

## **B. Fluoride and Yttrium Additions in Steel Weld Metal, Effects on Hydrogen and Weld Metal Properties**

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The current research was undertaken to study the effects of fluoride additions to yttrium-containing consumables on the development of diffusible hydrogen, weld metal oxides, microstructure, and mechanical properties in low alloy steel welds. The use of high-strength low alloy (HSLA) steels has been limited to due the lack suitable filler metals. Hydrogen assisted cracking is a major concern in HSLA steel weld metal. Optimal weld metal oxide size and spatial distribution will allow a microstructure consisting primarily of acicular ferrite to develop, which in turn improves the mechanical properties of the weld metal.

To study the effects of fluoride on weld metal microstructures produced with yttrium-containing consumables, flux-cored weld consumables were manufactured with varying amounts of fluoride and used to produce multiple pass low alloy steel weld deposits. The weld deposits contained approximately 2.8 weight percent nickel, 1.5 weight percent manganese, 0.4 weight percent molybdenum, 300 ppm titanium and 300 ppm yttrium. The characterization of oxides was performed by light optical microscopy. Microstructural characterization was performed by LOM on the top bead deposit. Mechanical properties of these deposits were determined through tensile testing and Charpy V-notch impact testing.

Welds containing a  $[\%Y]/[\%O]$  ratio between 0.20 and 0.45 resulted in a microstructure that is predominately acicular ferrite, which is expected to result in optimal mechanical properties. The microstructures comprise of 65 to 75 percent acicular ferrite, with the remaining being ferrite with aligned second phases. The oxides present in these welds are spherical and randomly distributed throughout the weld metal. Due to this ratio of yttrium to oxygen, titanium can combine with oxygen to form  $Ti_2O_3$ , which is known to act as nucleation sites for acicular ferrite. Diffusible hydrogen has been measured to be approximately 2.0 mL  $H_2/100$  g weld metal. The addition of fluorides to the consumable reduced the amount of hydrogen even further, by way of the formation of HF in the arc atmosphere and reduction of the partial pressure of hydrogen in the arc atmosphere. The additions of fluorides reduced the diffusible hydrogen content to less than 2.0 ml  $H_2/100$  g weld metal. After properly balancing the oxygen and hydrogen potentials, a predominately acicular ferrite microstructure resulted.

The use of the optimal consumable resulted in improved weld metal mechanical properties. Charpy V-notch impact testing shows a lower brittle transition temperature with the use of yttrium and fluoride additions than in the use of just yttrium or fluoride additions. Due to the formation of the acicular ferrite microstructure, tensile properties have also increased. An improved microhardness profile across the weld resulted as well. Hardness measurements have been determined to range from 240 in the weld metal reheated zones to 290 in the as-deposited weld metal.

The optimal mixture of yttrium and fluoride additions will result in a FCAW consumable which produces weld metal with improved mechanical properties and lower diffusible hydrogen content. The brittle transition temperature has decreased. Diffusible hydrogen content is less than 2.0 mL  $H_2/100$ g weld metal. The efforts of this research will be beneficial to naval shipyards and fabrication of low alloy steel structures.