SPECIAL PROCEDURES FOR THE JOINING OF TITANIUM-BASED DENTAL PROSTHETIC PARTS

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Abstract
In the case of titanium and of titanium alloys, the traditional methods for welding and soldering – as non-disassemblable joining methods – can not be used because of the high oxidation rate of titanium, of the great difference between the melting point of titanium and that of the possible additive materials and because of the chemical impurification or electrochemical corrosion effects which can occur in heterogeneous joints. The paper presents some specific, modern procedures for the non-disassemblable joining of titanium-based dental prosthetic parts, such as the laser welding, the plasma welding and the soldering with infrared radiation.

1. INTRODUCTION

Titanium is one of the most abundant chemical elements in the earth crust. Its outstanding properties - high corrosion resistance and biocompatibility, good mechanical strength and a reduced specific weight – have made it, especially in the recent years, a metal of choice for various industrial applications, ranging from the airspace industry, automotive industry and chemical industry to medicine.

Especially the usage of titanium in medicine has increased dramatically in the last years, due to the fact that this metal has been found to have the best biocompatibility among metals, expressed for example in the value of the Anodic Back Electromotive Force (ABE potential) – 3500 mV (gold has an ABE potential of only 1000 mV, while zirconium is at the limit of biocompatibility, with around 320 mV) [1]. In this respect, titanium is used for example for orthopaedic implants, for heart valves, in facial and mandibular surgery and for a large number of various applications in dental medicine.

In dental medicine, titanium, in pure state or alloyed with different other materials, has come to be used for prostheses, implants, inlays, but also for instruments and apparatuses, generally as parts of relatively small size, which can be obtained individually, preferrably by casting and then joined to form the desired part.

The processing of titanium, however, is not simple to carry out, especially because of the high melting point (1668°C) and the great affinity displayed by titanium versus a series of elements like oxygen, nitrogen, hydrogen, methane etc. Because of this, the casting of titanium, for example, requires the usage of special equipment and special auxiliary materials (protective atmosphere, usually based on argon, investment materials which do not allow the reaction between titanium and oxygen to take place, special melting crucibles etc.), the development of which has also increased very much in the recent years.

The joining of titanium parts by welding or soldering is also affected by the heavy oxidation of titanium, by the high temperature difference between the base metal and possible addition materials and not least by the chemical impurification or the electrochemical corrosion which might occur. Therefore, here too it is necessary to apply special procedures, such as laser welding, plasma welding or soldering with infrared radiation. These procedures and some results of their usage will be discussed further on in this paper.
2. LASER WELDING

Lasers are devices that amplify light by stimulated emission of radiation. For the welding of titanium, usually crystals of yttrium, aluminium and garnet (YAG), doped with neodymium (Nd) are used to emit laser beams, the device being known as Nd: YAG laser. Because the energy produced by the laser can be concentrated on a very small area, the area around the spot which is to be welded is less affected by heating and oxidation. The heat-affected zone is reduced and so the part distortion is minimal. Another advantage brought by this welding method is that, unlike conventional welding methods, it requires no investment materials or gas torches. Also, the base materials can be joined without solder and, if needed, the base metal can be used as solder. The laser welding method is a very rapid one, and it also eliminates the need for further processing steps.

The quality and strength of the resulting welded joint depends on the characteristics of the laser equipment being used (wave length, pulse energy, frequency and duration etc.) and on the type of welded metals. Titanium has a very low thermal conductivity (21 W/m⁻¹.K⁻¹), which is only a fraction of that of noble alloys (gold, for example, has a thermal conductivity of 397 W/m⁻¹.K⁻¹), so it is very well suited for laser welding. Also, the rate of laser beam absorption for titanium (0.4) is much larger than that of gold (0.03), which leads to a larger penetration depth and thus to a higher quality of the welding.

Currently, there are several laser welding units available on the market. Some of the better known ones in Europe are produced by the German companies Dentaurum (figure 1) Laser Haas and Schütz Dental.

The main characteristics of the new laser computer-controlled welding unit DL 3000 offered by Dentaurum are as follows:
- laser crystal type: Nd: YAG
- pulse duration: 0.5...20 ms
- maximal impulse power: 5 kW
- working environment: high-purity argon
- dimensions: 570x1230x800 mm

The main disadvantage of this installation is the relatively high price, which is about 4 times higher than the one for a plasma welding installation.

3. PLASMA WELDING

If an electric arc, created in an gaseous environment, is forced to pass through an intensely cooled nozzle, the gas or gas mix can reach a highly ionised state, the plasma, characterised among other factors by very high temperatures (10000-50000 K) which can easily melt even the most heat-resistant materials (figure 2).

The plasma arc works at relatively small current values (0.1...30 A), but reaches, because of the mechanical and electromagnetic strangling in the nozzle, high current densities and has a thin needle-like appearance, which gave it the name “needle-arc”. Usually, the plasmagenuous gas used is argon, while the electrode is usually made of tungsten.
Plasma welding allows the joining, with minimal distortions, of parts which can be even very thin (up to 0.01...0.02 mm). However, the usage of this method is made difficult by the increased affinity of titanium for oxygen at high temperatures.

4. SOLDERING WITH INFRARED RADIATION

This joining procedure has been developed by the Japanese companies J. Morita and Kobelco/Selec. The installation RS-1, produced by the company J. Morita Europe (figure 3) is composed of an air-tight quartz shade, under which the parts to be soldered are placed in the focal point of an external ellipsoidal mirror, in the other focal point being placed a special halogen light bulb, radiating in the infrared spectrum. After evacuating the air from the quartz shade (a 0.1 mbar vacuum is achieved), high-purity argon is filled in and the spot to be soldered is manoeuvred to the focal point of the mirror by a special handle.

The area on which the radiation is focused, is very small, allowing for the achieving of a high degree of precision and of minimal distortions in the surrounding areas of the joined parts.

An advantage of this unit is, among others, the relatively small size – 300x440x750 mm and weight – 25 kg (in both cases without taking into account the vacuum pump).

Problems related to this joining procedure arise due to the high temperature reached in the work area, and especially in the titanium part, temperature which is maintained for a longer time period. A direct consequence of this is the formation of an α-case layer on the surface of the titanium part, which is very hard and brittle and requires special measures to remove it.

Also, if using filler metals based on titanium, such as Ti-Ni or Ti-Cu, which have a relatively low melting point, there can appear problems related to the corrosion resistance of the joint area. An alternative would be the usage of filler metals which contain noble metals such as
silver or palladium, but also copper. However, these are generally expensive materials, whose usage should have been avoided by making the dental prosthetic parts of titanium. Widely used solders for the soldering of titanium parts with infrared radiation are Ag65Cu20Pd15 and Ag72Cu20Ti8.

5. COMPARISON AND DISCUSSION OF THE METHODS

For a practical comparison of the above-mentioned joining methods – laser welding, plasma welding and soldering with infrared radiation, tests were carried out in order to determine the variation of the mechanical properties of parts made of grade 3 titanium when subjected to laser welding with a DL 2000 unit manufactured by Dentaurum, Germany, and to soldering with infrared radiation on a RS-1 unit manufactured by J. Morita Europe GmbH (table 1).

Table 1. Tensile strength of welded or soldered joints realised in cast titanium parts

<table>
<thead>
<tr>
<th>Property</th>
<th>Base material (grade 3 titanium)</th>
<th>Laser welding</th>
<th>Soldering with infrared radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sample 1</td>
<td>Sample 2</td>
<td>Sample 3</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>552</td>
<td>443</td>
<td>441</td>
</tr>
<tr>
<td>Microhardness HV 0,1</td>
<td>182</td>
<td>237</td>
<td>238</td>
</tr>
</tbody>
</table>

As can be seen from the table, in both cases the mechanical strength is lower than that of the original base material, while the hardness in the area of the welding/soldering has increased. These results are consistent with the findings of [5] and [6].

The experiments show that laser welding is the best method in terms of tensile strength, which decreases on average only by about 20%. This could be attributed to the evolution of the microstructure. In the area of the joint, the microstructure remains in general fine-grained, only at the borders of the relatively small heat-affected zone being occasionally visible a dendritic growth of the grains. In the case of soldering with infrared radiation, the dendritic growth is much more visible.

In addition to the above results, it should be mentioned that plasma welding has been found to produce an even higher decrease of the tensile strength (up to 69%), due especially to an incomplete filling of the welding gap [6]. A microscopic analysis of plasma-welded parts shows a very pronounced increase in the grain size in the joint area [7].

Since in the case of laser welding, no material needs to be added, the joint area will show a slight constriction and the welding depth is reduced to under 1 mm, which reduces somewhat the application area for this method. Also, in the absence of added material, the two parts which need to be joined by laser welding must fit exactly.

The addition of metal in the case of soldering with infrared radiation (and also in the case of plasma welding) leads to the joint displaying a bulge.

For plasma welding, it has been found that the heat-affected zone had a thickness of up to 3 mm in the centre, so this method is suited especially for the cases in which thicker parts need to be joined together [1].

BIBLIOGRAPHY


