Future Trends on Carbon Equivalent Research

Wesley Wang, Senior Engineer
Materials Group, EWI

Introduction

In my blog series The Great Minds of Carbon Equivalent, Parts I, II, and III, I've discussed the value and evolution of carbon equivalent (CE) equations in the prediction of heat affected zone (HAZ) hardenability in steels. In this blog, I discuss two future CE research trends.

Applying Carbon Equivalent Equations to Higher-strength Steels for the Oil & Gas Industry

Higher strength steels (≥ X80 grade) are being increasingly used in deep-water exploration by the offshore oil and gas industry. In offshore structure fabrication, post-weld heat-treatment (PWHT) is used on the welding joint to lower the hardness of the heat-affected-zone (HAZ) and weld metal to below 250HV10 or 22HRC. While this method can effectively be used to meet the corrosion-control requirements of industrial codes and standards such as NACE MR0175 and MR0103, it is well-known that PWHT could significantly deteriorate crack tip opening displacement (CTOD) toughness and reduce cold-cracking resistance. The mechanism of CTOD toughness deteriorationby PWHT is not completely clear, warranting an in-depth investigation. To better control the hardness in both the HAZ and the weld metal, the welding cooling rate, PWHT, microstructure, and steel composition (i.e. carbon equivalent) must be correlated. The pseudo graph provided in Figure 1 correlates cooling rate, the balance of carbon and other alloying elements, and the predicted percentage of martensite in the microstructure. This allows fabricators to select base materials and welding procedures to effectively control hardness.

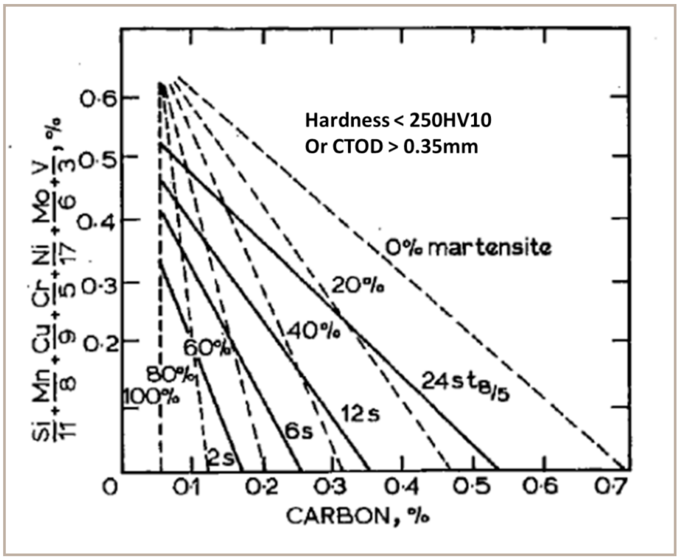

Figure 1: An example of mapping the correlation between carbon content, alloying elements, cooling rate, and micro-structure in as-welded and PWHT conditions

The Future Role of Carbon Equivalent in Additive Manufacturing

In addition to conventional fabrication, additive manufacturing (AM) is receiving increased attention from various industries. While significant research is being conducted on building AM components, these parts and assemblies may need to be joined to conventional base materials as part of assembly. As a result, weldability testing will be essential for AM materials. For example, the cold-cracking tendency of AM components made of 4140 or 4340 should be evaluated for arc- and laser-welding processes. AM component weldability evaluations will again explore the use of carbon equivalent to provide necessary guidance to industrial fabricators. Extensive research and experimental efforts will be required to re-visit the carbon equivalent application, adapt it to these applications, and establish new codes and standards.

Reference

[1] Lorenz, K. and Düren, C., 1981, "Evaluation of large diameter pipe steel weldability by means of the carbon equivalent", Proceedings of an international conference "Steels for line pipe and pipeline fittings", London, October 21-13, p322-332.

*Part I of **Great Minds of Carbon Equivalent: Invention of the Carbon Equivalent can be found here.***
*Part II of **the series can be found here. Part III of the series can be found here.***

***Wesley Wang** is a senior engineer in EWI's Materials group. His expertise includes ferrous and nonferrous welding materials (selection, development, evaluation/analysis, and qualification), WPS design, welding processes, weldability evaluation, failure analysis, microstructure and phase transformation, similar/dissimilar alloys welding, corrosion, pipe-line welding, underwater welding, and hardfacing. He possesses an in-depth understanding of welding metallurgy and strategies to optimize welding performance and weldment mechanical properties.*