Tantalum Surface Alloys
Prevent Corrosion

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Tantalum surface alloys provide unmatched corrosion protection at a reasonable cost.

Pure tantalum is one of the most corrosion-resistant metals, but its extremely high cost makes it an impractical option for all but the most corrosive applications. However, a new tantalum-based nanotechnology can provide the corrosion protection of tantalum at a reasonable cost. Tantaline's nanotechnology is based on heating and reacting pure tantalum metal to produce a gaseous atmosphere of tantalum. The tantalum vapor then creates an alloy bond on the surface (and into the core substrate), becoming a true surface alloy. Because the reaction is on the nano level, with tantalum atoms grown into and on top of all surfaces, its characteristics are very different from traditional coatings such as thermal spray or electroplating.

Process Technology

Here's how the Tantaline process works.

- A part is selected for treatment. Such parts include standard stainless steel valves, fittings, instrumentation, pumps, laboratory equipment, and custom parts.
- The furnace is heated to a temperature of more than 700°C (1290°F). At this temperature, the tantalum metal is chemically reacted and vaporized. The high temperature promotes conditions suitable for solid-state diffusion and alloy bonding at an atomic level.
- A gaseous atmosphere of tantalum is created, and individual tantalum atoms diffuse into the core substrate (typically stainless steel), and the surface alloying process begins. The deposited tantalum layer is securely alloyed to the core material by means of an inseparable alloy zone approximately a half micron thick **(Fig. 1).**
- The process continues until a dense excess layer of pure tantalum metal is grown onto the surface. The final tantalum surface is approximately 50 microns thick (0.002 in.) with all the characteristics and chemical properties of pure tantalum.

The completed part becomes an entirely new product that maintains the original size and shape, but in addition has the chemical properties and corrosion resistance of pure tantalum. It is also extremely rugged and durable, with the ability to be formed into various shapes after processing. Tantaline's tantalum surface alloy can handle an extremely high degree of stress caused by mechanical loads, vibrations, rough physical handling, and/or temperature variations during service.

Producing Hydrogen

Although Tantaline serves many industries, an energy application bests demon-

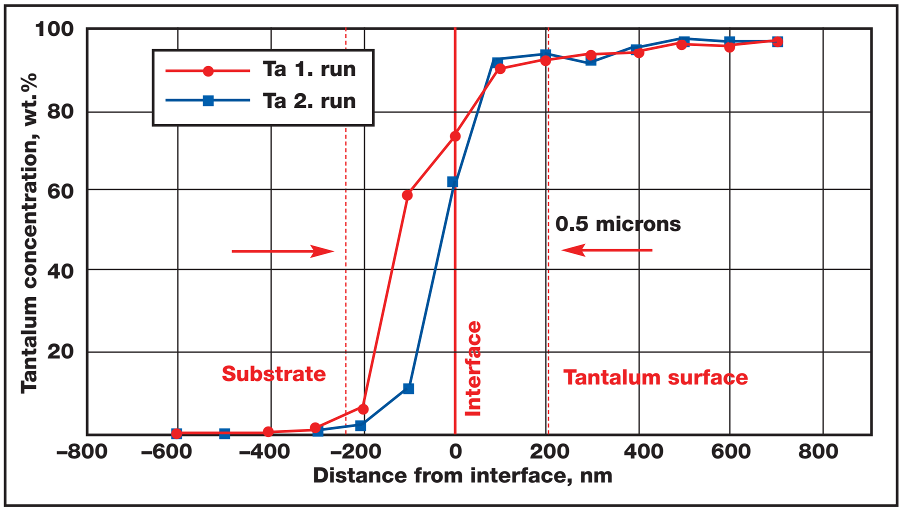

Fig. 1 — *Graph shows how tantalum nanoparticles penetrate the surface of the substrate.*

strates its impact and corrosion resistance. This application is the sulfur-iodine thermochemical process, driven by General Atomics as part of a demonstration to produce hydrogen. The sulfur-iodine process involves hydrogen production by thermochemical water splitting, bringing about the decomposition of water into hydrogen and oxygen without fossil fuels. Heat and water are the only inputs, while oxygen and hydrogen are the only outputs, resulting in zero emissions.

The sulfur-iodine water-splitting cycle consists of three chemical reactions that sum to the dissociation of water:

Eq. 1: $2H_2SO_4 \rightarrow 2SO_2 + 2H_2O + O_2$

Eq. 2: $I_2 + SO_2 + 2H_2O \rightarrow 2HI + H_2SO_4$

Eq. 3: $2HI \rightarrow I_2 + H$

One of the biggest challenges was the corrosive nature of the thermochemical process, as the process itself is aggressive both mechanically and chemically. The reaction involves concentrated sulfuric acid (H_2SO_4), hydro-iodic acid (HI), and phosphoric acid (H_3PO_4) solutions. Therefore, materials had to function in high temperatures and pressures, as well as concentrated corrosive acids and chemicals.

For General Atomics, this combination had led to corrosive failures, creating an unsafe and unstable process environment. This resulted in higher operating costs, making the project economically not feasible. This is where Tantaline had its greatest impact for General Atomics, as the tantalum surface alloy was the only material that could effectively resist the corrosive environment and make the process economically and technically feasible (costs are typically 20% less than nickel alloys). Tantaline succeeded where nickel-based alloys, titanium, zirconium, fluoropolymers, and glass had failed.

As a result, General Atomics installed more than 1500 Tantaline-treated parts, including Swagelok fittings, valves, and instrumentation. These parts enabled General Atomics to continue the project to demonstrate that the sulfur-iodine thermochemical process can be a viable commercial alternative for future hydrogen energy production. General Atomics also significantly reduced maintenance costs and significantly improved the safety of their process.

Other Applications

Biomass to Ethanol: One of the leading methods for converting biomass to ethanol is the acid hydrolysis process. In this process, concentrated sulfuric acid quickly digests waste biomass materials. Tantaline materials enable the most efficient processing environment.

Oil & Gas: As deeper, more difficult wells are pursued, sour gas (H_2S) corrosion is problematic at elevated temperatures and pressures. Tantaline materials provide the longest life possible in these extreme environments.

Chemical Processing: Tantaline-treated valves, fittings, pumps, and instrumentation serve a variety of applications dealing with strong acidic environments. Tantaline is chosen in this industry as a higher corrosion-resistant and lower-cost alternative to nickel alloys such as C-276, titanium, or zirconium.

Pharmaceutical and Food: Because of Tantaline's inertness, it does not contaminate sensitive products such as food and pharmaceuticals. With the chemical properties of glass and the strength of steel, Tantaline is able to solve some unique challenges in this area.

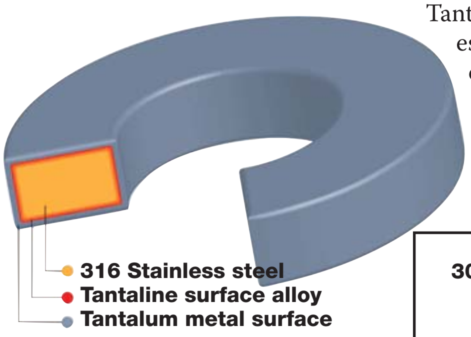

Fig. 2 — *Cutaway of a tantalum coated ring shows the tantalum surface and the interface with the substrate.*

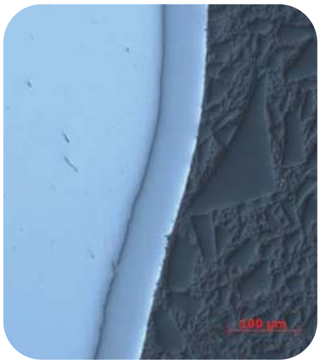

Fig. 3 — *Photomicrograph shows detail of the tantalum and the stainless steel substrate.*

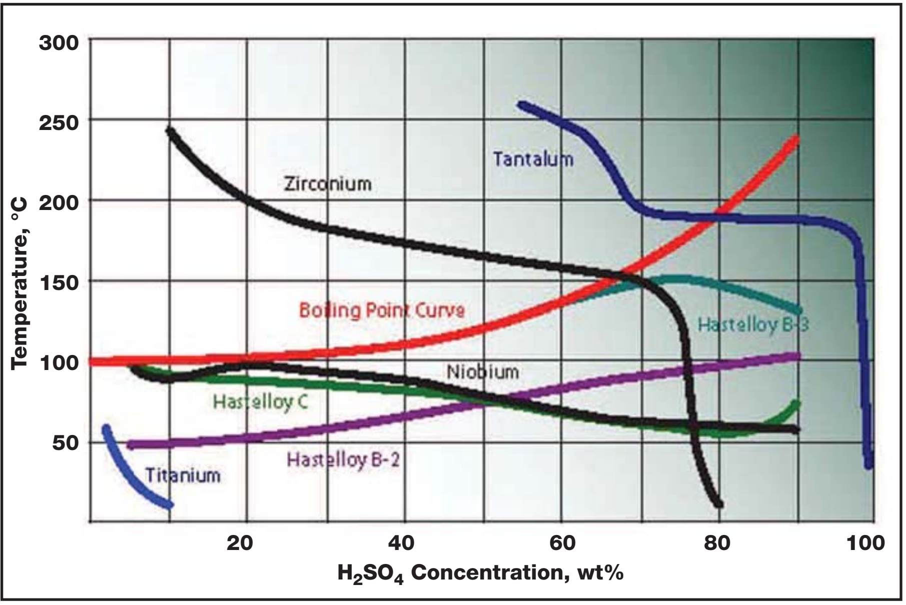

Fig. 4 — *Corrosion chart shows the corrosion resistance in sulfuric acid of tantalum compared with several other metals and alloys. A corrosion rate of 5 mils per year, or 0.13 mm/year, is shown for various temperatures and H_2SO_4 concentrations.*

Corrosion test demonstrates the ruggedness of the surface alloy

To evaluate the corrosion resistance and durability of the Tantaline process, treated parts were evaluated by Materials Selection Resources, an independent materials engineering and corrosion consulting firm.

The testing procedure involved creating both localized and uniform deformation across numerous samples, as well as corrosion testing to show the integrity of the surface after deforming.

The test had three steps:

- Indenting the sample coupons with a Rockwell C cone shaped hardness indenter to first create localized stress upon the surface. **(Fig. 5a)**
- Bending the coupons 180 degrees into a U shape. **(Fig. 5b)**
- Exposing the bent and indented samples to boiling 37% hydrochloric acid for a period of 24 hours. **(Fig. 5c)**

The results of the deformed coupons showed essentially a nil corrosion rate. Because the stainless steel substrate would quickly be attacked by the hydrochloric acid, this demonstrates the ruggedness, durability, and integrity of the tantalum surface alloy, as the surface showed no signs of cracking, delamination, spalling, or corrosion that might be expected with traditional coatings.

Results also show that the surface formed is in fact pure tantalum metal (as defined by ASTM B364), since only tantalum metal can survive the severe corrosion test environment. These results prove the extraordinary combination of mechanical and corrosion resistant properties of tantalum surface alloys.

Fig. 6a — *Sample coupons were indented with a Rockwell C cone shaped hardness indenter to create localized stress upon the surface.*

Fig. 6b — *After being coated with Tantaline, parts can be bent to a U shape with an undamaged surface.*

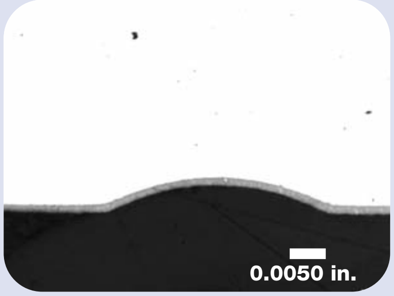

Fig. 6c — *This photomicrograph shows the localized deformation of the sample after it was indented with a Rockwell C indenter. The key is how the Tantaline surface deforms uniformly with the substrate material.*

Process Limitations

Although tantalum surface alloys represent a new material with some very unique properties, like any material it has limitations, and is not ideal for all applications. Components that deal with very abrasive slurries are not well-suited for surface alloys. The tantalum surface alloy is very rugged and durable, but it can be "sandblasted" off. In environments where abrasive slurries exist, solid materials should be considered.

> **"Because of its ruggedness and durability, it is unlike any coating I have ever seen."**
>
> *Dr. Hira Ahluwalia, Materials Selection Resources*

In addition, although Tantaline materials are very cost competitive with specialty alloys such as nickel alloys, titanium, and zirconium, if polymer solutions or various grades of steel could be used, it is more cost effective to do so if greater than two years of life could be achieved with those materials. ❍

For more information: Dean Gambale is President of Tantaline Inc., 1050 Winter St., Suite 1000, Waltham MA 02451; 888/268-2586; www.tantaline.com.

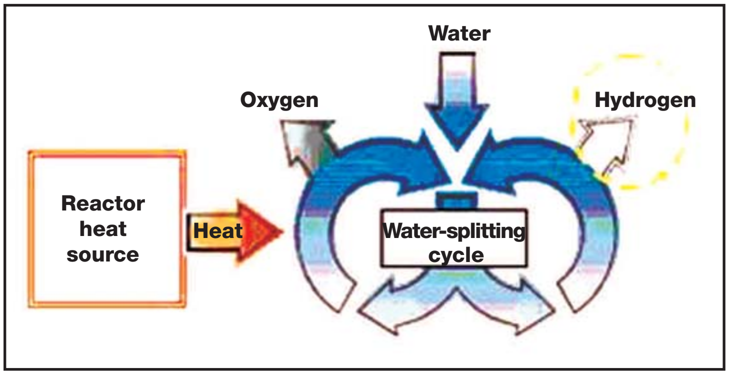

Fig. 5 — *Water splitting cycle. The sulfur-iodine water-splitting cycle consists of three chemical reactions that sum to the dissociation of water.*