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Do’s and Don’ts to minimize and/or eliminate “Hydrogen Embrittlement” on high strength steels, copper alloys or other alloys.

Hydrogen Embrittlement due to plating processes

What is hydrogen embrittlement? How does it form? What is the mechanism, i.e. how does it take place? Why does hydrogen cause embrittlement? I really do not know the answer to the preceding 4 questions. There are numerous scientific papers dealing with these questions. I have read many of them over time and I still don’t know. An excellent paper was given by Dr. Chris Raub when he received the “Scientific Achievement Award, AES SURFIN, 1992 titled “Hydrogen in Electrodeposits: Of Decisive Importance, But Much Neglected” (1)

What I do know is that hydrogen embrittlement can cause catastrophic failure of high strength steel and other alloys. The failure is usually cracking or complete separation. It can also cause blisters both in the basis metal and at the plating interface, reduced ductility, internal voids, lower yield strength.

What steels are subject to hydrogen embrittlement? I have found some controversy about this. In general, high strength steels, including “low alloy steels” and some stainless steels area vulnerable. Often steels susceptible to embrittlement are designated by their tensile strength. Dini (2) indicates that steels with 1240 to 2140 MPa (180,000-310,000 psi) are susceptible to embrittlement. Other references indicate risk above 1100MPa (160,000) psi and above. In general the higher the tensile strength of the steel the more the susceptibility to hydrogen inclusion and embrittlement. Even austenitic alloys are susceptible. Maraging high-strength steels of 2740 MPa (397,000 lbs./sq.in.) have higher susceptibility to hydrogen embrittlement.

In an article by Paatsch (Pl. & Surf. Fin., Sept. 1996, pgs 70-72) ultra-high strength steel fuse holder rings of C75 (German standard DIN 471) and were plated in various plating solutions and under a number of different preparation cycles. The results and conclusions are interesting. The processing used was as follows: an alkaline cleaner, followed by pickling in 12% HCl-inhibited acid for 0 to 600 seconds; followed by plating. The deposits studied included zinc plating in eight different zinc plating solutions, and Watts nickel, sulfamate nickel, cyanide copper and acid copper There were failures using a modified constant load test derived from ASTM Standard F 519(4) procedure; the notched C-ring and a slow strain rate extension to fracture test.

A summary of the results shows that all the samples using 60 seconds or more pickle time failed at time intervals up to 24 hours heating at 220C (427.5F) regardless of the plating solution used. Some samples required 70 hours heat treating, after plating, to pass the tests. The samples that used less than 60 seconds inhibited HCl pickle showed no failures at all regardless of the type of plating solution used.

A note about electroless nickel and hydrogen

Electroless nickel (EN) generates hydrogen as a part of the deposition reaction. Therefore Hydrogen embrittlement of high-strength steels can occur. What is different about electroless nickel deposits, you ask? Remember that electroplated deposits are crystalline. That is they have grain boundaries from which hydrogen can escape during the baking process. Electroless nickel is virtually amorphous (without grain structure). Since there are no grains, it is very difficult for hydrogen to pass through electroless nickel deposits, particularly thicker deposits where there is little or no porosity.

How then, can hydrogen relief take place? Sometimes EN deposits over 0.001” (2.54 Micro meters) will crack on heat-treating for high temperatures or low temperatures for a long time. Hydrogen can then escape. But we usually do not want cracks because they may induce cracks in the basis metal. Another method is to mask a non-critical area so that there is an unplated area from which hydrogen can escape on baking. Also baking should start at very low temperature for a long time then gradually increase the temperature to the recommended level. EN deposits or thickness of 0.001” (2.54 micro- Meters) or higher are very likely to crack if heated to 300C or higher. The cracking is due to the reduction in volume as the nickel phosphorus changes to crystalline (Ni₃P).

What did I learn from all this coupled with many years of experience? Here are a few precepts to consider:

Do’s
**Do** be aware that hydrogen embrittlement can cause serious failures.

**Do** use appropriate heat relief of entrapped hydrogen. The time and temperature combination must be such that tests prove no failure.

**Do** test very soon after plating 1-3 hours. Test another baked sample after many hours.

**Do** realize that the bake time and temperature required to do the job may be much more than the standards ask for. Always test.

**Do** use solvent degreasing, alkaline soak cleaning, or anodic alkaline cleaning (if required for specific soils).

**Do** use inhibited acid for pickling, if pickling is really necessary. Not all inhibitors work well. Test the results.

**Do** consider shot grit blasting, vibratory cleaning, and shot peening. Shot peening is good for lowering the surface stress.

**Do** consider alternative coating processes such as mechanical plating of zinc, Ti-cad or other suitable metals. There is also powder coating to consider.

**Don’ts**

**Don’t** assume that just because you followed the recommended post plating bake cycle that the hydrogen is removed sufficiently to pass the tests.

**Don’t** use strong or non-inhibited acid pickles.

**Don’t** use the same bake cycle for electroless nickel deposits unless there is an unplated escape area on the part.

**Don’t** rely on a simple bend test shortly after plating. Bend tests are not reliable for hydrogen embrittlement determination. There is no reliable quick test.

**Don’t** use cathodic pre-plating treatments. A nickel strike for activation of stainless and other nickel containing alloys may be required. Be assured that there will be significant infusion of hydrogen. A longer than usual bake cycle may be required.

**References (9), 30 (1993)**


