NCPWB
National Certified Pipe Welding Bureau

Technical Bulletin

January 2025

When to use E6010 welding electrodes.

Historical Background

As everyone in the welding industry is aware, electric arc welding was invented simultaneously by several people around 1881. Auguste DeMeritens was one of the earliest users of the process. He used a carbon electrode to weld together lead plates for making lead-acid batteries. His power source was – lead-acid batteries! It was covered by French Patent Number 146010.

The earliest attempts to arc weld steel using bare wire electrode were not very successful since bare wire provided no way to protect the elements transferring across the arc from the oxygen in the atmosphere. The resulting "weld metal" made Swiss cheese look solid. Various salt coatings were applied to the wire by dipping it in a solution saturated with sodium silicate and other salts, then and letting it air dry. Although these fluxing agents reduced the amount of porosity, there was still too much. They reasoned that if a little salt was good, more must be better, so they wrapped paper around the wire, attached it to the wire using twist-ties, then dipped the paper-wrapped wire in a salt solution. The composite electrode worked like a charm! It deposited sound weld metal with no porosity; in addition, the arc was forceful and penetrated the base metal well, ensuring good fusion.

Current Technology

Today's E6010 is essentially the same as described above -- wire encased in cellulose held together with salts and minerals. It produces the same weld metal soundness and good penetration characteristics as those old hand-made electrodes, plus the operator appeal is much greater.

The only serious disadvantage to cellulose-coated electrodes is that they contain 5 to 7% water in the coating. That water is part of what makes the electrode weld like it does, but when the water is heated to 15,000°F by the electric arc, the molecule separates into hydrogen and oxygen. The oxygen is collected by the silicon and manganese in the salts that are present and form slag, but because hydrogen is highly soluble in liquid steel, it is absorbed into the weld pool. See Figure 1. Since hydrogen is also soluble in the heat-affected zone (HAZ) (the area immediately next to the weld metal), the hydrogen diffuses into it also. See Figure 2.

As long as everything is hot, hydrogen in the weld metal and HAZ causes no problems. As the weld cools, however, the solubility of hydrogen in steel decreases. As the weld cools and hydrogen solubility decreases, the iron matrix shrinks, reducing the space available for the hydrogen. If a free surface is nearby, the hydrogen can escape to the atmosphere, but when the steel is thick, the hydrogen cannot escape quickly, and it becomes trapped in the iron matrix. As cooling continues, the space between the iron atoms gets smaller and smaller, squeezing the hydrogen and building up internal pressure in the steel matrix. If the matrix is soft and ductile (typical of ferrite plus iron carbide or Bainite microstructures), there is some loss of toughness and ductility, but the matrix stays intact. If the matrix is hard and brittle (typical of the microstructure known as Martensite), the hydrogen gas pressure causes the matrix to crack. The matrix must cool below 200°F for cracking to occur, but that process may take as long as 24 hours. This delay in cracking until the metal is cold gives this hydrogen-assisted cracking the alternate names of "delayed cracking" and "cold cracking."

Pipe Welding

The thicker the steel is and the more alloyed it is, the greater the likelihood that hydrogen-assisted cracking will occur. When welding thin carbon steel piping, the risk of hydrogen cracking when using E6010 type electrodes is low because the distance that the hydrogen must travel to escape is short and the cooling rates are usually sufficiently slow that Martensite formation is avoided. See Figure 3.

Standard weight carbon steel pipe has been welded using E6010 electrodes for decades without significant episodes of hydrogen cracking. Use of E6010 electrodes is preferred for this type of work because its superior penetration makes it easier to use than low-hydrogen electrodes for getting full penetration on piping welds particularly at the root.

With thicker pipe wall and with alloy steels, the conservative practice is:

- Use E6010 or other EXX10 electrodes as required by the WPS for the root to ensure adequate penetration
- Use low hydrogen (e.g., E7018) for the fill passes to minimize introduction of hydrogen.

When the root pass is deposited with E6010, hydrogen goes into the weld and HAZ. Since the root pass has the a comparatively slow cooling rate compared to the rest of the passes in the weld, the likelihood of Martensite formation is low. The subsequent passes made with low-hydrogen electrode introduces very little hydrogen into the weld. In addition, those passes reheat the root area, and this allows the hydrogen in the root to diffuse away. This is particularly effective since the root is at the pipe's internal surface, and any hydrogen in the weld metal or heat-affected zone will preferentially diffuse in the direction of minimum hydrogen concentration – towards the atmosphere on the inside of the pipe. See Figure 4.

Conclusion

Although welds on standard weight carbon steel pipe can be made using E6010, a more conservative approach is to take advantage of the superior penetration characteristics of E6010 when making the root pass and use low-hydrogen electrode such as E7018 for the fill passes to minimize the risk of hydrogen-assisted cracking.

Figure 1

Solubility of Hydrogen in Steel

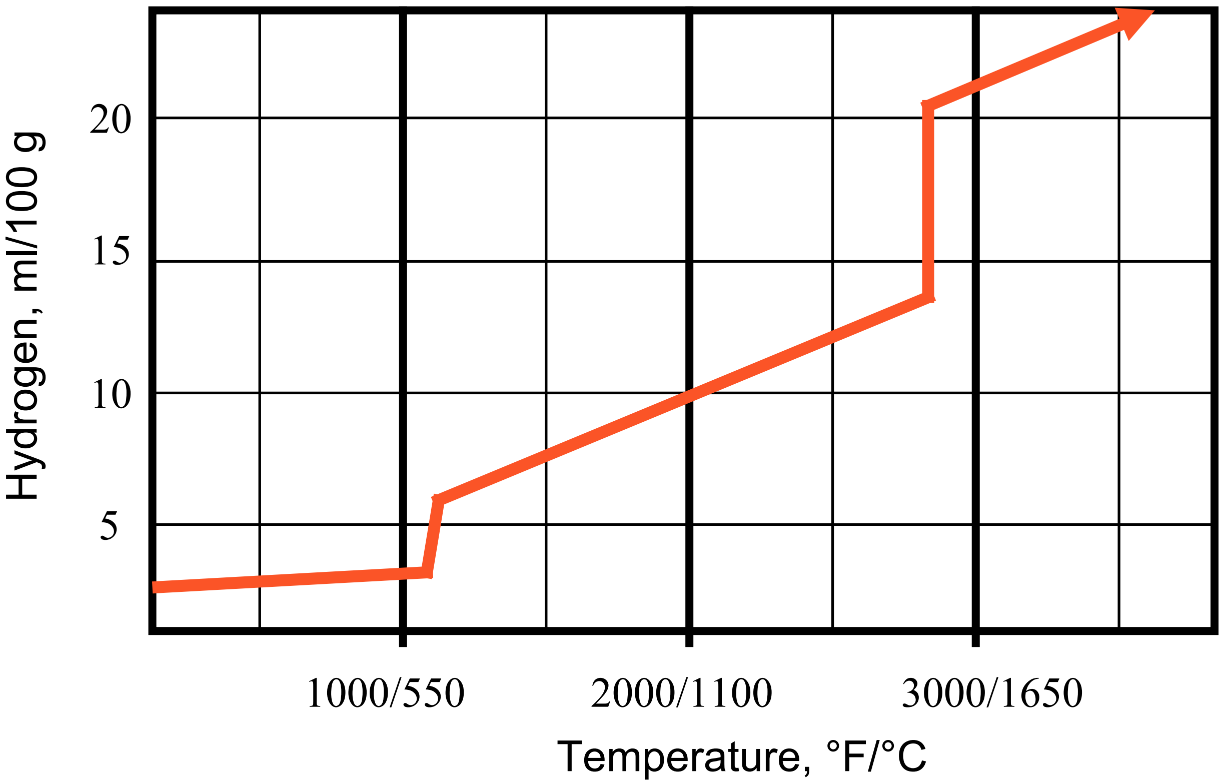
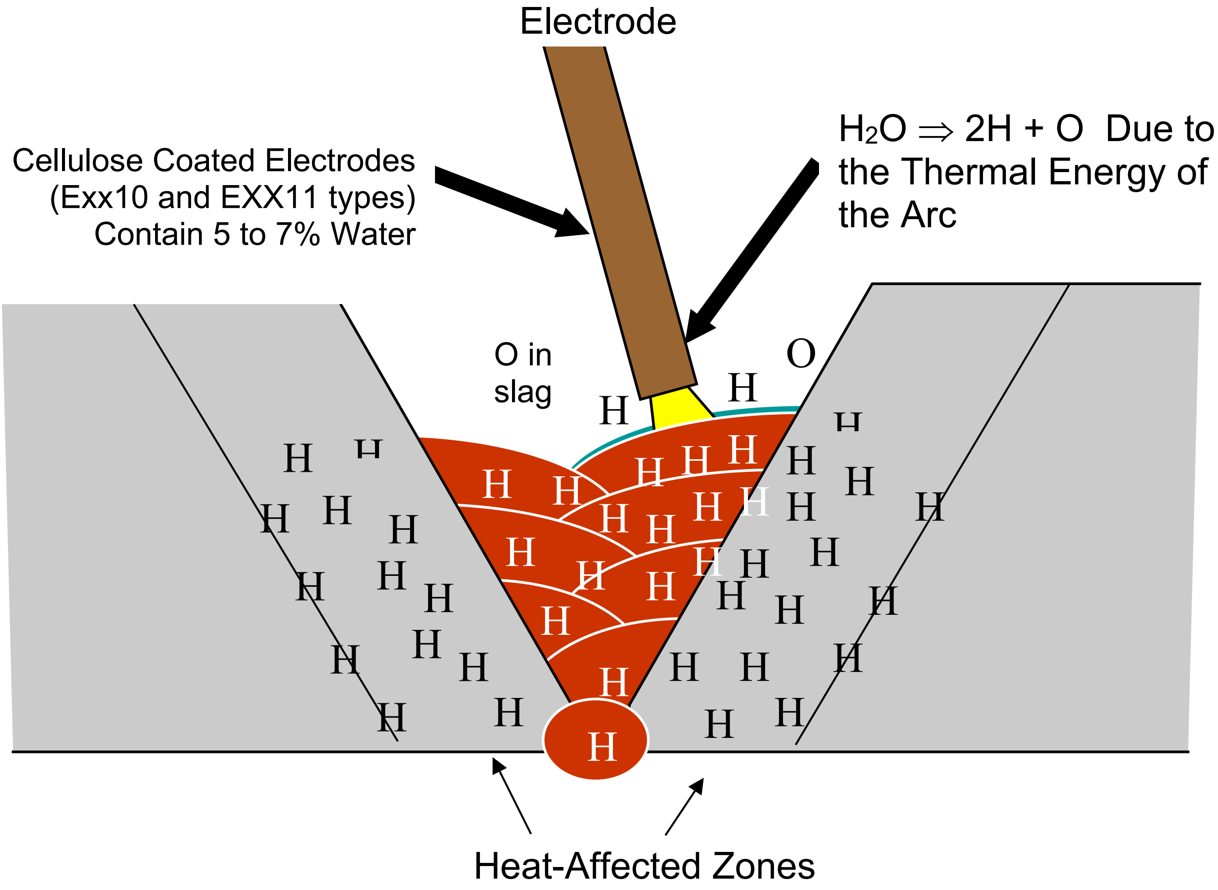


Figure 2

Hydrogen Build-up in a Weld



Cellulose Coated Electrodes (Exx10 and EXX11 types) Contain 5 to 7% Water

$H_2O \Rightarrow 2H + O$ Due to the Thermal Energy of the Arc

Figure 3

Hydrogen in Thin (3/8”, 8 mm and thinner) Steel Has a Short Diffusion Path.
Hydrogen Escapes Easily to the Atmosphere.

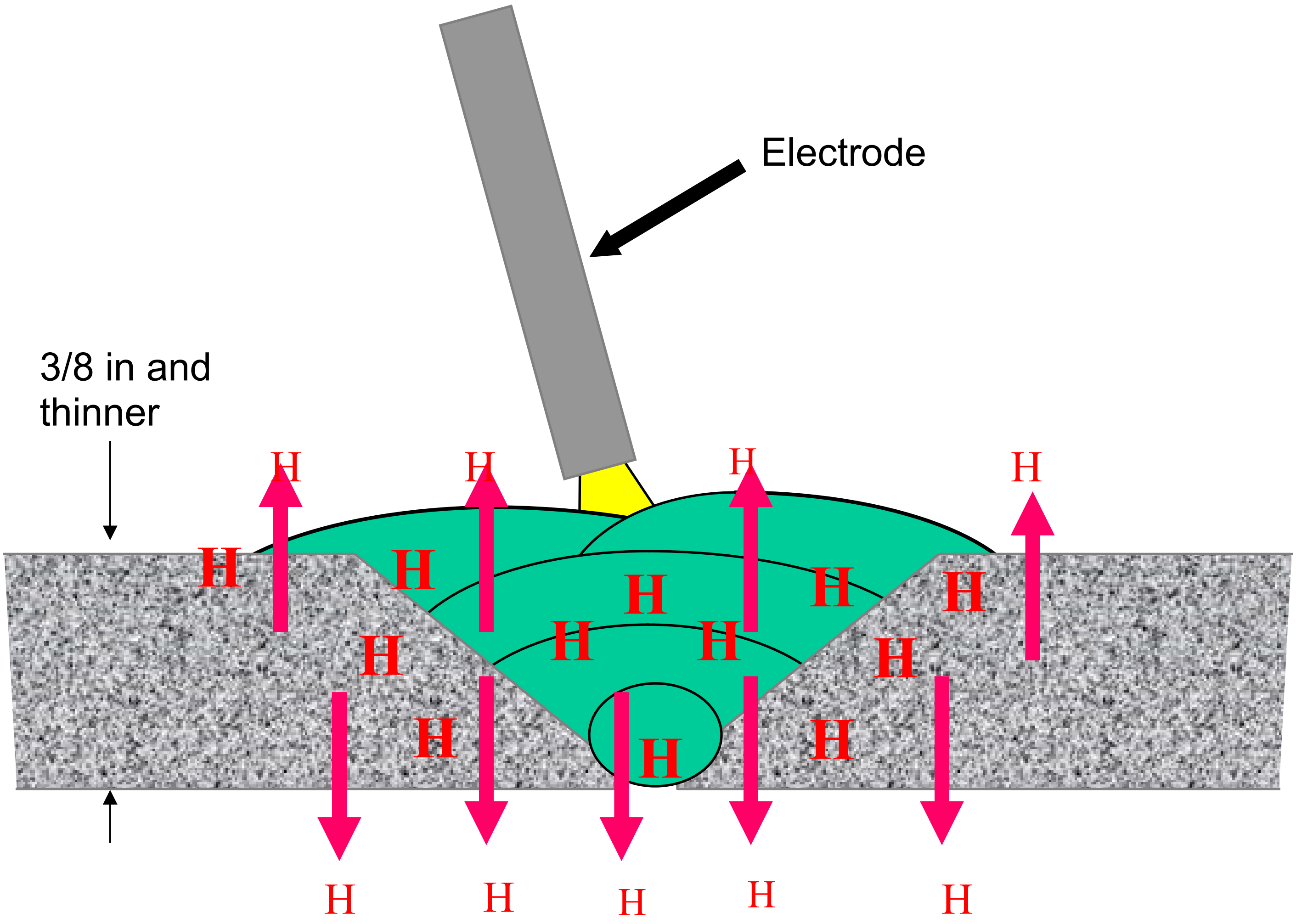
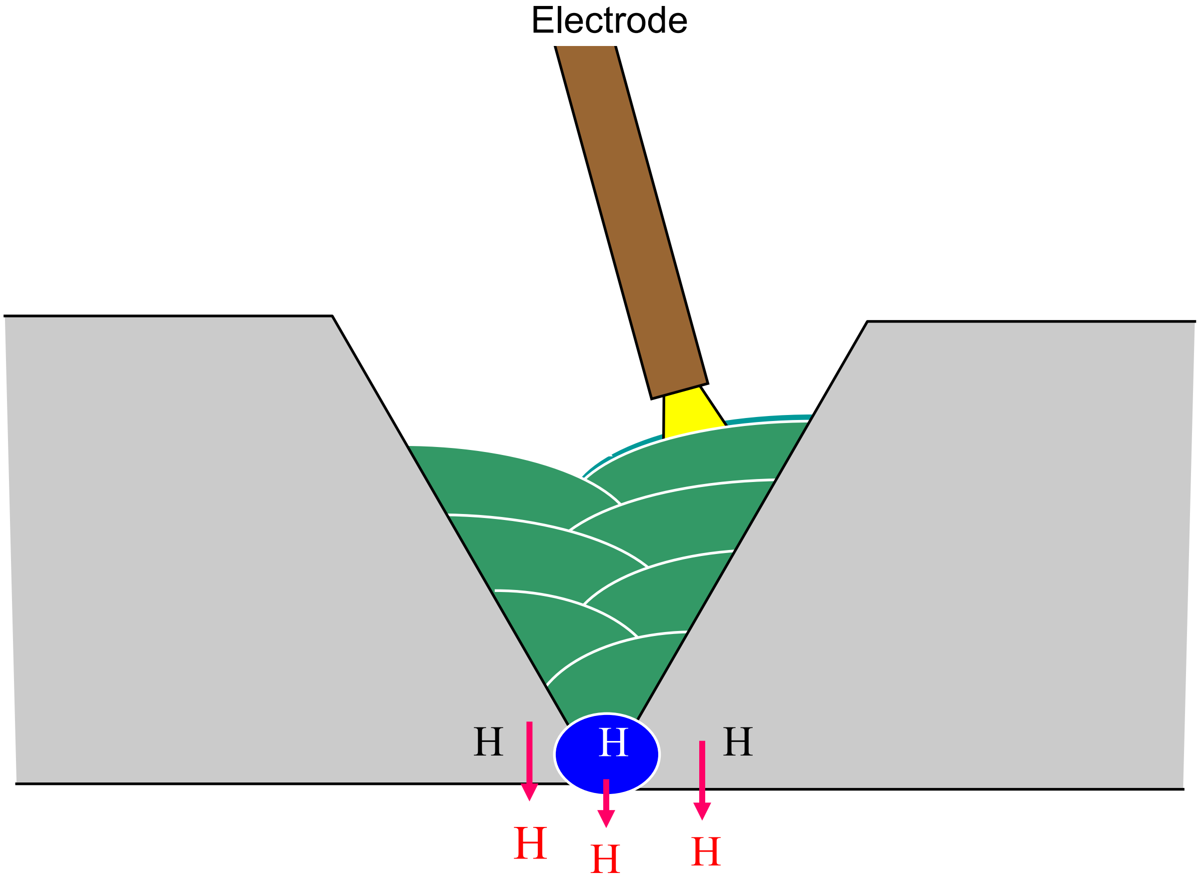


Figure 4

Hydrogen Distribution in a Weld made using E6010 followed by E7018.



Hydrogen diffuses easily out of the weld metal and HAZ
due to short distance to the surface.

🟩 EXX18 Weld Metal

🟦 EXX10 Weld Metal