



Review Article

Bonding behavior and chemical and mechanical properties of silver-based dental alloys

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ABSTRACT

This article presents a review of silver-based dental alloys, with a focus on their bonding behavior and their chemical and mechanical properties. The most effective pretreatment for bonding silver-based alloys involves alumina air-abrasion followed by the application of a metal adhesive primer containing both the vinyl-thione monomer and a hydrophobic phosphate monomer. Silver-based alloys are readily sulfurized, making it clinically important to limit their use to cast post and core restorations to avoid direct exposure to salivary components. Fracture of the post and core restorations can be prevented by reinforcing their mechanical properties by applying the cast joining technique with tougher metals.

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1. Introduction

Currently, gold, palladium and platinum based noble metal alloys are preferred in dental casting, while silver is not commonly used in this application. Silver-based alloys have seen little interest owing to the preference for the several other types of dental alloys. To the best of our knowledge, only silver–palladium (Ag–Pd) alloys are included in dentistry textbooks published in English. These alloys include substantial amounts of palladium and thus benefit from properties such as high tarnish resistance [1]. However, silver-based dental alloys have long been used in clinical practice in Japan as substitutes for dental gold or Ag–Pd–Cu–Au alloys owing to their economic feasibility. Unfortunately, very few articles on silver-based dental alloys have been published in English, despite the ubiquity of their clinical use in Japan.

2. Literature search methods

The articles cited in this review were limited to those published in English. Electronic searches were performed via PubMed based on the keywords “silver alloy” or “silver-based alloy”. However,

most of the literature obtained in this way was not relevant for our purposes. Far fewer articles on this subject have been published in English than in Japanese. This may be attributed to the fact that silver-based dental alloys are widely covered under Japanese health insurance. Table 1 summarizes the information about the references written in English that concern silver-based dental alloys [8–11,21–23]. Most of the titles that were initially identified were beyond the scope of this review and were therefore excluded. An additional electronic search using Google Scholar did not yield any further results. Therefore, we have used relevant literatures from the citations in the articles we collected.

3. Bonding behavior

Despite their apparently insufficient mechanical properties, the primary concern of silver-based dental alloys is the stability of the endodontic cast post and core restoration [2,3]. The long-term clinical success of post and core restorations is desirable. It is indisputable that there is a strong bond between the post and core restoration and the tooth structure that affects its retention in the root cavity. The effects of conditioning with organic sulfur-based monomeric primers, the bonding behavior of dental noble metals [4], gold alloys [5], and a Ag–Pd–Cu–Au alloy [6,7] have been widely studied; however, the behavior of silver-based dental alloys has received little attention. Our literature search discovered only four valid studies on the bonding behavior of silver-based dental alloys, including the bonding of sterling silver as a con-

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Table 1
Information on references written in English concerning silver-based dental alloys.

Matter	Alloy	Key terms	Authors	Year	Ref. No.
Bonding behavior	Ag–In–Zn	Thiol derivative primer	Matsumura et al.	1999	[8]
	Ag–In–Zn	Thiouracil primer	Matsumura et al.	2000	[9]
	Ag–Sn–Zn–In	Alumina air-abrasion	Shimizu et al.	2010	[10]
	Ag–Sn–Zn–In	VBATDT MDP	Imamura et al.	2014	[11]
	Ag–Zn–In–Sn–Pd	Corrosion electrolyzed water	Dong et al.	2003	[21]
Chemical properties	Ag–In–Zn–Pd, Ag–Zn–Sn	Corrosion gargle solution	Ochi et al.	2005	[22]
	5 Ag-based alloys	Low mechanical properties	GC Dental Products	2020	[23]

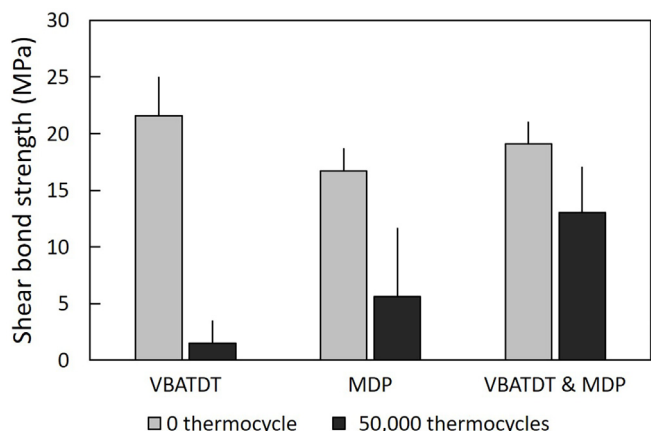


Fig. 1. Shear bond strengths (MPa) of a Ag–Zn–Sn–In alloy before and after 50,000 thermocycles with different monomer compositions. Vertical bars indicate standard deviation.

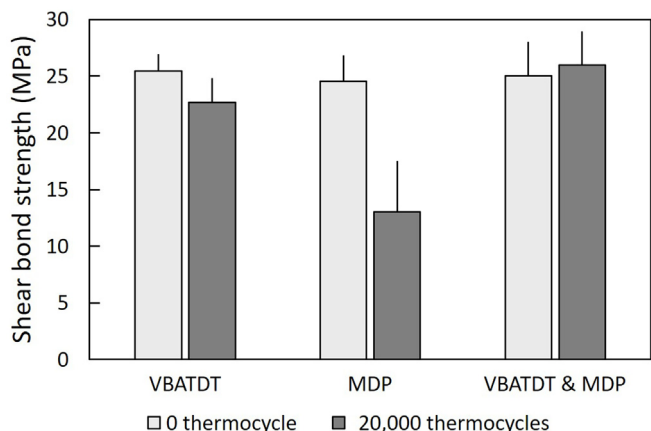


Fig. 2. Shear bond strengths (MPa) of a Ag–Pd–Cu–Au alloy before and after 20,000 thermocycles. Vertical bars indicate standard deviation. Note that the number of thermal cycling tests is lower than that of Fig. 1.

troil [8–11]. The main findings of these studies are depicted in Figs. 1 and 2. The weak bonding of sterling silver-based dental alloys to resin was mainly attributed to its insufficient corrosion resistance at the adhesive interface [8,9]. It is established that alumina air-abrasion effectively improves the bond strength and durability [10]. Imamura et al. investigated the bonding behavior of a Ag–Zn–Sn–In alloy and its component metals and found that conditioning using a metal adhesive primer containing vinylthione monomers such as 6-(4-vinylbenzyl-*n*-oropyl)amino-1,3,5-triazine-2,4-dithiol (VBATDT) for noble metals and hydrophobic phosphate monomers such as 10-methacryloyloxydecyl dihydrogen phosphate (MDP) effectively increases the bond strength between the alloy and adhesive resin cement [11] (Fig. 1). Such bonding behavior is apparently unique to dental alloys that are rich in silver. For comparison, the shear bond strengths of a

Ag–Pd–Cu–Au alloy before and after 20,000 thermocycles [12] are also shown (Fig. 2). Despite the different number of thermal cycling tests, the relatively low shear bond strength of the silver-based alloy with VBATDT after thermocycling can be clearly observed. We hypothesize that the sulfur in VBATDT adsorbs silver while the MDP monomer adsorbs zinc and tin, which are easily oxidized. However, the latter was unable to adsorb indium because of its extremely low hardness [11]. The initial bond strength and bond durability of 4-ethacryloyltrimellitate anhydride/methyl methacrylate-tributylborane initiated resin (4-META/MMA-TBB resin) cement were superior to those of a composite resin cement when used in combination with a Ag–Sn–Zn–In alloy [10].

Conversely, alumina air-abrasion of a Ag–Pd–Cu–Au alloy both mechanically roughens and chemically alters the surface, thereby increasing the surface area [12,13]. Two chemical alterations (the remaining alumina particle component and the oxidation of copper ions on the alloy surface) were observed by energy dispersive X-ray spectroscopy in conjunction with Scanning electron microscopy (SEM) and by X-ray photoelectron spectroscopy. Contrary to our expectations, the MDP-containing primer exhibited superior bond strength with the abraded alloy surfaces. Such acidic functional monomers are known to be suitable for base metal alloys [14–16]. Furthermore, surface oxidation was shown to be the main contributor toward the improved adhesive bonding of a Ag–Pd–Cu–Au alloy [13]. However, such mechanochemical changes in the surfaces of the silver-based dental alloys caused by alumina air-abrasion and the influence of these changes on the adhesive bond characteristics are still not fully understood. Further investigation is required to explain the bonding behavior of silver-based dental alloys.

A liquid Ga–Sn alloy, which can promote bonding to dental gold, Ag–Pd alloy, and Ag–Cu alloy by modifying their metal surfaces, did not enhance the bonding of a Ag–In alloy or base metal alloys [17,18], likely due to the low hardness of pure indium and base metals.

The tribochemical silica coating method with the Rocatec system improved the bonding in high-noble Au–Ag–Cu, Ni–Cr, and Co–Cr alloys [19]. However, it was unsuccessful on a Ag–Sn–Zn–In alloy [10]. The reason for this may be that both low hardness and weak bonding contribute to insufficient tribochemical silication.

4. Chemical properties

Silver has characteristic chemical properties that prevent the formation of a surface oxide at ambient temperature and pressure. Conversely, pure silver or silver-rich alloys are readily sulfurized and have exhibited this tendency in the oral cavity. It has been suggested that precious metal dental alloys with high nobility and a gold alloy with a lower silver/(gold + silver + copper) atomic ratio have a high corrosion resistance in the pseudo-oral environment [20]. However, the surface of a silver-based alloy turned to brown or black after immersion in electrolyzed water, the release of indium was predominant upon immersion in strong acid water, and the surface was nearly completely covered in granular corrosion products when immersed in weak acidic water [21]. In addition, silver-based dental alloys, including a Ag–Pd–Cu–Au alloy

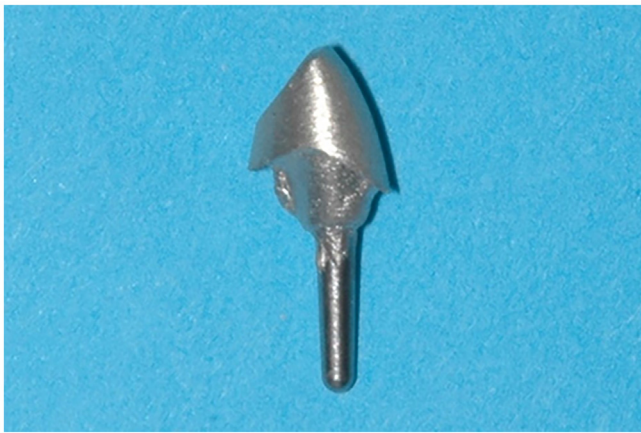


Fig. 3. A cast post and core restoration made using the cast joining technique with a ready-made tapered titanium post.

in a povidone-iodine gargle solution at its practical concentration, exhibited extremely rapid corrosion rates and the formation of AgI [22]. These findings strongly suggest that silver-based alloys have a low corrosion resistance. Several methods can increase the corrosion resistance of silver-based alloys, including the addition of gold and palladium. However, a more practical and pragmatical solution may be to limit the use of silver-based dental alloys to cast post and core restorations; thus, avoiding direct exposure to salivary components.

Two categories of low-melting casting silver dental alloys were defined by JIS T 6108:2005. As per this standard, type 2 low-melting silver alloys are allowed in the fabrication of inlays and crowns. However, it is strongly desirable to limit their application to post and core restorations, as is the case with type 1 silver alloys, owing to their chemical properties. As discussed below, the application of silver-based dental alloys in cast post and core restoration may be limited by their mechanical properties.

5. Mechanical properties

The mechanical properties of silver-based dental alloys are inferior to those of gold alloys or a Ag–Pd–Cu–Au alloy [23]. It has also been observed that post and core restorations of semi-precious alloys such as silver-rich casting alloys have a higher risk of fracture than high-gold-content alloys or base metal dental alloys. Clinicians therefore employ a practical approach to solve this issue. Applying the cast joining technique with ready-made posts fabricated from tougher metals such as titanium may compensate for the inferior mechanical properties of silver-based dental alloys (Fig. 3). To the best of our knowledge, no other studies on the mechanical properties of silver-based alloys have been reported.

In recent years, fiber posts combined with composite resins have been used to reduce root fractures owing to their similar elastic modulus compared to that of dentin [24–27]. In contrast, metal posts exhibit much higher elastic moduli values and ranges that limit their application. Simultaneously, a rise in esthetic dentistry has required that crown restorations have good esthetics. Depending on the material of the crown that is placed over the cast post and core restoration, some tooth-colored crowns restorations are translucent to internal tones, and so the dark tones of the metal structure are visible. Furthermore, we predict that materials exhibiting sufficient strength with a color tone close to that of natural teeth will become mainstream and eventually replace dental alloys for post and core restoration. Thus, the authors would like to recommend that for post and core restorations, the use of metals including silver-based dental alloys should be restricted to cases

in which a large amount of dentin remains and a non-translucent crown is placed.

Conflicts of interest

The authors declare no conflicts of interest. The authors alone are responsible for the content and writing of the article.

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