

# Dental casting alloys with a low content of noble metals: physical properties

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Several physical properties such as strength (UTS and fracture and proof stress), modulus of elasticity, strain (elastic and plastic elongation), hardness, and hardening ability were determined for five low-gold alloys and two conventional gold casting alloys (types III and IV). The composition and the structure (pores and defects) of the cast tensile test specimens were also studied. The results showed that alloys with a low content of noble metals could have properties comparable to those of the traditional types III and IV dental gold casting alloys. A marked difference was seen in the plastic elongation (ductility). A great number of defects (pores and oxide inclusions) were also observed, especially in the specimens with a high content of both palladium and silver. □ *Dental materials; casting technique; fixed partial prosthesis*

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The international specification for dental gold casting alloys has a requirement of minimum 75 weight percent (wt %) of gold and metals of the platinum group (9). From experience, the use of such alloys gives a reasonable security against tarnishing and corrosion in the mouth (5). The physical, chemical and biological properties of such materials are well known.

Dental alloys with a lower content of noble metals have been available for many years (3), but their use has been limited. The increased price level for gold, however, has been accompanied by a greater interest for low-gold alloys—that is, less than 75 wt % of Au, Pt, and Pd. A recent survey of the U.S. market showed that more than 140 dental alloys with a content of gold between 71.5 and 10 wt % were available (8). A similar survey in Scandinavia showed that approximately 70 alloys with a content of noble metals varying from 30 to 75 wt % were on the market (10).

Several investigations have been performed to study different properties of alloys with a low content of noble metals. They claim that some of these alloys can have properties comparable to those of the trad-

itional casting alloys (1, 6, 7). However, the structure of alloys with low content of noble metals is probably more complex than the traditional alloys, and the number of marketed alloys is very large. The clinical experience with these materials is limited, and their service behavior is difficult to predict.

The purpose of the present investigation was to gain information about some properties of cast low-gold alloys after a prescribed heat treatment.

## Materials and methods

### Materials

A group of seven dental casting alloys comprising two conventional casting alloys (one type III, one type IV) and five alloys with a content of noble metals varying from 70 to 30 wt % were used. Only alloys whose producer had specified the content of gold, platinum and palladium were studied. The trade name, manufacturer, composition, and some technical instructions given by the manufacturer are listed in Table 1.

Table 1. Metals and some technical specification given by the manufacturer\*

Type	Code	Manufacturer	Casting, °C	Hardening		Content of noble metals, wt %
				Min	°C	
Sjöding C-3†	SC-3	J. Sjöding, Solna, Sweden	1170	10	450§	78.0
Sjöding D‡	SD	J. Sjöding, Solna, Sweden	1150	10	450§	76.0
Begolloyd G	BG	Bremer Gold Schlägeri, Bremen, FRG	1090	15	400	68.5
Midigold	M	Bremer Gold Schlägeri, Bremen, FRG	1030	15	400	53.0
Alborium	M	J. F. Jelenko & Co., New Rochelle, N.Y., USA	1120	15	427	40.0
Hvitstøp	H	K. A. Rasmussen A/S, Hamar, Norway	1070	30	↓ 500 200	30.0
Palliang M	PM	Degussa, Pforzheim, FRG	1120	15	400	30.0

\* Annealing time and temperature similar for all products: 10 min at 700°C.

† Type III gold casting alloy.

‡ Type IV gold casting alloy.

§ As prescribed in ISO 1562 (9).

### Methods

Cylindrical specimens, as specified in the standard for dental casting gold (9), were made from all materials. Three specimens were made in one cast, as shown in Fig. 1. A phosphate-bonded investment was used (Aurovest soft, Bego, FRG), and castings were performed in air by an induction melting casting machine (Electromatic, Howmedica Inc, USA). Preheating and casting temperatures were in accordance with the manufacturers' instructions (Table 1).

When cast, the specimens were cleaned and adjusted on a lathe, and three disks (2 mm thick) were cut from each end of the specimen. The cylinders were then annealed and hardened according to the manufacturers' instructions (Table 1). The cylindrical specimens were mounted in a tensile testing machine (Instron 1193, Instron Ltd., Buckinghamshire, England) and loaded at a constant cross-head speed of 1.5 mm/min. The strain during loading was measured by a strain-gauge extensometer (Instron G-51-1614, Instron Ltd.) clamped to the specimen (Fig. 2). Both load and strain signals were transferred to a minicomputer (ABC 80, Luxor Industri AB, Motala, Sweden), which calculated the mechanical properties speci-

fied in Fig. 3 by means of a specially designed algorithm.

The metal disks were annealed and hardened similarly to the cylindrical specimens. Vickers hardness was measured at a load of 50 N in both quenched and hardened

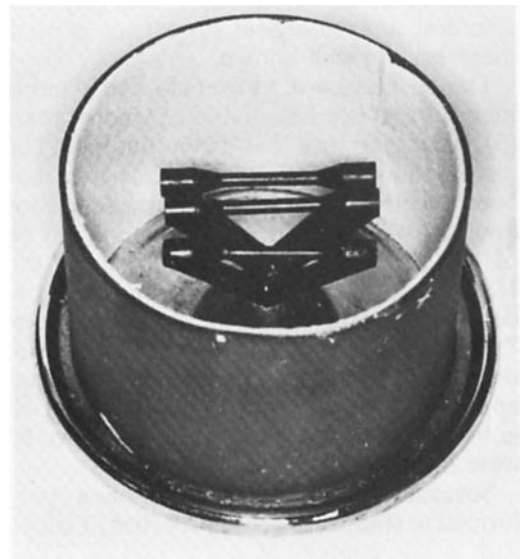


Fig. 1. Wax models of the tensile test specimens before investing.

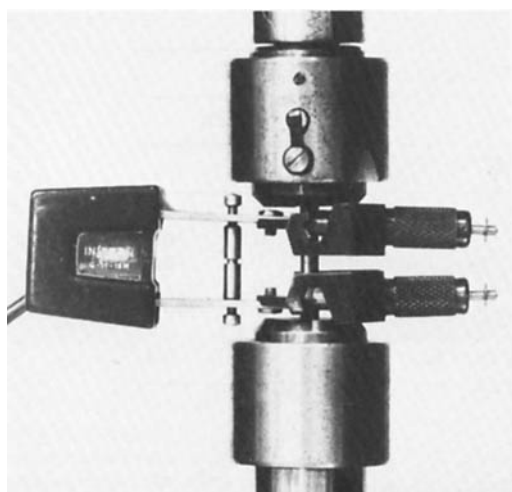


Fig. 2. Tensile test specimen with extensometer mounted in the testing machine.

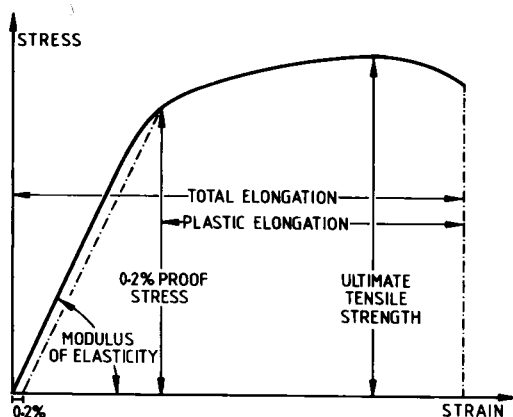


Fig. 3. Definitions of the mechanical properties studied.

state. Three disks from each alloy, with three impressions on each disk, were used for this test.

The composition of the cast alloys was determined by an electron microprobe connected to a computer for analytical corrections (SEM-Q, Allied Research Lab., Calif., USA). Analyses were made in 10 different positions on a polished cross-sectional area of one specimen from each product. Mean concentrations and standard deviations were calculated. Different longitudinal sections and cross-sections of the tensile test specimens were polished and subsequently studied in a stereomicroscope (Wild photo-

makroskope M 400, Wild Heerbrugg Ltd., Switzerland) and in a scanning electron microscope (Jeol JSM-50A, Scanning Microscope, Jeol Ltd., Tokyo, Japan).

### Results

The mechanical properties calculated from the tensile tests are presented in Table 2. The highest values of ultimate tensile strength were measured for alloy SD (type IV) and the largest plastic elongation (that is, ductility) for alloy SC-3 (type III). Alloy BG was found to have values of UTS and 0.2% proof stress between those of alloys SD and SC-3 but an elongation similar to that of alloy SD.

Of the other alloys in the low-gold group,

Table 2. Physical properties

Code	Modulus of elasticity, GPa		0.2% proof stress, MPa		Ultimate tensile strength, MPa		Fracture strength, MPa		Total elongation, %		Plastic elongation, %	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
SC-3	100	(9)	338	(2)	457	(12)	407	(90)	>23	—	>22	—
SD	95	(8)	534	(15)	699	(73)	648	(78)	11.3	(5.9)	10.6	(5.9)
BG	79	(11)	419	(16)	555	(10)	553	(14)	11.1	(0.1)	10.4	(0.9)
M	100	(8)	586	(24)	626†	(48)	479	(192)	1.4	(0.9)	1.1	(2.4)
A	99	(3)	500*	(39)	611	(38)	611	(38)	0.8	(0.1)	0.1	(0.1)
H	105†	(4)	497†	(17)	526†	(55)	523†	(51)	1.1†	(0.6)	0.5†	(0.7)
PM	109	(24)	325	(20)	411	(68)	336	(102)	5.6	(2.2)	5.1	(2.2)

\* Calculated on the basis of 0.1% plastic elongation.

† Calculated on the basis of two specimens.

Table 3. Composition of alloys

Code	Content, wt %									
	Au		Pd		Ag		Cu		Zn	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
SC-3*	71.0	1.1	3.5	1.3	10.2	0.7	10.6	0.7	0.4	0.1
SD	67.0	1.6	5.9	2.0	9.4	0.6	12.6	0.5	0.5	0.1
BG*	64.0	2.2	3.2	0.5	22.3	1.2	5.6	0.7	1.7	0.1
M	48.2	2.6	3.1	0.4	33.4	2.7	9.9	1.9	<0.1	
A*	13.0	0.5	23.8	2.2	43.2	1.1	14.2	2.1	0.7	0.1
H	4.6	0.6	25.1	1.3	56.4	1.7	13.9	2.6	<0.1	
PM	1.7	0.2	27.2	1.4	58.9	3.1	10.1	2.8	0.9	0.4

\* Pt  $\approx$  0.5 wt %.

alloy M had high values of strength and a proof stress exceeding that of alloy SD. The values of UTS and proof stress for alloys A and H were in the range between those of the two traditional casting golds, but the total elongation for all these three alloys (M, A, and H) was less than 2%. The ductility for alloy A was negligible, whereas alloy PM showed a medium elongation but low strength values.

The content of the main elements as found by the electron microprobe are given in Table 3. The coefficient of variation was relatively high, especially for copper in the alloys with a low content of gold.

The hardness values are given in Table 4. The alloys SD, BG, M, A, and H were observed to have a marked increase in hard-

Table 4. Hardness

Code	Hardness, kg/mm <sup>2</sup>			
	Quenched		Hardened	
	$\bar{x}$	s	$\bar{x}$	s
SC-3	143	1.7	169	2.1
SD	150	2.1	256	5.5
BG	126	2.6	204	4.9
M	126	4.3	238	2.0
A	198	2.6	280	2.0
H	138	4.5	211	1.7
PM	146	6.4	154	2.1

ness values after the hardening treatment, whereas the alloys SC-3 and PM showed a minor increase.

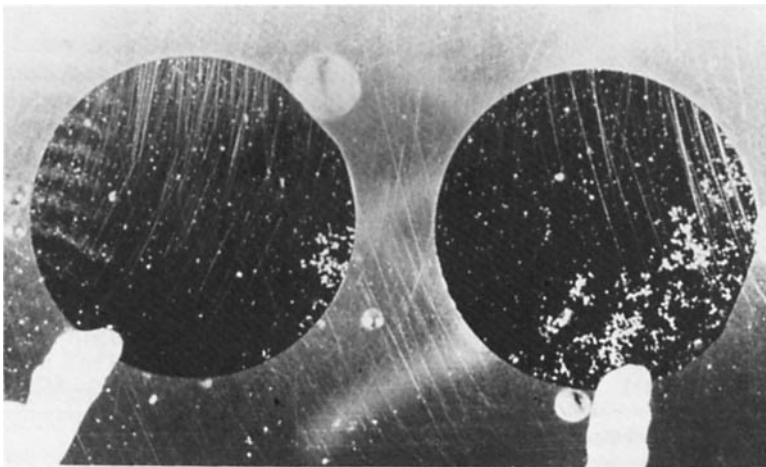


Fig. 4. Polished cross-sections of two specimens from alloy A.

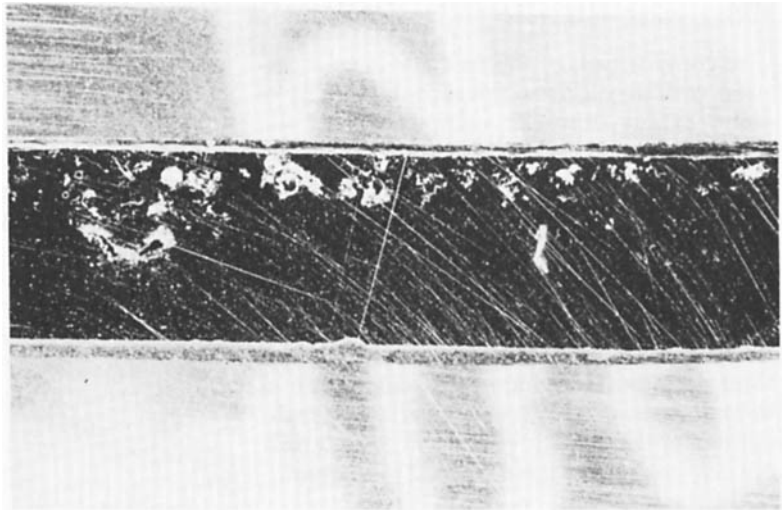


Fig. 5. Polished longitudinal section of a specimen from alloy PM.

The inspection in the stereomicroscope and in the scanning electron microscope showed a small amount of defects in the specimens from alloys SC-3, SD, and BG. A slight increase in the number of scattered defects was observed for alloy M. Alloys A, H, and PM, however, showed large areas of defects primarily located in a particular sector of the disks or along one side of the

length section of the rods (Figs. 4 and 5). Defects were also observed in the fracture surfaces of these alloys. Some of the observed defects were obviously pores, whereas others were inclusions (Figs. 6 and 7). A step-scan with an electron microprobe over some of the defects in alloy H (Fig. 7) revealed high concentrations of copper and oxygen.

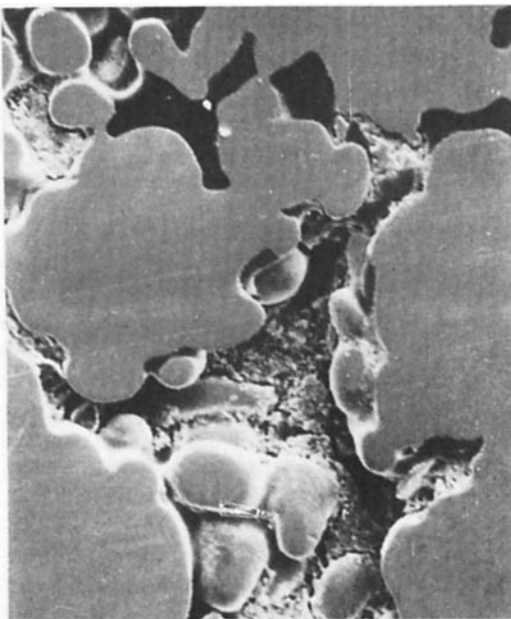


Fig. 6. SEM picture of defects in alloy A ( $\times 500$ ).

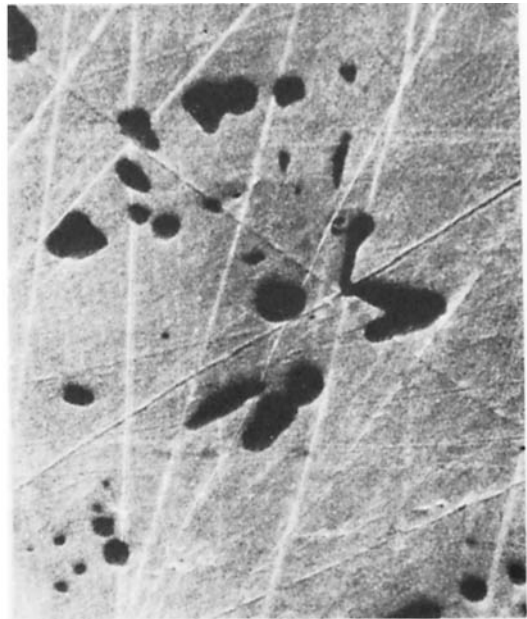


Fig. 7. SEM picture of defects in alloy H ( $\times 3000$ ).

## Discussion

The composition of the cast alloys as measured with an electron microprobe varied to some extent from the composition of the ingots as stated by the manufacturer. One reason for this could be the relatively great coefficient of variation partly related to an inherent error of the described method. However, a great variation was particularly shown for the measurements of copper content in alloys, M, A, H, and PM. Previous investigations have shown that such variations do indicate an increased segregation in dental casting alloys (2). Further investigations in the structure of some of the present low-gold alloys have verified this assumption (4).

The tensile tests showed that several mechanical properties, such as strength (UTS, fracture and proof stress) and modulus of elasticity, for alloys with a low content of noble metals were in the same range as that measured for the traditional gold casting alloys. The hardness values indicated that several low-gold alloys can have a considerable hardening ability similar to that of a type-IV gold alloy. Other low-gold alloys are obviously more similar to the type-III gold alloys in this respect. Qualitatively, there seemed to be a good correlation between the hardness and the mechanical strength. This indicates that, with regard to strength, the low-gold alloys could be classified in a standard in accordance with their obtainable hardness. The requirements for strength and hardness could be similar to those established for the traditional gold casting alloys (9).

The greatest difference between traditional casting golds and alloys with a low content of noble metals was found in the measured total elongation of the specimens. Alloy BG, with relatively high content of gold, seemed to be comparable to type-IV gold alloy. All the other low-gold alloys showed very small elongation and ductility.

The poor ductility can probably be associated with the great amount of defects in the specimens from the low-gold alloys (3). Such defects could be due to the ability of palladium and silver to absorb gases, especially

hydrogen, in molten condition, and/or to the oxidation of copper during the casting procedure. It was obvious that both gas absorption and copper slag could give serious defects in the cast specimens with effects on the ductility of the alloys, but it was not possible in the present study to identify which of the two factors caused the greatest amount of defects.

Other factors such as shrinking of the alloy during solidification could contribute to the formation of defects. Further research is going on to clarify the importance of various conditions during investing, pre-heating, and casting for the occurrence of such defects. It seems reasonable to believe that a specific investing and casting procedure will be necessary in a standard for low-gold alloys to ensure a reasonable quality of the tensile test specimens.

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