Quality criteria for pure titanium casting, laboratory soldering, intraoral welding, and a device to aid in making uncontaminated castings

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Procedures for casting, laboratory soldering, and intraoral welding of titanium for dental restorations are described and illustrated. Pure titanium and titanium 6Al-4Va alloy castings may be used for virtually any prosthodontic rehabilitation as well as for implants, with the proper equipment and technique. (J PROSTHET DENT 1991;66:561-5.)

Titanium is an abundant and relatively inexpensive chemical element of great interest for its unique physical and chemical characteristics that permit a variety of technologic applications.

In the surgical endeavors, hip and valvular prostheses and endosteal dental implants are often made of pure titanium and titanium alloys because of their high biocompatibility.

Recently, titanium has been cast for crowns, fixed partial dentures, and superosteal implants. This permits the use of a single metal in the oral cavity for prosthodontic rehabilitations with or without implants. The use of a single pure metal has physical, chemical, and biologic advantages over chemically inhomogeneous metal alloys that can form localized corrosion cells and permit the passage of metallic ions to saliva or to tissues.

This report describes the making of high quality pure titanium castings using a special Titan Decontaminator Hruska Device (prototype) instrument and quality laboratory soldering and intraoral welding using a Titan Welder Hruska (Hruska S.R.L., Rome, Italy) welding machine, described in previous articles.

METHODS AND MATERIAL

Pure titanium should be between 99.8% and 99.9% pure. The principal characteristics of pure titanium were described in a previous article. The most significant characteristic is its great reactivity at high temperatures. This reactivity can cause much trouble during casting, soldering, and other manipulation. In air at temperatures above 750°C (1382°F), titanium absorbs nitrogen, oxygen, hydrogen, and carbon to become contaminated and brittle. At temperatures below 750° C (1382°F), titanium exists in the alpha (α)-phase (a hexagonal close-packed crystal structure). At temperatures above 882.5°C (1620.5°F), it exists in the beta (β)-phase (a body-centered cubic crystal structure). Pure titanium in the α-phase has high mechanical strength, excellent weldability, and good high-temperature strength. Pure titanium in the β-phase has good formability and good weldability. Pure titanium in the mixed α/β phase condition has high mechanical strength but is difficult to weld.

Table 1. Observed dimensional change

<table>
<thead>
<tr>
<th>Casting sample</th>
<th>Contractions (mm)</th>
<th>Contractions (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0192</td>
<td>0.01</td>
</tr>
<tr>
<td>2</td>
<td>0.0327</td>
<td>0.28</td>
</tr>
<tr>
<td>3</td>
<td>0.0493</td>
<td>0.61</td>
</tr>
<tr>
<td>4</td>
<td>0.0988</td>
<td>0.56</td>
</tr>
<tr>
<td>5</td>
<td>0.0662</td>
<td>0.95</td>
</tr>
<tr>
<td>6</td>
<td>0.0839</td>
<td>1.30</td>
</tr>
<tr>
<td>7</td>
<td>0.0915</td>
<td>0.42</td>
</tr>
<tr>
<td>8</td>
<td>0.0599</td>
<td>0.82</td>
</tr>
<tr>
<td>9</td>
<td>0.0597</td>
<td>0.82</td>
</tr>
<tr>
<td>10</td>
<td>0.0228</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Average dimensional change = 0.49%.

An adherent oxide layer of 1 nm thickness forms on titanium after 1 msec in air at room temperature. This oxide coating gives the metal excellent corrosion resistance at room or mouth temperatures. The oxide coating is not effective at high temperatures because the oxide film thickens and loses its adherence. At temperatures slightly above room temperature, titanium absorbs hydrogen. At 820° C (1508° F), it decomposes steam, producing hydrogen. At much higher temperatures, it absorbs carbon dioxide and carbides. This high reactivity is the main reason for the difficulty in casting, soldering, and welding procedures reported by various researchers using traditional equipment.

Due to its high reactivity, the surface layer of oxide that forms during casting and soldering of pure titanium enhances the biocompatibility of this metal. The titanium oxide layer is apparently the key to explain the bacteriostatic action that has been described in a previous article and the ease with which plaque or calculus can be removed from titanium. Observations indicate that the use of a...
Fig. 1. A, Titan Decontaminator Hruska Device instrument consists of a sealed vacuum chamber (1) with valve (2), which can be closed to maintain a vacuum. B, Hose attached to valve, vacuum gauge, and vacuum pump. C, Crucible end of vacuum chamber is sealed with titanium foil shown partially melted after casting. Foil disintegrates immediately when molten titanium contacts it.

Fig. 2. Casting recovered from investment.

toothbrush, water picks, or similar device is sufficient to remove plaque or calculus on titanium surfaces.

The Titan Decontaminator Hruska Device instrument allows decontamination of the casting mold before inserting it into the casting machine, making the procedure much simpler and permitting production of castings free of voids and contaminating elements. The metal may be melted and cast in any electric arc centrifugal casting machine (a centrifugal system is not required to make removable partial denture castings).

The decontaminator is a closed cylinder into which the cold casting ring with the invested pattern is seated after the wax is eliminated. This device permits removing the air from the investment and maintaining a vacuum until the metal is cast (Fig. 1, A).

A valve on one end of the chamber is connected with a vacuum pressure gauge to measure the amount of vacuum (Fig. 1, B). Titanium foil seals the other end of the chamber (Fig. 1, C). This device makes it possible to decontaminate (remove air from) the refractory mold outside of a casting machine and the vacuum can be maintained until the instant of casting. When the melted titanium is cast against the foil, it melts immediately (Fig. 1, C) and the molten titanium is drawn into the casting mold under vacuum.

This device makes it possible to:

1. Make pure titanium and titanium alloy such as 6 Aluminum—4 Vanadium (6Al-4V) castings free of voids and contaminating elements such as oxygen, hydrogen,
and nitrogen (Fig. 2), using any electric arc centrifugal casting machine on the market (expensive specific machines are not required).

2. Conduct the entire decontamination procedure before the casting process, using a simple and inexpensive technique, easily learned by any dental technician.

3. Hold the casting mold under vacuum for hours, without losing the vacuum and without the mold's being contaminated with air.

4. Cast thin and precise margins of crowns because the melted titanium is drawn into the casting mold under vacuum.

DISCUSSION

A number of quality parameters are considered important for evaluating a titanium casting.

1. The color of the metal after casting, judged through experience and the eye of the dental technician, is an extremely sensitive parameter. Titanium oxides can give the metal virtually any color on the chromatic scale, and the presence of coloring indicates significant contamination of pure titanium as well as the loss of desirable physical and chemical characteristics. Good quality pure titanium castings must have a silvery color before sandblasting (Fig. 2). The titanium left in the crucible must also have a silvery color. Castings made following this procedure have been found to be completely in the α-phase (Fig. 3), and the intraoral welding of them is associated with the α-phase structure of the solidified metal.2

These parameters permit evaluation of the effectiveness of the decontaminator device. A silver color of the casting and slag in the crucible indicate the casting is not contaminated and that it will be easily worked with the usual laboratory and office rotating instruments. They also indicate that the casting will possess excellent weldability.

2. The ductility of sprues and vents also implies good purity of the casting and assures excellent ductility and...
stiffness. If the casting procedure is not conducted in a controlled atmosphere, the titanium will be brittle because of reactions with nitrogen, carbon, or hydrogen, and contaminated castings are not suitable for dental use.

Burnishability of titanium depends on the same factors. Pure titanium burns less than gold alloys, but its burnishability allows adaptability of margins during the usual finishing processes. When the casting is contaminated, thin, brittle margins will fracture quickly.

3. Casting accuracy was evaluated using the method that has been described by Eden et al. The observed values for titanium castings indicate that they underwent a contraction ranging from 0.01% (a nearly perfect fit) to 1.56% (Table I). This range of values is roughly comparable with those obtained by Eden et al. for manufacturer's castings of various nickel-chromium dental alloys.

4. Radiographs should show that the castings are free of voids (Fig. 4). All of the authors' castings are inspected by x-ray radiography to detect macroscopic voids. Voids have been a persistent problem. Voids inside castings (Fig. 5) can compromise the castings despite the high mechanical strength of titanium. Furthermore, voids are often associated with contamination of the pure metal of the ingot. The radiographic procedures have shown that all castings were quite free of defects except in one casting, where a small void of about 1 mm diameter was observed. This void was located well away from the casting surface where it would certainly not cause any problem. These results can be attributed to the special Titan Decontaminator Hruska Device instrument.

5. Microscopic examination of the surface quality of the castings showed little, if any, porosity. The absence of superficial porosity is the result of the authors' research regarding the particular type and treatment of the investment material and of the Titan Decontaminator Device instrument. With the authors' technique, it is relatively easy to produce high-quality titanium castings.

**Soldering titanium**

Soldering can be extremely difficult because of the high reactivity of titanium. The laboratory soldering machine must assure that: (1) the heat source is as concentrated as possible, (2) the atmosphere around the surfaces to be soldered is controlled, and (3) the high-titanium content soldering material flows between the two surfaces to be soldered.
The following quality parameters are important for evaluating laboratory soldering: (1) the color of the solder and surrounding titanium casting after soldering, (2) absence of macroscopic voids inside the soldering itself, and (3) penetration of the pure titanium or high-titanium content soldering material between the two surfaces.

It is most important that the soldered joint and surrounding titanium retain their bright silvery color (Fig. 6).

Good laboratory soldering will not weaken titanium crowns or make interproximal surfaces brittle and contaminated.

The absence of macroscopic voids in the soldered surface is important because of the high concentration of stress applied. Every laboratory soldered joint should be evaluated by x-ray examination.

The authors' research and technical experience permitted them to obtain good penetration and flow of the pure titanium or high-titanium content soldering material with sound microstructures, indicating strong and reliable joints.

Intraoral welding of titanium

The intraoral welding machine (Titan Welder Hruska) uses interchangeable welding tips to obtain optimum welding in any part of the patient's mouth. It is possible in this way to obtain a true monomeric restoration in the oral cavity.

The same three quality parameters that have been described are important for evaluating intraoral weldings.

Plastic and porcelain veneers on titanium

There are no problems in using any kind of plastic for veneers or denture bases with titanium. Plastic can be used in the same way with titanium as with any commercial noble or non-noble dental alloy now on the market. However, there are many problems in using porcelain because of the titanium's surface oxide and its lack of mechanical stability. Attempts have been made to use low-fusing temperature porcelain for titanium as well as the more traditional porcelain. However, this procedure is not completely satisfactory. Too many problems remain to be solved before clinical applications are widely adopted. For the last 3 years, all titanium/porcelain crowns used for patients in the clinic have been made by cementing the porcelain veneer onto the titanium using an adhesive cement (Panavia EX, J. Morita, Tustin, Calif.).

Furthermore, this system is as simple and economic to use as that required for other precious or nonprecious alloys. As reported by many investigators, pure titanium has better biocompatibility and corrosion characteristics compared with other non-noble dental alloys on the market. With available technology, pure titanium can be used for virtually any prosthetic rehabilitations with or without implants.

REFERENCES


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