Plasma Arc Diagnostics to Clarify Hydrogen Reduction Mechanisms due to Fluoride Additions

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Introduction

Welding of high strength steels without hydrogen-assisted cracking (HAC) has been an important issue for many years. Since diffusible hydrogen content in the weld metal is attributed to be a major cause of HAC, consumables capable of minimizing hydrogen in the arc plasma and eventually in the molten weld pool must be developed.

Fluorides, such as fluorspar (CaF_2), in the flux ingredients have been suggested to reduce the amount of diffusible hydrogen in steel welds. It is generally speculated that fluorides react with hydrogen in the arc atmosphere to form HF, with extremely low solubility in iron. Thus, HF is eliminated from the molten weld pool. However, it is still questionable if HF formation is the only cause for hydrogen reduction in the steel weld metal.

In this research, the concentrations of hydrogen in the arc, based on the results of arc temperature determination, were determined by emission spectroscopy to clarify the mechanism(s) of hydrogen reduction in the arc by means of fluoride additions.

Experiments

Emission spectroscopy was performed using a GTAW system on a water-cooled copper plate with 100% argon and Ar-1%H_2 shielding gas. The test welding current and arc gap were 56-90 A and 3 mm, respectively. CaF_2 was the fluoride tested. The fraction of hydrogen in the arc was determined with respect to the arc temperature using the off-axis peaking method.

Results and Discussion

The fraction distribution of hydrogen in the arc established with Ar-1%H_2 shielding gas was determined (Fig. 1). The highest fraction of hydrogen in the gas was 0.10 in the region right below the cathode, where the temperature was the highest in the arc. On the other hand, the hydrogen fraction decreased to 0.02 at the periphery of the arc.

With addition of calcium fluoride (CaF_2), the hydrogen fraction decreased from about 0.09 to less than 0.07 at the location close to the anode (Fig. 2). The molecular mass of HF (20.0) is ten times larger than that of H_2 (2.00). If hydrogen atoms are associated with fluorine to form HF molecules, the velocity of HF will be 3.3 times smaller than that of H_2. Although this effect is only expected below the dissociation temperatures of HF (4,700 K) and H_2 (4,575 K), it may affect the hydrogen mass transport in the periphery of the arc above the cathode tip and eventually suppressing the hydrogen accumulation.

Even though the fluorine spectra could not be identified, fluorine was expected to have gone into the welding arc, since the calcium spectra were successfully identified and characterized. According to the experimental results, fluorine in the arc must have the roles described above to reduce the hydrogen besides HF formation frequently discussed by previous researchers.

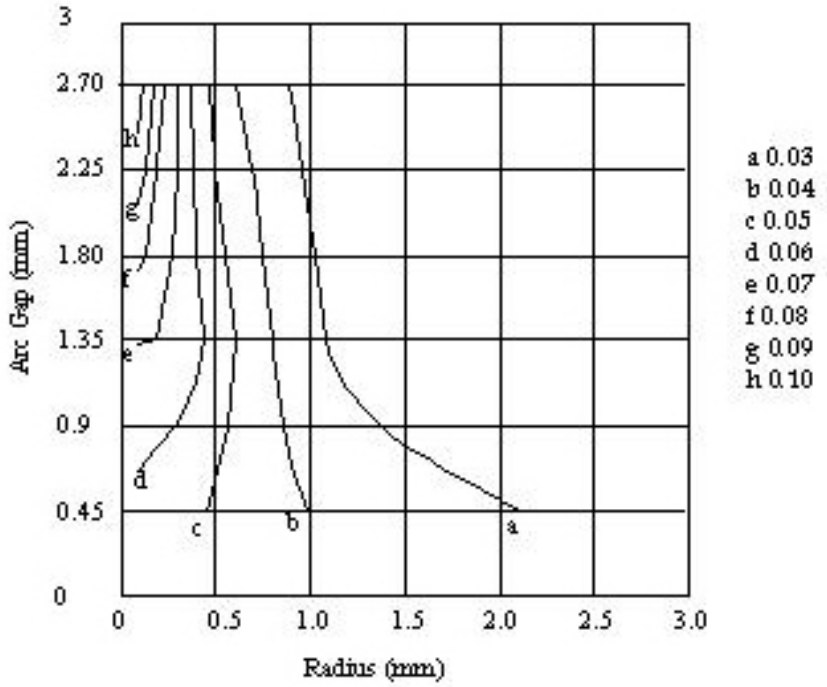

Fig. 1 Contour Plot of Hydrogen Fraction (Sum of Neutral and First-Ionized Atoms) in the arc. [1% H_2-Ar shielding gas, 3mm Arc Gap, 56 A]

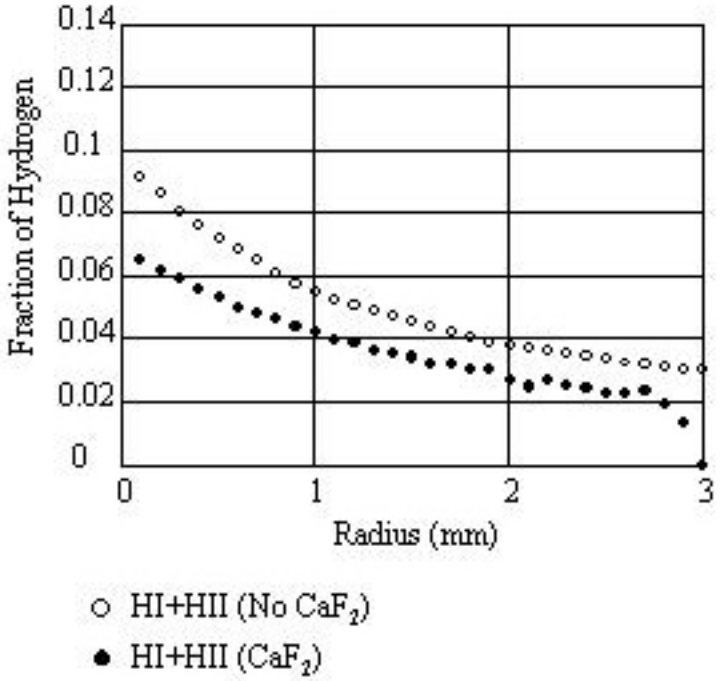

Fig. 2 Influence of CaF_2 on Hydrogen Fraction (Sum of Neutral and First-Ionized Atoms), measured at 0.45 mm from Anode. [1% H_2-Ar shielding gas, 3mm Arc Gap, 90 A]