Inspectioneering

Asset Intelligence Report

A PRIMER ON

HYDROGEN BAKE-OUT

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Overview

As a procedure, hydrogen bakeout is used in many process industries, such as oil & gas, chemicals, and petrochemicals, to help remove hydrogen that has dissolved in metals before performing welding. Typically, hydrogen can enter steel via diffusion or chemical reactions at the surface. Once within the metallic matrix, it can make the steel brittle and/or prone to fracture through several mechanisms collectively called hydrogen embrittlement.

Why Do We Bake Out Steels?

Regardless of the source (with hydrogen service or aqueous corrosion being the most common), atomic hydrogen dissolved into any material interferes with atomic-scale reorganization processes. With yielding behaviors restricted, most materials suffer a loss in ductility and fracture toughness with increasing hydrogen content. At around 1 ppm dissolved hydrogen, effects begin to be noticeable in a material's workability—affecting our ability to perform hot work such as welding or grinding. Most industrial exposures are, at a minimum, expected to deliver 6-10 ppm (wt%) hydrogen into steel, certainly enough to present challenges to tradesmen tasked with repairing or modifying equipment. Wet H_2S exposure can be much, much more severe than gaseous hydrogen service, enough to promote fissures in the steel without any outside influence (i.e., blistering and hydrogen-induced cracking). Regardless of the exposure route, responsible management of industrial assets requires the consideration and management of hydrogen content before work can proceed.

What is Hydrogen Bake-Out?

Hydrogen within steel exists as the H+ ion, which is very tiny compared to the iron, carbon, and other elements that are present. Given enough time, dissolved hydrogen (H+) would eventually leave a charged material due to natural diffusion, even at room temperature. Hydrogen bake-out is a process in which we promote the migration of hydrogen out of the steel by raising the temperature—increasing the atomic distance between iron atoms, and encouraging hydrogen to move around the matrix more rapidly. In general, raising the temperature means increasing H+ diffusion speed, making bake-out a time-saver when hydrogen embrittlement is suspected.

Typically, owner/operators will opt for bake-out targets between 600°F and 800°F. This reflects a desire to eliminate hydrogen as quickly as possible while hoping to avoid adverse metallurgical changes. The dependency on time and material thickness to achieve thorough hydrogen removal can be illustrated below in **Figure 1**. This is for a 90% reduction in dissolved hydrogen, which is far more thorough than other applications for "clean" hydrogen service would require.

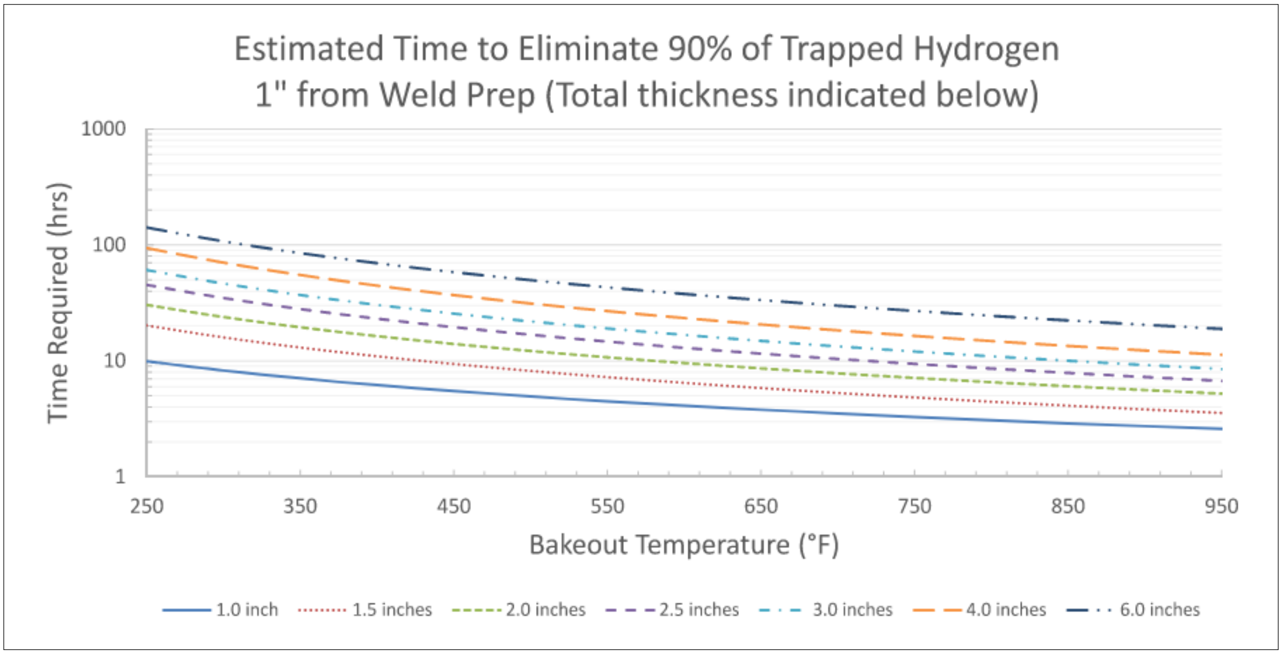


Figure 1. Thickness-Time Interdependence in Hydrogen Bakeout

Industry Applications and Recommendations

Hydrogen bake-outs should be used on many examples of steel equipment where any of: (1) high material strength, (2) PWHT requirements exist due to welding difficulties or (3) vigorous hydrogen charging exists in service. Ultimately, the goal is to remove atomic hydrogen (H+) to prevent it from causing cracking during or after welding/grinding. If the charging environment is sufficiently minor or the material is not hardenable, bake-out may not be necessary (or even beneficial).

If you have a question about weldability in advance of a weld repair, one easy test is a "test bead": simply run a small weld bead under conditions similar to your planned repair and wait 24 hours. Delayed hydrogen cracking usually manifests within the first few hours, so a sensitive surface NDE method should be able to determine if the steel is susceptible to the level of dissolved hydrogen. As you're already planning a weld repair, even the formation of a crack would confirm the need for bake-out before continued repairs.

The following considerations are often useful when determining the need for bake-out:

- Is the steel in hydrogen charging service? If not, then no bake-out should be required.
- Most low-thickness sections of forgings or pipe (without PWHT requirements) do not require bake-out, even if in wet H2S service. This is because the diffusion distance, even from the deepest point, is small, and hydrogen removal can occur naturally at ambient temperatures over a few days.
- Plate steels, however, often contain layered structures or inclusions that can serve to decrease the rate of hydrogen removal. Plate steels above ½ inch in wet H2S service should almost always receive a bake-out to help ensure adequate removal of hydrogen unless their open-to-atmosphere time has been quite long.
- Thicker sections (>1.25 inches) in charging service should almost always receive some form of hydrogen management planning.

Potential Complications

In recent years, much study has focused on the effects of austenitic cladding layers on the hydrogen mobility into, out of, and through a vessel segment. Notably, most austenitic steels have a much higher solubility for H+ at temperature, which

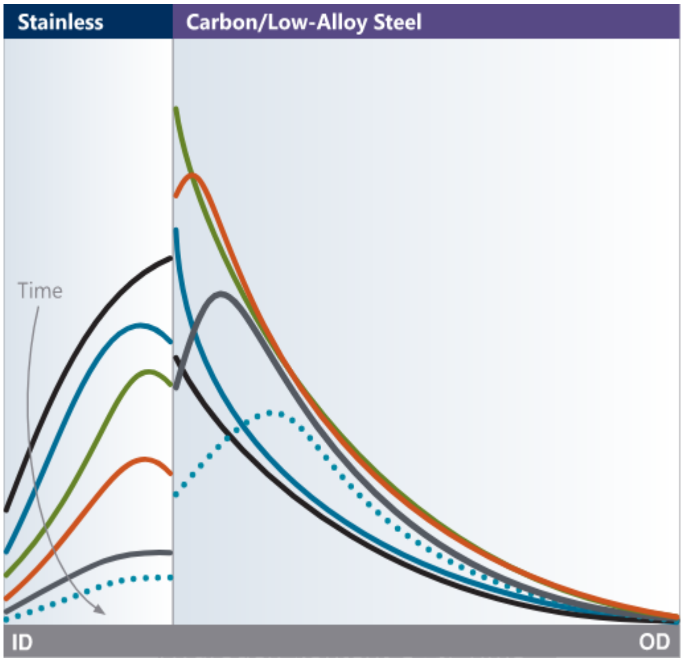


Figure 2. Accelerated charging due to cladding

means a clad layer will represent a large reservoir of hydrogen available to diffuse into the base metal upon cool-down. Additionally, austenitics tend to reject hydrogen more strongly than ferritics at ambient temperatures. This effect is akin to squeezing a wet sponge against a countertop – the rejected water spills out into the surrounding area. In clad vessels, the hydrogen squeezed out of the stainless layer is pushed into the base metal, driving hydrogen deeper into the base metal as the vessel cools down. Mobility of the dissolved hydrogen falls at the same time, trapping high concentrations deep in the base layer. This is shown schematically below in **Figure 2**.

We see the dissolved hydrogen increases in deep sections upon cooling when a clad layer is present, leading to hydrogen embrittlement concerns upon shutdown that did not exist during operation. Bake-out can take longer in these sections—not just from the higher concentration at the start of the bake-out, but also because the hydrogen is less motivated to leave the austenitic material at elevated temperatures. For these reasons, achieving adequate hydrogen removal from a thick-walled clad vessel is difficult and is likewise difficult to properly analyze. Various avenues exist to accelerate the hydrogen removal process, but some plans must be in place before the equipment cools down to be maximally effective. Reducing bake-out times by a factor of two (or more) is possible with careful planning.

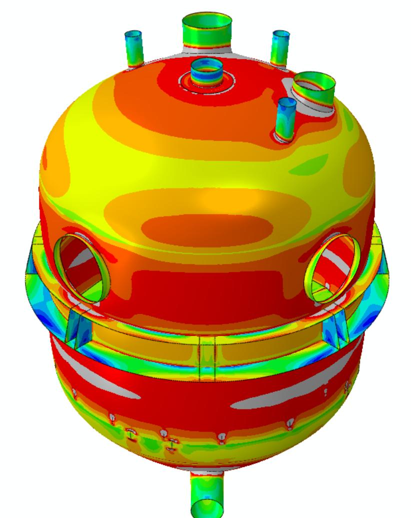
Relevant Codes, Standards, and Best Practices

- AMS 2759/9D - *Hydrogen Embrittlement Relief (Baking) of Steel Parts*
- ASTM G142 - *Standard Test Method for Determination of Susceptibility of Metals to Embrittlement in Hydrogen Containing Environments at High Pressure, High Temperature, or Both*
- ASTM F519 - *Standard Test Method for Mechanical Hydrogen Embrittlement Evaluation of Plating/Coating Processes and Service Environments*
- ASTM F1459 - *Standard Test Method for Determination of the Susceptibility of Metallic Materials to Hydrogen Gas Embrittlement (HGE)*
- ASTM F1624 - *Standard Test Method for Measurement of Hydrogen Embrittlement Threshold in Steel by the Incremental Step Loading Technique*
- ASTM F1940 - *Standard Test Method for Process Control Verification to Prevent Hydrogen Embrittlement in Plated or Coated Fasteners*
- NACE TM0284-2011, *Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen-Induced Cracking*

Further Reading

- Industrial Dogma and You – How, When, and Why to Perform Hydrogen Bake-out
- Hamstrung by Hydrogen Damage Mechanisms
- The Hype about Hydrogen Bake-Outs! - Part 1
- A Discussion on Hydrogen Bake-Outs! - Part 2
- 99 Diseases of Pressure Equipment: Hydrogen Bake-Out



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