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Hydrogen embrittlement in tantalum

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Tantalum has outstanding corrosion resistance and tends to perform "as expected" the majority of the time, meaning few bad surprises. Those traits tend to make customers use phrases like bullet-proof, which is great to hear, but also concerning. It's important to understand that even tantalum has its limits. One important limitation that isn't always completely understood is its potential for hydrogen embrittlement. Tantalum does not necessarily have a higher inherent tendency toward hydrogen damage than other metals. It's remarkable corrosion resistance results in it being exposed to process conditions that would be far too aggressive for other metals.

Hydrogen, especially H+ (also called monoatomic hydrogen), is the smallest possible atom. This small size allows it to penetrate into the structure of other materials quite easily, including tantalum. In tantalum, hydrogen atoms fit into the interstitial gaps between the tantalum atoms, which are positioned in a BCC crystalline structure. These H+ atoms are soluble in tantalum metal to thousands of parts per million. Atmospheric hydrogen, or H2, does not penetrate into the structure in the same manner, so it's just H+ that is of interest in the context of this discussion.

Tantalum from a mill that conforms to ASTM B521 and/or B708 will have less than 1.5 ppm Hydrogen as manufactured. Some additional Hydrogen will be absorbed in the process of welding, but levels should still be well below 10 ppm if the welding is done properly. In fabricated equipment, tantalum with absorbed hydrogen at levels above 100 ppm is generally considered embrittled. The metal lattice becomes expanded due to the absorbed hydrogen, creating stresses which cause the brittleness. As tantalum embrittles it becomes harder but loses toughness, fracturing easily. Tantalum does not lose corrosion resistance as it embrittles, so mechanical damage is the primary concern when embrittlement occurs. The other concern, however, is that severely embrittled tantalum can not be welded or formed, making repairs more difficult or impossible. Restoration of embrittled tantalum can be done in a vacuum anneal, but this is rarely practical or cost-effective for process equipment.

For tantalum to embrittle, it needs exposure to H+ atoms. The primary source for H+ atoms is active corrosion of any material. Below are some hypothetical embrittlement scenarios to illustrate the concept:

1) One type of scenario that can result in hydrogen embrittlement of tantalum is corrosion of tantalum. For this reason, general guidance is that tantalum should be only be used in environments where the expected corrosion rate is less than 0.01 mm/a (0.39 mpy).
2) Another scenario is another metal actively corroding very near tantalum. Imagine, for example, a steel nut being left in a horizontal tantalum-lined after an outage. As this steel corrodes in the process, the H+ generated from corrosion would be absorbed by the adjacent tantalum. The degree of embrittlement with decrease as a function of distance from the corroding steel, so it may only result in something like a 6-12 inch diameter area of tantalum that is embrittled. The size of that area depends on several factors of course.
3) A third scenario to consider is when a tantalum lining develops a through hole and subsequent leak of process fluid to the annulus behind the liner. As the process fluid corrodes the now exposed carbon steel substrate, it generates H+ which can be absorbed through the backside of the tantalum lining. For this reason, when leakage is detected at the purge ports on tantalum, it is desirable to shut the equipment down as

quickly as possible to minimize any embrittlement damage that could make repair more difficult or extensive.

It was discovered in the 1960's that coupling tantalum with platinum group metals reduces the tendency of tantalum to absorb hydrogen. The paper found a surface area ratio of 1:10,000 was sufficient to substantially reduce the amount of hydrogen uptake/embrittlement at very aggressive conditions. Based on this prior work, the convention has become to apply platinum plating in spots on tantalum liners when specified at a ration of 1:1000 (10:1 safety factor).

More recent work has shown that at extremely aggressive conditions, hydrogen uptake and embrittlement will still occur even with coupling from platinum group elements, just at a much slower rate. This inability to completely eliminate the hydrogen uptake at very aggressive conditions is the reason tantalum should not be used at anticipated corrosion rates higher than 0.01 mm/a (0.39 mpy). The high acceptable corrosion rates used for metals like carbon steel are not appropriate for a material like tantalum.

It is important that a fabricator utilizes best practices in applying the platinum coating for it to stay in place and remain effective. Tricor recommended utilizing tests described by ASTM B571 for ensuring the quality of platinum plating is sufficient.

It is not practical to apply platinum spots on some surfaces, like the inside surface of a heat exchanger tube. In these cases, another option is to utilize Ultra 76 alloy, manufactured by Materion. This alloy incorporates Ruthenium (a PGM) into the alloy to provide that same protection as platinum plating.

Figure 1 Platinum spots being electroplated onto a tantalum-lined heat exchanger bonnet in Tricor's shop.

Hydrogen embrittlement is not generally a concern for tantalum-lined equipment other than in operating conditions right at the edge of its corrosion resistance capability. Also, platinum spotting serves as a great insurance policy to greatly reduce the risk of hydrogen embrittlement of tantalum-lined equipment. It's just good to have an understanding of the mechanism and how to avoid it.

Applicable references for further reading:

1. *A Method for Prevention of Hydrogen Embrittlement of Tantalum in Aqueous Media, Claude Bishop and Milton Stern, Corrosion, NACE publication, December, 1961.*
2. *Corrosion Data Survey on Tantalum, 2nd ed, Mortimer Schussler and Charles Pokross, Fansteel, 1985.*

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