Analytical Practice For Weld Metal Property Predictions

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Abstract

After a half-century in the development of methods to predict weld properties and to select welding parameters, analytical approaches and practices are now achieving more reliable results. The first analytical expressions were based primarily on composition and had a "rule of thumb" usefulness in achieving the selection for the degree of preheat and/or post weld heat treatment that would be required for a specific steel composition. These compositional tools would only correlate to results for the same medium carbon steel, plate thickness and welding parameters, usually for SMA welding. With the introduction of higher strength low carbon steels, which have properties that are based on strengthening mechanisms other than the austenitic decomposition, new predictive expressions were required. As new welding processes increase productivity, it also becomes essential to present the cooling rate, $\Delta t_{8/5}$, into these expressions.

Fundamentally derived forms of the predictive equations have been suggested by considering both thermodynamic and kinetic approaches to their formulation. For athermal transformations, a microstructural sensitive property, such as *CE,* can be given by the following:

$$CE = K_o\left[C + K_{Mn}Mn + K_{Si}Si + \ldots + K_{C'}CLnC + K_{Mn'}MnLnMn + K_{Si'}SiLnSi + \ldots\right] \quad (1)$$

where K_o is a proportionality constant and K_i are coefficients for the various alloying additions and are subject to fundamental interpretation. *Mn*, *Si*, *C*, ...are concentrations of the different elements expressed in weight percent. Omission of the nonlinear terms will simplify the equation to a form similar to the IIW carbon equivalent equation. It becomes apparent that in high alloy systems,

some of the information about alloying behavior may be lost without the nonlinear terms.

Assuming that the carbon equivalent can be directly related to the thermodynamic driving force for carbon transport, a new form of the equation for *CE* can be obtained and expressed as:

$$CE = K_o'C\left[1 + K_C'C + K_{Mn}'Mn + K_{Si}'Si + \ldots\right] \tag{2}$$

This form suggests a multiplication relationship to the interaction between carbon and other alloying elements and should better fit the low carbon microalloyed steels in which there is carbo-nitride precipitation.

For para-equilibrium conditions, in which carbon is observed to partition, the following expression is developed:

$$CE = K_o''C\begin{bmatrix} 1 + K_C''C + K_{Mn}''Mn + K_{Si}''Si + \ldots + K_{LC}''LnC \\ + K_{LC}''CLnC + K_{LMn}''MnLnMn + K_{LSi}''SiLnSi + \ldots \end{bmatrix} \tag{3}$$

Notice that the equation is again different from the commonly used form of carbon equivalent expressions.

It is questionable whether these expressions have the ability to predict properties and transformation behavior of weld metals. Influences from solidification, such as dendritic segregation, and second phase particles, such as inclusions, will also affect the weld metal solid state transformation reactions. At lease the oxygen content must be included to make these expressions useful in predicting weld metal properties.

Empirical expressions have been developed to predict hardness, yield and ultimate tensile strength as well as ductility and toughness for low carbon and low alloy higher strength steels weld metal. Various approaches, including a deterministic, statistical, and neural net analytical approaches have been attempted. These approaches will be discussed.

Acceptable welds can be achieved with a large range of combinations of weld composition and welding parameters, but some combinations are more resilient to process parameter variation. With more reliable constitutive equations to predict weld properties, analytical methods will be discussed for selection of resilient sets of welding parameters and thus reduce the rejection rate.

With the availability new analytical approaches, the selection of welding consumables can be based on a quantitative footing. It soon should be possible to rapidly select the welding consumable composition for a specific alloy and welding thermal experience. The necessary features for these analytical methods are described.