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Development of silver-base alloy for crown and bridge prostheses

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Three silver-base alloys containing varying amounts of tin and copper were prepared by induction melting and centrifugal casting, and their properties were evaluated and compared with those of the type III gold alloy, for their suitability for non-porcelain crown and bridge work in dentistry. Among these the alloy II (Ag–Sn–Cu–Zn) was found to possess the best combination of strength and ductility and highest corrosion resistance in artificial saliva. Also its wear resistance was found superior to alloys I and III and was comparable to that of natural tooth. Thus the alloy II was found to be quite a promising indigenous and economic silver-based cast alloy for crown and bridge prostheses.

1. Introduction

There are various types of restoration process which can be applied to decayed or damaged teeth in order to regain the "tooth function". Among these, crowns and bridges are very common cast-type restorations. These are fabricated outside the mouth and fixed over the prepared tooth or teeth with a luting agent.

Gold as pure metal, or in the form of alloy has been recommended for the fabrication of crowns and bridges, because of its excellent working properties, biocompatibility and mechanical properties. Type III gold alloy is considered one of the most suitable materials for crowns and bridges. However, the marked increase in the price of gold has led to the development of cheaper alternative alloys such as low gold [1], silver–palladium [2, 3], nickel–chromium [3], aluminium–bronze [4], postizo gold [5], silver–copper [6], silver–copper–germanium [7] and silver–tin–copper [8].

It is important to mention that even the alternative alloys referred to above are imported to India, and hence they are expensive. Further, import of these alloys leads to loss of foreign exchange. In view of this an attempt was made to develop an indigenous silver–copper alloy in the authors' laboratory [9]. However, the hardness of the indigenous alloy was found to be low. Therefore, a ternary alloy of Ag–Sn–Cu was prepared and its properties evaluated. The present work is concerned with the preparation and characterization of different properties of this ternary alloy.

2. Materials and methods

Three alloys of silver, with varying proportions of tin and copper, were formulated, prepared and their various properties characterized.

2.1. Material processing

The alloys were prepared using commercial purity silver, tin and copper. The compositions of the alloys are recorded in Table I. Cylindrical rods of 4 cm length and 8.5 mm diameter were cast using an investment casting technique with induction casting machine, Modular-3N.

2.2. Microstructure

Small pieces of about 1 cm length were cut from each cast rod. The transverse sections were smoothed on a lathe and mechanically polished using up to 4/0 grade emery paper. The polished samples were etched by a solution containing 100 cm^3 of a saturated solution of $K_2Cr_2O_7$, 2 cm^3 of a saturated solution of NaCl and 10 cm^3 concentrated H_2SO_4. The microstructures were examined using an optical microscope (Metalux-3).

2.3. Hardness test

Cylindrical specimens with polished transverse sections were used for Vickers hardness testing at an applied load of 5 kg. Six readings were taken for each specimen.

2.4. Tensile test

Cylindrical specimens of 14 mm length and 4.53 mm diameter were machined for tensile tests. The specimens were tested using an Instron Universal testing machine at a crosshead speed of 0.05 cm/min and load range of 500 kg.

2.5. Compression test

Cylindrical specimens with length to diameter ratio of approximately 1.5 were tested in compression on an Instron Universal testing machine, at a crosshead speed of 0.02 cm/min. The tests were conducted up to a 60% reduction in height.

TABLE I Chemical composition of the three silver alloys (wt %)

Alloy	Ag	Sn	Cu	Zn
I	80	16.5	3.5	0
II	80	16.0	3.0	1
III	70	25.0	5.0	0

2.6. Fracture characteristics

The fracture surfaces of the specimens tested in tension were examined using a JEOL-840 scanning electron microscope (SEM). The fracture ends were cleaned in acetone using an Ultrasonic cleaner before the examination.

2.7. Wear test

Cylindrical specimens of 6 mm diameter were machined and polished with emery paper and tested for wear using a wear resistance testing machine, at a constant load of 2 kg and circular speed of 104 mm/min. The specimens were weighed before the test and at least eight readings of the weight loss were taken every 30 min. Plots of wear weight per unit area versus sliding distance of wear were drawn for the three alloys. A wear test was also conducted for a natural tooth after machining to a uniform cross-section.

2.8. Corrosion study

Corrosion tests were conducted in artificial saliva (NaCl–0.4 g, KCl–0.4 g, $CaCl_2 \cdot H_2O$–0.795 g, NaH_2PO_4–0.005 g, urea–1.0 g and balance distilled water to give 1 l) using Potentiostat machine (EG&G PAARC Model 173) to potentio-dynamic polarization curves.

2.9. Tarnish test

A full cast crown of alloy II (Table I) with acrylic veneer on a buccal surface was made over an upper left second premolar tooth (No. 25) and cemented with Kalginol cement in a patients mouth. The crown was closely watched for discolouration for a period of 1 year.

3. Results and discussion

3.1. Microstructure

The compositions of alloys I and II correspond to the ε_2 phase and that of alloy III corresponds to the $\varepsilon_1 + \varepsilon_2 + \upsilon$ phase regions of the ternary phase diagram of the Ag–Sn–Cu system [10]. It is important to mention here that the compositions of alloys I and II are essentially the same except that the tin and copper contents in alloy II are lower by 0.5 wt % each and there is 1 wt % zinc. It may be noted that the addition of zinc is essentially to reduce oxidation of the alloy during melting [11]. Thus in terms of composition, alloys I and II are essentially identical.

The microstructures of the three alloys in the cast condition are shown in the optical micrographs in

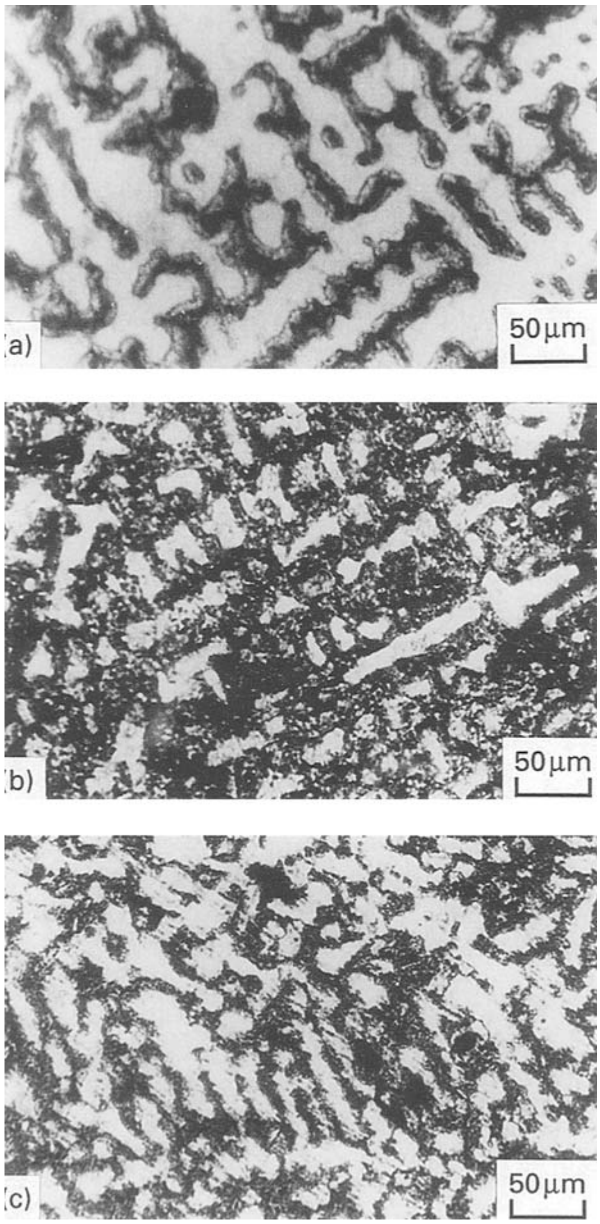

Figure 1 Optical micrographs of the silver alloys: (a) I; (b) II; and (c) III.

Fig. 1. These microstructures clearly show a dendritic structure. However, there are differences in the size, distribution and volume fraction of dendrites in the three alloys. The dendrites in alloy II are finer than in alloy I. Thus it may be seen that the addition of zinc results in refinement of the dendritic structure. The size of the dendrites in alloy III appears to be comparable to that in alloy II. However, the volume fraction of dendrites in alloy III is seen to be more than that in alloys I and II.

3.2. Mechanical properties

The mechanical properties of the three alloys along with those of type III gold alloys are recorded in Table II. It may be seen that hardness of the silver alloys increases in order from I to III. The hardness of alloy II is comparable to that of type III gold alloy. The compressive yield strength of the three silver-based

TABLE II Mechanical properties of the three silver alloys in comparison with the gold alloy

Properties	Silver alloy I	II	III	Type III gold alloy
Hardness (V_{HN})	113	133	183	120–150
Compressive yield Strength (MPa)	232	224	220	–
Tensile yield strength (MPa)	180	223	–	200–240
UTS (MPa)	202	285	196	400–500
Tensile elongation (%)	0.5	2.1	–	10–30

alloys is nearly comparable. The tensile yield strength of alloy II is higher than that of alloy I. The tensile yield strength of alloy III could not be evaluated because of its extreme brittleness. The ultimate tensile strength (UTS) of alloy II is remarkably higher than those of alloys I and III. However, the UTS of alloy II is less than that of type III gold alloy. Among the three silver-based alloys, alloy II exhibits tensile ductility of about 2.1%, the ductility of the other two alloys being extremely low. The ductility of alloy II is considerably lower than that of type III gold alloy. It is obvious from the data in Table II that alloy II possesses the best combination of strength and ductility among the three silver-based alloys investigated.

As pointed out above, the hardness and tensile yield strength of alloy II are nearly comparable to those of type III gold alloy. However, the UTS and tensile elongation values are much lower than those of type III gold alloy. It is relevant to mention here that the lower UTS value of type II silver-based alloy is due to premature failure of the material as a result of casting defects, revealed by fractographs of the tested specimens (Fig. 2).

The fracture characteristics of silver alloys I, II and III tested in tension are shown by SEM in Fig. 2. It may be seen that in general the fracture is brittle in nature for all three alloys. Further, the fracture surfaces appear to show the dendritic structure of these alloys. The presence of large spaces in the interdendritic regions may clearly be seen. Examinations of the fracture surfaces at higher magnification showed a typical feature similar to that of the human backbone arrangement with ribs. The low strength and poor ductility of these alloys may thus be understood in terms of the coarse dendritic structure and the large interdendritic spaces.

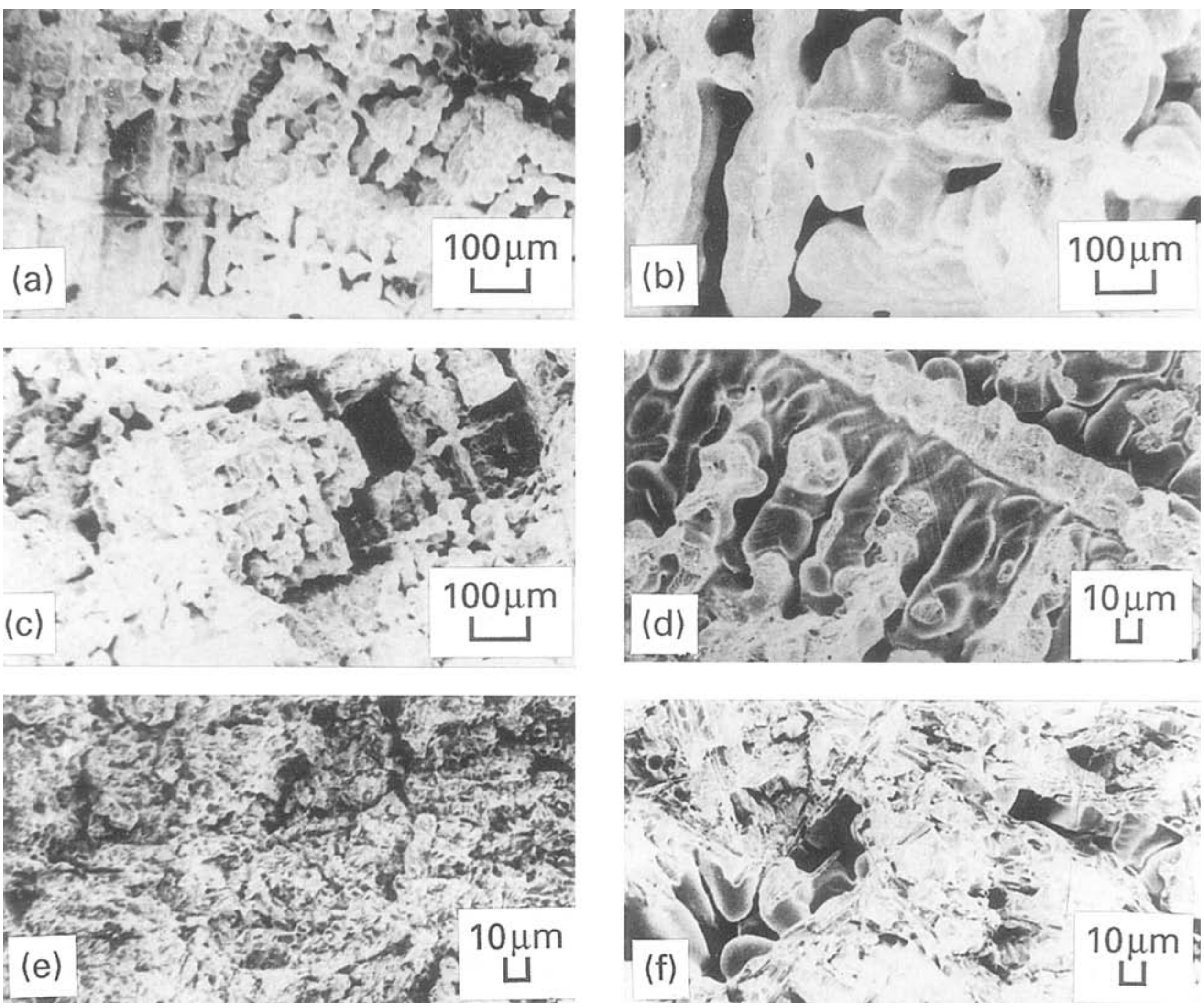

Figure 2 SEM fractographs of the silver alloys I, II and III tested in tension. Low magnification (a) type I; (b) type II; (c) type III; high magnification (d) type I; (e) type II; (f) type III.

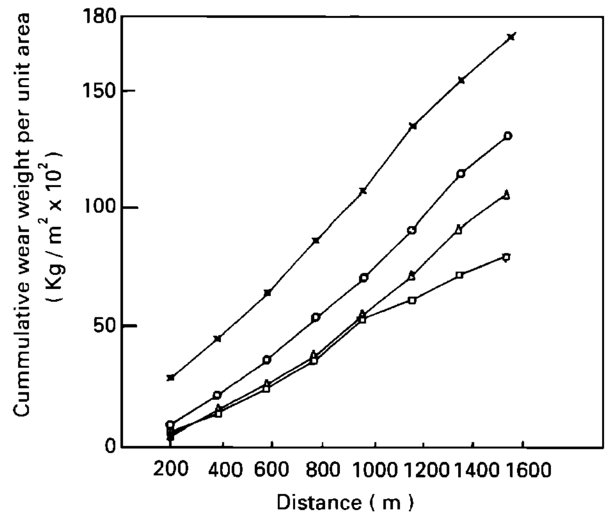

Figure 3 Plots of cummulative wear weight per unit area vs distance of wear for the three silver alloys I (○–○), II (△–△) and III (× – ×) and the natural tooth (□–□).

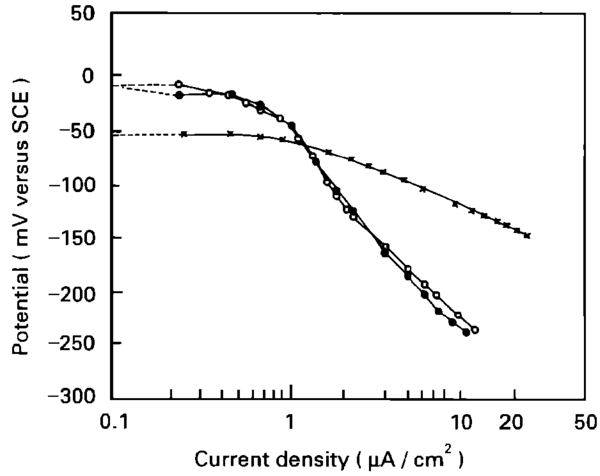

Figure 4 Plots of corrosion potential versus current density for the three silver alloys I (○–○), II (●–●) and III (× – ×) in artificial saliva.

The wear characteristics of the three silver alloys along with that of natural tooth are shown in Fig. 3. It may be seen that the wear resistance of alloy II is highest among the alloys and it is nearly comparable to that of natural tooth.

The differences in the mechanical properties of the three alloys may be attributed to the differences in the microstructural features and the constituent phases in them.

TABLE III Corrosion potential and corrosion current densities of the three alloys in artificial saliva

Alloy	Corrosion potential (mV)	Corrosion current density (μA/cm^2)
I	– 10	0.17
II	– 10	0.158
III	– 52	0.192

3.3. Corrosion and tarnish behaviour

The corrosion behaviour of the three alloys studied in artificial saliva is represented by potential versus current density plots in Fig. 4. The corrosion current density was determined from the point of intersection of straight lines of the initial horizontal portion and the later slanting portion of the curve. Corrosion current density is an important parameter to characterize the corrosion resistance of a material since it is directly proportional to the rate of corrosion. The values of corrosion current density for the three alloys in the artificial saliva are recorded in Table III.

It may be seen that the corrosion current density of alloy II is lowest among the three alloys. The lower corrosion resistance of alloy III may be attributed to the lower content of silver, the noble metal, and the presence of the additional phases ε_1 and υ in the alloy. Since the corrosion resistance of alloy II was found highest among the three alloys, the tarnish test in a patient's mouth was conducted only for this alloy. The condition of the crown and its tarnishing behaviour in the patient's mouth was constantly observed for a period of 1 year. The frequency and details of observation are recorded in Table IV. It is important to mention that, even after a period of 1 year, no discolouration was observed either on the metallic surface or on the acrylic veneer. Also there was no loss of surface details. There was only mild dullness in the appearance, which may be attributed to accumulation of dental plaque.

4. Summary

Three silver-base alloys containing tin and copper in varying proportions were prepared by an induction melting and centrifugal casting technique and their microstructure, mechanical properties and corrosion and tarnish behaviour were evaluated to assess their

TABLE IV Tarnish behavior of the type II silver alloy crown in patient's mouth

Clinical trial	Period (days)	Frequency of observation	Observations	Remarks
1.	1 to 20	Daily	No change in colour and lusture	
2.	21 to 40	Weekly	Dullness on 35th day on embrassure area of the crown	Dullness may be attributed to the plaque deposition
3.	41 to 365	Monthly	Dullness is only at the embrassure, no colour change in metal and no discolouration through the acrylic veneer. No surface cracks	

suitability as a material for non-porcelain crown and bridge prostheses. Among the three alloys, alloy II (Ag 80%, Sn 16%, Cu 3%, Zn 1%) was found to possess the best combination of strength and ductility, and its corrosion resistance in artificial saliva was superior to those of the other two alloys. Thus, alloy II shows good promise as an indigenous and economical material for non-porcelain crown and bridge prostheses. Work is in progress to further improve the properties of the alloy.

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