Tensile and Shear Breaking Force of the Joints Between Stainless-Steel Orthodontic Bands and Buccal Tube Attachments Joined by Laser and TIG Welding Without Filler Material

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Orthodontic appliances usually require the joining of different stainless-steel parts in order to achieve adequate control over tooth movement during the active treatment. The aim of this study was to assess the tensile and shear breaking force of the joints between forty orthodontic bands and forty attachments (buccal tubes), joined by laser and TIG welding, without filler material. For the laser welding technique, we used an XXS Laser (OROTIG) welding unit and for the TIG welding technique, a PUK D2 (LAMPERT) welding unit. The tensile and shear breaking force of the welded joints was determined using the Z010 Zwick/Roell testing machine. The independent-samples t-test showed statistically significant differences between the laser and TIG groups for both the tensile and the shear breaking force tests, the laser welded samples having better mechanical strength than the TIG welded samples. For practical use, under normal loading forces, both techniques are suitable for this particular application in orthodontics. In patients with parafunctional habits, that could develop higher bite forces, the failure of the welded joints might occur if the welding surface is not increased, especially for the TIG welding technique.

Keywords: tensile breaking force, shear breaking force, orthodontic bands, buccal tubes, laser welding, TIG welding

Orthodontic appliances usually require the joining of different metal parts in order to achieve adequate control over tooth movement during the active treatment. Stainless-steel, a mixture of several chemical elements (C, Si, Mn, P, S, Cr, Ni, Fe etc.), is one of the most common alloys used to produce these metal components [1,2]. In order to function properly, no matter the technological process they are subjected to prior to the insertion into the oral environment, the alloys used in dentistry are required to maintain several characteristics: biocompatibility, corrosion resistance and optimal mechanical properties in order to counteract the forces produced during the functions and sometimes the parafunctions of the dento-maxillary system [3].

The components of the fixed orthodontic appliances are joined together using different methods, with or without filler material: soldering, plasma welding, resistance (spot) welding, single pulse tungsten inert gas (TIG) welding or laser welding [4].

Using crystals of yttrium aluminum garnet doped with neodymium, laser welding found its way in dentistry mainly through prosthodontics and was later applied in orthodontics [5–8]. Several parameters (pulse energy, peak pulse power, wave length, output energy, pulse frequency, pulse duration, spot diameter and the type of materials) have an important

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impact on the mechanical properties of the laser welded joints [4, 8, 9]. TIG welding, an arc welding process, was introduced in orthodontics as a lower cost alternative [10]. Laser and TIG welding systems offer several advantages over conventional welding techniques: more ergonomic working conditions, because of the stereomicroscope included with the welding units, higher precision and the possibility to prevent oxidation of the welding area using a shielding atmosphere of argon [11].

In the therapy of dento-maxillary anomalies, fixed orthodontic appliances (braces) rely on the use of orthodontic bands and attachments to achieve proper anchorage and a constant control over dental movements. The aim of this study was to assess the tensile and shear breaking force of the joints between the bands and the attachments (buccal tubes), joined by laser and TIG welding, without filler material.

Experimental part

Materials and methods

We used a set of forty orthodontic bands (stainless-steel alloy AISI 304L/305L, second upper left molar bands, size 21, Leone, Italy) and forty attachments (stainless-steel alloy AISI 316L, upper left buccal tubes, 0.022x0.028-inch slot, Leone, Italy), divided into four equal groups. The size and the producer were randomly chosen. All the attachments were prepared using flat nose orthodontic pliers to ensure a good fit with a gap less than 0.5 mm between the foot of the attachment and the surface of the band, in order to allow a welded joint without the use of a filler material. The attachments were set in place and properly aligned in the middle of the buccal surface of the molar bands using a Pean forceps for easier handling (Fig. 1). To prevent oxidation, the welding was carried out under a protective atmosphere of argon.

Fig. 1. Handling of the samples

For the laser welding technique, each corner of the foot of the attachment was welded using three welding spots with a diameter of 0.7 mm, each spot overlapping 80 % to 90 % of the surface of the previous one. An XXS Laser (OROTIG) welding unit (Fig. 2) was used with the following parameters: an output power of 1.5 kW, a pulse duration of 3 ms and a frequency of 1 pulse/s. The incident angle was approximately 45°.

Fig. 2. XXS Laser (OROTIG) welding unit.

For the TIG welding technique we used a PUK D2 (LAMPERT) welding unit (Fig. 3) set for the steel welding program with an output power of 40% and a duration of 3 ms. In order to produce a welding surface similar in size to the laser welding surface (four welded corners totaling approximately 2 – 2.5 mm^2), an electrode with a 0.6 mm tip was used to obtain two welding points for each corner of the foot of the attachment. The tip of the electrode was resharpened after each buccal tube was completely welded to the corresponding molar tube.

Fig. 3. PUK D2 (LAMPERT) welding unit

The tensile and shear breaking force of the welded joints was determined using the Z010 Zwick/Roell testing machine (Fig. 4), capable of producing a maximum force of 10 kN, equipped with mechanical holding grips. The measurements were recorded with the use of the testXpert II (v. 1.43) testing software. The crosshead speed was set to 30 mm/min.

To facilitate the proper grip of the samples, a round steel orthodontic wire of 0.6 mm was run through the buccal tube and adapted in a U-shaped loop. Before the testing procedure, the orthodontic bands were filled with a core consisting of an 8 mm circular section with a 5 mm height steel rod in the center and an orthodontic self-cured and heat-cured acrylic resin (Leocryl, Leone) as a filler on the periphery (Fig. 5), in order to improve the grip of the sample and to reduce the deformation of the samples during testing. The orthodontic acrylic resin filler was cured at approximately 40°C and a pressure of 2.5 Atm, for 20 minutes.

For the tensile breaking force tests the samples were fixed in the mechanical holding grips by the steel core on one end and by the U-shaped loop on the other end (Fig. 6), while the wire loop was perpendicular to the foot of the attachment. For the shear breaking force tests the samples were fixed using a separate custom-made jig with a horizontal slot to accommodate the height of the steel core, while the wire loop was parallel to the foot of the attachment (Fig. 7).

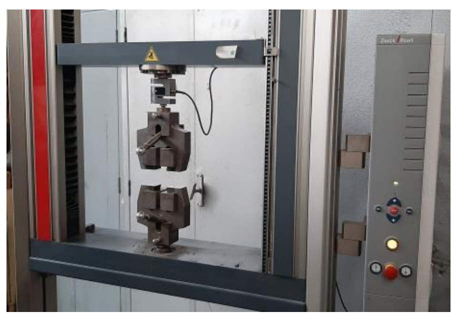

Fig. 4. Z010 Zwick/Roell testing machine

Fig. 5. Orthodontic molar band specimen.

Fig. 6. The setup for the tensile breaking force tests.

7.a. 7.b.

Fig. 7. The setup for the shear breaking force tests: a) frontal view; b) side view

Statistical analysis

The data were statistically analyzed using specialized software (IBM SPSS, version 24, SPSS Inc., Chicago). Inspecting the boxplot diagrams, we concluded that the data had no outliers, with one exception in the shear breaking force tests group (175.05 N), among the TIG welded samples. The outlier was not extreme and was included in the analysis, because it did not affect the overall results. The data was normally distributed, as assessed by Shapiro-Wilk's test ($p>0.05$) and the assumption of homogeneity was not violated, as assessed by Levene's test for equality of variances ($p=0.159$ for the shear breaking force tests group and $p=0.121$ for the tensile breaking force tests group). An independent-samples t-test was applied to compare differences between the laser and the TIG group for the tensile and shear breaking force tests. We considered the results to be statistically significant at $p<0.05$.

Results and discussions

The results of the tensile and shear breaking force tests are presented in Table 1 and in Fig. 8-11 and the descriptive statistics are shown in Table 2.

Table 1

THE RESULTS OF THE TENSILE AND SHEAR BREAKING FORCE TESTS

	Tensile breaking force (N)		Shear breaking force (N)	
Sample no.	Laser	TIG	Laser	TIG
1	483.76	249.71	193.93	159.23
2	326.42	195.63	230.93	113.24
3	557.74	266.08	276.53	134.66
4	546.02	275.90	230.63	175.05
5	412.90	180.25	250.34	131.26
6	421.75	323.65	227.75	137.95
7	391.35	281.32	158.03	124.70
8	355.85	267.59	250.27	107.71
9	440.17	192.61	284.43	116.93
10	363.02	248.17	203.90	130.69

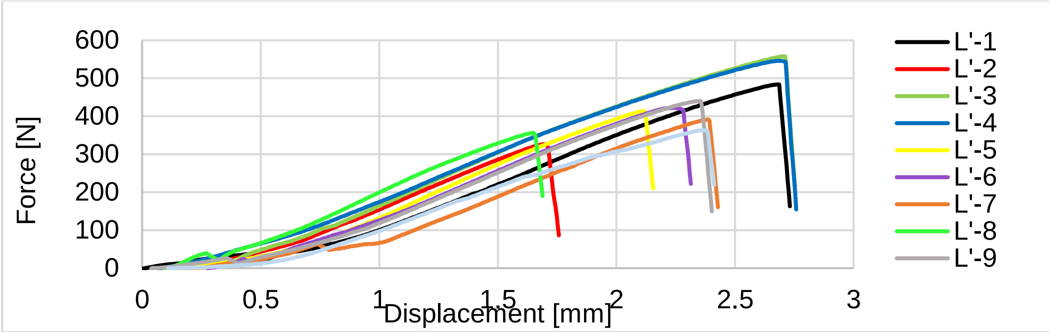

Fig. 8. Tensile breaking force and displacement diagram for the laser welded samples

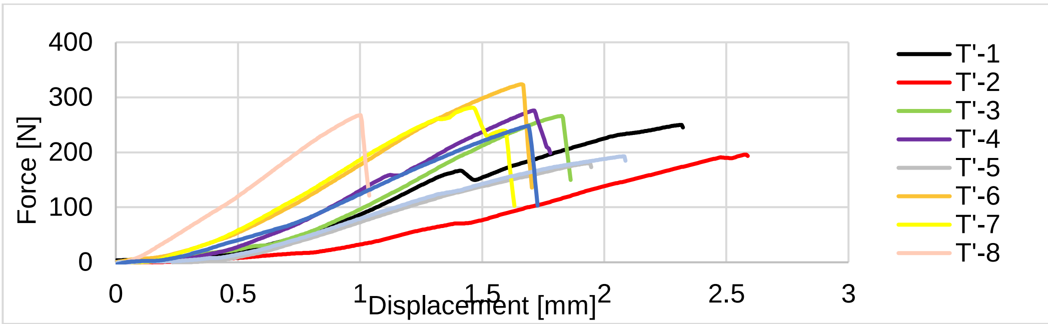

Fig. 9. Tensile breaking force and displacement diagram for the TIG welded samples

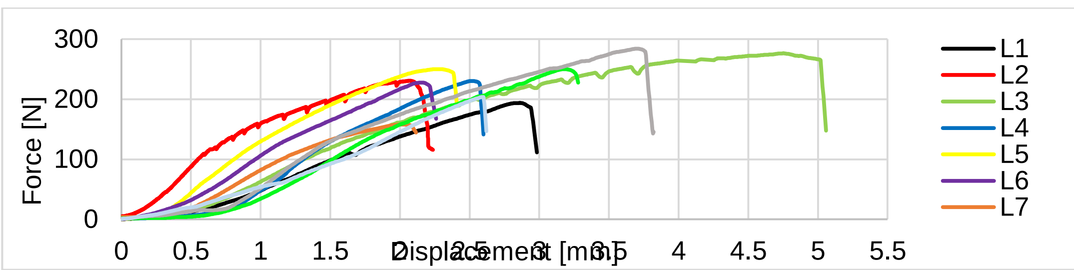

Fig. 10. Shear breaking force and displacement diagram for the laser welded samples

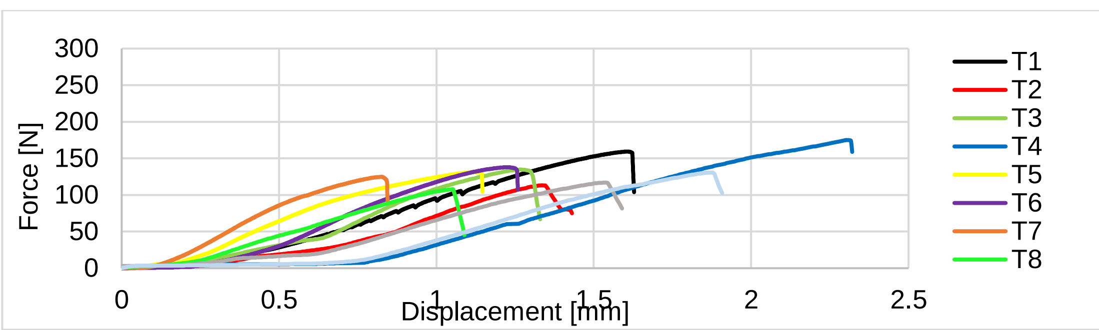

Fig. 11. Shear breaking force and displacement diagram for the TIG welded samples

Table 2
DESCRIPTIVE STATISTICS

	Tensile breaking force (N)		Shear breaking force (N)	
	Laser	**TIG**	**Laser**	**TIG**
Mean	429.898	248.090	230.674	133.142
Std. Error	24.797	14.424	12.072	6.539
Median	417.325	257.893	230.780	130.978
Std. Deviation	78.415	45.614	38.176	20.679
Minimum	326.416	180.251	158.032	107.712
Maximum	557.739	323.648	284.430	175.047

The independent-samples t-test (Table 3) showed statistically significant differences between the laser and TIG samples for the tensile and the shear breaking force tests. The laser group had higher breaking force values for tensile breaking force tests, 181.808 (95% CI, 121.538 to 242.077), t(18)=6.338, p<0.005, as well as for the shear breaking force tests, 97.532 (95% CI, 68.687 to 126.377), t(18)=7.104, p<0.005.

Table 3
INDEPENDENT-SAMPLES T-TEST, COMPARING DIFFERENCES BETWEEN THE LASER AND THE TIG GROUP FOR THE TENSILE AND THE SHEAR BREAKING FORCE TESTS

Variables	t-test						
	t	df	p	Mean Diff.	SED	95% CI	
						Lower	Upper
Tensile breaking force (N)	6.338	18	0.000*	181.808	28.687	121.538	242.077
Shear breaking force (N)	7.104	18	0.000*	97.532	13.730	68.687	126.377

df – degrees of freedom; Mean Diff. – Mean Difference; SED – Std. Error Difference;
*95% CI – 95% Confidence Interval of the Difference; *p<0.0005.*

There are few studies published in the literature about the mechanical behavior of welded orthodontic attachments. The wide variety of welding techniques and devices can lead to different results when applied to similar conditions, making it even more difficult to compare results from different sources and studies.

The data derived from welding precious and non-precious alloys used on a large scale in prosthodontics can only be applied in limited situations when referring to the fracture strength of the welded joints that are designated for orthodontic clinical applications [5,12]. The type of material, the type of welding devices and their working parameters (e.g. output energy, pulse frequency and duration, spot diameter in laser welding units) can also influence the characteristics of the welding surface, the heat-affected zone and the mechanical properties of the welded joints [6–8,13].

In our study we used the general working parameters recommended by the manufactures, but also optimized them, following the guidelines provided by previous studies [3,14] to achieve a reliable welded joint, with a high enough output power to produce an optimal penetration depth, but not as high as to produce the perforation of the orthodontic band. We also want to mention that the conditions needed to cure the orthodontic acrylic resin filler (most of which are similar to those found in the oral environment, with the exception of the high pressure) had no influence on the mechanical properties of the steel alloy or the welded joints. These types of acrylic resins also showed good mechanical properties, with good dimensional stability during testing [15].

Both welding methods have many advantages, but the literature reported conflicting results about the mechanical properties of the welded joints. Rocha et al. [9] reported increased flexural strength for the TIG welding samples when using non-precious alloys, while the laser welding achieved lower values for the flexural strength. Bock et al. [10] reported comparable results in the tensile strength and microhardness of TIG and laser welding and stated that the TIG welding method should be considered as a low-cost efficient alternative for orthodontic applications. In contrast, our study showed better results in the tensile and shear breaking force tests in the laser welded samples.

The bite force varies greatly depending on age, gender, cranio-facial morphology, periodontal and dental status, associated temporomandibular pain and disorders, the presence of parafunctional habits (e.g. bruxism) [16–18]. In a study conducted on 18-year-old subjects, Varga et al. [19] reported a maximum voluntary molar bite force of 777.7±78.7 N in males and 481.6 ±190.42 N in females, similar to the values found by Braun et al. [20] in older adult subjects of 738 N and by Gibbs et al. [21] of 720 N. On the other hand, in a different study, Braun et al. [22] found lower values of 176 N for young adults (18-20 years of age). The forces are usually even higher in subjects with bruxism, especially among the male subjects [18] and during nocturnal bruxism [23].

Under normal loading (bite) forces of about 70 to 150 newtons, developed by the dento-maxillary system, both welding techniques should be adequate for orthodontic purposes, but under higher bite forces, with or without the accidental interposition of harder objects or food fragments, welding points failure might occur if the welding surface is not increased, especially for the TIG welding technique. Similar situations could occur while using band remover pliers that exert excessive forces on the welded attachments.

Conclusions

The joints between stainless-steel orthodontic bands and buccal tube attachments joined by laser welding without filler material showed better mechanical strength than the samples joined by TIG welding, when subjected to tensile and shear breaking forces.

For practical use, under normal loading forces, both techniques are suitable for this particular application in orthodontics. In patients with parafunctional habits, that could develop higher bite forces, the failure of the welded joints might occur if the welding surface is not increased, especially for the TIG welding technique.

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