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HYDROGEN EMBRITTLEMENT & STRESS CORROSION

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WHAT

Stress Corrosion Cracking:

- Always associated with high tensile fasteners (core hardness > 32 HRc) made of quenched and tempered alloy steels or work hardened mild steel. Most likely when core hardness is >36 HRc
- A variety of environmental and chemical exposures can introduce hydrogen into micro cracks, where higher concentrations of tri-axial stresses occur under residual or applied loading, causing Stress Embrittlement. Stress Corrosion Cracking (SCC) is not a only hydrogen related event, it may also result from various corrosive substances that attack small cracks, wedging into them until they fracture.
- A delayed failure can occur within minutes or years after the fastener is first loaded. Still; the fastener satisfies all tensile strength standards.
- An inter-granular brittle failure. No evidence of necking, elongation or progressive fatigue lines. Fracture surface is typically along transverse axis. Micro plug and socket type inter-granular structures (crystalline) can be observed on the fracture surface.
- Always located at the head /shank interface or at the first engaged thread from the head. Looks like material has been scooped out of the under side of the head.
- Not all inter-granular brittle failures are due to SCC.

Hydrogen Embrittlement:

- Hydrogen Embrittlement (HE) occurs through the absorption of hydrogen (H_2)
- HE occurs in areas of high stress loading such as under the bolt head, and at the thread run-out to shank location. Fracture can occur within minutes or days from the initial installation, and is not restricted to bolt installations alone, HE of nuts can also occur and nut bursting / splitting takes place under high stress.
- Hydrogen absorbed into the steel part migrates to areas of high stress when parts are loaded in tension.
- The most common cause is exposure to hydrogen in the manufacturing process. Typically, processes such as heat treatment furnace atmosphere, acid pickling and electroplating provide H_2 rich environments.

WHY

- Although a large amount of ongoing investigation and research has been conducted on SCC/HE still there is a lot not yet understood..
- It has long been established that interstitial alloying elements such as carbon, nitrogen, hydrogen, oxygen and boron will, in small quantities, affect the behaviour of metals.
- Hydrogen is widely recognised for its potential to severely embrittle steel and other metals.
- It was recognised that under the influence of a stress gradient, hydrogen atoms (H^+) will diffuse or migrate to regions of high tri-axial stress. The hydrogen will migrate to prior austenitic grain boundaries, martensitic lathe boundaries, and carbide interfaces. This will reduce the cohesive forces between the metal atoms. When the concentration of hydrogen exceeds a critical value in the boundary or interface, rapid brittle fracture occurs.
- In almost all HE failures in fasteners, the head/shank interface (or any other location with a notch or a micro-crack) becomes the primary area for hydrogen atom collection. This migration is thought to produce a sudden catastrophic separation of the fasteners' head from its shank.
- In SCC above, the phenomenon occurs because hydrogen introduced by a chemical reaction induced by the service environment.
- In HE, a hydrogen rich environment is generated as a by-product or a result of a manufacturing process.

WHERE

- Any process that uses acid pickling on high strength fasteners (Core Hardness >HRc 32, or most likely >HRc 36) introduces risk of HE.
- Any coating or plating process needs clean parts. Heat treatment processes introduce surface scales and oxides that will inhibit plating adhesion. The most economical method of getting rid of these stubborn scales is acid pickling. Most coating processes such as electroplating, electroless plating, mechanical plating, organic or inorganic dip-spin coatings, or phosphating, use acid pickling as the method of cleaning, and as a result has the potential to introduce risk of HE.
- Non-porous coatings such as electroplating have a higher potential to trap hydrogen as diffusion out of the fastener is hindered.
- Room temperature does not provide adequate energy to diffuse hydrogen away from high strength fasteners, even if a porous-coating is used.

- The higher the hardness, the higher the energy required to diffuse hydrogen away from the fastener.
- Non-porous coatings reduce the risk of SCC in the service life if the risk of HE can be mitigated at manufacturing.

ELIMINATION

Based on above hypothesis the only ways that SCC/HE can be avoided are:

- Use lower strength materials (Property Class 8.8, Grade 5 or lower) where hydrogen can diffuse away from the fastener under room temperature.
- Avoid high tri-axial stresses applied to the fastener. This can be achieved by removing sharp corners, micro cracks, notches and the like through appropriate design of the fastener and manufacturing methods.
- Avoid exposure to hydrogen.

MITIGATION

The following will minimise the risk of SCC/HE.

- Do not use fasteners above Property Class 10.9 or SAE Grade 8.
- Design joints so that the clamping force is around 65% of the proof load of the fastener.
- Design fasteners and manufacturing processes to minimise stress concentration.
- Use low hydrogen cleaning and plating baths. This, however, may not give adequate cleaning required for reliable coatings. If so, use sand blasting.
- Reduce the resident (soaking) time of parts in acid pickles.
- Use appropriate inhibitors to reduce acid attack on the base metal surface.
- Use mechanical agitation in pickling and plating to quickly remove the hydrogen generated.
- Bake parts at high risk of HE (Core Hardness >HRc 32, gone through acid pickle and electroplating) within *1 hour* of electroplating (*otherwise there exists the possibility of developing hydrogen embrittled micro-cracks due to residual stresses*) to a temperature of 204 °C – 218 °C for four hours (ASTM F1940-99).
- Carryout the baking process on parts that were pickled in strong acid baths independent of the subsequent coating.
- Test final parts for HE using methods described in (ASTM F 1940-99) or any other proven equivalent method.

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Ajax Fastener Innovations (AFI) offers a consulting service to assist in the design of bolted joints in specific applications. AFI has the experience; test equipment, analysis methods, and analysis tools developed over many years, to provide our customers with a greater level of confidence in the design of critical joints. Furthermore, AFI is dedicated to developing fastening solutions that cater for the specific needs of industry.

If you need any further assistance please contact us.