Lightening in a Bottle

State of the art joining techniques in dental technology

Part 1 in a series

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Introduction

This is part one in a series of articles about dental connecting techniques that will feature the important basics of welding. A theoretical and practical approach will be discussed and demonstrated through the many case samples that cover crown & bridgework, CoCr partial fabrication and repair, implant bars, closing holes in crowns, extending margins, and adding contacts to occlusal and interproximal areas.

Key Words: joining, soldering, brazing, plasma arc welding, tungsten inert gas welding (TIG), laser welding, phaser mx1, dental alloys, pure metals

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Material science methods and requirements for connecting alloys and metals in dental technology >>

In general, dental technology uses different thermal joining methods to connect alloys or metal structures. These methods are:

- Soldering
  - Flame soldering (different flammable gases mixed with compressed air or oxygen)
  - Post soldering (porcelain furnace)
  - Infrared soldering (IR)
- Resistance welding (spot-welding)
- Plasma welding (torch)
- Laser welding (Nd:YAG-laser-machines)
- Single pulse tungsten inert gas welding (TIG)

The common characteristic of these different methods is to achieve a mix of the atoms of either the parts to be joined and/or the added materials, such as solder or welding rods.
Depending on the type of work to be connected, three general case types can be defined:

1. Connecting identical metals/alloys, such as Titanium to Titanium (i.e. implant case)
2. Connecting similar metals/alloys, such as AuPt to AuAgCu (i.e. attachment case)
3. Connecting different metals/alloys, such as AuPt to CoCr (i.e. “gold” crowns to partial)

The common requirement for each of these joining methods (soldering/welding) is a joint stability of at least 350 Mpa (according to the standard DIN EN 29333). In addition, the metallic structure has to be free of any macro defects and must to be stable and corrosion resistant. The dental literature discusses the different methods in regards to the DIN standard requirements, clearly favouring the welding techniques.

From Soldering to (Laser/Phaser) Welding >>

This development can actually be considered one of the mayor breakthroughs (advancements) in dental technology in the last 15 years. To understand this statement, the main differences between soldering and welding need to be analysed. In general, these differences are seen in the areas of biocompatibility and productivity.

Category	Composition	Application	Corrosion Resistence	Clinical Notice
Silver solders	AgCuZn	orthodontic wires and apparatus	very low	not acceptable
Gold solders	AuAgZn, containing appr. 60 – 75 % Au, Ag and up to 15 % zinc. others Sn, Cu, In	objects in gold-, silver- and palladium alloys, non precious alloys	moderate	acceptable with limitations
Universal Gold Solders	AuNiZn, approx. 75% gold, 12 – 18 % nickel and zinc	objects in gold-, silver- and palladium alloys, non precious alloys	moderate	acceptable
	AuCdZn, approx. 75% gold, 12 – 15 % cadmium and zinc		moderate	not acceptable
White Gold Solders	AuPtAg	Objects in high melting gold-, and palladium alloys, non precious	moderate	acceptable
Solders for Non-Precious Alloys	Co70Cr13Mo5Si5BFe	CoCr alloys	good	acceptable, but difficult to process, high working temperature
	Ni66Cr19Mo6Si4B1Fe4	NiCr alloys	good	
Titanium Solders	TiPdCu	pure titanium and titanium alloys	bad	not acceptable, difficult to process, high working temperature, not used in dental technology

Table 1 : Different kinds of metallic solders in dentistry

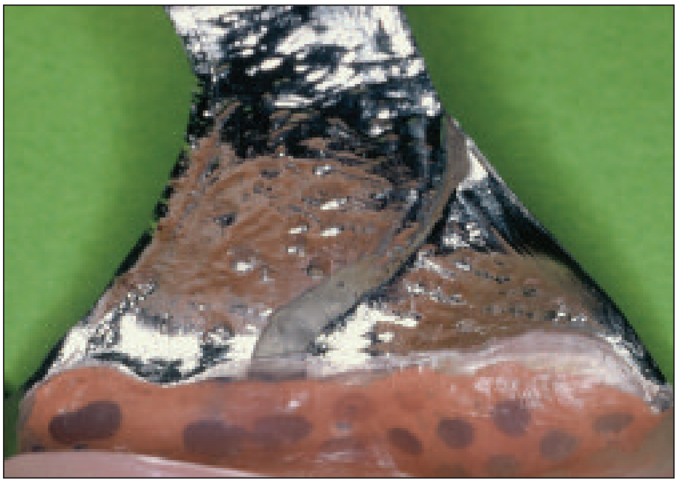


Fig. 1. A dull, porous and discoloured grey solder joint on a CoCr partial, has been in the mouth for approximately one year

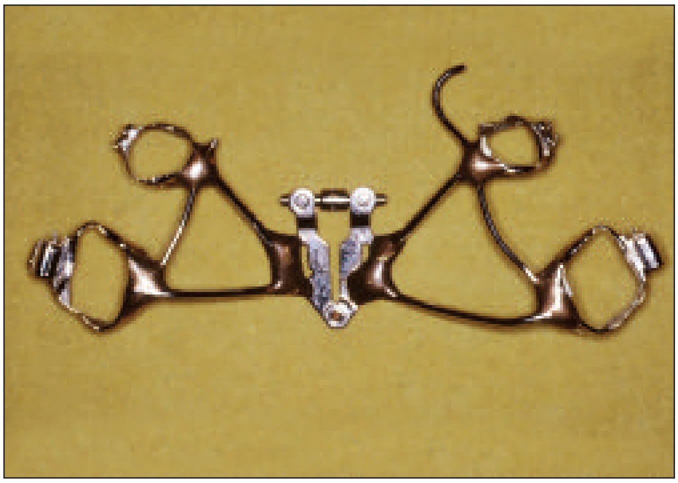


Fig. 2. Corrosion on orthodontic appliances can show different discolorations depending on the solders used.

1. Biocompatibility: to join cast dental alloys by soldering, a “third” low fusing alloy (solder) is required. The melting range of this solder must be lower than the melting range of the alloys; otherwise the metalwork you are joining would be deformed or melted by the torch during the soldering procedure. To decrease the melting range of the solder, low fusing elements such as cadmium, gallium, nickel and copper are mixed into the soldering alloy. Universal gold solder alloys contain approximately 75% gold and 12 – 18 % nickel and zinc. An overview is shown in table 1. These elements, however, have a questionable corrosion resistance and in many cases will constantly dissolve in the oral environment. The dissolved metal ions settle in organs (kidney, liver, etc.), leading to allergic reactions (i.e. nickel) and other health problems for the patient. The corrosion on soldered Co-Cr cases that have been in the mouth for some time is easily observed when these cases come back to the lab for a repair. The soldered areas which where homogenous and shiny when the case was originally delivered are now dull, discoloured, and porous, clear evidence of corrosion *(fig. 1 and 2)*. Furthermore the mechanical stability of soldered joints is often questionable *(figs. 3 and 4)*.

Fig. 3. shows a failed bridge with defects in the solder joint.

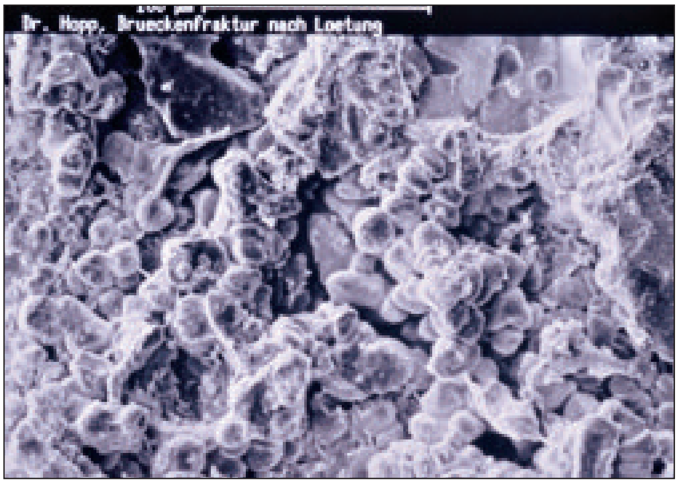


Fig. 4. An SEM of the broken solder joint in fig. 3

The color of regular dental solders ranges from yellow or light yellow for high gold content alloys, to variations of silver/white for AuPdAg, NiCr, and CoCr-solders. It is very rare that the color of the solder matches the color of the alloy that was soldered. Consequently, the soldered area is visible long before the case goes into the mouth for the first time.

Compared to soldering, welding does not require a "third" low fusing alloy (solder) as additional material for joining two pieces together. The material used for welding is always the same composition and the same color as the alloy to be welded. There are no low fusing alloy components that can corrode and the joint will have the same corrosion resistance as the original cast alloy. When a case that has been welded instead of soldered returns to the lab for repair, it will still be as shiny and homogenous as it was when the case was new. Therefore, welding dramatically increases the corrosion resistance and ultimately the biocompatibility of the dental prosthesis. (For more information, see the review of statements and observations regarding soldering and welding at the end of this article.)

2. Productivity: When soldering with a torch, the pieces to be joined must be connected first on the master model with some cold cure acrylic. Then they are removed from this model and invested in a solder investment material, forming the solder model. This procedure consumes not only valuable working time, but includes long waiting periods for materials to set, heat or cool. In addition, when restorations with porcelain or acrylic components are returned to the laboratory for repair, soldering generally requires that they be disassembled or stripped before soldering can begin.

On the contrary, laser/phaser welding is done right on the regular master model. This is possible because the heat created by welding is strictly limited to the area right around the welding spot itself. Consequently, solder models are not required even when it is necessary to weld right next to acrylic or porcelain. This means that there is no need to strip a case of porcelain or acrylic when it has been returned for repair *(fig. 5)*. Welding is a far more efficient process that typically saves the technician up to 80% of the time required to solder the same case.

Fig. 5. The secondary crowns had broken off. They were welded back to the CoCr-partial without removing the pink acrylic or the veneers

However, not all welding methods are equally efficient. Conventional electric spot welding has proven worthwhile for joining wires when making repairs [2], but this method is not useable for all alloys or seam welds. For example, when Titanium and Titanium containing wires were introduced in orthodontics, the challenge was to connect them without destroying the Titanium. Heating Titanium made it vulnerable to heavy oxidation, a characteristic that is undesirable in dental alloys.

The Need for Welders in Dental Technology >>

Even though the biocompatibility and productivity advantages of laser welding had been realised in the laboratory industry by Gordon & Smith in the 70's [8], the real need for welders would surface in the early 90s when Titanium casting was introduced. Titanium being a highly reactive metal when heated required a joining method that incorporated an inert protection gas (Argon). Argon protected against a chemical reaction with oxygen, nitrogen and other gases during the joining process that would cause the Titanium to become discoloured, extremely hard, brittle and consequently useless.

Fig. 6. The bridge fits perfectly after sectioning and welding

Fig. 7. A new clasp arm is welded to a partial without removing the acrylic components.

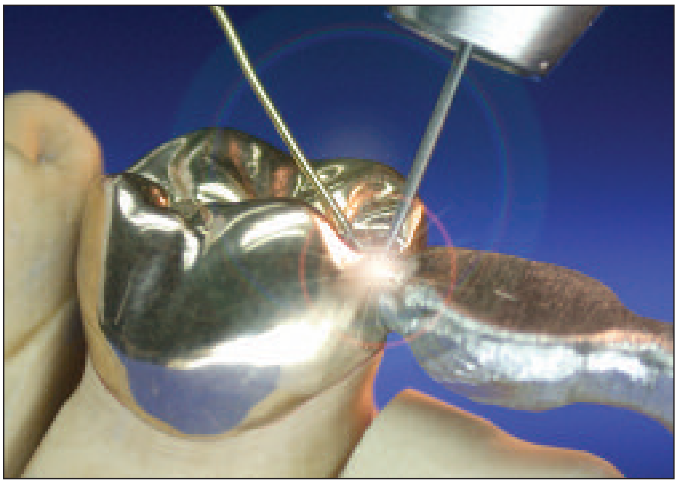


Fig. 8. Non-precious ceramic alloy welded to a high gold, full-cast crown using the “Lego Brick” principle.

Laser welders work with Argon (4.6 or higher = 99,996% purity) as a protection gas which allows them to weld Titanium and preformed Titanium elements without any negative chemical reactions. Jempt et al [12] confirmed that laser welded superstructures on Titanium implants using pre-fabricated abutments and bars, produced results comparable to cast structures. It is no coincidence that when Titanium casting systems and preformed abutments started spreading in the dental field that the number of laser welders increased as well. The advantages to this kind of welding are not limited to Titanium but apply to all other dental alloys as well. As a result, the demand for dental welders has increased even among laboratories that do not cast Titanium.

Further Advantages of Welding Over Soldering >>

1. In general, laser welded joints are as strong as the original cast alloy while a soldered joint is substantially weaker.
2. Properly welded joints will lead to a perfect passive fit *(fig. 6)*.
3. Welding can greatly increase the corrosion resistance of the restoration
4. The heat is strictly limited to the welding area which allows you to weld in direct proximity to acrylic or porcelain *(fig. 7)*
5. Different types of alloys such as High Gold and Cobalt-Chrome can be welded together easily when mechanically supported *(fig. 8)*
6. No time consuming preparations or corrections are necessary
7. Working time can be reduced up to 80%
8. The number of different elements and alloys in the patients mouth are reduced to the minimum
9. Titanium can be welded easily; soldering Titanium in dentistry is not possible.
10. Welding is done right on the stone master model *(fig. 9)*

Different Types of Dental Laboratory Welding Machines >>

1. Plasma and laser welding machines: In the 1980’s, only so called plasma torch welders were known in dental technology. The only advantage of this type of welding over conventional soldering was the fact that the plasma torch welders worked with a protection gas (Argon) eliminating oxidation of the welded area. Taylor et al [21] researched the effects of the joint configuration on the tensile strength for plasma arc welded cast Ti6Al4V alloys. They could not detect any significant difference in tensile strength on joint configurations between 0,25 mm and 1,00mm. However, the torch and heat control of these machines was very rough and detailed working was rather difficult even for very experienced technicians. The area heated by these plasma welders was comparable in size to a soldering torch ***(fig. 10).***

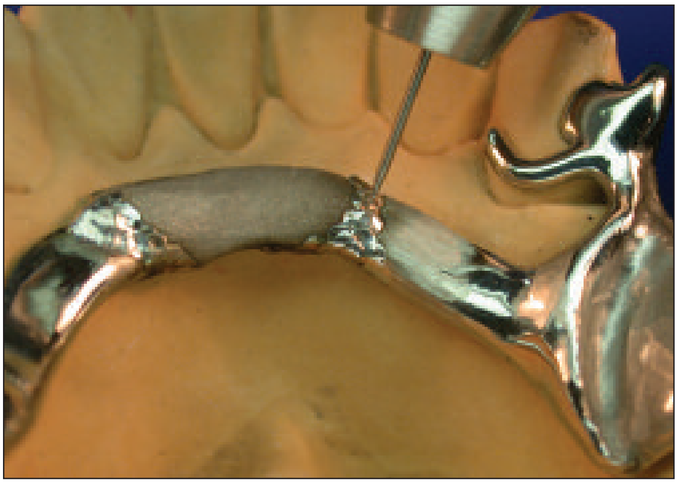


Fig. 9. A miscast sublingual bar. The missing piece is added and welded directly on the master model.

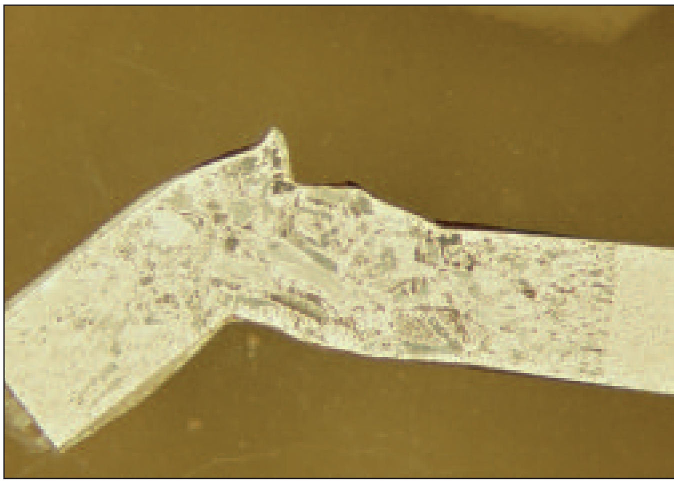


Fig. 10. Rough grain structure in the heat effected zone of plasma

Consequently it was not possible to weld without first removing all the acrylic parts from the restoration. Even though the biocompatibility advantages of welding could be obtained with the plasma torch welders, the productivity was similar to soldering.

This situation changed drastically when laser welders were introduced to the market because they could offer all the advantages previously discussed. The energy from a laser that is applied to the object to be welded is not emitted as a flame but as a spot of stimulated and amplified light radiation (LASER = Light Amplification by Stimulated Emission of Radiation). The laser head, which is considered the "heart" of a laser welder, consists of a laser lamp (comparable to the flash light of a camera) and a laser crystal (Nd-YAG crystal) that are arranged parallel to each other. The laser impulse is initiated by pushing a foot switch which will make the laser lamp flash. This flash light energy stimulates the laser crystal that bundles and amplifies it. An arrangement of mirrors finally brings this "concentrated light energy" to the focus plain in the working chamber of the laser machine where it hits the object to be welded with a defined energy (power, time and area are adjustable parameters). It is important to note that when laser welding, it is "light" that melts the alloy. Consequently, the surface condition of the components to be welded (highly polished or sandblasted) will influence the effect of the laser energy. The shinier the surface, the less effective the laser will be as more of the light energy hitting the object will be reflected away, reducing the "melting" effect. Shooting a mirror with a laser has no effect on the mirror as almost 100% of the laser light energy hitting the mirror is reflected. While this may not be considered a real disadvantage to laser welding, it is important to keep in mind for our daily work. The same alloy will react differently to the same (laser) light energy depending on its surface condition. Consequently Sjörgren et al. [19] proved that laser welding Titanium in dentistry is possible if the material properties and surface conditions are taken into consideration. Research as to the relevant settings and data for Nd:YAG lasers was requested prior to a wide introduction of laser welders in dental technology. (For additional reading on the advantages of laser welding over soldering and plasma welding see review at the end of article.)

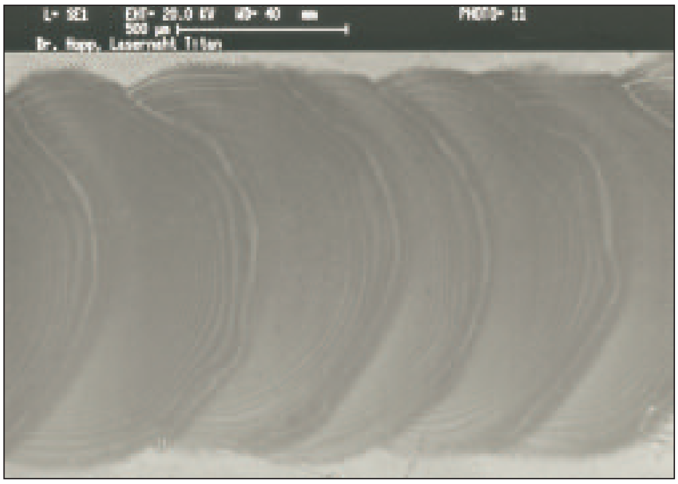


Fig. 11. SEM picture of a proper Titanium laser welded seam

Welding has demonstrated clear advantages over soldering and laser welding in particular has proven superior among the welding methods (or systems). One of the disadvantages of laser welders is the rather high initial investment required as well as the operating and maintenance costs. The size and noise of laser welders has been a factor for many, however this is a bit less problematic now that smaller desktop machines have come to the market.

2. Single pulse tungsten inert gas welding (TIG):
To overcome these minor issues associated with laser welders, a new development in dental welders was introduced at the IDS meeting in Cologne in March 2003. The phaser mx1 *(fig. 12)* is a pulsed micro electric arc welder obtaining the same precision quality welding results as a laser welder *(figs. 13 and 14)*.

This welder uses tungsten inert gas (TIG), welding with single pulses. This technology was initially used in the metal industry to join light metal alloys such as Titanium and Aluminium, as well as special steel alloys. The phaser mx1 is not the first application of this technological

Fig. 12. complete set primotec phaser mx1 including controller unit, zoom-microscope and handpiece

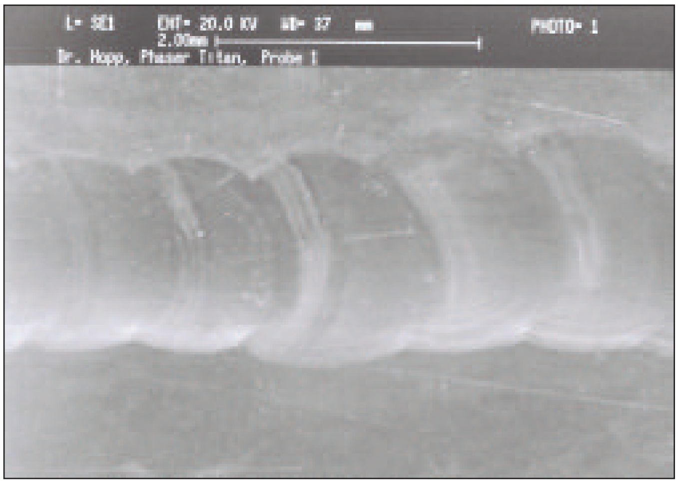


Fig. 13. SEM picture of a proper Titanium phaser mx1 welding seam

principle to the dental field,[24,26] however it is the first machine consequently designed for the specific needs of the dental technician. Successfully applying this kind of welding (TIG) to dental technology has already been described by Zukunft[26] in regards to CoCr alloys.

The main difference between the laser and the single pulse TIG principle is that the laser applies "light" energy to the object while the single pulse TIG applies "electric" energy. The object however "does not care" if the energy is created by light or by electricity, when the heat energy hits the object it just melts. Unlike laser "light" (reflection, mirror principle), "electricity" welding is not influenced by the surface condition of the object. The other advantages of the pulsed electric arc micro welder are greatly reduced investment costs (appox. 1/3 of a laser), very compact dimensions resulting in minimum space requirements in the lab and the low weight. Also it has no audible noise during operation, as the technology does not require any fans or pumps for cooling. The phaser mx1 is maintenance-free and has extremely low operating costs compared to a laser welder. In addition to regular replacement of the filters and viewing glass, laser welders typically need service and maintenance once a year and a new laser lamp every three years.

Developed by technicians with an extensive laser background, the phaser mx1 was designed with "automatic" Argon inert gas coverage of the welding spot delivered directly through the handpiece. In a laser welder the argon nozzles need to be adjusted almost every time before welding and the position of the nozzle is often in the technicians way. Also the phaser mx1 handpiece can be used in the fixed stand or it can be removed in order to use it freely in the operators hand. The laser output is fixed in only one direction (from top to bottom). This technology also features shadow-free and glare-free illumination. The light sources in the welding chamber of a laser welder are often placed in a way that the operators hands or model work create a shadow on the welding area when holding and focussing the workpiece. Wang & Welsch[24] researched laser welding, tungsten inert gas welding (TIG) and infrared soldering (brazing) on Titaniun. The area affected by heat was the smallest with laser welding, but the bending strength of the TIG welded joints was two to three times higher than the bending strength of the laser welded joints.

Prerequisites for Successful Welding >>

It is most important to understand that welding and soldering are two different methods that require different techniques and approaches. If the conventional solder technique in regards to case preparation and material science would be applied to welding without any changes, the welding would most likely fail. As an example, the thermal conductivity of a dental alloy versus its melting range needs to be considered carefully. For laser or phaser welding, the energy required to melt the alloy depends more on the alloys thermal conductivity than its melting range. Because of its high thermal conductivity, a high gold content alloy will absorb the energy faster and therefore requires greater energy input (power x impulse duration) than cobalt-chrome or titanium. This is true even though the melting range of the Co-Cr alloy (and/or the melting point of titanium) is much higher than that of high gold content alloys. When soldering, more flame-heat is needed to melt Co-Cr than to melt a gold alloy. In this case the thermal conductivity of the alloy is less important because the entire object is heated during the soldering process.

When a bridge is rocking and needs to be separated for soldering, the separating cut needs to be made at the interproximal connector. Ideally, soldering requires two parallel surfaces with a defined gap width of 0.2 mm so that the solder can "shoot" through the gap with capillary action and completely fill it. When the same bridge is welded rather than soldered, it is not necessary or ideal to separate at the interproximal connector. It is much easier and more productive to cut the crown and weld it directly on the master model (fig. 15 and 16). This would be impossible with soldering.

Future articles in this series will focus on step-by-step laser/phaser welding techniques, demonstrated on a variety of different alloys and actual case situations.

Method	Equipment Expenditure	Application Depth, Versatility	Educational Prerequisites	Biocompatibility	Heat Affected Zone
Torch (flame) Soldering	small	high	moderate	small	large
Post (ceramic furnace) or Infrared Soldering	moderate	high	moderate	small	large
Spot Welding	small	small	small	good	small
Plasma Welding	moderate	medium	medium	moderat	medium
Laser Welding	high	high	medium	good	very small
Phaser Welding (TIG)	moderate	high	medium	good	very small

Table 2 : Evaluation of different joining methods

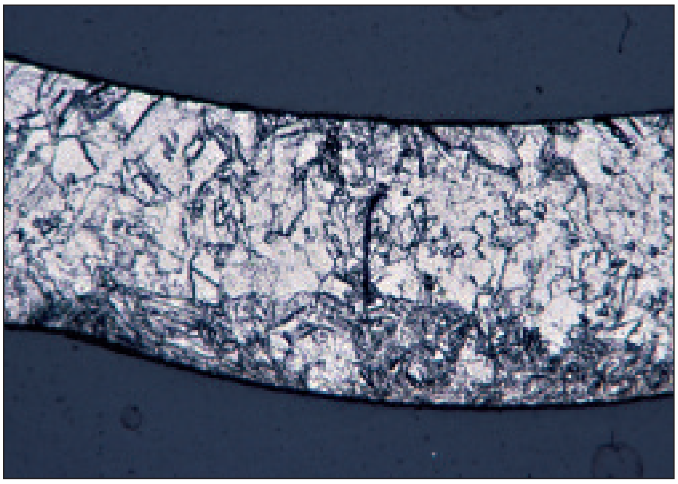


Fig. 14. Metallographic picture of the Titanium phaser mx1 welding seam shown in fig. 13

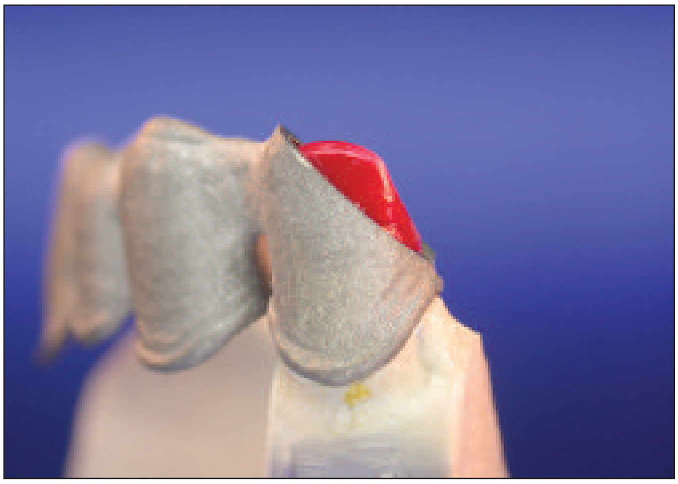


Fig. 15. A casting that rocks. Instead of cutting the connector, an alternative preparation for welding is to cut through the crown

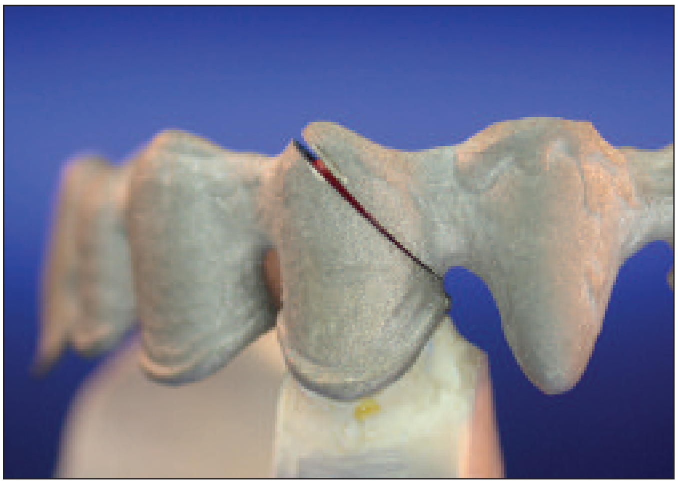


Fig. 16. The cut edges are not parallel. This shows the initial distortion in the bridge

Review of statements and observations regarding soldering and welding in dental publications:

* Wiskott et al. [25] found comparable tensile strength when soldering gold alloys with torch or infrared, while the tensile strength was significantly higher when the same gold alloys were laser welded.

* Comparing soldered and laser welded joints of different metals such as AuPt and CoCr, Kassenbacher & Dielert found the mechanical stability by far superior to conventionally soldered joints.

• Staffanou et al. [20] see the connection of different ceramic alloys by soldering as technically complicated and find inferior material data.

• Post soldering can be problematic. Sloan et al. [17] find the solder material itself, the low (post) soldering temperature and the use of flux as critical factors. Glassy residue of flux on the surface of the prosthesis, containing reduced or dissolved oxides can negatively influence the further working procedures and decrease the corrosion resistance.

• A lack of homogeneity in the material and severe disturbances of the grain structure in soldered areas were found by Preston & Reisbick [15]. The measured stability, however, was more or less identical no matter which gas mixtures had been used.

• When soldering CoCr cases, the CoCr solders reached acceptable mechanical data [9]. Even though the working process is more difficult, data comparable to the original material may be achieved.

• Angelini et al. [1] researched the influence of corrosive solutions on CoCr alloys that had been soldered with universal gold solders (type: AuNiZn) and CoCr solders. After simulated corrosion in Ringer solution and artificial saliva, tensile strength of the specimen dropped more than 50% when the universal gold solders had been used. This effect was substantially reduced with the use of CoCr solders.

• Soldering of Titanium in the dental laboratory, as well as intraoral resistance welding were described by Hruska&Borelli [10]. Both methods did not have any success due to the poor results and very difficult handling.

Review of statements supporting the advantages of laser welding over soldering and plasma welding:

• Geis-Gerstorfer et al. [7] researched the tensile strength of plasma and laser welded Titanium stating that the strength of the laser welding was only slightly lower than the originally cast material. The lowest strength was found on plasma welds. Specimens soldered under inert gas coverage and using industrial solders showed a tensile strength between the data for plasma and laser welding.

• The comparison of soldering, plasma and laser welding on dental alloys done by Dielert & Kassenbacher [3] resulted in the fact that the welding methods are by far superior over soldering and that laser welding is to be preferred as it is more versatile than plasma welding and has less influence on the grain structure of the welded material.

• When laser welding gold alloys, Eshleman et al. [6] found differences in the mechanical strength of differently pretreated cast objects. A heat treatment of cast objects after laser welding could, depending on the alloy, improve or decrease the mechanical strength.

• Researching a laser welded Degudent U specimen, van Benthem & Vahl [22] found that the strength of the welded specimen is slightly lower than the original cast material but two times higher that the soldered specimen.

• Smith et al. [18] found that laser welding is an effective method with good results on high gold content alloys.

• Comparing laser and plasma welded specimens, Roggensack et al. [16] achieved similar mechanical strength, while the plasma welded objects showed a wide heat affected zone with changes in the grain structure and increased hardness.

• In the works of NaBadalung & Nicholls, laser welded CoCr alloys showed convincing results compared to electric (plasma) welds, with results only slightly below the cast CoCr specimen.

• Dobberstein &Dobberstein [4] achieved good results with laser welded CoCr alloys. They mentioned the mechanical stability and the increased corrosion resistance as major advantages.

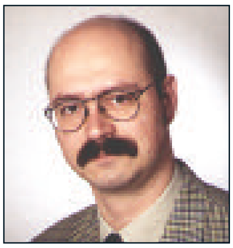
• Van Benthem & Vahl [23] detected a perfect corrosion resistance in laser welded joints of non precious materials when only minimum welding energy was applied with an ideal welding spot diameter.

Bio >> Joachim Mosch, CDT

Joachim Mosch was born in 1959, studied dental engineering and technology as well as international business. Mr. Mosch has been working for 18 years (for the last 11 years as general manager) at the European headquarters of an American dental company before he started his own business (primotec /primodent) in the year 2000. Mr. Mosch has published various articles on different dental subjects such as Light Cured Wax (the Metacon System), functional bite splint therapy using light cured splint materials (primosplint), welding techniques and laser, a.s.o. and gives lectures on these subjects throughout the world. Mr. Mosch is married, has two children and lives with his family in Bad Homburg/Germany.

Bio >> Andreas Hoffman, MDT

Andreas Hoffmann, born in 1956 achieved his German Master Dental Technician degree in 1985. As of then he was managing director and shareholder of a German dental laboratory group. He sold his shares and started his new laboratory 1. DSZ in the year 2000. At the same time he was appointed director of the "Akademie Umfassende Zahntechnik", a highly respected post graduate education program by one of the major German laboratory associations (VUZ) where he is also member of the board of directors. He received the Straumann prize in 1998 and is known in Germany and Europe for his outstanding publications, lectures and courses on Metacon (light cured wax), phaser and laser welding techniques, Cercon, Versyo.com, Cerec, Procera, and Galvano. Mr. Hoffmann is married, has two children and lives with his family in Bilshausen/Germany.



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