

Identifying Hydrogen Embrittlement Failures

Over the past thirty years, I have become aware of many suspected cases of hydrogen embrittlement in screws and bolts. Experience has shown that many of these suspected hydrogen embrittlement failures were eventually proven to have causes completely unrelated to hydrogen embrittlement. It is important for fastener suppliers to learn how to quickly determine whether or not a reported failure could be attributable to hydrogen embrittlement.

True Failures Have Common Characteristics

My understanding and experience related to confirmed cases of hydrogen embrittlement failures in fasteners indicate that the following elements must all be true:

- Fasteners must be core hardened to at least Rockwell C32.
- The parts must have come into contact with acid at some point in their processing.
- The failures must occur some time after installation, usually between one and twenty four hours.
- Parts must have a nonporous finish (usually electroplated). The most common finish associated with hydrogen embrittlement failures in screws and bolts is electroplated zinc.
- The parts must be under stress when failure occurs.

If any of these factors are not present, the chances of the failure being confirmed as hydrogen embrittlement are unlikely.

Unhardened fasteners or those of Grade 5 or Property Class 8.8 or lower do NOT fail due to hydrogen embrittlement. Fasteners with phosphate and oil do NOT fail due to hydrogen embrittlement. Parts that are cleaned by mechanical processes instead of acid are highly unlikely to fail due to hydrogen embrittlement. Failures that occur while parts are being installed are NOT due to hydrogen embrittlement.

Head to Body Junction is Most Common Failure

Hydrogen embrittlement failures occur where the stress in the screw or bolt is most highly concentrated when installed in an application. The most common location of hydrogen embrittlement failures in parts is where the head joins the body of the screw or bolt. Frequently, it looks like material has been scooped out of the underside of the head. The second most common failure location is immediately above where the external thread is engaged with the internal thread in the application. If the failure is somewhere else on the part, the cause is probably something other than hydrogen embrittlement.

Hydrogen Embrittled Parts Exhibit Intergranular Failures

Metallurgists refer to hydrogen embrittlement failures as intergranular brittle failures, as opposed to ductile failures. My understanding of this is that when parts fail from hydrogen embrittlement, the connections between the material's grains let go very abruptly from one another when they are put under stress. They leave sharp edges on the surface of the fracture with an appearance much like rock candy. There is usually no evidence of any tearing action on the surface of the fracture and the fractures are relatively straight across the part transverse to its axis. This is different from failures that look like the part has pulled apart like clay where there is some "necking down" before total failure occurs. When a failed surface looks pulled or twisted it is called a ductile failure instead of a brittle or intergranular fracture.

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One complicating factor in confirming hydrogen embrittlement failures is that not all brittle and/or intergranular failures are hydrogen embrittlement. Similar appearing failures commonly come from hardened parts being side loaded to the point where they break instead of bending. Intergranular failures are also seen in parts that are exposed to environments in their installation that produce hydrogen in the parts after they are in place. This type of failure is referred to as "stress corrosion" and is frequently confused with hydrogen embrittlement. Whenever a delayed failure is reported, particularly when the failure is more than a week after installation, the application should be investigated very thoroughly. If the parts are used in a damp environment where the assembly components are of a different material than the fastener and/or the assembly incorporates components of different types of metals, stress corrosion instead of hydrogen embrittlement is very likely.

Parts with Core Hardness of Rockwell C36 or Below are Less Likely to Fail from Embrittlement

In recent years I have been consulted on a number of suspected hydrogen embrittlement failures. I have made an observation I believe is very significant in avoiding hydrogen embrittlement in fasteners, and in the removal of hydrogen embrittlement when it is confirmed in unused parts. My experience has indicated very strongly that hydrogen embrittlement is highly unlikely to occur in any part that is Rockwell C36 or below in its core hardness, whether it is case hardened or not.

In all of the cases of hydrogen embrittlement I have been involved with that were ultimately confirmed, the core hardness of the parts has been Rockwell C37 or higher. In the cases where some of the parts were not yet used, they have been rid of hydrogen by lowering their core hardness to Rockwell C36 or below. After having concluded this independently, I found a small footnote in *SAE J933 "Mechanical and Quality Requirements for Tapping Screws,"* that provides this same suggestion. Section 4.5 states, "Core Hardness After Tempering - Shall be Rockwell C28-38¹..." Note 1 at the end of the standard states, "Hardness shall not exceed maximum shown and preferably should be no higher than Rockwell C36 to insure against failure in assembly and service."

All alloy steel hex socket products are above Rockwell C36 making them the commercial threaded fasteners that are the most susceptible to hydrogen embrittlement when they are electroplated. I contend that alloy steel hex socket products should never be electroplated. If a customer wants corrosion resistance, phosphate and oil can provide as much corrosion resistance, as zinc and clear or zinc and yellow dichromate without inducing hydrogen embrittlement. If the customer desires silver screws for appearance reasons, suggest supplying the screws with silver painted heads as opposed to zinc plated screws.

New ASTM Spec Helps Platers Detect Embrittled Parts Quickly After Processing

A lot of effort continues to go into the prevention and detection of hydrogen embrittlement. A great advance in hydrogen embrittlement detection has been the development of *ASTM F1940-99* that provides a means of monitoring plating processes to determine if hydrogen embrittlement is being created in the parts being plated. This process verification standard and its described technique is just starting to be accepted by members of the plating industry, but wide acceptance and use is expected in the future. The adoption of this standard by platers will be a major step forward in the elimination of future hydrogen embrittlement failures in fasteners.

Post plating baking should always be performed on electroplated parts having a core hardness of Rockwell C32 or above. The most widely suggested baking procedure is for the parts to be baked for a minimum of four hours at 400°F to 425°F (204°C to 218°C) within one hour after the plating process. It is critical the parts are not only in the furnace for four hours, but that they are at the target temperature for four hours.

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Testing Electroplated Hardened Fasteners Can Catch Embrittled Parts Before They are Installed

All electroplated screws and bolts having a core hardness of Rockwell C32 or above should be tested for hydrogen embrittlement before shipment to customers. The most widely accepted hydrogen embrittlement test is that which simulates extreme use where the parts are tightened to a torque value higher than recommended for application tightening and evaluated at least 24 hours after initial tightening. The specific test procedure is as follows:

1. **Washers:** Place a hardened washer of any type on the screw or bolt to be tested.
2. **Test Plates:** Machine screws and bolts (non tapping screws) should be driven into hardened, threaded test plates having a thickness equal to at least one thread diameter. Tapping screws should be driven into untapped test plates as described in the applicable screw standard.
3. **Determine Failure Value:** Tighten at least five parts with a calibrated torque wrench into the test plates until the parts fail, then record all the failures' values.
4. **Calculate Test Torque:** Calculate the average failure torque. Multiply that average times 0.8 to determine the test tightening torque value.
5. **Initial Installation:** Install at least eight randomly selected samples from the production lot into the test plate with washers under the head of each part and then tighten all parts to the calculated test tightening torque value.
6. **Timed Torque Test:** Leave the parts for at least 24 hours. Once again apply the calculated test torque to each part in the tightening direction, usually clockwise. For greatest assurance repeat this procedure at 48 and 72 hours after the initial installation.
7. **Lot Acceptance:** If any of the parts break before or during the application of the test torque at 24, 48 or 72 hours after the initial installation, the lot is embrittled and should be reworked or scrapped. If no failures are observed, the lot can be considered acceptable.

Thermal Treatment After Stripping is Critical When Reworking Electroplated Parts

If parts are found to have hydrogen embrittlement, an attempt can be made to save them, but there are no guarantees that hydrogen is entirely removed after it is found in the parts. The recommended procedure that has worked successfully in reworking parts is as follows:

1. Strip the plating from the parts.
2. Temper parts at the original tempering temperature or higher to lower the core hardness as much as possible within the part's spec (preferably RC36 or below for tapping screws).
3. Plate the parts again.
4. Bake the parts for at least four hours at 400°F to 425°F (204°C to 218°C) within one hour after plating.
5. Conduct the torque method hydrogen embrittlement test as described above again, but quadruple the original test sample size and test the parts at 24, 48 and 72 hours.

I am aware of two hydrogen embrittlement failures that resulted in claims of over US \$1 million where it was found the parts had been plated improperly and were stripped and replated. Removal of plating is usually done by stripping parts in an acid bath. The longer parts are exposed to acid, the greater the likelihood that hydrogen will be induced into the parts.

It is strongly recommended that when plated parts are stripped, they be baked for at least four hours at 400°F to 425°F (204°C to 218°C), or preferably they go through a tempering cycle to thoroughly purge them of hydrogen before replating. After the parts are plated again they should be baked and tested for hydrogen embrittlement before they are put into use by the end user.

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Gather Samples & Facts Immediately When a Suspected Embrittlement Failure is Reported

Fastener suppliers should take precautions to avoid hydrogen embrittlement failures by encouraging platers to adhere to *ASTM F1940*, by requiring baking after electroplating, and by testing all lots of electroplated screws and bolts that have a core hardness of Rockwell C36 or above by the time-delay torque test. When a customer reports a suspected hydrogen embrittlement failure, suppliers should not panic. Ask many questions and get samples of both failed and unused parts from the same lot for evaluation. Keep in mind that if the parts do not have core hardness of Rockwell C36 or above, they are not electroplated and the failure occurs during the assembly process or more than a week after installation, it is highly unlikely the failure is associated with hydrogen embrittlement.

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