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FINAL ANALYSIS

Palladium in Temporary and Permanently Implantable Medical Devices

For more than forty years platinum alloys have been employed extensively in a range of medical devices and components (1). What is less well known is that palladium, another of the platinum group metals, has recently emerged as a viable alternative to platinum in certain medical device applications. The relative cost of palladium has been much lower than that of platinum (2) and this has led some medical device designers and developers to consider palladium as a replacement for platinum in temporary and permanently implantable electronic devices. Palladium is already widely used in dental applications, where its biocompatibility has proven to be satisfactory; and palladium shares many of the properties and performance characteristics which make platinum so suitable for medical use, such as strength, corrosion resistance and radiopacity. Work has been undertaken at Johnson Matthey Inc, USA, to compare the mechanical properties of platinum and palladium alloys and to develop suitable palladium alloys for a range of biomedical applications.

Palladium in Dentistry

Palladium-based alloys have been used as dental restorative materials for more than two decades with a good clinical history. Palladium alloys have long been tested and used in dental implant applications as dental casting alloys and have been shown to be reliable and relatively risk free (3). Palladium has a good range of solubility with several metals (helpful for alloying) and an ability to impart good mechanical properties including strength, stiffness and durability to the resulting alloys. It has excellent tarnish/corrosion resistance and biocompatibility in the oral environment. These properties make it ideally suited for use in dental crown and bridge alloys (those fitted in the as-polished state) and generally such palladium-based alloys are 'white', however many gold-based alloys also contain small amounts of palladium (typically 1–5%) to improve resistance to tarnishing and corrosion without significant loss of colour (4). Palladium is usually mixed with gold or silver as well as copper and zinc in varying ratios to produce alloys suitable for dental inlays, bridges and crowns where the alloy forms the core onto which porcelain is bonded to build up an artificial tooth.

Mechanical Properties

Palladium shares many of platinum's mechanical properties despite its lower density and melting point. **Table I** summarises the mechanical properties and currently available product forms for a variety of these alloys. The density of pure palladium is 12.02 g cm^{-3}, approximately 40% lower than that of platinum at 21.45 g cm^{-3}, making its relative consumption rate significantly lower for a component of the same dimensions. This, combined with the lower weight-for-weight cost of palladium compared to platinum (2), makes it an attractive substitution choice, as long as other requirements in terms of its properties can be met.

To date, most of the technical development has been focused on replacing platinum alloy wires with palladium alloy wires on feedthrough filter housings which make up parts of cardiac pacemaker, defibrillator and neurostimulator device terminals (**Figure 1**). Such filter housings serve to shield electronic components from electromagnetic interference, with the terminal pins transmitting and receiving electrical signals to and from a patient's heart while hermetically sealing the inside of the medical instrument against body fluids that could otherwise disrupt the instrument's operation (5). The replacement of platinum and platinum alloys by palladium and its alloys can currently offer lower cost, without loss of mechanical properties. After high temperature brazing, there was found to be no significant degradation in the mechanical properties of palladium, such as in strength and elongation. Palladium also has comparable soldering and welding characteristics and good radiopacity. It has been found to be biocompatible under both soft tissue and bone studies (6) and is regarded as chemically inactive within the body environment.

The replacement of platinum-based alloys with palladium-based alloys can be carried out using the

Table I

Mechanical Properties and Product Forms of Platinum and Palladium Alloys for Biomedical Applications

Material	Density, g cm^{-3}	Melting point, ºC	Ultimate tensile strength, kpsi			Elongation, %			Young's modulus, kpsi	Resistivity, μΩ cm	Product form		
			As-drawn	Stress relieved	Annealed	As-drawn	Stress relieved	Annealed			Sheet	Tube	Wire
Pure platinum	21.45	1769	70	55	23	<2	>5	>20	168	10.6	Yes	Yes	Yes
Platinum 5% iridium	21.51	1775	130	80	40	<2	>2	>10	171	19	Yes	Yes	Yes
Platinum 10% iridium	21.56	1790	155	140	55	<2	>2	>10	172	25	Yes	Yes	Yes
Platinum 15% iridium	21.62	1820	200	160	75	<2	>2	>10	187	29	Yes	Yes	Yes
Platinum 20% iridium	21.68	1830	210	175	105	<2	>2	>10	199	31	Yes	Yes	Yes
Platinum 25% iridium	21.74	1860	230	195	120	<2	>2	>10	218	33	Yes	–	Yes
Platinum 4% tungsten	21.34	1780	180	140	75	<2	>2	>10	195	36	–	–	Yes
Platinum 8% tungsten	21.23	1870	220	170	130	<2	>3	>20	210	62	–	–	Yes
Platinum 10% nickel	18.8	1650	240	190	120	<2	>2	>20	215[a]	29.8	–	–	Yes
Platinum 30% nickel	15.07	1460	300	200	120	<2	>5	>20	218[a]	22.7	–	–	Yes
Platinum 49% nickel	12.69	1430	300	190	110	<2	>2	>20	222[a]	19.1	–	–	Yes

(Continued)

Table I (Continued)

Material	Density, g cm^{-3}	Melting point, ºC	Ultimate tensile strength, kpsi			Elongation, %			Young's modulus, kpsi	Resistivity, μΩ cm	Product form		
			As-drawn	Stress relieved	Annealed	As-drawn	Stress relieved	Annealed			Sheet	Tube	Wire
Pure palladium	12.02	1554	110	65	25	<2	>5	>10	118	9.98	Yes	Yes	Yes
Palladium 5% rhenium	11.71	1560	115	200	55	<2	>2	>10	125[a]	21.2	Yes	Yes	Yes
Palladium 10% rhenium	12.29	1620	230	200	80	<2	>2	>10	195[a]	32.5	–	–	Yes
Palladium 14% rhenium	12.79	1650	250	200	100	<2	>2	>10	200[a]	40[a]	–	–	Yes
Palladium 5% iridium	12.31	1590	100	70	40	<2	>2	>10	225	11.6[a]	Yes	Yes	Yes
Palladium 10% iridium	12.61	1625	110	75	50	<2	>2	>10	232	16.3	Yes	Yes	Yes
Palladium 15% iridium	12.93	1675	160	85	60	>2	–	>10	270	20.3	–	–	Yes
Palladium 20% iridium	13.27	1740	200	100	80	<2	>2	>10	292	25[a]	–	–	Yes
Palladium 20% platinum	13.18	1600	110	55	35	<2	>5	>10	155[a]	12.3	Yes	Yes	Yes

[a] *Estimated values*

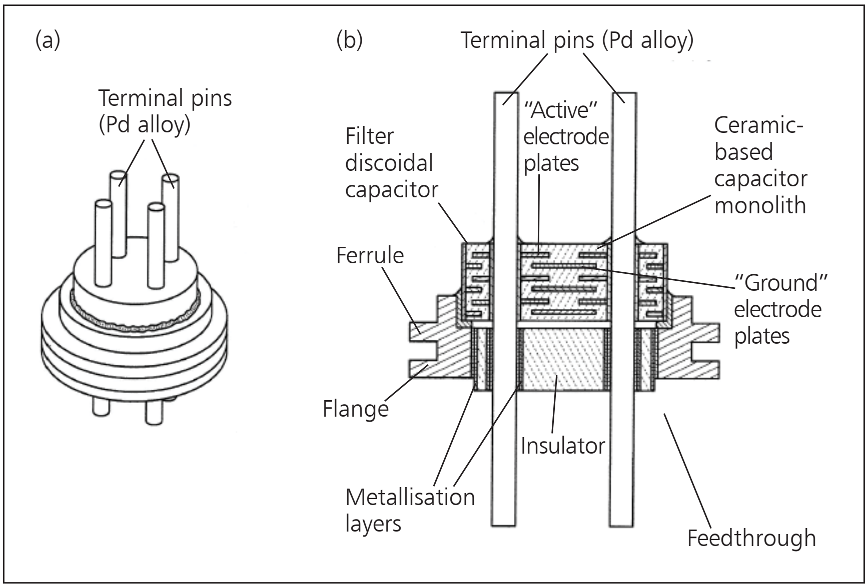

Fig. 1. (a) A perspective view of an internally grounded feedthrough capacitor assembly with palladium terminal pins; (b) an enlarged sectional view (5)

same manufacturing processes and generally without adding a secondary manufacturing stage. Palladium therefore provides a good alternative to conventional platinum or platinum-iridium alloys as a corrosion resistant material for terminal pins in feedthrough filter housings.

Radiopacity of Palladium Alloys

Palladium alloys have also been tested as catheter guidewire and electrode components on temporary implants used to treat cardiovascular and peripheral vascular disease. Palladium and platinum, when alloyed with superelastic metals such as nickel-titanium (Nitinol), have also been shown to improve the radiopacity in tubular stents compared with those made from stainless steel (7). Johnson Matthey manufactures a wide range of palladium-based alloys for these applications ranging from pure palladium to palladium-20% platinum (**Table I**). **Figure 2** shows the results of an investigation into the relative radiopacities of two palladium alloys compared to two traditional platinum alloys used in guiding catheter applications, plus Nitinol, demonstrating a good level of equivalency in the radiopacity of the precious metal alloys.

Conclusions

The most recently developed platinum substitution materials for certain temporary and permanently implantable medical devices have been palladium alloys. Palladium's physical, mechanical and chemical properties have been found to be comparable to those of platinum in a variety of biomedical device applications. Palladium has a long history of reliability for use in dental restoration applications. However, while palladium has been demonstrated to be a good replacement for platinum in certain medical device applications, platinum and platinum alloys continue to

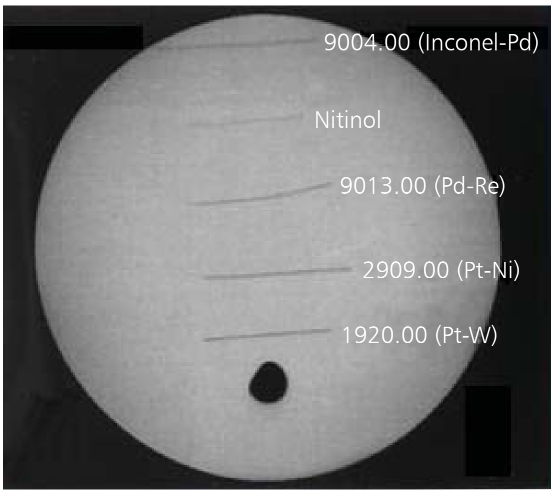

Fig. 2. Comparative radiopacities of two platinum alloys, two palladium alloys and Nitinol as coiled fine wire

be the first choice for device companies seeking a proven and reliable implantable metal that is biocompatible, radiopaque and electrically conductive.

BRIAN WOODWARD

Johnson Matthey Medical Components,
12205 World Trade Drive,
San Diego, California 92128, USA
Email: woodwbk@jmusa.com

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The Author

Brian Woodward has been involved in the electronic materials and platinum fabrication business for more than 25 years and is currently the General Manager of Johnson Matthey's Medical Components business based in San Diego, CA, USA. He holds BS and MBA degrees in Business and Management and has been focused on value-added component supply to the global medical device industry.

