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Journal of Prosthodontic Research 57 (2013) 186–194

Journal of Prosthodontic Research

www.elsevier.com/locate/jpor

Original article

Fatigue resistance and retentive force of cast clasps treated by shot peening

Ai Tokue DMD[a,*], Tohru Hayakawa PhD[b], Chikahiro Ohkubo DMD, PhD[a]

[a] *Department of Removable Prosthodontics, Tsurumi University School of Dental Medicine, Japan*

[b] *Department of Dental Engineering, Tsurumi University School of Dental Medicine, Japan*

Received 4 July 2012; received in revised form 26 December 2012; accepted 29 January 2013

Available online 25 June 2013

Abstract

Purpose: The fatigue failure of denture clasps has often been observed in removable partial denture rehabilitation. To increase their fatigue strength, shot peening was evaluated as a surface treatment. In this study, we evaluated the fatigue resistance and retention of cast clasps by using a shot peening treatment.

Methods: A cobalt–chromium (Co–Cr) alloy, commercial pure titanium (CP Ti), silver–palladium–gold (Ag–Pd–Au), and a gold–platinum (Au–Pt) alloy were cast and then treated with shot peening. The retentive forces of the clasps were measured up to a repetition of 10,000 insertion/removal cycles in distilled water at 37 °C. A fatigue test was also performed using a 15-mm cantilever. Specimens were loaded with a constant deflection of 2.0 mm with 20 Hz. A shot peening treatment indicated a better stability of retentive forces than that without shot peening. The retentive force of Co–Cr clasps without shot peening was remarkably decreased at 500 cycles of insertion/removal repetition.

Results: The clasps with a shot peening treatment provided approximately 1.4–3.6 times higher fatigue strengths than those without a shot peening treatment.

Conclusion: To prevent the fatigue failure of the denture clasps and use the dentures for long term, a shot peening treatment would be recommended.

Keywords: Clasp; Shot peening; Titanium; Surface modification; Fatigue strength

1. Introduction

A removal partial denture (RPD) is used for a patient with partially edentulous jaws in dental clinics. Patients are likely to remove and insert an RPD in the mouth many times in the course of normal daily life. Metallic materials, such as a cobalt–chromium (Co–Cr) alloy, commercial pure titanium (CP Ti), silver–palladium–gold (Ag–Pd–Au) alloys, and a gold–platinum (Au–Pt) alloy, have been widely used for the cast clasp of an RPD. Clasp arms play a significant role in the retention of RPDs by grasping the teeth, and a clasp arm should deflect at removal and insertion of an RPD. Thus, two properties are needed for a clasp, namely, a high level of toughness for long-time retentiveness of RPDs and bending stiffness for repetition of removal and insertion of RPDs.

Fatigue failure of a cast clasp occurs sometimes in dental clinics due to the combination of stress during removal and insertion of RPDs and masticatory force [1]. It has been reported that an RPD treatment sometimes showed a higher failure rate than other prosthetic appliances [2]. Yeung et al. reported that two-thirds of the RPDs with a Co–Cr framework had broken occlusal rests and then broken clasps [3]. Finite element analysis indicated the location of greatest risk to be at the junction of the clasp arm with the body [4–6]. The biomechanical behavior of round and half-round cross sections of clasp arms was also investigated by using finite element analysis, and the results showed that half-round wire reduced the stress concentration on enamel in comparison with round wire [7]. Improvement of the fatigue resistance of the clasp is necessary for the long-term usage of RPDs while maintaining an appropriate flexibility for the repetition of removal and insertion of RPDs. Heat treatment is well known as an effective procedure for improving the fatigue resistance of a precious metal but is not effective for non-precious metals, such as Co–Cr alloys and titanium. Hardening techniques, such as shot peening, rolling, and burnishing, can produce favorable

* Corresponding author at: Department of Removable Prosthodontics, Tsurumi University School of Dental Medicine, 2-1-3 Tsurumi, Tsurumi-ku, Yokohama 230-8501, Japan. Tel.: +81 45 580 8420; fax: +81 45 573 9599.

E-mail address: tokue-ai@tsurumi-u.ac.jp (A. Tokue).

1883-1958/$ – see front matter
http://dx.doi.org/10.1016/j.jpor.2013.01.006

Table 1
Commercial alloys and peening conditions used in the study and their compositions.

Metal alloy	Brand name	Manufacturer	Composition (%)[a]	Shot peening particles	Peening duration (s)	Nozzle distance (mm)	Air pressure (MPa)
Co–Cr	Wisil	Elephant Dental B.V., Hoorn, The Netherlands	Co 64, Cr 28, Mo 5.1	ZrO_2	10	70	0.3
CP Ti	T-alloy H	GC Corp., Tokyo, Japan	Ti 99.2	CP Ti	30	70	0.3
Ag–Pd–Au	Kinparabest12	Ishifuku, Tokyo, Japan	Au 12.0, Ag 49.45, Pd 20.0, Cu 19.0	ZrO_2	10	70	0.3
Au–Pt	PGA-3	Ishifuku, Tokyo, Japan	Au 70.0, Pt 6.0, Ag 4.7, Cu 19.0	ZrO_2	10	70	0.3

[a] Product information.

compressive residual stress to the metallic surface and, as a result, can improve the fatigue strength [8].

Shot peening is a method of cold working in which compressive stresses are induced in the exposed surface layers of metallic parts by the impingement of a stream of shots directed at the metal surface at high velocity under controlled conditions [9]. The compressive stresses in the metal surface layer can help the improvement of fatigue strength [9]. The advantages of shot peening are the following: (1) adjustability of the strengthening effect; (2) high processing quality; (3) easy surface cleaning; and (4) sufficient establishment in the industry. Currently, the shot peening technique is widely applied to improve the fatigue strength of highly stressed automotive and aeronautical engine components [10,11]. Moreover, shot peening has been used for other distinct applications, such as metal formation, straightening, and improvement of resistance to stress corrosion [12]. Gao investigated the effect of shot peening on the fatigue property of industrial titanium alloys and reported that the fatigue limit of the tension–tension fatigue test could be increased by approximately 28% for titanium alloys [13]. Croccolo et al. found that the combination of nitriding and shot peening could be successfully applied in order to increase the fatigue limit when extreme performance in notched components is sought [14]. The effectiveness of the shot peening processing condition, such as the velocity and impact angles, was analyzed using a high-speed camera. It was shown that the velocity of shot particles depends on the peening pressure; the higher the peening pressure, the higher the particle velocity [15].

There are only a few reports regarding the change of the fatigue resistance of dental metallic material by shot peening for dental applications. Gil et al. applied shot peening, which they called shot blasting, for improving the fracture and fatigue behavior of titanium dental implants [16,17]. They concluded that the layer of compressive residual stress on the titanium surface caused the prevention of fatigue failures. The corrosion resistance of titanium dental implants was also improved by a shot peening treatment [18].

Hayashi and Hanatani examined the effect of shot peening on the fatigue strength of a Co–Cr alloy and pure titanium as a clasp material for RPD [19]. Fatigue resistance increased more than twice without change of the elastic modulus or bending strength by using Fe particles for shot peening. However, the effect of shot peening on the fatigue property of clasp material after shot peening is limited, and research on the effect of shot-peened clasps on maintaining adequate retentive force and fitness accuracy has not been conducted, to the best of our knowledge.

The purpose of this study was to clarify the influence of a shot peening treatment on the fitness accuracy and retentive forces of a clasp to a simulated first molar and the fatigue resistance of the clasps.

2. Materials and methods

2.1. Materials

A Co–Cr alloy, commercially pure titanium (CP Ti), an Ag–Pd–Au alloy, and an Au–Pt alloy were used as cast materials, as listed in Table 1. As particles for the shot peening treatment, CP Ti (Titanium beads, Fuji Kihan, Nagoya, Japan) and zirconia (Fuji zircon beads, Fuji Manufacturing, Tokyo, Japan) particles were used. The diameter of spherical CP-Ti particles was approximately 250 μm, and that of ZrO_2 was approximately 50 μm.

2.2. Fitness accuracy and retentive force of cast clasps toward simulated first molar

Fitness accuracy and retentive force of each clasp were evaluated for two sets of specimens, i.e., with and without shot peening. Flow chart of the scheme of the present study is shown in Fig. 2.

2.2.1. Specimen preparations

First, an 18–8 stainless steel die (10.0 mm diameter, 8.0 mm high, 7.5 mm radius of curvature) was prepared for simulating the first molar. After an impression for the die was made using silicone impression material (Duplicone, Shofu, Tokyo, Japan), a master cast was fabricated using extra-hard stone plaster (Fuji-rock, GC Corp., Tokyo, Japan). Duplicate casts for the master cast were also made using different investment materials for each metal. Namely, phosphate-bonded investment material