The Use of Tantalum in the Process Industry

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Tantalum is one of the refractory metals, so named because of their excellent high-temperature properties. These metals, especially tantalum, have remarkable corrosion-resisting properties due to an inherent, self-healing oxide layer that protects the tantalum against the most hostile environments (except those containing fluorine or fluorides). In this article, the production, fabrication, and applications of tantalum are discussed, as are the advantages and disadvantages of using the material.

INTRODUCTION

The refractory metals group (which includes tantalum, tungsten, molybdenum, niobium, zirconium, titanium, chromium, osmium, vanadium, and rhenium) are characterized by high melting points and strength at high temperatures, making them useful as furnace-construction materials and for applications in the aerospace and electronics industries. In addition to these excellent properties, refractory metals show remarkable resistance to many of the most hostile chemical environments.

Tantalum is the most versatile refractory metal due to its relative ease of fabrication and its excellent corrosion resistance, which may be compared to that of glass. Like other refractory metals, tantalum reacts with air above approximately 250°C; thus, at high temperatures, suitable protective atmospheres or vacuum should be used. However, at lower temperatures, tantalum has remarkable corrosion-resisting properties.

Table I. The Properties of Tantalum

Density	16.9 g/cm^3
Crystal Structure	body-centered cubic
Melting Point	2,996°C
Coef. Linear Expansion	6.5 × 10^{-6} per °C
Specific Heat	0.142 J/g°C
Thermal Conductivity	54.4 W/m°C
Elasticity Modulus	186 kN/mm^2 at 20°C
Yield Stress at . . .	
20°C	179–1,060 N/mm^2
500°C	44–310 N/mm^2
Tensile Strength (20°C)	
Annealed	280–330 N/mm^2
Cold-Worked	600–1,400 N/mm^2
Hardness	
Annealed	70–110 VPN
Cold-Worked	180–300 VPN
Ductile/Brittle Trans. Temperature	Below –196°C

PRODUCTION AND FABRICATION

The physical properties of tantalum are listed in Table I. The mined ore (tantalite), which also contains tantalum's sister element niobium, is ground and dissolved in hydrofluoric acid, then a solvent-extraction process recovers the tantalum and niobium as separate, purified streams. The resulting potassium tantalum fluoride (K_2TaF_7) is reduced to tantalum metal powder by the action of molten sodium. The metal powder is pressed into ingots, followed by vacuum sintering at high temperatures or by electron-beam or vacuum-arc melting to consolidate the material for processing by forging, rod rolling, or sheet rolling.

Electron-beam melting produces the purest material (>99.99%), but sheets produced from electron-beam melted ingots tend to have a course grain size, hence, components produced from this material by spinning tend to have a rough surface finish. For finer-grained material, a powder, metallurgical, or arc-cast product is preferred with a purity >99.9%. However, because of residual oxygen, carbon, and nitrogen, these materials can cause problems during welding (e.g., a tendancy to produce gassy welds).

In order to improve specific properties of tantalum, it is often alloyed with other metals such as tungsten. This improves the tensile and hardness properties of the material, while having little effect on the corrosion resistance. Common alloys of tantalum are Ta-10W, Ta-2.5W, and Ta-40Nb; the alloys formed with tungsten have superior mechanical properties to pure tantalum, while the alloy with niobium costs less. Tantalum alloys are not normally available from stock and require a special order. The corrosion resistance of tantalum is almost as good as that of platinum or gold, but it costs less than the precious metals.

Tantalum can be turned, drilled, spun, sheared, and welded. Turning and drilling should be carried out with care by using suitable lubricants, as the metal tends to stick to the tools. No structural transformations exist up to the melting point, so pure tantalum cannot be hardened by heat treatment. Hardening can only be achieved through cold-working or by the addition of hydrogen or nitrogen during a special annealing treatment. Hydrogen is added at around 800°C and is reversible; heating to a higher temperature in high vacuum removes the hydrogen, hence, restoring the material to its original softness.

Due to its reactivity to all permanent gases when hot, conventional welding

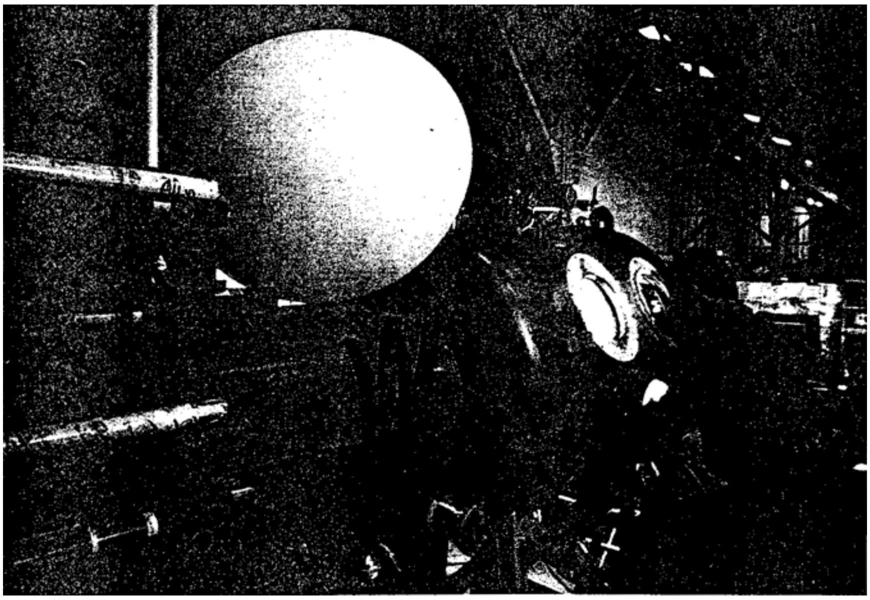


Figure 1. One of the inert gas welding chambers used to fabricate tantalum products.

techniques cannot be used, and welding is limited to tungsten inert gas (TIG), electron-beam, or plasma-arc welding. TIG welding must be carried out in a sealed glove box filled with high-purity argon (Figure 1) because any impurities in the argon may contaminate the weld, reducing its strength and impairing corrosion resistance. Correctly welded, the weld material is at least as pure and as strong as the parent material and shows similar resistance to corrosion. It is also possible to spot-weld tantalum using a conventional spot welder fitted with a suitable argon shield or under water, a technique useful in the assembly of tantalum fabrications prior to welding in the inert atmosphere glove box.

TIG welding is used for sheets as thin as 0.5 mm. Below this thickness, electron-beam welding is recommended. For thin sheets, the joint is normally designed so that filler material is not required. For sheets between 0.75 mm and 5 mm, pure tantalum wire of 1 mm or 1.5 mm may be used as filler material. Due to the weight and the cost, tantalum sheets 5 mm thick are not normally used in construction. In this case, it is normal to clad or line other materials (e.g., steel or copper) with sheets that are usually 0.5 mm thick, so that the strength or thermal conductivity of the backing material can be cost-effectively combined with the excellent corrosion resistance of tantalum.

Such cladding can be achieved by purely physical contact or by explosive bonding. Cladding by contact is used for general applications, but explosive bonding can be used where the tantalum may be subjected to vacuum or low-pressure conditions that would tend to pull the tantalum away from the substrate. Although technically superior, explosive bonding does present fabrication problems, especially during welding, where getter strips must be inserted between the tantalum and the substrate to prevent contamination of the weld region. Any contamination of the weld region would have a detrimental effect on the corrosion resistance.

Some of the modern structural adhesives may be useful in bonding tantalum linings to substrates, especially where good thermal conductivity between the lining and substrate is not a necessity. Some examples of clad items include a tantalum-lined steel reaction vessel (Figure 2) and tantalum-clad copper bayonet heaters. Tantalum is very soft and ductile, so pressurizing the clad vessel expands the tantalum to be in close contact with the steel, ensuring good thermal conductivity. In the case of the tantalum-clad bayonet heaters, the copper, being a fully annealed material, is hydraulically expanded onto the tantalum. In both cases, the gap between the tantalum and the substrate is normally less than 1 μm after the expansion process.

CORROSION

Tantalum has been evaluated for corrosion in more than 2,000 different reagents and has exhibited corrosion in only about 40 of these. The excellent corrosion resistance of tantalum is due to a thin surface film of tantalum pentoxide (Ta_2O_5), which is naturally present on all tantalum exposed to air. This oxide layer immediately reforms when the surface is abraded in a manner similar to that of the aluminum-oxide layer on the surface of aluminum. The oxide layer makes the metal passive and gives it a corrosion resistance on par with gold or platinum.

Reagents that attack this layer corrode tantalum—strong alkalis, fuming sulfuric acid containing free SO_3, fluorine, hydrofluoric acid, and solutions containing fluoride ions in excess of 5 ppm. Concentrated solutions of sodium and potassium hydroxides attack at room temperature, and some corrosion occurs with 10% solutions above 95°C. Fused sodium or potassium hydroxides attack violently.

Tantalum is basically resistant to sulfuric acid in most concentrations and temperatures (except hot fuming), nitric acid at all temperatures and concentrations, and hydrochloric acid at all temperatures and concentrations up to 190°C. Above this temperature, attack begins to occur with concentrated solutions. Fluoride-free phosphoric acid does not attack tantalum at up to 85% concentration and up to 204°C. Mixtures of nitric and hydrochloric acids do not attack tantalum in all concentrations up to the boiling point, even in the presence of sulfuric acid or sulfates. Tantalum also has good resistance to all low melting-point metals, but is slightly attacked by molten bismuth (above 1,000°C), calcium (above 1,200°C), lithium (above 1,000°C), silver (above 1,200°C), oxygen-free so-

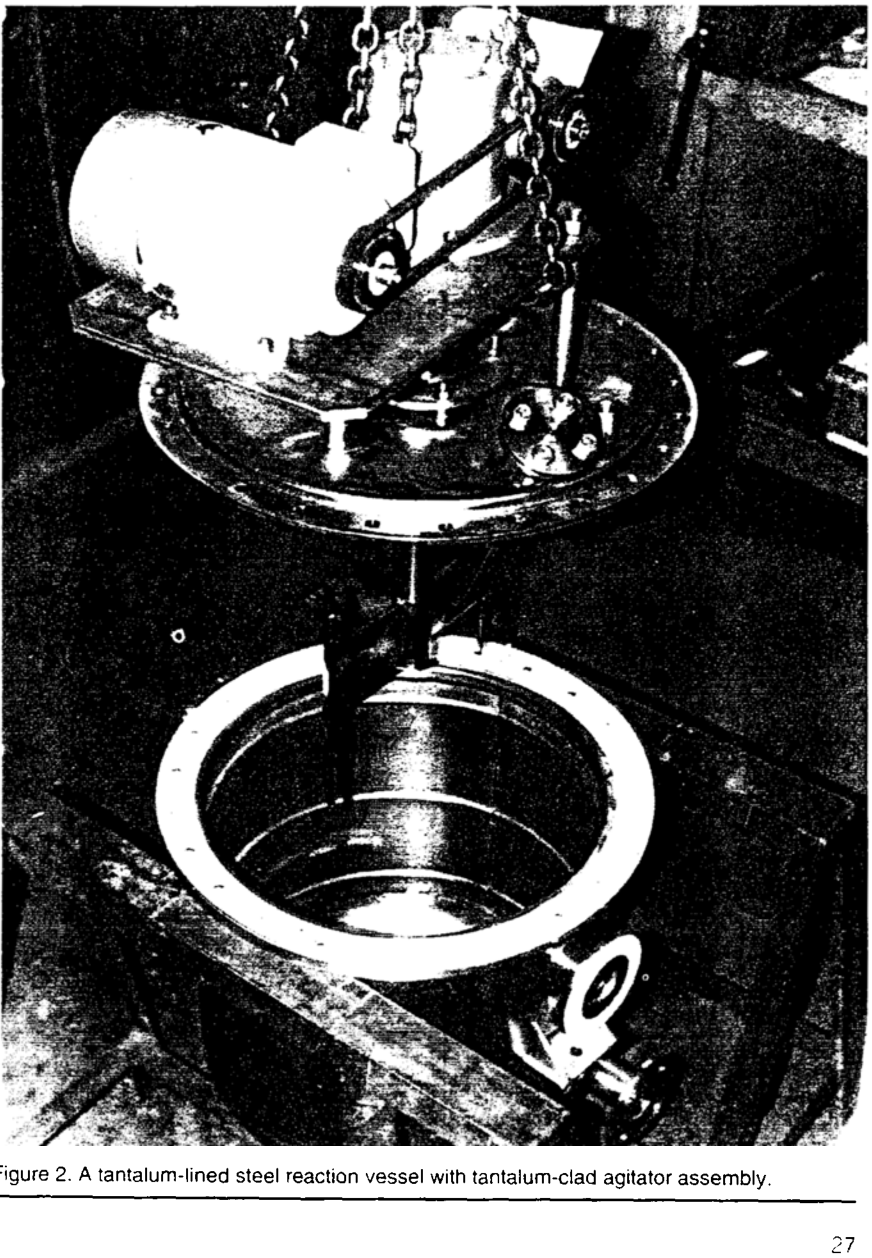
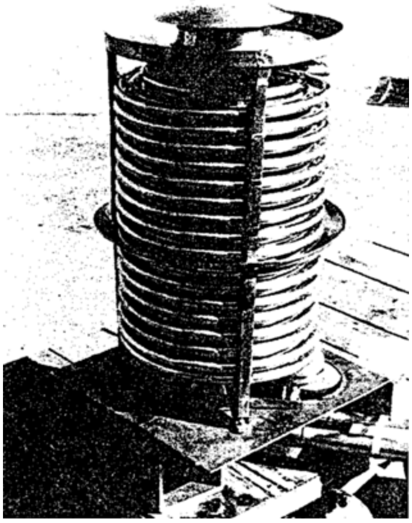


Figure 2. A tantalum-lined steel reaction vessel with tantalum-clad agitator assembly.



a

Figure 3. Some applications of tantalum, including (a) a multiturn tantalum evaporator coil for use in glass vessel, (b) six-tube tantalum bayonet heaters, (c) a tantalum-lined steel elbow, and (d) the ribbed lining of a tantalum evaporator head.

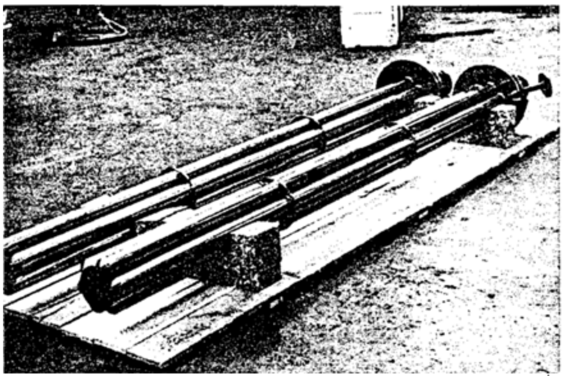
dium and potassium (above 1,200°C), and zinc (above 450°C).

This excellent corrosion resistance makes tantalum appear to be one of the most useful materials available, however, a major disadvantage is its hydrogen embrittlement, which can have disastrous consequences in seemingly benign environments. Tantalum must never be allowed to become cathodic in the presence of any environment containing hydrogen ions or gas (especially nascent hydrogen), which rapidly attacks the tantalum grain boundaries, causing the material to literally crumble into powder. Thus, it should not be used in electrolytic contact with nickel alloys or stainless or carbon steel, even at quite low electrolytic concentrations. To survive under such conditions, it must be electrically insulated from the rest of the plant or the tantalum must be plated or clad with an area of platinum or gold.

Plating attracts the hydrogen ions, causing them to combine to form hydrogen gas that bubbles safely away, leaving the tantalum free from attack. A plated area of platinum 1–2 μm thick and 1/20,000 the area of tantalum is sufficient to protect the tantalum from embrittlement. Thus, a few 12 mm diameter spots plated on the tube plates of a tantalum shell and tube-heat exchanger are sufficient to protect it from hydrogen attack. Tantalum is anodic to aluminum and lead, so it may be safely used in contact with these materials.

APPLICATIONS

Typical uses of tantalum in chemical plants are shown in Figure 3. Figure 3a shows a multi-turn tantalum evaporator coil for use in a glass reactor. Figure 3b



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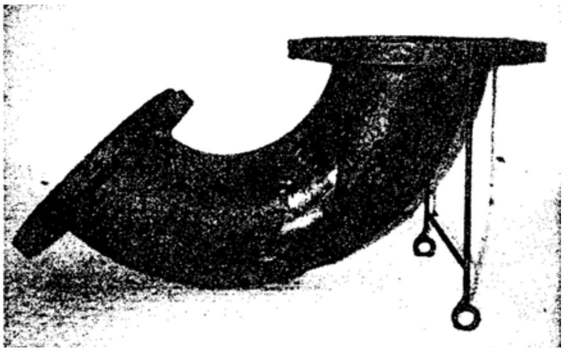

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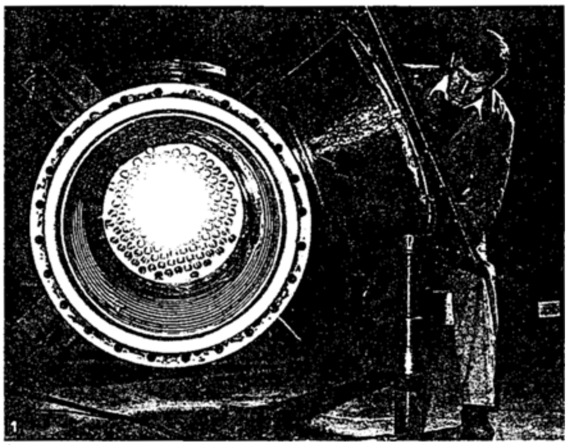

d

shows a pair of six-tube tantalum bayonet heaters. A tantalum-lined 130 mm steel pipe elbow is shown in Figure 3c. Here, the flange became loose and acid dripped from the joint, quickly corroding the flange and part of the steel elbow, while the tantalum remains intact. Figure 3d shows the tantalum lining of a large evaporator, ribbed to prevent collapse under vacuum conditions.

Tantalum is also used for thermowells, either machined from solid material for small wells or clad onto stainless steel for larger ones. Other uses for tantalum include employment as repair parts for glass-lined reaction vessels as well as bursting disks to prevent overpressurization in chemical plant. Here, domed disks of a thin-gage material act as safety-release devices. The design of the disks is critical, as they must burst within five percent of the desired pressure without fragmentation. This is achieved by either scoring the tantalum surface, or allowing bursting to take place against specially designed knife edges.

Tantalum also serves as spinnerets for the manufacture of synthetic fiber. Here, cups or troughs of tantalum sheets are perforated with minute holes through which the fiber is extruded into strong acid solution. These spinnerets are hardened through hydrogen or nitrogen addition.

ADVANTAGES

For normal processing temperatures and in the majority of corrosive environments, other less expensive materials such as stainless steels, nickel alloys, titanium, graphite, glass, or special ceramics can be used. However, tantalum offers distinct advantages.

Consider a heat exchanger, for example. Made from graphite, its cost is only a third of tantalum's. However, the graphite heat exchanger lasts only 3–5 years, while a tantalum-clad exchanger has a potential life span of 20 years. In the long term, tantalum is more cost effective in many applications, as down-time and maintenance costs are reduced. Also, because graphite heat exchangers are necessarily thick walled, they respond to temperature changes more slowly than tantalum-clad or tubed exchangers, thereby, ensuring more precise control of chemical processes. For high-pressure steam applications, the Ta-2.5W alloy is recommended, which has a 25% increase in tensile strength with very little increase in weight. It is superior to tantalum for heating 96% sulfuric acid above 200°C.

ABOUT THE AUTHOR

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