

# INVESTIGATION AND EVALUATION OF DIFFERENT LASER WELDED AREAS

**Meda Negrutiu<sup>1</sup>, Cosmin Sinescu<sup>1</sup>, Radu Negru<sup>2</sup>, Cosmin Locovei<sup>3</sup>, Carmen Todea<sup>4</sup>, Dalibor Cozarov<sup>5</sup>, Cosmin Balabuc<sup>4</sup>**

## REZUMAT

**Introducere:** Pentru sudura în laboratorul de tehnică dentară se poate utiliza un laser Nd:YAG care lucrează în regim pulsat. **Obiective:** Scopul acestui studiu îl reprezintă investigarea și evaluarea a trei tipuri de solidarizare utilizate în tehnica dentară, comparativ cu sudura cu laser. **Material și metode:** S-au realizat diverse suduri cu laser utilizând un echipament Nd-Yag (Orotig), care lucrează în regim pulsat. S-au realizat și alte tipuri de solidarizări, utilizând trei tehnici diferite: topire cu flacăra de hidrogen și lipire, sudură cu electrozi de carbon și solidarizare prin transfer. Toate aceste zone de solidarizare au fost investigate în ceea ce privește calitatea și rezistența la coroziune prin imersie în clorură ferică și salivă artificială, verificându-se dacă tehnicianul dentar a respectat instrucțiunile de solidarizare. Coroziunea a fost confirmată prin microscopie electronică. **Rezultate:** Investigațiile realizate au confirmat calitatea superioară a sudurilor cu laser. În cazul celorlalte metode clasice de solidarizare utilizate au apărut următoarele defecte: umplere incompletă a spațiului de solidarizare, rezistență scăzută la coroziune, fapt ce le diminuează specificitatea pentru această tehnologie. Diferențe de calitate s-au observat și în funcție de modul de lucru al tehnicianului. **Concluzii:** Probele realizate prin tipurile investigate de sudură cu laser au prezentat coroziune minimă și calități superioare față de celelalte metode de solidarizare investigate.

**Cuvinte cheie:** sudură cu laser, metode de solidarizare, coroziune

## ABSTRACT

**Introduction:** Laser welding using a pulsed Nd:YAG laser has been developed to be applied as a standard for joining purposes in the dental laboratory. **Objectives:** The aims of this study are represented by the investigation and evaluation of three types of soldering compare to laser welding. **Material and methods:** The method is represented by the laser welding with a pulsed Nd:Yag Laser equipment (Orotig). Other joints were produced, using three different soldering techniques: Hydrogen Flame Soldering, Carbon Tip Electrode Soldering and Transfer Soldering. These joining areas were investigated for their quality and their corrosion properties during immersion in ferric chloride and artificial saliva. Observance of the soldering instructions by the dental technicians was checked. Corrosion attack was confirmed by electron microscopy. **Results:** The investigations confirm the quality of laser welding. Incomplete filling of the soldering gaps, porosities resulting from the production process, poor corrosion properties and in particular a high variability of the measured values point out the insufficient reliability of classical soldering technique. Variations in quality were also detected related to technicians' modes of operation. **Conclusion:** The investigated different laser welding methods revealed minimal corrosion and offers clear-cut advantages compared to the other soldering methods.

**Key Words:** laser welding, soldering methods, corrosion

## INTRODUCTION

One of the earliest and most widely practiced applications of laser material processing was joining of metallic parts using a continuous wave laser.<sup>1,2</sup>

Laser joining is applicable to inorganic/organic and similar/dissimilar materials with an extremely high precision, versatility and productivity that can only be matched by electron beam welding. Moreover, laser welding can be done in air, unlike the vacuum processing needed in electron beam welding.<sup>1,2</sup> In comparison to conventional or arc welding, laser welding scores several advantages like narrow welds with controlled bead size, faster welding with a higher productivity, less distortion, narrow heat-affected zone and minimum contamination.<sup>3</sup>

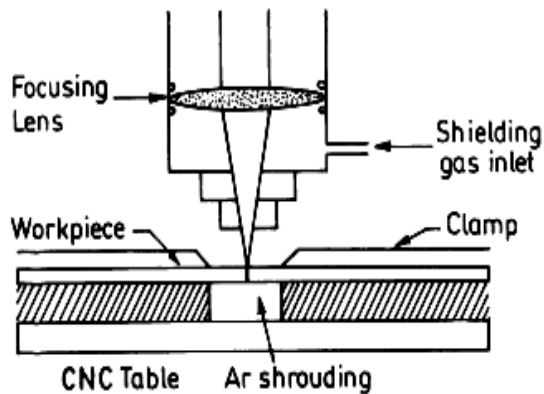
Laser welding constitutes the most important operations among the laser joining processes.<sup>2,4</sup> Figure 1 shows the front view of the schematic set-up for laser welding without a filler rod. The focused laser beam is made to irradiate the work piece or joint at the given level and speed. A shroud gas protects the weld pool from undue oxidation and provides

<sup>1</sup> Department of Prosthesis Technology and Dental Materials, Faculty of Dental Medicine, Victor Babes University of Medicine and Pharmacy, Timisoara, <sup>2</sup> Department of Materials Strength, Faculty of Mechanics, <sup>3</sup> Faculty of Mechanics, Polytechnic University, Timisoara, <sup>4</sup> Department of Oral Rehabilitation and Dental Emergencies, Faculty of Dental Medicine, Victor Babes University of Medicine and Pharmacy, Timisoara, <sup>5</sup> Dal's Dent Tech Dental Laboratory, Timisoara

Correspondence to:  
Assoc. Prof. Dr. Meda Negrutiu PhD, DMD, 9 Revolutiei din 1989 Blvd.,  
300070 Timisoara, Tel. +40-745-166620  
Email: meda\_negrutiu@yahoo.com

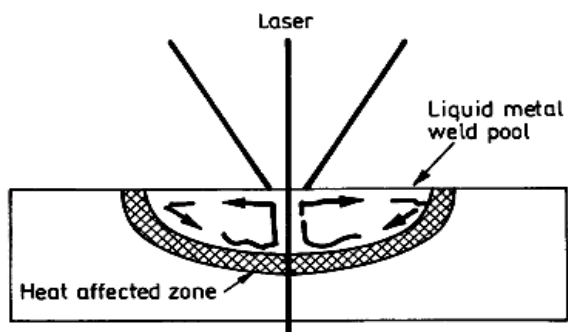
Received for publication: Sep. 09, 2007. Revised: Sep. 25, 2007.

with the required oxygen flow. Laser heating fuses the work piece or plate edges and joins once the beam is withdrawn. In case of welding with filler, melting is primarily confined to the feeding wire tip while a part of the substrate being irradiated melts to insure a smooth joint. In either case, the work piece rather than the beam travels at a rate conducive for welding and maintaining a minimum heat affected zone.<sup>3-5</sup>



**Figure 1.** The front view of the schematic set-up for laser welding without a filler rod.

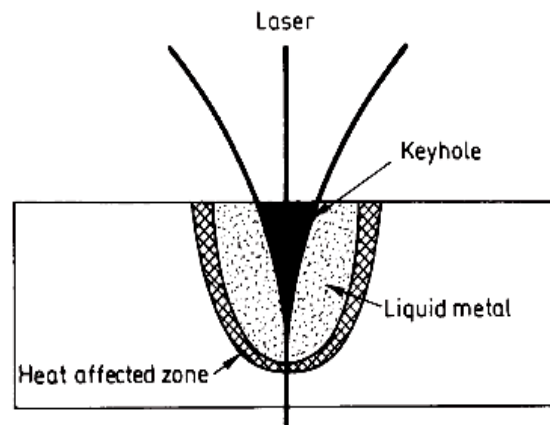
There are two fundamental modes of laser welding depending on the beam power/configuration and its focus with respect to the work piece: conduction welding and keyhole or penetration welding.<sup>6</sup> Conduction limited welding occurs when the beam is out of focus and power density is low/insufficient to cause boiling at the given welding speed. (Fig. 2)



**Figure 2.** Conduction limited welding.

In deep penetration or keyhole welding, there is sufficient energy/unit length to cause evaporation and hence, a hole forms in the melt pool. (Fig.3) The ‘keyhole’ behaves like an optical black body in that the radiation enters the hole and is subjected to multiple reflections before being able to escape.

The transition from conduction mode to deep penetration mode occurs with increase in laser intensity and duration of laser pulse applied to the work piece.



**Figure 3.** Deep penetration or keyhole welding.

The purpose of this study is to investigate and evaluate three types of soldering and compare them to laser welding.

## MATERIALS AND METHODS

The method is represented by the laser welding with a pulsed Nd-Yag Laser equipment (Orotig). (Fig. 4) The following parameters were used: 1064 nm wavelength, 10 ms repetition rate and 6.58 kJ/cm<sup>2</sup> energy density (for Ti specimens) and 12 ms repetition rate and 7.49 kJ/cm<sup>2</sup> energy density for Ni-Cr and Co-Cr alloys.



**Figure 4.** The Nd-Yag Laser equipment (Orotig) used for the weldings.

Other joints were produced, using three different soldering techniques: hydrogen flame soldering, carbon tip electrode soldering and transfer soldering.<sup>1,2</sup>

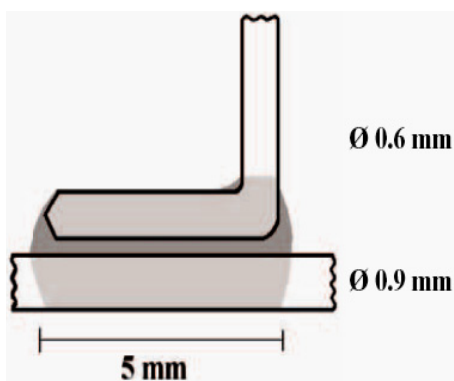
In the hydrogen flame soldering technique, the wire elements are heated directly, so that the temperature of the wire mostly rises to levels exceeding the fusing temperature of the solder.

A spot welding unit (Master 2002, Dentauro, Pforzheim, Germany) was used for carbon tip electrode soldering. A small soldering pad containing flux and the workpieces to be soldered was clamped between the carbon and copper electrodes. The current running through the workpieces resulted in direct heating of the wire elements and thus in melting of the solder. The soldering time did not vary significantly among

the technicians; the mean values were 2.5 to 3 seconds and thus below those observed in the hydrogen flame and transfer soldering techniques.

Transfer soldering is also performed with a spot welding unit. The spot welded wire elements are held manually against the solder-bearing end of a brass wire electrode. The latter is heated by the current flow from a carbon tip electrode until the solder fuses and flows into the soldering gap. In this technique, the parts to be soldered are heated only indirectly, so that they just reach the solder melting temperature at the point of contact with the soldering globule, whereas the temperature is lower at more distant sites.

All the joints were produced as overlapping connections between a right-angled spring-hard wire of 0.6 mm diameter and a hard wire of 0.9 mm diameter. (Fig. 5) After the soldering/welding procedures, the joints were immersed in three different corrosive agents: 60 minutes in 10% ferric chloride, 48 hours in Kukis® cleaner, and 90 days in 70 ml artificial saliva at 37°C.<sup>7-9</sup>



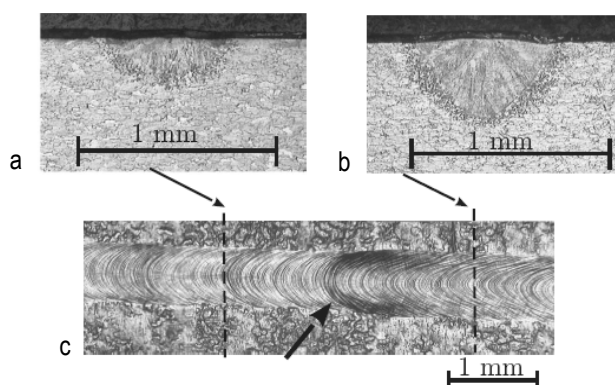
**Figure 5.** The Welder/Solder joint geometry (schematic drawing).

Observance of the soldering instructions by the dental technicians was checked. Corrosion attack was confirmed by electron microscopy.<sup>10</sup>

## RESULTS

The investigations confirm the quality of laser welding.<sup>10-12</sup> Figure 6 presents the surface appearance of the laser weld at the transition from conduction mode to keyhole mode welding (c) and cross-sections of both, a conduction mode weld just before the transition (a) and a keyhole mode weld directly after the transition (b).<sup>6</sup>

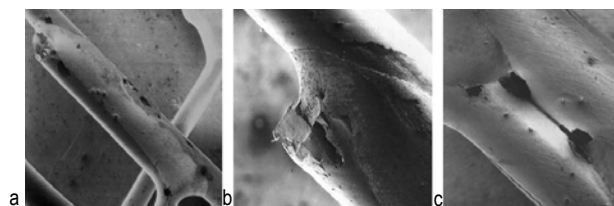
Incomplete filling of the soldering gaps, porosities resulting from the production process, poor corrosion properties and in particular a high variability of the measured values point out the insufficient reliability of classical soldering technique.



**Figure 6.** The surface appearance of the laser weld at the transition from conduction mode to keyhole mode welding (c) and cross-sections of both, a conduction mode weld just before the transition (a) and a keyhole mode weld directly after the transition (b).

Figure 7 shows scanning electron microscopy images of various solder joints in 17x (a) and 50x (b) magnification after immersion in ferric chloride (c). Massive defects in the steel wire occurred primarily at the uncovered snipped-off spring ends (a,b), uncovered soldering gap areas (c), and impressions of the carbon tip electrode (a).

Variations in quality were also detected related to technicians' modes of operation.



**Figure 7.** Scanning electron microscopic images of various solder joints in 17x (a) and 50x (b and c) magnification after immersion in ferric chloride.

## CONCLUSIONS

The two different investigated laser welding methods revealed minimal corrosion and offers clear-cut advantages compared to the other soldering methods.

Dental alloys are subjected to functional influences in the oral cavity and interact with the intraoral environment. These interactions are of a complex nature and are influenced by a wide range of environmental factors (quantity and quality of saliva, dental plaque, pH value, foods and drugs).

## REFERENCES

1. Bratu D, Nussbaum R. Bazele clinice si tehnice ale protezarii fixe. Timisoara: Signata, 2001.
2. Negrutiu M, Sinescu C, Leretter M, et al. Tehnologia protezelor dentare. Vol. I: Proteze unidentare. Timisoara: Litografia UMF, 2005, p. 73-86.

3. Shin C, Miura H, Okada D, Yamazaki A. Accuracy of temporary laser welding of FPDs by Nd:YAG laser in the oral cavity. *Dent Mater J* 2006;25(3):604-10.
4. Watanabe I, Baba N, Chang J, Chiu Y. Nd:YAG laser penetration into cast titanium and gold alloy with different surface preparations. *J Oral Rehabil* 2006;33(6):443-6.
5. Rocha R, Pinheiro AL, Villaverde AB. Flexural strength of pure Ti, Ni-Cr and Co-Cr alloys submitted to Nd:YAG laser or TIG welding. *Braz Dent J* 2006;17(1):20-3.
6. Zupancic R, Legat A, Funduk N. Tensile strength and corrosion resistance of brazed and laser-welded cobalt-chromium alloy joints. *J Prosthet Dent* 2006;96(4):273-82.
7. Al-Ali S, Oshida Y, Andres CJ, et al. Effects of coupling methods on galvanic corrosion behavior of commercially pure titanium with dental precious alloys. *Biomed Mater Eng* 2005;15(4):307-16.
8. Vande Vannet B, Hanssens JL, Wehrbein H. The use of three-dimensional oral mucosa cell cultures to assess the toxicity of soldered and welded wires. *Eur J Orthod* 2007;29(1):60-6.
9. Sestini S, Notarantonio L, Cerboni B, et al. In vitro toxicity evaluation of silver soldering, electrical resistance, and laser welding of orthodontic wires. *Eur J Orthod* 2006;28(6):567-72.
10. Bardin F, Cobo A, Lopez-Higuera JM, et al. Optical techniques for real-time penetration monitoring for laser welding. *Appl Opt* 2005;44(19):3869-76.
11. Chao Y, Du L, Yang L. Comparative study of the surface characteristics, microstructure, and magnetic retentive forces of laser-welded dowel-keepers and cast dowel-keepers for use with magnetic attachments. *J Prosthet Dent* 2005;93(5):473-7.
12. Huang HH, Lin MC, Lin CC, et al. Effects of welding pulse energy and fluoride ion on the cracking susceptibility and fatigue behavior of Nd:YAG laser-welded cast titanium joints. *Dent Mater J* 2006;25(3):632-40.