A REAL-TIME QUANTITATIVE ANALYSIS OF ATMOSPHERIC CONTRIBUTIONS OF HYDROGEN TO WELD ARC PLASMAS

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INTRODUCTION

Hydrogen contamination of weldments, particularly in the welded joints of high strength steels, can cause significant reductions in weld integrity, often resulting in failure of the joint. Inspection and repair of hydrogen assisted cracks in weldments is both costly and time consuming, thus real-time methods of detecting hydrogen levels during welding are essential. Analytical emission spectroscopy is a promising method of weld analysis, providing quantitative information in real time about the amount of hydrogen in the arc atmosphere.

Hydrogen assisted cracking (HAC) of welds has become an international topic of discussion and concern among construction industries, manufacturing companies, and research laboratories. However, the occurrence of this phenomenon remains frequent and unpredictable [1,2]. As an estimated one half of our nation's GNP is associated with welding and joining processes [3], it is of vital concern that effective methods of quality assurance and quality control are developed in all facets of welding research, especially in problems regarding potential failure of the weld.

Initially, the damaging effects of hydrogen were thought to occur only in iron and steel [4], but presently it is known that HAC can occur in titanium and nickel based metals as well. Furthermore, it has been determined that this cracking mechanism is inherent in stress corrosion cracking [5] and could possibly occur in aluminum based alloys [6]. Thus, the impact of an effective quality control process with respect to hydrogen detection is extensive.

Methods of preventing hydrogen cracking in welding have long been examined, yet no real-time methods of weld analysis have been achieved. The present methods of weld inspection are ineffective in the evaluation of hydrogen assisted cracks as these cracks can occur after a considerable delay period (dependent on the diffusivity of hydrogen in the fusion zone). Spectroscopic analysis of the weld arc plasma provides an effective means for monitoring the arc environment, allowing detection of hydrogen in the arc during the welding process. This method can be applied to both the investigation of HAC mechanisms and the prevention of such cracking in weld fabrication. The present phase of research at USA-CERL involves the analysis of atmospheric humidity and the role it plays as a source of hydrogen in welding.

POTENTIAL SOURCES OF HYDROGEN IN WELDING

There are several possible sources of hydrogen in the welding process, but the most common sources are believed to be: 1) organic contaminants such as grease or oil found in the lubricants of many filler wires; 2) hydrogen trapped within the filler material during the wire drawing process; 3) moisture pick-up in the flux coating of SMAW electrodes [7]; and 4) atmospheric contributions. Quantitative evaluations of these particular sources have been made as well as attempts to reduce the hydrogen potential of the respective sources. However, very few studies have been performed in analyzing atmospheric humidity as a hydrogen contributor. Since it is not possible to weld in a"dry" environment at all times, a method is needed that will predict the probability of hydrogen contamination resulting from atmospheric humidity. Emission spectroscopic analysis is an effective method of quantitative non-destructive testing that will provide information on the hydrogen concentration present in the arc atmosphere during the welding process.

In order to isolate the effects of atmospheric humidity on the occurrence of HAC, it is necessary to control the atmospheric conditions as well as the weld process parameters. Thus, welding was performed in a stainless steel, partially enclosed, positive pressure chamber. This chamber contains several entry ports in which different gases can be selectively added to serve as a purge gas for the system or as an atmospheric layer during welding. In this way, it is possible to add atmospheric moisture to the weld environment in a controlled manner.

EMISSION SPECTROSCOPY IN ANALYZING WELD ARCS

Analytical spectroscopy has long been used in the study of material composition, but only recently has it been applied to the characterization of welding processes and specifically to the problem of hydrogen cracking. The process of emission spectroscopy as applied to weld arc processes involves the gathering of discrete wavelengths of light that are emitted when constituents of the arc plasma are first ionized (i.e. in an excited state) and subsequently drop back to a ground state level. The light is collimated and passed through a grating where it is broken down into discrete wavelengths of measurable intensities. The relative intensity emission of an element reflects the density distribution of that constituent in the arc, thus making it possible to monitor the increase or decrease in the concentration of the constituent. The spectroscopic technique employed in this research involves the use of an armored fiber optic bundle to transmit the light emitted from the arc to an entrance slit of an ISA HR-320 monochromator configured as a spectrograph. The monochromator contains a 0.32 Czerny-Turner grating which breaks the light down into discrete wavelengths. The spectrograph operates over wavelengths ranging from approximately 0.35 - 1.2 micrometers, and it has a resolution of about 0.5 angstroms. A photodiode array is placed at the exit point of the monochromator for the purpose of imaging the emitted spectra. A data acquisition controller (DAC) acts as an outboard interface, providing timing and synchronization to the photodiode array. The DAC also serves as an A/D converter, interfacing with an LSI-11/23 microcomputer which runs all data acquisition software and stores the data on floppy disks. Data scans are run at a rate of 0.5 seconds per scan, so large numbers of scans can be gathered during a single weld pass. An oscilloscope is used to monitor the spectra during the data acquisition process.

ATMOSPHERIC EFFECTS ON HAC IN WELDING

The probability of HAC in welding can be quantified by determining a series of relationships. Ultimately, it is necessary to correlate the concentration of hydrogen detected in the weld arc plasma to the mechanical properties of the weld as well as to the diffusible hydrogen content of the weld [8]. This relation can then be used to predict, in real-time, the probability of hydrogen cracking. However, there is a great need to understand both the sources and the mechanisms of hydrogen entrained to the arc atmosphere. The analysis of the humidity effects on a welding process provides information on the ambient atmosphere as a source of hydrogen as well as augmenting the understanding of hydrogen absorption mechanisms.

Overview of Experimental Procedure

Hydrogen assisted cracking is most common in the SMAW process, occurring less often in the GMAW process and infrequently in the GTAW process. The analytical test procedure adopted in this research follows a logical progression of stages in welding, proceeding from a non-consumable electrode, gas shielded process (GTAW) to a consumable electrode, gas shielded process (GMAW) to a consumable electrode, flux shielded process (SMAW). Gas tungsten arc welding is the cleanest process, and it is the simplest process to analyze through the use of emission spectroscopy. Each successive stage of testing adds another element of complexity to the test procedure.

One difficulty in using emission spectroscopy as a method of arc plasma analysis is that spectral intensities of a constituent do not remain constant during the welding process. As the emitted intensity is dependent on both the temperature of the plasma and the concentration of the constituent in the plasma, fluctuations in the temperature of the weld arc can cause the intensity of spectral lines to vary dramatically. However, as stated by both Shea et al. [9] and White [8], these effects can be minimized through the use of a two-line method of analysis. This method involves the normalization of the hydrogen line intensity to a strong internal standard. In this case, the hydrogen line, at 6562.72 angstroms, was normalized to an argon line at 6965.43 angstroms (Figure 1). The two-line method greatly reduced the amount of error in the hydrogen detection process. Measurements of line intensity were made by subtracting out the background radiation of the data and then integrating the area under the spectral peak. Software developed at USA-CERL provided the integration capabilities as well as other analytical functions.

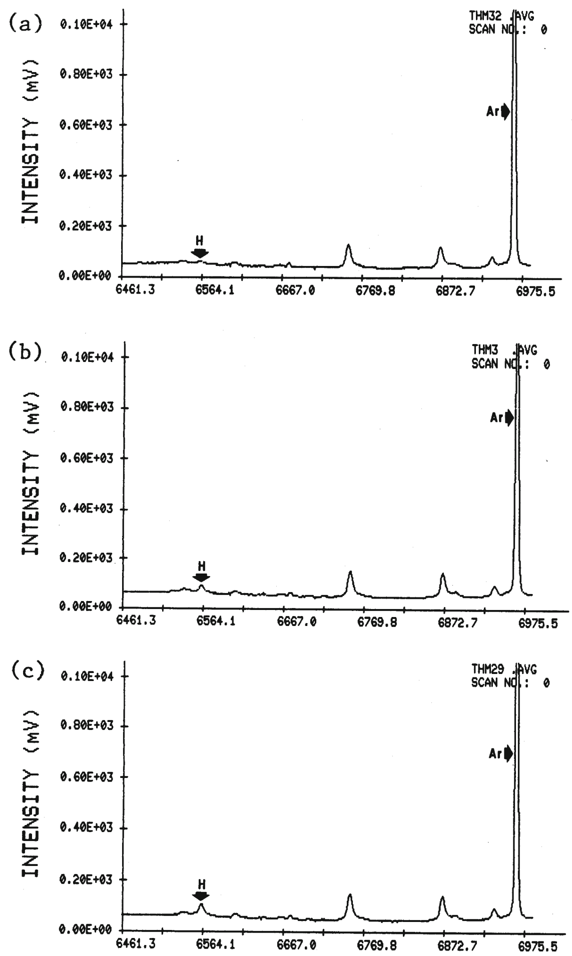

Figure 1. Incremental increase of hydrogen peak intensity with increase of humidity:(a) T=64 F, R.H.=20%, I^{H}_{REL}=1.91E -2;(b) T=75 F, R.H.=38%, I^{H}_{REL}=3.68E -2;(c) T=90 F, R.H.=85%, I^{H}_{REL}=6.77E -2. NOTE: All hydrogen relative intensity measurements (I^{H}_{REL}) were made using the two-line method of analysis.

In developing the experimental procedure, it was necessary to employ a calibration process in which the spectral intensity of the hydrogen emission line was related to a known amount of hydrogen introduced into the shield gas. The calibration curve was determined by introducing hydrogen in controlled amounts ranging from .025% to 5.0% hydrogen in the shield gas and measuring the respective relative intensity of the 6562.72 angstrom hydrogen line. This relationship can be further quantified by relating the concentration of hydrogen in the shield gas to the hydrogen partial pressure in the gas line [8], but this was not done in the tests performed at CERL. The H/Ar gas flow was controlled by a linear mass flow meter which eliminated any difficulties in flow measurement due to back pressure at the welding torch. The results of the calibration curve are shown in Figure 2, where the relative intensity of the hydrogen line emission is related to the concentration of hydrogen in the shield gas.

The next step in the test process was to add humidity to the weld atmosphere and record the resulting relative intensity of hydrogen detected in the arc plasma. Previous work has shown that the amount of hydrogen absorbed in a weld increases when absorbed in the form of humidity rather than in gaseous, diatomic form[10]. The research done at CERL, however, represents a much more accurate simulation of atmospheric humidity during welding, and it is more concerned with the amount of hydrogen in the arc plasma due to the ambient atmosphere.

Welding was performed by striking a stationary arc from a GTAW torch on a tungsten button with no further addition of a consumable filler material. Humidity control during welding was achieved by a humidifier with a titanium ultrasonic transducing element and a digital hygrometer

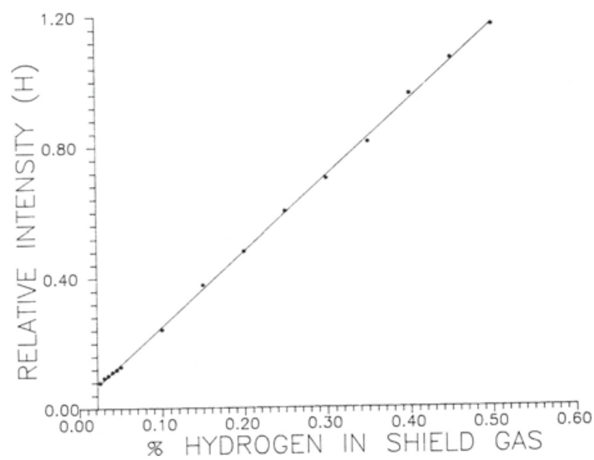

Figure 2. Calibration curve relating the relative intensity of hydrogen to the hydrogen introduced to the shield gas.

relative humidity (RH) sensor. The sensor detects humidities over a range of 10% to 95% RH within a temperature range of 0 to 60 C. The "wet" argon gas entered the welding chamber, simulating atmospheric humidity, and tests were run with temperatures ranging from 65 to 90 C with relative humidities from 20% to 90%. In order to compensate for the lack of sensitivity in the controls of the humidifier, the stream of "wet" argon was mixed in controlled amounts with dry argon in order to produce an atmospheric gas with the desired relative humidity.

Results of Humidity Additions to the GTAW Process

The results of the humidity additions to the weld atmosphere were obtained by analyzing the intensity of the hydrogen emission in the arc plasma and correlating this data to the previously determined calibration curve. Thus, it was possible to estimate the amount of hydrogen entering the weld arc under specific humidity conditions. Figure 1 shows the increase in hydrogen peak intensity as the temperature and relative humidity of the weld environment are increased. The resulting values of the hydrogen peak intensities are graphed versus the absolute moisture content of the ambient atmosphere, shown in Figure 3. Using the calibration curve, Figure 2, generated in previous tests, the amount of hydrogen entering the weld arc plasma can successfully be determined. As expected, only a small fraction of hydrogen (approximately 0.024% under the most humid conditions) enters the arc plasma as a result of atmospheric humidity in the GTAW process. This result represents, however, only the simplest and purest of welding conditions. In most cases, the torch would be moving and a filler material would be used, and both of these conditions would tend to increase the amount of hydrogen observed in the arc plasma.

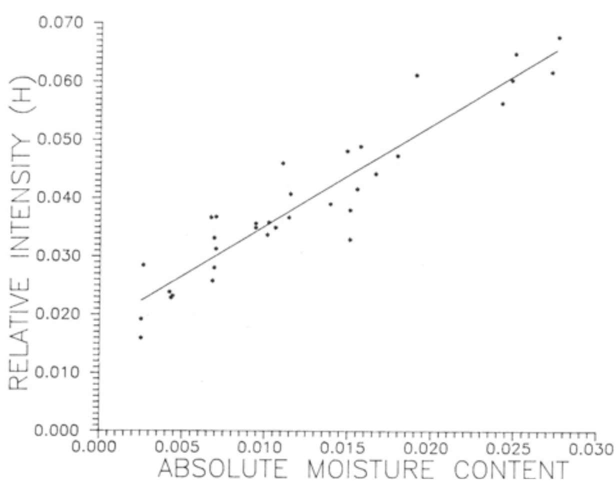

Figure 3. Graph relating the relative intensity of hydrogen to the absolute moisture content of the ambient atmosphere.

Having completed the first stage of the experimental procedure, work is presently being conducted on the intermediate stage. In this stage, the effects of humidity on HAC in the GMAW process are being analyzed. The test apparatus is somewhat different than that used in the GTAW analysis. The weld arc is mobile in this stage of research, and a filler wire is being used as well as welding on a steel specimen. Initial results appear to indicate that the GMAW process has a much higher hydrogen potential than the GTAW process.

The final stage of testing will be conducted on the SMAW process. There are several difficulties in measuring emission intensities in the SMAW process such as the obscuring smoke produced during welding and the complex chemistry within the arc arising from the flux coating of the electrode. Also, the ability of the flux coating to pick up moisture will be another variable to consider in the analysis process. However, as the highest incidence of HAC occurs with the SMAW process, the data gathered on this process should prove very valuable.

REFERENCES

1. Dorschu, K. E., "Factors Affecting Weld Metal Properties in Carbon and Low Alloy Pressure Vessel Steels", Weld Research Council Bulletin, 231, pp. 28-31.
2. North, T. H. et al., "Weldability of High Strength Line Pipe Steels", Weld. Journal, Aug. 1982, pp. 243-257s.
3. Gross, J. H., "The Status of Welding Technology in the United States", Weld. Journal, Dec. 1983, pp. 30-36.
4. Johnson, W. H., "On Some Remarkable Changes Produced in Iron and Steel by the Action of Hydrogen and Acids", Hydrogen Damage ASM Source Book, Mar. 1979, pp. 1-12.
5. Smith, J. A. et al., "Electrochemical Conditions at the Tip of an Advancing Stress Corrosion Crack in AISI 4340 Steel", Hydrogen Damage ASM Source Book, Mar. 1979, pp. 255-258.
6. Speidel, M. O., "Hydrogen Embrittlement of Aluminum Alloys?", Hydrogen Damage ASM Source Book, Mar. 1979, pp. 329-351.
7. Chew, B., "Moisture Loss and Regain by Some Basic Flux Covered Electrodes", Weld. Journal, May 1976, pp. 127-134s.
8. White, D. R., "In Process Measurement of Hydrogen in Welding", USA-CERL Technical Report M-86/15, Sept. 1986.
9. Shea, J. E., and Gardner, C. S., "Spectroscopic Measurement of Hydrogen Contaminations in Weld Arc Plasma", Journal of Applied Physics, Sept. 1983, pp. 4928-4938.
10. Savage, W. F. et al., "Hydrogen-Assisted Cracking in HY-130 Weldments", Aug. 1982, pp. 233-242s