Key Concepts in Welding Engineering

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Selecting Filler Metals: Low Hydrogen

This is part two in a series on selecting filler metals. When selecting filler metals, the specifier may elect to require "low hydrogen electrodes." Such electrodes may be required to minimize the possibility of hydrogen related cracking. In some cases the engineer may specify low hydrogen electrodes because he believes these electrodes will also provide weld deposits exhibiting a high minimum level of notch toughness. While this may be true, it can not be assumed. This article will address specifying filler metals that resist hydrogen related cracking while also providing good mechanical properties.

"Low hydrogen" can be understood differently by engineers, contractors, or inspectors....

The term "low hydrogen" has been around for about 60 years. It was first introduced to differentiate this classification of shielded metal arc welding (SMAW) electrode (e.g., E7018) from other non-low hydrogen SMAW electrodes (e.g., E6010). They were created to avoid hydrogen cracking on high strength steels, such as armor plate.[1]

Confusion About the Term

Although so-called "low hydrogen electrodes" have been around for many years, there is some confusion about what is meant by the term. Many codes and specifications use the designation, however, neither "low hydrogen" nor "low hydrogen electrodes" are listed in the American Welding Society's (AWS) *Standard Welding Terms & Definitions* (AWS A3.0-94)[2]. This may come as a surprise to some, especially to engineers that have been specifying that "only low hydrogen electrodes shall be permitted," or "all welds shall be low hydrogen", or that "all welding processes shall be low hydrogen." Without a formal definition, the term "low hydrogen" can be understood differently by engineers, contractors, or inspectors, which can lead to confusion and conflicts.

"Low Hydrogen Electrode" Means SMAW Electrode

The closest thing to a formal definition for low hydrogen SMAW electrodes is found in the AWS A5.1 filler metal specification[3]. This specification lists several electrode classifications with "low hydrogen" coatings. These classifications must have a coating moisture level of less than 0.6% when tested at 1800 °F (980 °C), according to AWS A5.1. This moisture level corresponds to a relatively low diffusible hydrogen level in the deposited weld metal, typically less than 16 mL/100g. For example, AWS A4.3, Standard Methods for Determination of Diffusible Hydrogen[4], shows that when E7018 is welded at 70 °F and 60% relative humidity a 0.6% coating moisture equates to approximately 12 mL/100g of diffusible hydrogen. Many of today's E7018 products have actual coating moisture content levels much lower than the maximum of 0.6% in the as-received condition. Table 1 lists the SMAW electrodes with low hydrogen coating contained in A5.1.

Table 1. AWS SMAW Electrodes with Low Hydrogen Coverings

EXX15-x
EXX16-x
EXX18-x
EXX18M-x

Can Hydrogen Affect Mechanical Properties?

The influence of hydrogen can be observed in mechanical testing; however, its effects on the test results are limited. A high hydrogen content in a tensile specimen can produce "fish-eyes" on the fracture surface as seen in Figure 1.

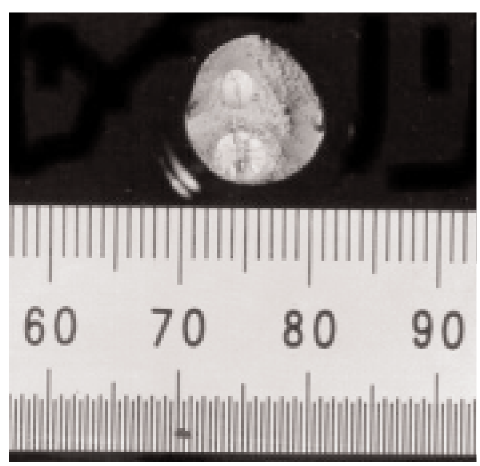

Figure 1. "Fish-eyes" on an all-weld-metal tensile specimen fracture surface.

Additionally, the presence of hydrogen can reduce ductility (as expressed by elongation and reduction in area). Hydrogen, however, does not typically influence the impact toughness, ultimate tensile strength or yield strength results. It is only in severe cases that it can influence the ultimate tensile strength.

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Since low hydrogen SMAW electrodes like E7018 are also required to have a minimum specified level of Charpy V-notch (CVN) impact energy, low hydrogen is sometimes equated with a minimum CVN level. This has led some people to specify low hydrogen when the real desire is for notch toughness. The better approach is to specify notch toughness requirements since there is no automatic link between low diffusible hydrogen content in the weld and CVN values. Actually, some deposits with high hydrogen levels can deliver relatively high levels of notch toughness. For example, the E6010 classification (non-low hydrogen, 30-50 mL/100g) has a minimum CVN requirement of 20 ft-lbs at minus 20°F.

Use of the Term in Codes and Specifications

Some codes and specifications refer to hydrogen control in terms of either (1) requiring low hydrogen SMAW electrodes or (2) placing specific limits on diffusible hydrogen. The *Structural Welding Code – Steel* (AWS D1.1-2000)[5] has provisions related to hydrogen in the preheat table (Table 3.2). In the table, Category "A" is applicable to "shielded metal arc welding with other than low hydrogen electrodes." The minimum preheat temperatures listed in Category "A" are higher than Category "B" because Category "B" is for "shielded metal arc welding with low hydrogen electrodes, submerged arc welding, gas metal arc welding, flux cored arc welding."

In the *Interim Guidelines: Evaluation, Repair, Modification and Design of Welded Steel Moment Frame Structures*[6] published by the Federal Emergency Management Agency (FEMA), a comparison between low hydrogen SMAW electrodes and FCAW and SAW is made. This document states, "All of the electrodes that are employed for flux cored arc welding (both gas shielded and self shielded), as well as submerged arc welding, are considered low hydrogen." Implied is the assumption that FCAW and SAW will provide weld deposits with diffusible hydrogen levels similar to SMAW electrodes with low hydrogen coverings.

Weld Deposit Hydrogen Levels

As mentioned above, no definition exists for a "low hydrogen weld deposit." The word "low" is an imprecise description. The preferred method of controlling the level of hydrogen in a weld deposit is to use the optional hydrogen designators as defined by the American Welding Society. These designators are in the form of a suffix on the electrode classification (e.g., H8, H4, and H2). The filler metal manufacturer may choose to add the hydrogen designator to the electrode classification if the filler metal meets the diffusible hydrogen requirements in the applicable AWS A5.x filler metal specification. Following are examples of the designator requirements:

Table 2. Optional Hydrogen Designators

	Diffusible Hydrogen, mL/100g
H8	8
H4	4
H2	2

To avoid hydrogen induced cracking, the hydrogen level in the material must be held to a certain maximum level. This level is a function of the microstructure susceptibility, constraint (or restraint), and residual stresses. Microstructure susceptibility to hydrogen induced cracking often increases with increasing steel strength. Therefore, for higher strength steels lower levels of hydrogen are required. To simply state "use low hydrogen" is not enough. For example, "low" for a 50 ksi steel may not be "low" for a 100 ksi steel. Rather than require that "only low hydrogen electrodes can be used," engineers and fabricators are should use statements such as, "only electrodes or electrode-flux combinations capable of depositing weld metal with a maximum diffusible hydrogen content of 8 mL/100g (H8) are permitted."

Codes That Use Hydrogen Designators

The AWS D1.1 Structural Welding Code also has several provisions that utilize hydrogen designators (e.g., H8). For example, Category "D" in the minimum preheat and interpass temperature table (Table 3.2) allows only "…electrodes or electrode-flux combinations capable of depositing weld metal with a maximum diffusible hydrogen content of 8 mL/100 g (H8)." This is a good example of properly using the H-designators.

To simply state "use low hydrogen" is not enough

The AWS D1.1 Code also has an alternate method to determine the minimum preheat temperature (Annex XI) that uses three levels of diffusible hydrogen. In Annex XI, category H1 is called an "extra low hydrogen" at less than 5 mL/100g. Category H2 is labeled as "low hydrogen" at less than 10 mL/100g. The third category, H3, is a hydrogen level that is not controlled. Although category H2 is labeled "low hydrogen," this does not define low hydrogen electrode as less than 10 mL/100g. The actual diffusible hydrogen value can also be used to calculate the minimum preheat temperature with this method instead of using the H1, H2 and H3 categories.

Job specs should be written clearly and precisely regarding the use of "low hydrogen"

The Fracture Control Plan of the AWS *Bridge Welding Code*[7] (AWS D1.5-95) is another fine example of hydrogen control. This code requires the following for welding Fracture Critical Members:

- H16, H8 or H4, when the minimum specified yield strength is 50 ksi or less.
- H8 or H4, when the minimum specified yield strength is greater the 50 ksi.

Furthermore, SMAW electrodes can be used for tack welding without preheat if the electrode has an H4 designator, according to AWS D1.5.

Other agencies such as the United States Military[8] and the American Bureau of Shipping[9] also set limits on the diffusible hydrogen levels. Both use limits of 15, 10 and 5 mL/100g, and the military specification has a stricter limit of 2 mL/100g for some applications. Today, a logarithmic system (i.e., H16, H8, H4, and H2) is preferred in the United States.

Other Issues

Using an H8, or even an H4, electrode with controlled diffusible hydrogen alone provides no guarantee of eliminating problems related to hydrogen during or after welding. In addition to the electrode, several other factors can influence the diffusible hydrogen level and the potential for cracking. These should be considered as well.

- base metal surface condition (contamination from oils, grease, dirt, moisture, acid, rust and other hydrogen containing materials can increase hydrogen levels);
- relative atmospheric humidity (humid conditions generally lead to higher hydrogen levels);
- welding shielding gas (higher moisture content results in higher hydrogen levels);
- consumable storage conditions (improper or prolonged storage can lead to higher hydrogen levels);
- welding procedures (electrical stick-out, arc voltage, wire feed speed and other parameters can influence diffusible hydrogen).

Conclusions

1. A "low hydrogen electrode" refers only to a SMAW electrode that has a coating moisture of less than 0.6%.

2. The maximum diffusible hydrogen level associated with low hydrogen SMAW electrodes has been a point of confusion because SMAW electrodes with low hydrogen coatings are not tied to any specific hydrogen level.

3. "Low hydrogen" should not be specified in order to achieve specific impact properties. If notch toughness is required, then it should be listed separately from the hydrogen limits (if any).

4. Job specifications should be written clearly and precisely regarding the use of "low hydrogen." The intent of the specifier should be listed in such a way that the contractor will understand what is required.

5. If a contractor has any questions regarding in the intent of the engineer, or if the specifications are not clear, the contractor should seek clarification before welding. For example, if "use low hydrogen electrodes only" is listed on the contract, then the contractor may want to ask: "Is only SMAW allowed, or can other processes also be used?"

6. Supplemental hydrogen designators (e.g., H8 and H4) are the preferred way to define a specific level of diffusible hydrogen in the weld deposit and should be used when needed.

7. Finally, there are applications where low hydrogen electrodes are not required or where non-low hydrogen SMAW electrodes, like E6010, are preferred. Therefore, utilizing the blanket statement "use low hydrogen" should be avoided.

References

[1] Robert O'Con. "Welding with Low Hydrogen Electrodes: A Look at the Past with Tips for Today." *Practical Welding Today.* March/April 2000, pp. 33-35.

[2] American Welding Society. *Standard Welding Terms and Definitions*. (ANSI/AWS A3.0-94), 1994.

[3] American Welding Society. *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*. (ANSI/AWS A5.1-91), 1994.

[4] American Welding Society. *Standard Methods for Determination of Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding.* (AWS A4.3-93), 1993, p. 16.

[5] American Welding Society. *Structural Welding Code – Steel.* (AWS D1.1:2000), 2000.

[6] Federal Emergency Management Agency. *Interim Guidelines: Evaluation, Repair, Modification and Design of Welded Steel Moment Frame Structures*. (FEMA 267), August 1995, p. 8-11.

[7] American Welding Society. *Bridge Welding Code.* (AWS D1.5-95), 1995.

[8] United States Military. *Military Specification – Electrodes – Welding, Flux Cored, Ordinary Strength and Low Alloy Steel*, (MIL-E-24403/1D), November 14, 1985.

[9] American Bureau of Shipping. *Rule Requirements for Materials and Welding, Part 2*, 1997.