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ORIGINAL ARTICLE

Variation in Surface Morphology and Microstructure of 316L Biomedical Alloys Immersed in Artificial Saliva

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Objective: The objective of this study was to compare changes in the surface morphology and microstructure of different types of 316L orthodontic bracket alloys such as one-piece injection molding (Group A) and two-piece soldering (Group B) that were immersed in artificial saliva solution (37 °C/pH 7.0) for various periods.
Methods: An optical microscope, atomic force microscope, X-ray diffractometer, and a scanning electron microscope equipped with an energy-dispersive X-ray spectrometer were used to investigate the surface properties including microstructure, roughness, and chemical compositions.
Results: The study results demonstrated that corrosion in both types of orthodontic brackets (A and B) initially occurred in the 3rd month, and an austenite (γ) → [γ + (Fe, Cr)O compound] microstructure transition occurred in the matrix of the bracket body when both orthodontic brackets were subjected to immersion for more than 3 months.
Conclusion: The Group A brackets, which exhibited better surface characteristics, maintained a low and constant level of surface roughness after various immersion times. Therefore, a modified metal injection molding (MIM) process based on a thermosetting resin developed with 316L stainless steel showed fewer pores and higher corrosion resistance.

1. Introduction

The bracket bonding technique has widely replaced the traditional banding as the contemporary orthodontic treatment.[1,2] There are three types of component material used for brackets and they are metal, plastic, and ceramic.[3,4] Of these, metallic brackets are still widely accepted by most orthodontists.[5,6] They are primarily composed of stainless steel,[7,8] of which many types exist. Most attachments are made from AISI 316L stainless steel. The major elements comprising this type of stainless steel are Fe, Cr, Ni, and Mo.[9,10]

Corrosion is one of the natural characteristics of metals. It is a process in which a metal deteriorates when it reacts with the environment.[11,12] Corrosion increases the wear rate of the bracket slot, which may reduce the transfer of torque or tip to the teeth from an activated wire to the bracket, resulting in poor orthodontic prognosis.[13,14] Therefore, the rate of corrosive attack frequently increases over time.[15,16] The three different types of methods used to manufacture metallic brackets are milling, casting, and metal injection molding (MIM).[17,18] Combined brackets are made by either soldering with brazing alloys to join the base and wings of the brackets or laser welding the wing directly to the base.

Brazed silver-based filler alloys of stainless steel that form a galvanic couple lead to ionic release of mainly copper and zinc.[19,20] Recently, gold-based brazing materials have been introduced. But, these new brazing materials, which also form a galvanic couple, might lead to the dissolution of stainless steel.[21] Previous studies indicated that the immersion time may be too short to acquire the corrosion resistance of metal orthodontic brackets.[22–27] However, none of these studies compared the changes in surface morphology and microstructure between one-piece injection molding-type brackets and two-piece combined-type brackets soldered with a brazing alloy after long-term immersion. Therefore, the objectives of this study were to select a bracket manufactured by one-piece MIM and a two-piece bracket with body and mesh base each made of AISI 316L stainless steel, soldering them together, immersing each in artificial saliva for a prolonged

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Table 1 Chemical compositions of the artificial saliva

Amount	Chemical composition							
	NaCl	KCl	$CaCl_2$ anhydrous	$MgCl_2 \cdot 6H_2O$	K_2HPO_4	Sorbitol solution 70%	Methyl paraben	Hydroxyethyl cellulose
(mg)	0.844	1.2	0.146	0.052	0.342	60	2	3.5

period, and then observing and detecting changes in surface morphology as well as microstructure under high magnifications.

2. Methods

2.1. Materials

2.1.1. Bracket selection

Two types of AISI 316L stainless steel brackets (right upper bicuspid) made by Rocky Mountain Orthodontics were selected. There were 50 samples for each type of metal bracket (a total of 100 samples). The samples for each type of bracket were randomly divided into five groups (A1–5 and B1–5, respectively), each of which was immersed in the solution for 1, 2, 3, 4, and 5 months, respectively. Each type of bracket was examined and compared with nonimmersed control.

2.1.2. Immersion solution

The immersion solution used is commercial artificial saliva obtained from Sinphar Pharmacy (Taipei, Taiwan) and its chemical compositions are shown in Table 1.[27] To mimic oral conditions, 0.02 ppm of NaF was added to this solution, following which the pH was adjusted to 7.0 by adding 0.1M NaOH. Each bracket was placed in a 10-mL glass bottle (5 mL solution content) and sealed with wax until testing. Each bottle was stored at 37 °C for 1, 2, 3, 4, and 5 months, and agitated 10 times once every week. At the end of each immersion period, the brackets were removed from the bottles with a plastic tip holder and washed for 5 minutes with distilled water, acetone, distilled water, and alcohol in an ultrasonic water bath. They were then dried and stored in an airtight box until testing.

2.2. Methods

2.2.1. Preparation of specimens for observation

The brackets were randomly selected and compression mounted in conductive powder in a direction parallel to their longitudinal axes. Specimens were ground with SiC papers (400–4000 grit size) under water cooling, polished with alumina suspensions with a grinding/polishing machine (LECO VP160, St. Joseph, MI, USA), and each was cleaned four times for 5 minutes in an ultrasonic water bath. One-piece injection molding (Group A) and two-piece soldering (Group B) were prepared for study. Observations of changes in the surface morphology and microstructure focused on the body for Group A brackets and the brazing zone for Group B brackets.

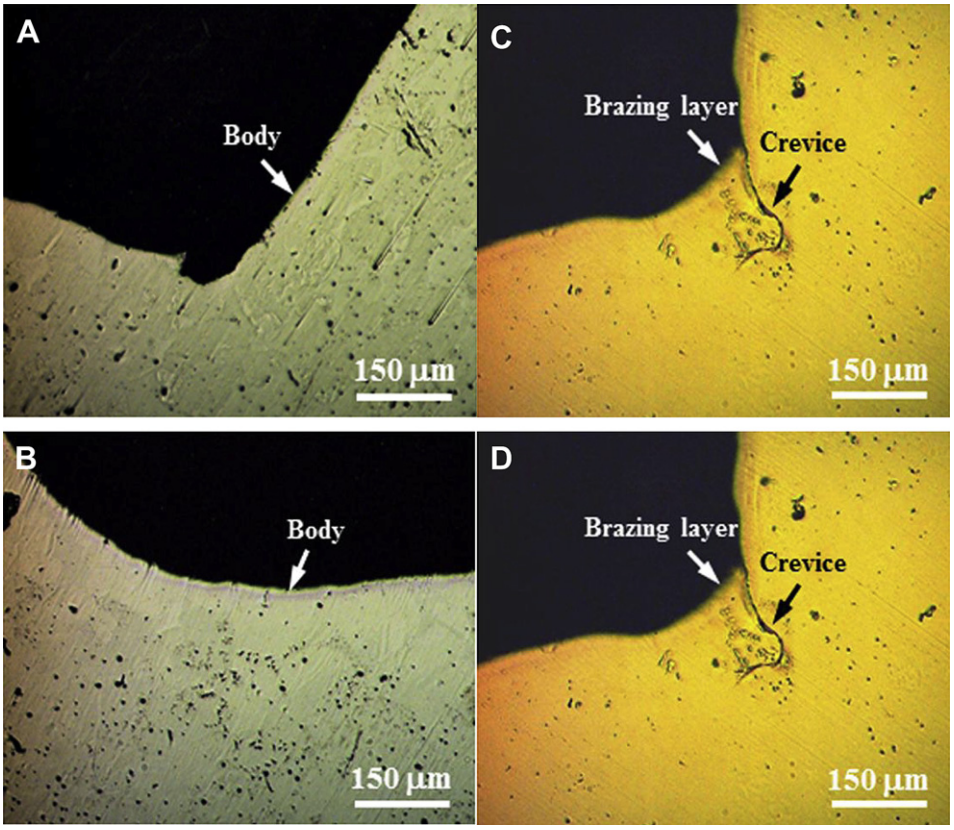

Figure 1 Cross-sectional optic microscope images of the brackets before and after immersion in artificial saliva for 3 months. Group A is a one-piece injection molding bracket and Group B represents a two-piece soldering bracket. (A) Control sample of Group A, (B) control sample of Group B, (C) Group A after 3-month immersion, and (D) Group B after 3-month immersion.