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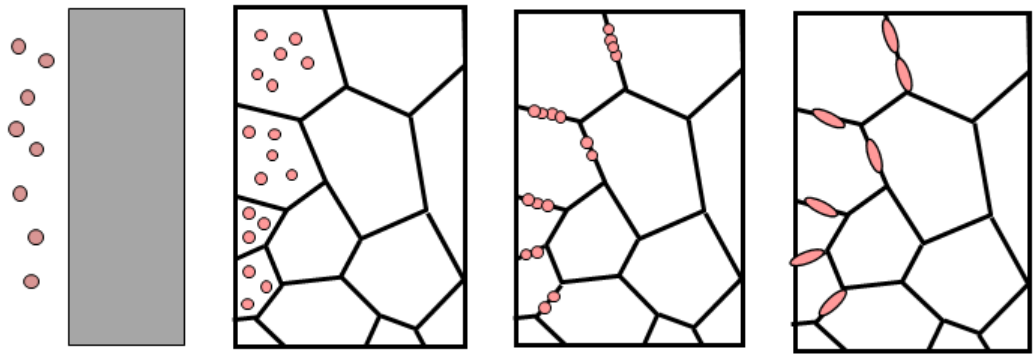
www.imetllc.com
847.528.3467

Hydrogen Embrittlement of Carbon Steel

Hydrogen embrittlement is a metalôs loss of ductility and reduction of load bearing capability due to the absorption of hydrogen atoms or molecules by the metal. The result of hydrogen embrittlement is that components crack and fracture at stresses less than the yield strength of the metal.

Embrittlement process

At room temperature, hydrogen atoms can be absorbed by carbon steel alloys. The absorbed hydrogen may be present either as atomic or molecular form. Given enough time, the hydrogen diffuses to the metal grain boundaries and forms bubbles at the metal grain boundaries. These bubbles exert pressure on the metal grains. The pressure can increase to levels where the metal has reduced ductility and strength.



Situations leading to hydrogen absorption

Hydrogen can enter and diffuse through steel even at room temperature. This can occur during various manufacturing and assembly operations or operational use - anywhere that the metal comes into contact with atomic or molecular hydrogen

Processes for which there is a possibility of absorption of hydrogen include acid pickling and electroplating. Hydrogen is present in acid pickling baths. During electroplating, hydrogen is produced at the surface of the metal being coated. Acid pickling is used to remove oxide scale from the surface of steel and electroplating is commonly used to deposit zinc on steel nuts, bolts, screws and other fasteners for galvanic corrosion protection of the steel. Other electroplated coatings are used for different applications.

Hydrogen absorption can also occur when a component is in service if the steel is exposed to acids or if corrosion of the steel occurs.

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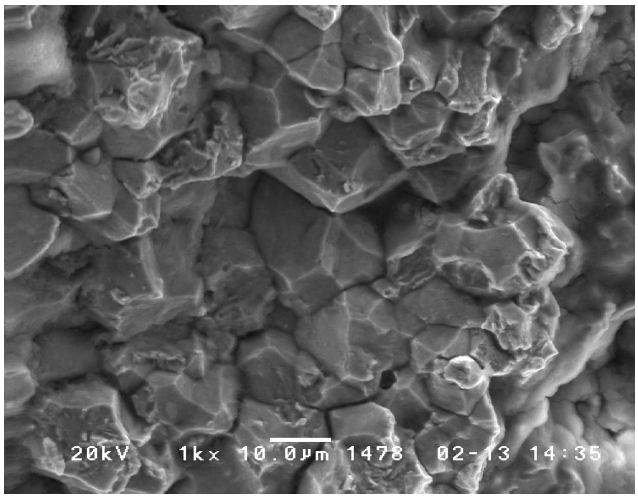
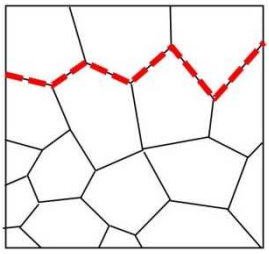
Intergranular Fracture

An example of failure due to hydrogen embrittlement is shown in the figures below. The left image shows a macroscopic view of a fractured, zinc-plated, steel bolt. The right image shows a scanning electron microscope image of the fracture surface. In this image the individual grains at the metal fracture surface can be seen, which is indicative of intergranular fracture. The bolt became embrittled during the zinc electroplating process.



Intergranular cracking occurs when cracks form and grow along weakened grain boundaries in a metal. In the case of hydrogen embrittlement, the hydrogen bubbles at the grain boundaries weaken the metal.



Requirements for failure due to hydrogen embrittlement

There are three requirements for failure due to hydrogen embrittlement:

1) A susceptible material.
2) Exposure to an environment that contains hydrogen.
3) The presence of tensile stress on the component.

High-strength steels with tensile strength greater than about 145 ksi (1000 MPa) are the alloys most vulnerable to hydrogen embrittlement.

As mentioned earlier, exposure to hydrogen occurs during surface finishing process steps such as acid pickling and electroplating and during service if the steel is exposed to acids or if corrosion occurs.

As for the stress to cause fracture, even tensile residual stress within a component can be sufficient to cause failure of an embrittled material.

Preventing hydrogen embrittlement

Steps that can be taken to avoid hydrogen embrittlement include reducing hydrogen exposure and baking after electroplating or other processes that lead to hydrogen absorption. Hydrogen

embrittlement of electroplated components can be prevented by baking them at 375 to 430 °F (190 to 220°C) within a few hours after the electroplating process. During baking, the hydrogen diffuses out of the metal.

For applications where there will be hydrogen absorption while a component is in service, the use of lower strength steels and reduction of residual and applied stress are ways to avoid fracture due to hydrogen embrittlement.

Evaluating for hydrogen embrittlement

Finally, there are tests that can be performed to evaluate whether processing leads to steel hydrogen embrittlement. Here are two such tests:

- ASTM F1940 Standard Test Method for Process Control Verification to Prevent Hydrogen Embrittlement in Plated or Coated Fasteners
- ASTM F519 Standard Test Method for Mechanical Hydrogen Embrittlement Evaluation of Plating Processes and Service Environments

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