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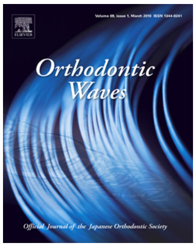

Original article

Corrosion of laser-welded stainless steel orthodontic wires

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ABSTRACT

Purpose: Fabricating orthodontic appliances using laser welding has the clinical advantage of biocompatibility, because the welded joint does not require soldered alloy. The purpose of this study was to investigate the corrosion of laser-welded stainless steel wires in acidic environments.

Materials and methods: Laser welding of stainless steel wires with a 0.021×0.025 in cross-section was performed at an energy output ranging from 0.5 to 1.3 kW. A control sample was prepared using conventional soldering. The samples were immersed in 1% lactic acid aqueous solution for 7 days. After immersion, the concentrations of metallic ions in solution were measured using inductively coupled plasma atomic emission spectroscopy. Tensile loading tests were carried out with and without lactic acid immersion. Scanning electron microscopy was used to examine the microstructure of laser-welded samples.

Results: The concentrations of metallic ions detected in solution for laser-welded samples were significantly lower than that for soldered sample. There was no significant difference among the mean tensile strengths with and without immersion for laser-welded samples. The penetration depth and the localized region fused by laser irradiation increased with energy output, and ductile fractures were observed in the fused region of laser-welded samples.

Conclusion: Laser welding of stainless steel orthodontic wires should be acceptable for clinical use, because the joints showed sufficient strength and the original structure was not significantly altered. Immersion in acidic solution had minimal effect on the mechanical performance at the joint regions, and showed minimal acceleration of metallic ion release.

1. Introduction

The joining of a metal framework is frequently necessary to create individual orthodontic appliances and to achieve efficient treatment procedures [1]. Conventional soldering and electrical resistance welding have been used in clinical orthodontics to join orthodontic alloys due to their ease of operation. There are four major orthodontic alloys currently in widespread use for orthodontic wires: nickel-titanium,

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beta-titanium, stainless steel, and cobalt-chromium [2]. Among them, only stainless steel and cobalt-chromium can be soldered using a conventional silver-based solder alloy [3], which has been used to fabricate many orthodontic metallic appliances [1,4]. Although it is possible to join the beta-titanium alloys by electrical resistance welding, the application is limited to thin sections of materials, such as wires and molar bands [5,6].

Research and applications for lasers in dentistry have expanded over the last few decades. Laser welding was recently introduced in orthodontic bracket manufacturing as an alternative to alloy soldering. This technique eliminates the intermediate phases such as soldering alloys and shows acceptable mechanical performance with a low risk of joint failure [7]. Laser welding could be used for fabricating orthodontic appliances, such as welding the screw expander to the molar bands and miniscrew-assisted customized appliances [8,9]. In addition, laser welding for joining titanium-based alloy wires has become popular in clinical applications [4,10,11], as conventional soldering is not suitable for joining titanium-based alloys due to their extremely high reactivity with oxygen at high temperatures. Furthermore, previous studies reported that laser-welded wires showed clinically sufficient joint tensile strength, although the joint strengths were lower than those achieved with conventional soldering [4,10]. In conventional soldering, the parent alloys are joined using different types of alloys, which may accelerate the release of metal ions due to galvanic corrosion [12,13]. An in-vivo study detected a high concentration of metallic ions in the oral cavity after placement of an orthodontic appliance fabricated via conventional silver soldering, suggesting long-term risks of ion absorption and retention that may have deleterious health effects [14]. Another study found that conventional soldering was toxic toward osteoblast differentiation, fibroblast viability, and keratinocyte growth [15]. Therefore, laser welding in orthodontic applications may be clinically advantageous for biocompatibility, because the process eliminates the need for solder alloys. In addition, the surfaces around conventionally soldered orthodontic appliances are more susceptible to galvanic corrosion due to stagnate plaque, difficulty in teeth-cleaning, and decreasing pH values with increasing bacterial growth.

The purpose of this study was to investigate the corrosion of laser-welded stainless steel orthodontic wires in acid environments by analyzing metallic ion release and measuring joint tensile strength. Scanning electron microscopy (SEM) was used to examine the microstructure of laser-welded samples.

2. Materials and methods

2.1. Materials

Stainless steel is the most common metallic material in modern orthodontics. Preformed stainless steel orthodontic wires with cross-sectional dimensions of 0.021 × 0.025 in (stainless steel archwire, 3M Unitek, Monrovia, CA, USA) and a silver-based alloy solder (Tomy International, Tokyo, Japan) were purchased. The nominal compositions for stainless steel wire and silver-based alloy solder were confirmed by X-ray fluorescence spectrometry (EDX-720, Shimadzu, Kyoto, Japan) and are summarized in Table 1. The wire contained approximately 9% nickel (Ni), 18% chromium (Cr), and a small amount of iron (Fe); thus, the composition was determined to be type 304 austenite stainless steel (ISO No. 4301-304-00-I). The solder material was a silver alloy containing approximately 25% copper (Cu) and 20% zinc (Zn).

2.2. Sample preparation

The wires were cut into 5-cm segments with a slow-speed water-cooled diamond saw (Isomet 11-1280, Buehler, Lake Bluff, IL, USA), the segment pairs were placed end-to-end, and the samples were fixed in a custom-made jig. These segments were then joined using a Nd:YAG laser welder (Neolaser L, Girrbach, Pforzheim, Germany) under argon gas shielding to prepare test samples. Double-welding on each 0.025-in. surface was performed, and the pulse duration and spot diameter were fixed at 2.5 ms and 0.6 mm, respectively. The focal distance was 35 mm. The energy output ranged from 0.5 to 1.3 kW. A conventionally soldered sample was prepared as a control using a dental soldering torch in air. Stereomicroscope photomicrographs of soldered and laser-welded specimens are shown in Fig. 1. The end-to-end configuration joint was used in this study because it has generally been used for testing joint strength.

2.3. Static immersion test (analysis of released ions)

Fresh 1% lactic acid aqueous solution comprising 0.1 mol/L lactic acid and 0.1 mol/L sodium chloride was prepared immediately before use (pH 2.3) according to ISO 10271. The laser-welded and soldered wire samples were immersed in separate plastic vials containing 14 mL of solution for 7 days at 37 °C (n=5). After the immersion period, the concentrations of

Table 1 – Nominal compositions for stainless steel wire and silver-based alloy solder used in the present study (wt%).

	Composition (wt%)													
	Cr		Mn		Fe		Ni		Cu		Zn		Ag	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Stainless steel wire	18.28	0.02	1.39	0.06	70.98	0.13	9.35	0.11	–	–	–	–	–	–
Silver solder	–	–	–	–	–	–	–	–	25.49	0.05	19.62	0.33	54.89	0.30

Determined by X-ray fluorescence analysis.

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