º 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.

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 CO₂, MGS-XXX wires use Ar-CO₂ admixture (e.g., 80%Ar-20%CO₂).
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CO₂ is more economical but causes much more spatter than the other. In contrast, Ar-CO₂ 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 CO₂ 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 CO₂ (CO₂ → 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.

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.CO₂ admixture or CO₂. 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.
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.
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.

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.

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.

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.