MATERION

Tech Brief

High Performance Alloys

High-Strength Copper Alloys for Service in Hydrogen or Hydrogen-Containing Environments

Hydrogen has begun to play an ever-increasing role in the development of future energy production. Unfortunately, many common materials used in engineering applications are susceptible to hydrogen-induced failure mechanisms. Using advanced, specialty materials enables safe design without sacrificing performance.

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Hydrogen is becoming a more common choice for energy technology because of its lower environmental impact when compared to conventional fuels. However, hydrogen also causes issues in materials exposed to it, such as hydrogen embrittlement. Hydrogen embrittlement may cause a decrease in the toughness or ductility of a metal so that it takes less stress for cracks to appear. Materials exposed to hydrogen in service must be able to perform without becoming embrittled.

We investigated the entire life cycle of hydrogen - from the production to the transportation and storage to the final use. Choosing materials that will be safe at each step in the cycle is the most important requirement for an accepted technology. Consideration must be taken for long-term effects, especially with respect to possible hydrogen embrittlement. Our high-strength copper alloys provide dependable performance and durability in hydrogen and hydrogen-containing environments.

DETERMINING IF SPECIALTY MATERIALS SHOULD BE CONSIDERED FOR YOUR APPLICATION

Examples of applications where resistance to hydrogen exposure is important include:

- Chemical production, such as fertilizer
- Oil refineries
- Power generation
- Direct combustion or fuel cells in vehicles, ships, planes and trains
- Synthetic fuels
- Steel production

When you are preparing your design for contact with hydrogen, be aware of any situation that might put your application at risk for hydrogen embrittlement. To determine if this risk exists for your use case, ask the following questions:

- Is the material known to suffer from hydrogen embrittlement, i.e. a reduction in ductility/toughness?
- Are there any unexplained component failures associated with hydrogen, such as widely varying operating times or failure rates?
- Is there a risk to exceed the yield strength in the application (static stress or residual stresses due to forming, machining, heat treatment or welding)?
- Are there hydrogen-rich environments involved, or is there a risk of hydrogen formation due to corrosion?
- Does the material contain carbon and is the application at elevated temperatures?
- Does the material have a high yield strength (beyond 800 MPa)?
- Does the material contain hydride-forming elements such as tantalum or niobium?

If your material is being used in any of the above situations, be certain that it will perform when needed. An advanced material may be safer and improve results.

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CHOOSING MATERIALS FOR HYDROGEN EXPOSURE

In any new design when there is known or potential hydrogen exposure, all processes and materials in the system should be validated by testing under service conditions. When selecting materials to use in testing such new designs, it is always a best practice to choose from materials that have demonstrated resistance to hydrogen embrittlement as shown in independent laboratory testing. For that reason, we arranged for testing of Alloy 25, a copper-beryllium alloy, PerforMet® alloy and commonly-used steel to determine how susceptible they would be to hydrogen embrittlement.

The German research institution DECHEMA-Forschungsinstitut measured hydrogen ingress over a 192 hour period at ambient temperature when the alloys were cathodically charged. Both Alloy 25 and PerforMet alloy showed much lower hydrogen ingress than the steel. Similarly, Ruhr Universität Bochum, a public research university in Germany, found minimal hydrogen ingress in either material after a 21 day exposure to high-temperature, high-pressure hydrogen gas.

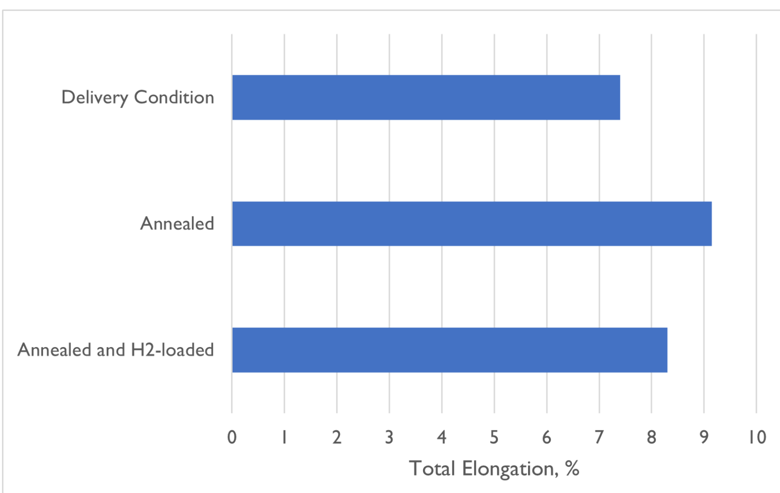
Table 1: Results of Hydrogen Exposure Testing

Material	Measured Hydrogen Content (ppm) after 192 h (cathodically charged)*	Measured Hydrogen Content (ppm) after 21 Days (300°C, 200 bar) Exposure**
Alloy 25 Copper Beryllium	0.7	< 0.1
PerforMet	0.4	< 0.1
Steel P91	3.2	Not measured

* Results courtesy of DECHEMA-Forschungsinstitut, Theodor-Heuss-Allee 25, 60486 Frankfurt, Germany
**Results courtesy of Ruhr Universität Bochum, Universitätsstr. 150, 44801 Bochum, Germany

Furthermore, slow strain rate tensile test results after hydrogen charging showed no reduction in elongation in the CuBe compared to the as-received condition, suggesting no embrittlement occurred. Figure 1 below displays this data, provided by Ruhr Universität Bochum.

Figure 1: Total Elongation Values from SSRT Investigations for CuBe



The results in Figure 1 show no significant influence of hydrogen-loading. This was confirmed by scanning electron micrograph images of the fracture surfaces in both the hydrogen-charged and the as-received conditions, both showing signs of ductile failure without signs of embrittlement. See Figure 2.

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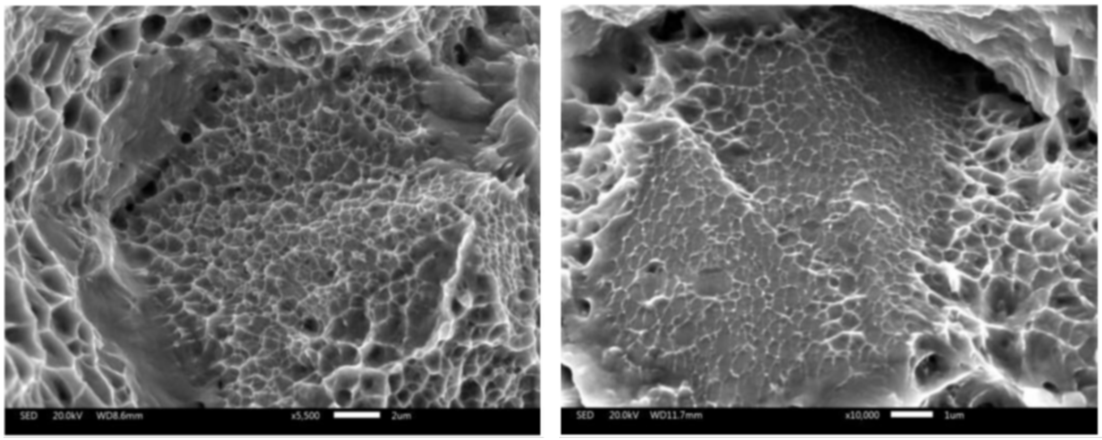
Figure 2: Images from SEM Investigations: Fracture Surface from Sample CuBe in Delivery Condition (left) and H2-loaded Condition (right)



The images in Figure 2, provided by Ruhr Universität Bochum, show no difference in fracture mechanism.

ALLOY 25 AND PERFORMET ALLOY SOLUTIONS FOR HYDROGEN SERVICE

Alloy 25 is a versatile material that combines high strength with electrical and thermal conductivity considerably greater than other copper alloys. PerforMet alloy is a nickel-silicide-strengthened bronze that withstands high pressures and temperatures. These alloys are available as ingot, strip, bar, tube and wire in various tempers.

Both materials offer many advantages over other alloys for use in hydrogen or hydrogen-containing environments, including:

- No or negligible hydrogen embrittlement in H_2/H_2 bearing environments
- High strength
- Large safety margin compared to alloys known to be non-susceptible towards H_2
- No H_2-permeation, no degassing
- No embrittlement or reduction of ductility from room temperature to cryogenic conditions (such as -252°C)
- No surface decarburization
- No internal cracking due to methane or hydride formation
- Resistant to biofouling
- Non-magnetic
- Excellent spring properties
- Hot and cold formability
- High electrical and thermal conductivity
- Non-galling
- Spark resistant

HEALTH AND SAFETY

Hydrogen can be handled as any other compound that has a certain risk potential. The designer should be careful in selecting material based on reported property values because test and material conditions are highly variable. Properties used for design should be based on tests conducted under conditions that simulate service or worst case conditions..

SAFE HANDLING OF COPPER BERYLLIUM

Handling copper beryllium in solid form poses no special health risk. Like many industrial materials, beryllium-containing materials may pose a health risk if recommended safe handling practices are not followed. Inhalation of airborne beryllium may cause a serious lung disorder in susceptible individuals. The Occupational Safety and Health Administration (OSHA) has set mandatory limits on occupational respiratory exposures. Read and follow the guidance in the Safety Data Sheet (SDS) before working with this material. For additional information on safe handling practices or technical data on copper beryllium, contact Materion's Technical Service Department at +1-800-375-4205.

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