

CHAPTER FIVE

DISCUSSION

5.1 Materials and methods

5.1.1 Materials

Titanium and its alloys were used as biomaterials with its property being relatively inert and corrosion resistance because of its thin surface oxide layer. Titanium has become one of the most important metals in prosthodontics because of its desirable physical and mechanical properties (William, 1984). As such, titanium alloy was selected in this current study. Titanium grade II has low concentration in nitrogen and oxygen impurities. Apart from this, it has excellent corrosion resistance and biocompatibility, high ductility, low thermal conductivity, and adequate hardness. In addition, its atomic weight is 47.90, which is half of the weight of other nonprecious metals used in dentistry and one quarter the atomic weight of gold. In addition, the low density of titanium is advantageous because it allows lightweight prostheses to be fabricated. For the above mentioned reasons, titanium and its alloy are interesting in dentistry as an alternative constituent for removable partial dentures.

The cobalt-chromium alloys have enough physical and mechanical properties as per standard; also have excellent biocompatibility (Merk Index, 1983). They are low density and lightweight compared to the precious metal alloys. Therefore, this alloy used mostly in dental laboratory, for the above reasons this alloy was selected in this study.

In the beginning of this study, both titanium and cobalt-chromium considered as the control group. However in the pilot study, the titanium specimens were found to be tough and it bent only at high tensile strength. Even the three points bending test procedure could not even fracture it. For this reason, the cobalt-chromium was chosen as control group.

5.1.2 Method

5.1.2.1 Specimens preparation:

Before casting procedure, the plastic model was used for formulating each specimen as designed by (ISO 6871-1). This would create specimens with similar in dimensions to ensure there are no changes in dimension during investment stage.

5.1.2.2 Titanium investing

For the titanium investment, it is necessary to tolerate the initial molten titanium at nearly 1700°C without reacting with the surface of the titanium cast and without significant sintering. Also, the investment material (silica bonded investment material) should have an ability to compensate for shrinkages of titanium cast, because the metal should returns to room temperature after casting procedure.

5.1.2.3 Titanium casting technique

Casting is a method in which the molten metal liquid pours in a casting mould and treats by vacuuming, centrifuging or die casting to become a casting piece of specimens once the metal liquid is condensed.

Reducing considerably the mould temperature before casting titanium is a way of decreasing the thickness of contamination layer (Oliveira et al., 2006). The surfaces of titanium castings are contaminated with oxygen because of reaction with the oxide mould material. This brittle surface layer, called alpha case, must be removed before use. Prediction of the thickness of the contaminated layer would allow modification of mould design and to reduce the contamination. It would also provide a proper estimate of the extra dimension to be added to the casting to allow for alpha case removal. The accelerated rate of cooling created defects in the casting, like porosities, not visible to

the naked eye, but which decreases the mechanical strength of the casting. Problems of reactivity of molten titanium with oxygen have been solved by introducing combination of primarily vacuum and injection of argon gas for five times respectively, which is needed in this study.

Titanium and its alloys are very light, therefore they need higher pressure than other metals and alloys during casting and low vacuum during melting (Watanabe et al., 1997). Oxidation of titanium becomes actually less important. A higher pressure, a bigger vacuum, a greater purity of atmosphere, a shorter way from the melting place of metal to investment and a more inert investment material are needed in order to produce titanium casting with better shape and less contamination. This is because titanium has a high reaction with oxygen. All of the above can be fulfilled with (Manfredi Neutrodyn Easyti, Italy) with maximum casting capacity 30g of titanium and maximum consumption 5KW It can produce very fast vacuum and high pressure. The processing time is reduced by the short way from the C15Ti crucible to investment.

The low density of titanium also allows the use of conventional dental X-ray units to detect internal defects (porosity) due to casting procedure. Nevertheless, titanium may be an ideal alternative for patients allergic to other metals; however, the casting technology of titanium is limited for several laboratories. This due to the machine so expensive, for this reason it's difficult to use by many technician.

5.1.2.4 Polishing

All the specimens in this study were polished as recommended by Nabadalung and Nicholls (1998).The sectioned surfaces and adjacent areas where the joint was to be formed were sand blasted with 50 μm SiO_2 at 25 psi to create dull surfaces. This was required to reduce laser beam reflection during welding. Rhoadset al. (1986) also

advocated sandblasting (air particle abrasion) and conservative polishing of the fit surface to maximize the potential fit between the framework and the abutment. The specimens were then cleaned with acetone, washed with 70% methyl alcohol, and dried with nitrogen gas.

5.1.2.5 Laser welding

Laser welding has increasingly been applied in dentistry (Ishikawa et al., 2002), because of the convenience of using concentrated laser energy to fix broken metal frameworks with combustible acrylic resin (Roggensack et al., 1993).

The factors affecting the mechanical strength of joints welded by laser welding are the types of metals welded, and the wave length, peak pulse power, pulse energy, output energy, pulse duration, pulse frequency and spot diameter of the laser. In this study, the output energy (current or voltage), pulse duration and spot diameter of the laser can be adjusted, and the combinations of these three variables change the penetration depth of the laser into the metal in the area being welded. (Watanabe, Liu, & Atsuta, 2001) examined the effect of these operating conditions on a laser-affected depth (penetration depth) into the gold alloy. The penetration depth is a main factor affecting the strength of laser-welded prostheses, because the deeper of penetration, the larger the laser-welded region when the surface areas irradiated by the laser are the same. When laser welding involves two different metals (dissimilar metal), the penetration depth by laser is different among the parent metals because the rate of laser beam absorption, thermal conductivity and melting point are different in each metal. In general, it can be said that the greater the rate of laser beam absorption and the lower the thermal conductivity, the greater the penetration depth to each metal. Among dental alloys, base metals (Co, Cr, and Ti) have a greater rate of laser beam absorption and lower thermal conductivity compared to noble metals (Au, Ag, Pt and Pd) and therefore, it is advantageous for laser

welding. Titanium in particular has a very low thermal conductivity ($0.17 \text{ W cm}^{-1}\cdot\text{deg}^{-1}$), which is approximately one twentieth that for Ag ($3.97 \text{ W cm}^{-1}\cdot\text{deg}^{-1}$) and Au ($2.97 \text{ W cm}^{-1}\cdot\text{deg}^{-1}$). Therefore, laser welding is the most advantageous method for titanium (Liu et al. 2002). The same author presented the penetration depths resulting from a pulse duration of 10 ms at different levels of output energy (current: A). Increasing the current increased the penetration depth of laser to alloy. The penetration depth varied from 0.52 mm (160 A) to 2.27 mm (300 A) at a spot diameter of 1.0 mm. There were no notable differences in penetration depth among pulse durations except for the pulse duration of 1 ms, which had the lowest value. This was more remarkable when the spot diameter is less than 1.2 mm (Liu et al., 2002). In this study; the pulse duration was fixed at 10 ms, the output energy (current) of 270W, and welding spot diameter of 1.0mm. This was found to be the best parameters in the pilot study.

5.2 Results

Many properties contribute to the characterizing of a material like the yield, strength, hardness, tensile strength, modulus of elasticity, etc. Several factors can be varied at some stage in denture fabrication which may affect the properties and performance of the dentures. Moreover, a denture would go through various loading conditions during the process of mastication and hence it is interesting to inspect all of these parameters.

5.2.1 Three point bending test

To evaluate the flexural strength of the laser welded area, three-point bending test was conducted so the specimens will be subjected on a form of indentation to tensile stress

on the indented surface until it fractures. The results of bending test can vary a great deal depending upon specimen size, fabrication methods, span to depth ratio, duration of loading, etc. (Cattell et al., 1997; Seghi& Sorensen, 1995; Tinschert et al., 2000). The test was performed with a cross head speed of 5mm/min (Albakry et al., 2003). Normally, metals exhibit a Gaussian (normal) distribution of strength values. The findings of the current study showed normal distribution of flexural strength values as shown in Figure 4.2, which corroborated the general statement of the metal behaviour under loading. In this test, it was found that the mean flexural strength values for laser welded cobalt-chromium-titanium specimens were less than that of intact unwelded cobalt-chromium specimen. The results showed that the flexural strength of laser welded cobalt-chromium-titanium was inferior to the intact non welded specimen.

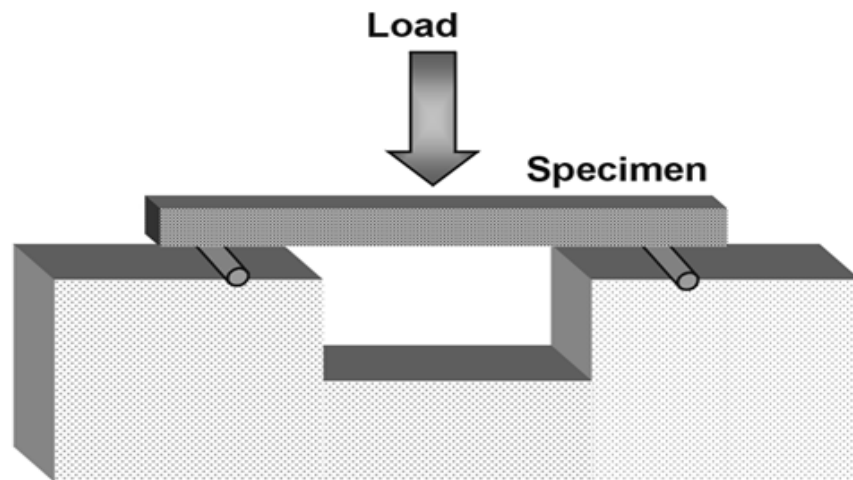


Figure 5.1 Schematic illustration of three-point bending test.

(<http://www.sirim.my/plastics/flexuraltest.html>)

5.2.2 Tensile strength

The average tensile strength of laser-welded specimens in the current experiment was 401.87 ± 124.64 MPa. The average tensile strength of laser-welded Co-Cr and Ti dental

alloy joints investigated thus far has ranged from 480 to 751 MPa, which exceeds the average strength of laser welds in this study (404 and 405 MPa) as reported by Bertrand et al. (2001, 2004). An important reason for the relative weakness of laser-welded joints in the current study was the small effective cross-section of specimens that was actually joined. This is a problem associated with low weld penetration depth, which is in agreement with that reported by (Bertrand et al., 2004). The control specimens showed a greater value than the laser-welded specimens, which was 813.07 ± 50.07 .

For laser welding, the manufacturer recommends an alloy without carbon (Remanium 900; Dentaaurum, Germany). Nevertheless, laser welding of cobalt-chromium denture frameworks has been used with considerable success in clinical practice. A feasible explanation is that during mastication, prostheses are rarely subjected to isolated tensile loads. In bending stress, most of the load is placed on the peripheral portions of the framework. One side is subjected to tension and the other to compression, while central portions are less involved. Since the examination of fracture surfaces in this study showed that the laser welding technique was much more effective in the peripheral than in the central portions of the specimens. It is possible that the strength would be adequate clinically, while an inferior tensile strength was compared to the specimens (Zupancic, et al., 2006). Studies by Liu et al. (2002) concluded that the hybridization between pure titanium and any other alloys is not good. In addition he suggested that the effect of laser welding for different alloys is ideal except with pure titanium.

5.2.3 Modulus of elasticity

A number of researchers (Brunette et al., 2001; Boyeret al., 1994) showed that the Young's modulus for titanium (100-110 GPa) is about one half that of stainless steel or

cobalt-chromium alloys. It should be observed that titanium has a modulus of elasticity that is lower than that for cobalt-chromium, which increases its resiliency and makes it more like gold alloys (Phillips, 1991). This characteristic is useful in clinical situations where aesthetics or periodontal health is a primary concern. However, the flexibility of a material affects the retention and function of an removable partial dentures (RPD) (Stratton & Wiebelt, 1988.) If a material is too flexible, it may not provide adequate retention for the RPD when the framework design is based on principles used for cobalt-chromium alloys. In the present study, the modulus of elasticity of laser-welded specimens was 5046.42 ± 584.18 MPa, which was less than the control specimen, 5635.05 ± 583.10 MPa; however it was not significantly different. These results indicated that the modulus of elasticity of test specimens is statistically not significantly different compared to control specimens.

5.2.4 Scanning electron microscopy

Scanning electron microscopy (SEM) was conducted as described in Section 4.4. Because it is difficult to keep the fracture cracks intact during electro-polishing, it is very difficult to determine the fracture planes in Transmission Electron Microscope (TEM). In contrast, Electron Backscatter Diffraction (EBSD) on an SEM is an ideal technique for identifying local crystal orientations and the correlation with the GB/fracture plane can be obtained from SEM images in bulk samples (Randle & Davies, 2001). Because of the excellent corrosion resistance, wear behaviour, and biocompatibility, cobalt-chromium alloy became of interest amongst other materials used in dental application (Browne & Gregson, 2001; Chen et al., 2004).

In the SEM micrographs, many small pores were observed in the laser welded region Fig. 4.7 These pores are attributed to the incorporation of gas such as argon and ambient air in the chamber of the laser welding machine. Titanium has high reactivity with ambient elements at high temperature. During the short time it takes to complete the welding processes, gas is incorporated into the molten alloys, creating small pores.

SEM was used in this study to determine the types of fracture that is occurred and to evaluate the presence of porosity. The SEM results of the fracture surfaces for control specimens (Co-Cr) showed a completely ductile fracture by necking, revealing a cup-and-cone-type fracture surface. The cup section of the cup-and-cone fracture surfaces and the reduction of area in a control specimen were clearly visible (Fig. 4.5). Shear lips were ductile fracture regions that form during the final stage of fracture and usually make an angle of 45 degrees with the loading axis. Angled dimples (shear dimples) with different morphology were observed on these regions with the SEM. The ductile fracture mechanism involves void formation, void coalescence, and formation of shear lips at the last stage. The fracture process for the present specimens was completely ductile. The laser-welded specimens, however, failed without having a neck, and the fracture was located at the welded zone (Fig.4.6). All specimens were fractured between the weld and the parent metal. The reason for that was possibly due to distribution of porosities at joint point, which will make it less hard with weak properties.

CHAPTER SIX
CONCLUSION AND SUGGESTIONS

The overall result showed that the laser welded specimens had inferior mechanical properties compared to the control specimens.

Under limitations of the study, the following conclusions can be drawn:

1. The results showed that flexural strength and tensile strength of laser welded joint of cobalt-chromium and titanium were significantly weaker than in the control group.
2. There were no significant difference in modulus between laser welded specimens and the control specimens.
3. Micro porosity was distributed at joint area.
4. Laser welded fusing of cobalt-chromium and titanium could be used in RPD as a method in repairing works and retainers' fusing to the connectors as the bonding is strong enough when increasing the welded surface area.

Further tests with different joint types may improve the bonding between the titanium and cobalt-chromium as the titanium could serve as a very good clasp material in dental prostheses, perhaps modifying the joints by increasing the welding surface area of the joint and eliminating the micro porosity the joint area would enhance this conjugation between the cobalt-chromium and titanium which is expected to improve the quality of the prostheses in dental practice.