MECHANICAL PROPERTIES OF WELDED ORTHODONTIC METAL APPLIANCES

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Abstract: *The soldering of metal appliances is frequently required in order to create individual orthodontic appliances and to achieve efficient treatment procedures.*
Aims: The purpose of our study was the evaluate the mechanical strength and the microhardness of joints welded with universal silver solder and with laser technique.
Materials and Methods: The joints were produced by various dental technicians using three different soldering technique- flame, ultrasound and laser. The tensile strengths were measured with a universal testing machine, while smooth surface and characteristic nugget formation were microscopically evaluated. Results were statistically analysed.
Results: The laser welding technique provided superior strength results compared to the silver solderingand flame method.
Conclusions: Laser welding represents an expansive but efficient technique that will be more frequently used in the future.

Keywords: *orthodontic materials, laser soldering*

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1. Introduction

The soldering procedures occupy a well-defined place, as they are frequently required fororthodontic laboratory.
Joining a metal framework is frequently necessary to create individual orthodontic appliances and achieve efficient treatment procedures(figure 1)Bertrand, 2001;Prasad, 2009;Bertrand,2004).

Fig. 1. Welded orthodontic constructive solutions

The easiest usage came back for a long period of time withwelding with flame and filler material, at melting degrees higher than 450^0 C. The heat input on a relatively large volume of material and the difficult controlling of the process induces structural transformations in the processed materials, with adverse effects upon the reliability and security of the joints. Usage is associated with biocompatibility and corrosion phenomena. The mechanical strength of the joint does not rise to the level of basic materials, due to the peculiarity of thefiller materials that were used.
As an alternative to thermal conjoining procedures by melting, one might use the ultrasound procedure. The procedure carries out the conjoining in a solid form, without filler material, and the structural transformations due to thermal fields are practically absent. You can observe the possibility of joining materials that are metallurgically different. The lack of heat affected areas raises problems with regards to plastic deformation, or corrosion.
Remarkable progress in the laser technology brought the procedure in the field of making joints for orthodontic appliances. Interactions between lasers and materials are very complex phenomena. The success of laser welding procedures in dental metals depends on the operator's control of many parameters.
Laser welding technique was chosen for its versatility in Ni-Ti dental metal processes. With this research we are to assess the accuracy, quality and reproducibility of this technique as applied to conjoining wires. The advantages of laser welding systems can be summarized as follows: no solder and thus no galvanic corrosion at the joint. Some phenomena can be blurred by using protection inert gases in the area of the joint(Jens Johannes Bock, 2008; Szuhanek, 2006).
The application of laser welding technology allows titanium to be welded predictably and precisely in order to achieve an accurate fit of a milled framework. Laser energy results in localized heat production, thereby reducing thermal expansion. Unlike soldering, laser energy can be directed to a small area.
Laser welding yields strong, seamless connections. Research indicates that laser welds are stronger than traditional solder joints and close as strong as the original alloy. As a result, they provide greater patient comfort. Therefore itis fast becoming

an essential part of today's dental laboratory. The reasons are simple: it is quicker, easier and produces better results.

The purpose of this experimental programmeincluded a comparative evaluation between welding with different techinques- flame, ultrasounds, laser. The determined features were specific to tensile tests, metallographic examination, hardness aimed to highlight performances, compared evaluation and to promote technically and technologically efficient solutions with applications in orthodontics.

2. Material and method

The experimental programme took part at the Politechnica University of Timisoara, in collaboration with Faculty of Dental Medicine, University of Medicine and Pharmacy „Victor Babes" Timisoara. The materialswere those currently used for elements of fixed orthodontic appliances, alsofor removable ones. Samples where welded joints between rings and arms holding tension screws, also between adjacent wires, are needed (figure2).The vast majority require weding between a plane surface of rings and the screw holding wire with round or profiled section, which technologically can be easily done.

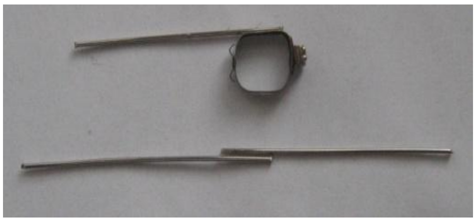

Fig. 2. Welded samples

We used for welding an orthodontic stainless steel wire which had a diameter between 0,96 – 0,99 mm, which represents a section of 0,746 mm^2.In the delivery set the tensile strength of 1800 - 2000 N/mm2 is specified. The rings had the minimum section along the welded wire of 3,16 x 0,15 mm, which brings the section in the contact area for welding at 0,474 mm^2.

In light of the welding to be done, a metallic contact of at least 6mm along the wire generator and prefab rings was ensured. A similar contact length was also ensured between the generators of joined wires. Joints between wire and ring were used, also between two wires, welded with flame and filler material, ultrasounds and laser, prepared according to the previous image.

Flame welding used bottled butane gas. The filler material had the diameter of one millimeter.For ultrasound welding there was thebearing force of 100N, with the duration of 1s. Laser joints were made at the pulse power of Pp = 900 W, duration Dp = 10 ms, with the energy Ep = 8 J.

The welded samples were tensile tested, submitted to metallographic examination, and the microhardness of HV 0.5 was established in the specific areas of joints.

With the tensile test the tensile strength was established and the location of the breakage was analyzed. The referential for the tensile test was the normative SR EN 10002-1/2002, with the tensile testing machine in Figure 3. Thus, one end of the wire was immobilized in the jaw of the machine, and the cotter of the working device was introduced in the ring attached to the wire. The wires welded along the generator were tightened at the extremities between the adapted jaws of the machine that was used.

Fig. 3. Machine for tensile testing

The metallographic examination highlighted joining defects, the configuration of the joint, the nature of structural constituents, according to SR EN 4590-90.
Transversally over the joint areas there are hardness traces of HV 0.5. The referential for establising hardness is SR EN ISO 14271-2002.
The number of samples allowed to evaluate the results by using the principles of mathematical statistics. For an accurate determination of the distribution of experimental results location indicators and statistical variability were calculated, for all analyzed variables, by applying specific relations, determining the arithmetic average, amplitude and medium square deviation [Szuhanek 2008, ADA specifications]. The facilities offered by calculation programs EXCEL 7.0 andMATHE-ASS, which run in Windows '97, were used.

3. Resultsand discussions

We have joints welded by flame with filler material, ultrasounds and laser for compared analysis of the results.
The results that were obtained on samples welded with ultrasounds were superior to the results obtained with welding with flame and filler material, but under than those obtained with laser welding.
The flame welding procedure allows the difficult control of thermal fields which can be seen in the determined results. The more favourable features of laser joints are ensured because of a more stern control of technological parametres, in comparison with the other procedures involved in the experiment. The values of tensile strengths are superior to the values needed in orthodontic treatments highlighted through mathematical modelling, namely by concepts of finite elements [6, 7]. Still, what differentiates the tested conjoining procedures are the important dispersions in flame welding compared to laser welding. The consequence is found in the behaviour during the usage of joints which has effects upon the pacients’ disconfort.

1. Tensile testing led to the results in Table 1.The graphic representation of tensile strengths is found in figure 4.

Sample nr.	Weldingprocedure	Wire-ring joint				Wire-wire joint			
		Rm /N/mm^2/	R /N/mm^2/	S	Breakpoint	Rm /N/mm^2/	R /N/mm^2/	S	Breakpoint
1	Flame with filler material	782,5	155,9	5,1	ring	1051,1	25,18	9,4	weld
2	Ultrasounds	801,2	100,6	3,9	weld	1602,3	120,9	6,1	wire
3	Laser	955,5	85,4	2,8	ring	1751,1	101,1	3,9	wire

*Rm –Tensile strength, R - amplitude, S – medium square deviation.

Tab. 1. Results of tensile testing *

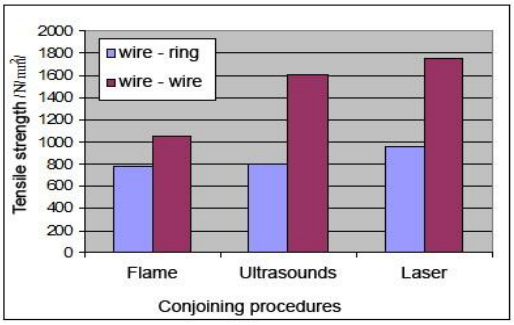

Fig. 4. Tensile strength of welded joints

a. Results of the metallographic examinations are presented in figure 5with images of joints made with flame welding, ultrasoundwelding and also laser welding.

a) b) c) d) e)

Fig. 5. Metallographic images of joints made with flamewelding (a), ultrasoundwelding(b, c), laser welding (d, e)

Metallographic examination of samples welded with flame and filler material highlightsincomplete permeation to the joining between wire and ring, under the conditions of the negative angle created between curved surfaces (figure5. a). The cause can be due to incondite moistening and fluidity of the melted filler material. Partial adhesion of the components conjoined with filler material is observed. No microfissuresare identified. The thermal influenced area is 1 mm wide, namely it is superior to the thickness of the material of the conjoined ring, but comparable with the thickness of the used wires.One can notice the presence of precipitations of compounds specific to the main elements of alloying, with favourable effects upon the fragilization of the joint, but unfavourable with regards to its elasticity.

With joints done with ultrasound welding one can observe interference by diffusion of the materials of components. According to the macroscopic image it appears that no joining took place, and this is contradicted by the microscopic image (figure 5. b,c). The non-linearity of the interface confirms the coalescence of the materials of components. It is crucial to prepare the surfaces: smoothness, roughness, cleaning, in order to ensure metallic contact.

With laser welding there is the liquid state of materials in the joining area, metallurgical phenomena of structural transformation and solidification carried out at high speed are induced (figure5. d, e). The thermal influenced area is reduced. No microfissures are identified. High temperature favours the occurrence of chemical and intermetallical compounds.Their presence is materialized by high hardness of the area submitted to thermal cycles, but also with tendencies towards fragilization.

b. Results of HV 0,5 hardness determinationsare presented in tables 2 and 3.

In figures6and7there are evolutions of HV 0.5hardness values, in transversal direction over joint areas.

Sample	Welding procedure	Basic material wire			Thermal influenced area 1			Deposited material			Thermal influenced area 2			Basic material ring		
		HV0,5	R	S	HV 0,5	R	S	HV0,5	R	S	HV0,5	R	S	HV 0,5	R	S
1	Flame with filler material	390	11,9	3,9	379	15,2	4,1	330	17,2	6,2	372	16,3	4,9	361	10,3	3,6
2	Ultrasounds	401	10,9	3,5	398	14,1	2,7	-	-	-	362	14,7	3,0	364	11,9	3,5
3	Laser	396	10,4	3,6	419	12,0	3,5	414	14,1	4,2	405	14,0	3,7	362	9,9	3,5

Tab. 2. Results of investigations on wire-ring joints

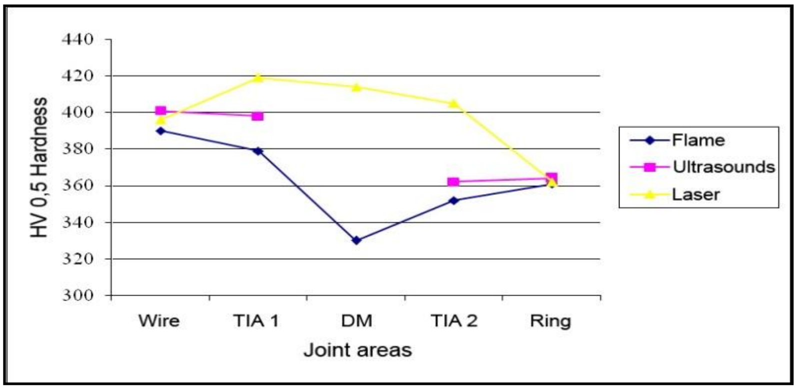

Fig. 6. Hardness evolution in wire-ring joint areas

Crt. no.	Welding procedure	Basic material			Thermal influenced area 1			Deposited material			Thermal influenced area 2		
		HV0,5	R	S	HV0,5	R	S	HV0,5	R	S	HV0,5	R	S
1	Flame with filler material	390	11,9	3,9	381	14,9	4,6	335	15,9	6,8	379	13,9	5,3
2	Ultrasounds	401	10,9	3,5	389	14,0	3,5	-	-	-	391	14,0	3,1
3	Laser	396	10,4	3,6	420	12,1	3,9	421	13,6	4,8	425	12,5	3,7

Tab. 3. Results of investigations on wire-wire joints

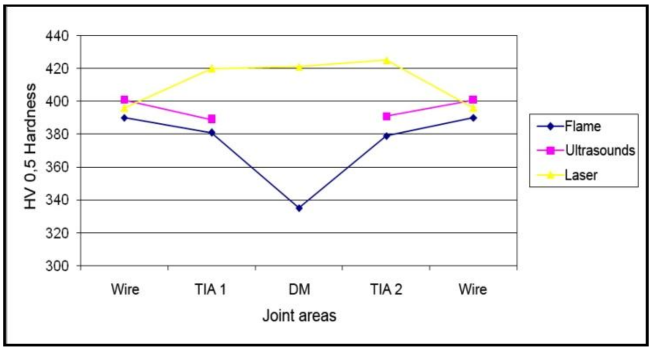

Fig. 7. Evolution of hardness in wire – wire joint areas

The previous representation underlines the effect of concentrated thermal fields associated with the laser procedure, in comparison with other used procedures. With flame welding a filler material was used whose melting did not reclaim thermal effects and structural changes with pronounced hardening.In the thermal influenced areas of the joint one finds the effect of melted mixture of basic materials with the filler material.
Note that ultrasound welding is done in a solid state, without filler material, and we do not have the problem of melted material. Structural transformations in the area of welded components were not significantly affected by heat. Consequently, hardness registers comparable values, and sometimes even lower than in basic materials that were used.
Laser welding procedure, with high concentrated heat input, induces structural changes with rapid heating and cooling, favourable to the appearance of hard structural constituents, with the tendency of fragilization of the joint.
Among the used procedures noticethe lower values of the amplitude of hardness, namely medium square deviations in laser joints, compared with flame joints, and also ultrasound joints. The explanation derives from the control and a more rigorous monitoring of technological parametres when using the laser procedure, related especially to flame usage for conjoining experimented materials.
After analyzing the results that were obtained after attempts and analysis of three conjoining procedures obvious differences were noticed. Intensile testing, using a filler material with medium fusion temperature implicitly led to lower values of tensile strength than in the case of samples welded with laser in which the melted material came from joint components. The situation is correlated with the results of the metallographic analysis, where the working temperature and fluidity of the melted

material favoured adherence of joints that were done by using the laser procedure. Concentrated energy specific to laser joints induced thermal cycles with high temperature gradients, with fast thermic effects.

4.Conclusions

1.The welding procedures bring a thermal input that is different in the joining areas. This was highlighted by lower values in tensile strength of joints made with flame welding and ultrasound welding compared to joints made with laser welding.
2.Structural changes associated with the laser technique are correlated with higher hardness values in areas affected by welding, related to the effects generated by flame welding and ultrasoundwelding.
3. There is a lack of thermal transformations on the surface ofan ultrasoundjoint, which leads to hardness values that are comparable to those of basic materials.
4.The parameters of laser welding were superior to those from other techniques, but optimizations of technological parametres are necessary in order to minimizethermal effects that generate areas of hardness and high fragility.

5. Acknowledgments

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***ANSI/ADA Specification No. 32—*Orthodontic Wires*

***ANSI/ADA Specification No. 88—*Dental Brazing Alloys*