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Assessment of gold with titanium alloy weldability in conditions of a dental technique laboratory

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ABSTRACT

Purpose: In dental practice, there is necessary to weld gold with titanium under the conditions of a dental technique laboratory, which is difficult. The aim was to assess the weldability of pure gold with the titanium alloy Ti6Al4V using a prosthetic laser welding machine.

Design/methodology/approach: Gold wire in a diameter of 0.4 mm made with the use of a jewellery drawbar (GOLDPORT, Szczecin, Poland) was welded to a titanium alloy Ti6Al4V substrate of dental implant abutment screw (MegaGen). Dental laser welding parameters (Bego Laser Star T plus) were 230 V; 6.5 ms; 2.5 Hz; laser spot 0.3 mm, and argon blow. Samples were included in resin, ground (500-4000 SiC), polished (Al_2O_3 suspension) and etched (Kroll solution) per 20 s before observation under a light microscope.

Findings: There were well-welded and poorly joined zones. The discontinuities and voids there were not visible or sparse next to the initial weld point. Dendritic structure at well-welded remelting zones and two-phase microstructure of titanium and Ti_3Au phase were found. The heat-affected zone was about of 20 microns.

Research limitations/implications: Light microscopy was used, and precise phase identification required further investigations. Weld strength assessment requires further micro-hardness and load-bearing ability tests. Weldability concerns the model system with pure gold.

Practical implications: In the case of elements with dimensions below 0.4 mm, the use of a laser with a smaller spot should be considered for better control of the remelting zone and mechanical positioning of the elements in order to stabilize and avoid discontinuities and voids.

Originality/value: Prosthetic laser welding with a laser spot about of 0.3 mm allows to obtain well-welded parts of 0.3 mm in diameter under stable stitching conditions and higher than 0.4 mm in dimensions.

Keywords: Titanium alloy, Gold, Laser welding, Prosthetic dentistry, Implant denture, Microstructure

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BIOMEDICAL AND DENTAL MATERIALS AND ENGINEERING

RESEARCH PAPER

1. Introduction

Titanium and its alloys are widely used in dentistry, prosthetics and implantology due to corrosion resistance, low density, high strength, and biocompatibility resulted from titanium oxides, which under the conditions of the body lead to healing and osseointegration – mechanical maintenance implant into the bone [1-7].

Titanium and its alloys are used for removable prosthetic restorations, such as skeletal dentures, frameworks or plates of dentures, and fixed restorations, such as crown inlays, crown-root inlays, onlays, crown substructures and prosthetic crowns, implant-prosthetic structures, bars, superstructures, connectors, snaps and studs, screws or intraosseous implants [8-10].

In prosthetic laboratories, titanium is packaged as ready-made prosthetic elements such as connectors, implant screws, and semi-finished products for further processing, such as premill implant bases, discs or blocks for milling with numerical machine tools, or laser sintering/melting powders SLS/SLM technology.

Examples of other materials used in prosthetics are alloys such as chromium-cobalt and precious alloys based on gold (gold - platinum, gold - platinum - palladium). In the conditions prevailing in a specific patient, prosthetic works often consist of many solutions used over time with elements made of various prosthetic materials. A prosthetic structure requires a permanent combination of various materials in technical conditions corresponding to a prosthetic laboratory. One of the poorly understood methods is joining gold alloys with titanium and its alloys. Gold-titanium alloys are widely described and used in medicine, but weldability deserves additional research. The welding process of titanium with its alloys is generally defined as difficult. It requires a protective atmosphere and results from the high affinity of this metal, among other things, to oxygen at elevated temperatures, already above 350°C. The protective atmosphere, as shown by the research on Ti and Ti-6Al-7Nb, has a positive effect on the strength of the weld, increasing it twice [11,12]. Among the α-Ti, β-Ti and α + β-Ti titanium alloys, the two-phase alloy is characterized by good weldability, high corrosion resistance, strength, and fracture toughness, which combines the best features of α and β titanium alloys [13,14]. Pure gold as a material is not suitable for dentistry and prosthetics due to its low strength; its alloys are used, for example, the previously mentioned gold-platinum-palladium alloy. Joining gold alloys with other metals and alloys in the context of prosthetic materials required adding elements to the existing ones using the lost-wax method, soldering, arc welding, plasma welding and welding techniques. Currently, laser welding is used more often due to several advantages such as precision, welding accuracy, greater control or faster operating time [15].

The phase equilibrium system Figure 1 drawn by Murray [16] shows that in a wide range of Au contents in Ti, one can expect the influence of Au-Ti on the microstructure, properties and phases. The best known are alloys up to 0-40 wt.% [17-20].

The work aimed to combine gold with the Ti6Al4V titanium alloy in a model system using a gold wire of 99.999% by weight. In order not to introduce alloying elements, which at the present stage of research make the analysis difficult

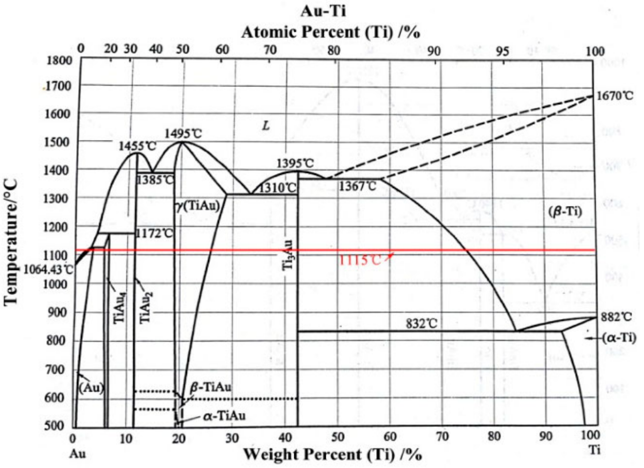

Fig. 1. Au-Ti phase diagram [16]

2. Materials and methodology

Fragments of screws were used in the research, and abutments for dental implants fixing the prosthetic superstructure with an endosseous implant made of the Ti6Al4V Grade 5 alloy by MegaGen. The size of the samples ranged from 1.3 mm to 1.5 mm, with a thickness of about 1.2 mm. The Ti alloy substrate was obtained by cutting the screw with water cooling and then making a part of the screws in the thread area to obtain the edge and the surface for plane contact with a gold wire that can be welded. Gold Au wire with a purity of 99.999% by weight was used as the second material. Calibrated with a diameter of 0.4 mm made with a jewellery drawbar. Between the cycles of drawing the wire in order to obtain the appropriate diameter, the wire was subjected to heat treatment – annealing several times. After the end of the process, it was purified in a 50% aqueous solution of nitric acid (GOLDPORT, Szczecin). The joining process was carried out using a prosthetic laser (Bego Laser Star T plus) to connect prosthetic materials in a prosthetic laboratory. The materials were joined manually by directing the laser pulses between the two materials, Figure 2. The welding process parameters are presented in Table 1. Welding was carried out in an argon shield.

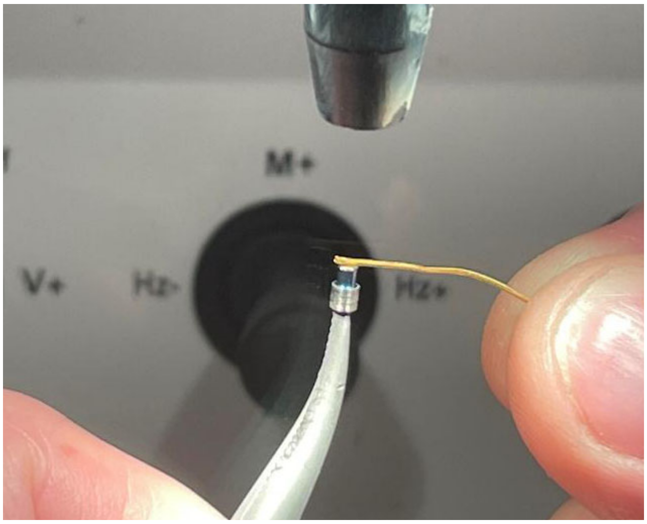

Fig. 2. Au wire applied to the surface of the titanium screws before welding

Table 1.
Welding process parameters

Voltage	Time	Pulse frequency	Spot diameter	Impulse
230 V	6.5 ms	2.5 Hz	0.3 mm	Constant power

During the welding tests, a set of parameters was searched for that gave the best results and the initial appearance of the weld. Reducing the voltage to the value oscillating around 200 V did not melt the titanium alloy. Increasing the voltage to about 250 V caused an oval concentration of gold or the melting of titanium. Increasing the time caused the titanium to heat up excessively. Increasing the frequency of pulses reduced the control over the welding process; however, if the elements were well stabilized, it could even out the weld, creating a characteristic "stack of coins". The increase in the spot size was associated with the increase in power, which caused excessive heating of the joined elements and gold granulation on the surface of the titanium alloy. Changing the pulse parameters to increasing or decreasing did not positively affect the welding process. The element did not connect. After obtaining the weld, the samples were incorporated. The grinding process was started on water-based abrasive papers from gradation 500 to 4000. Final polishing was carried out on an automatic polisher, on a polishing cloth, using Al_2O_3 suspension. Etching was carried out with the use of Kroll reagent during 20 s. The samples were observed under a light microscope.

3. Result and discussion

Preparation of the weld sample for microstructural tests was difficult due to the significant differences in the hardness of the joined materials. This difficulty results in the formation of scratches on a material that is too soft when using fine-graded papers or leaving scratches on a harder material that is impossible to polish when switching to polishing soft material. Both materials are difficult to etch and differ in reagents capable of revealing their structure when viewed under a light microscope. Due to the possibility of removing the effects of plastic processing of the titanium alloy, the research focused on the heat-affected zone in the titanium substrate. Microscopic observations showed discontinuities in the weld in some samples in the form of voids and the lack of weld, cracks Figure 3. They are caused by the small size of the sample, difficulties in arranging the welded elements and inaccuracies typical of carrying out this process manually. Moreover, the small transverse dimension of the joint turned out to be too small to survive the polishing process along its entire length. For the above reasons, the focus was on analysing the weld in the places where it occurs and on samples without major defects in the weld (Fig. 4).

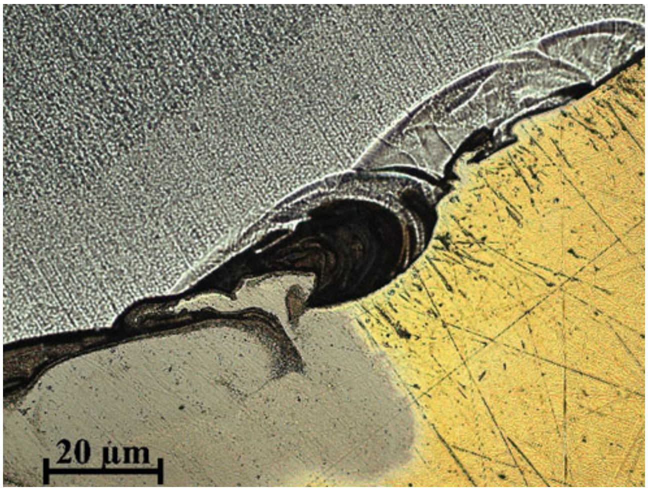

Fig. 3. Discontinuities in the weld. Sample before etching. Light microscopy

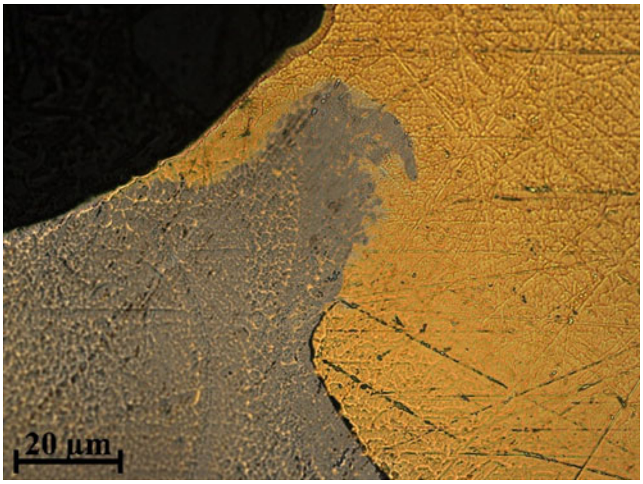

Fig. 4. Joint and mixing of the two materials. Sample before etching. Light microscopy

The microstructure of α and β titanium and the heat-affected zone (HAZ) is shown in Figure 5.

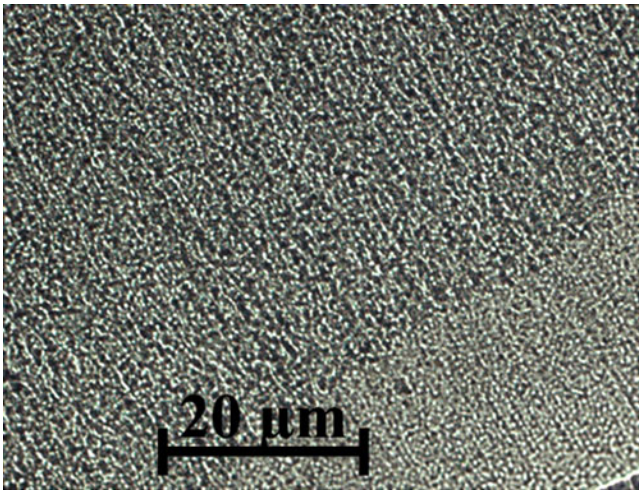

Fig. 5. Microstructure of α and β and heat affected zone (HAZ). Sample before etching. Light microscopy

The observations showed significant mixing of gold and titanium, Figures 5, 6 and 7. The microstructure of the weld has a dendritic structure, which indicates a good fusion of both materials by remelting. Based on the research in [17], as well as analysing the phase equilibrium diagram, the Ti_3Au phase should be present in the weld. The structure obtained in Ti6Al4V – Au alloys, for example, research on Au-Ti coating deposited on Ti-6Al-4V substrate by electron beam powder fusion, had a column shape, and was composed of a eutectoid mixture, was characterized by different crystallographic orientation, a continuous network of AuTi intermetallic phase 3 [21]. Due to the dynamic occurrences accompanying laser smelting and rapid cooling, the phase identification based on the comparison of morphology in the obtained sponium is insufficient and requires further research. A separated fragment of the weld partially etched, showing the dendritic structure of the weld, also visible α and β titanium phases shown in Figure 6.

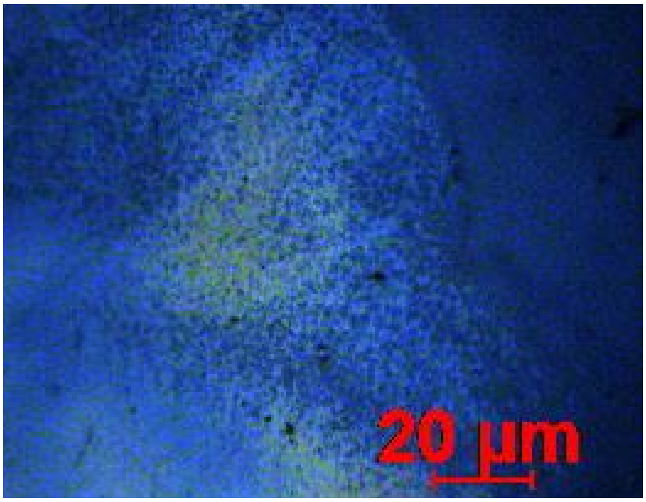

Fig. 6. Mixing of two materials. Separated part of the weld. Sample after etching. Light microscopy

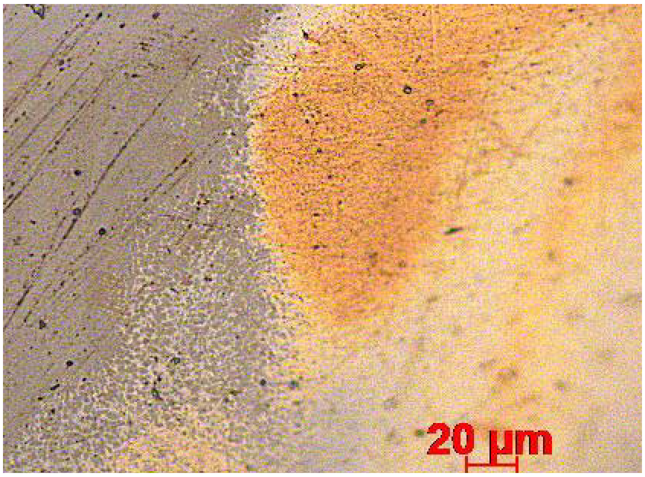

Fig. 7. Joint and mixing of the two materials. Light microscopy

A fragment of a weld, a sample after the etching process with vanished Au dendrites, a slightly visible fine-grained structure of α and β titanium is shown in Figure 8.

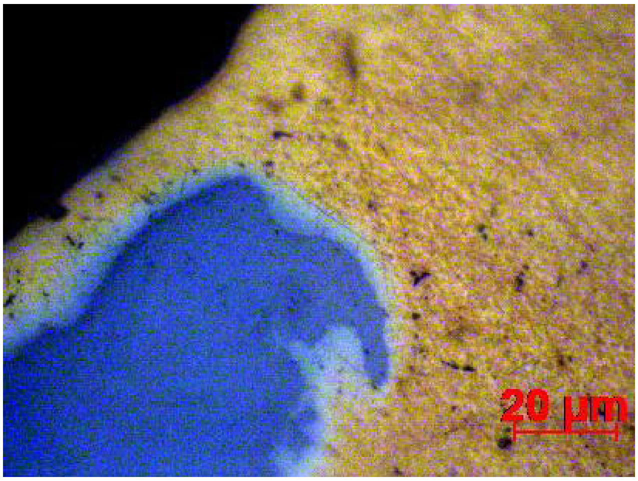

Fig. 8. Joint. Sample after etching. Light microscopy

Literature analysis indicates that the combination of gold and titanium has been investigated for industrial processes. In one of the works, an attempt was made to synthesize a gold foil placed between two titanium plates by resistance welding. As a result, a weld was obtained without defects, discontinuities, cracks or inclusions. The average gold content in the weld was 16 at.%. (42 wt.%) [22].

Using known industrial bonding processes in the dental laboratory would require developing a special device. The work attempts to use widely available welding technology.

In order to broaden the analysis of Ti and Au weldability, the research should be extended to SEM microscopy, as well as subjecting the weld to a microhardness test and determining its exact composition. It was also necessary to replace the manual welding process typical of a dental laboratory by mechanically positioning the elements in order to stabilize them during welding. Moreover, a laser with a smaller spot should be considered in the case of elements with dimensions below 0.4 mm, which will allow for better control of the remelting zone.

4. Conclusions

1. In the conditions of a prosthetic laboratory, the use of laser welding allows for obtaining a combination of gold with the two-phase titanium alloy Ti6Al4V.
2. In order to obtain a weld along the entire length, the dimensions of the gold elements should be increased in the case of manual positioning, or mechanical stabilization of the joined elements should be used.
3. The heat-affected zone in the titanium alloy substrate reached up to 20 micrometres. In the case of elements where the local range of the decrease in strength properties may affect their load-bearing capacity (especially those subjected to cyclic bending), the possibility of reducing the heat flux by using a laser with a smaller spot should be sought.

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