Dimensional fit of cast titanium restorations

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Undersizing of cast Ti crowns has been reported to be a problem. The diameter of standardized, cylindrical crowns was studied in this investigation using a photographic technique and cold moulds. The results show that the dimensional problem can be avoided by selecting a standard phosphate-bonded investment with a sufficiently high thermal expansion coefficient. Appropriate casting conditions with a good vacuum (13.3 Pa) gives only a thin (<10 µm) oxide film and reproducible dimensions of the castings. A ZrO_2 coating eliminates or reduces the oxide film and follows the movements of the investment. The diameter of the crown can largely be accounted for by the measured expansion of the investment and thermal contraction of the Ti casting.

1. Introduction

Crowns, bridges and inlays of Ti have gained increased and widespread interest in recent years [1, 2]. This is due to the well-documented biocompatibility of the metal in combination with a much lower price than for noble-metal alloys. Special casting machines need to be applied because of the extreme reactivity of Ti to elements such as O, N and C, and its high melting point (1660 °C). Problems concerning an extensive oxide film on the surface, dimensional fit and porosity of Ti castings have been reported [1, 3, 4]. The removal of an oxide film may lead to dimensional inaccuracy. Furthermore, the use of special investments because of the high reactivity of Ti has been reported. Partly because most conventional investments cannot be used, the crowns have been found to become "undersized" [2]. As a solution to this problem, a thin plastic film has been applied on the gypsum model [1], and Herø et al. [5] obtained the desired dimensional fit of 25–50 µm between the crown and tooth for the cement by using a phosphate-bonded investment with a high coefficient of thermal expansion. Minke [6] also obtained satisfactory space for the cement by applying an alumina–silica phosphate-bonded investment from the manufacturer of a commercially available casting machine (Ohara, Japan).

The aim of the present work was to correlate the observed inner diameter of standardized, cast cylindrical crowns with the investment expansion, the thermal contraction of the casting and the thickness of the oxide film removed from the surface of the casting. A new photographic technique was applied to measure the inner diameter of the cylindrical crowns.

2. Materials and methods

The casting machine was of an Ar-arc vacuum/Ar-pressure type which was described previously [7]. The machine was similar to that used by Waterstrat and

Giuseppetti [8]. A foil of Ti sealed the melting chamber from the mould chamber until it was penetrated by the molten Ti. A vacuum of 13.3 Pa was established in both chambers before Ar was let into the melting chamber until a pressure of 6.7 kPa was reached. During this operation a vacuum level of 13.3 Pa was maintained in the mould chamber.

Twelve cylindrical wax models for measurement of dimensional accuracy were made on a tapered steel mandrel that could be rotated. The inner dimensions of the wax crown were thus determined by the corresponding shape of the mandrel. The carving of the outer surface is shown in Fig. 1. The shape of the crown is illustrated by a cross-section of a casting in Fig. 2. The inner diameter of the wax crown at the margin was 6.02 mm. The margin had a 30° angulation. The inner and outer diameters of the cast crown at the margin before sandblasting were measured by photographing the opening of the crown head-on (Fig. 3). The magnification of the photographs was calibrated by measuring the outer diameter of the cast crown, using a micrometer, with an accuracy of 10 µm.

Six of the 12 cylindrical wax models were coated with a 1 mm-thick layer of ZrO_2 and Zr acetate as a mixing liquid by careful painting and slow drying. All wax models, with or without a ZrO_2 coating, were invested in a conventional phosphate-bonded quartz-based material (Bellavest T; BEGO, FRG), using a cylindrical steel ring and a 1 mm-thick lining material of glass fibre. The long axis of the crown and the steel ring were parallel. After being fired at 800 °C for 1 h, the moulds were cooled to room temperature.

The expansion of the investment in the as-fired state at room temperature was measured by machining three cylindrical wax models with inner and outer diameters of 22 and 25 mm, respectively. These wax models were embedded in the same investment using a lining material and steel ring, as for the smaller wax
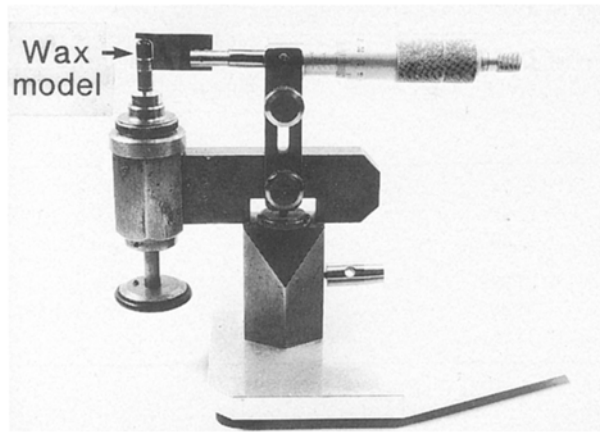
Figure 1 Preparation of the outer surface of the wax model. The cutting edge could be moved sideways by a micrometer.
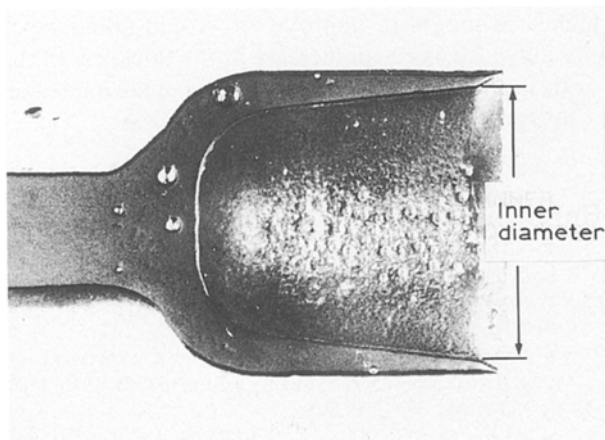

Figure 2 Cross-section of a cylindrical cast crown showing the position of the measured inner diameter.

TABLE I Inner diameter of cast cylindrical crowns before sandblasting (mould temperature 20 'C)

Mould surface	Mean ± SD inner diameter (mm)
No coating	6.12 ± 0 002
ZrO_2 coating	6.13 ± 0.003

models. They were then fired under the same conditions. The inner and outer diameters of the fired mould cavity at room temperature were measured with a micrometer on the moulds after being cut vertical to the long axis.

The structure of the surface region was studied on cross-sections of the castings by means of scanning electron microscopy (SEM).

3. Results

The diameter of the cast cylindrical crowns is shown in Table I. Compared with the diameter of the steel mandrel (6.02 mm), the inner diameter of crowns at the margin (Fig. 3) before the sandblasting were approximately 0.10 mm larger. Careful sandblasting was
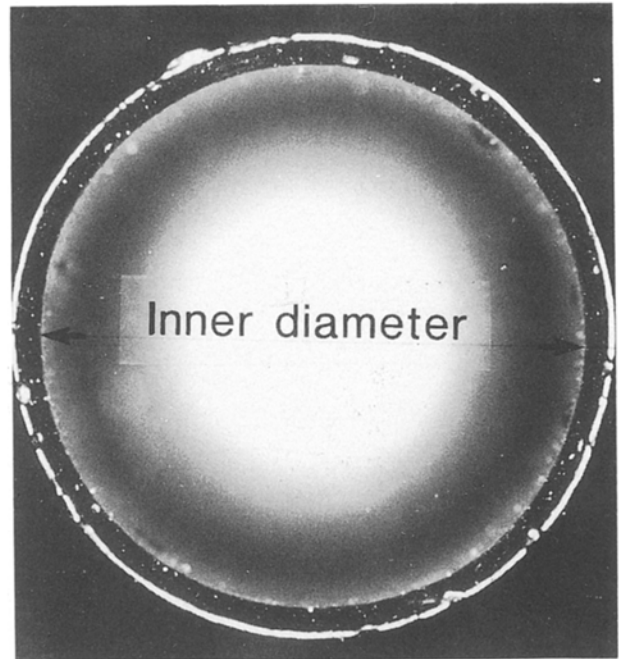

Figure 3 Photograph of a cast cylindrical crown taken head-on to its opening.
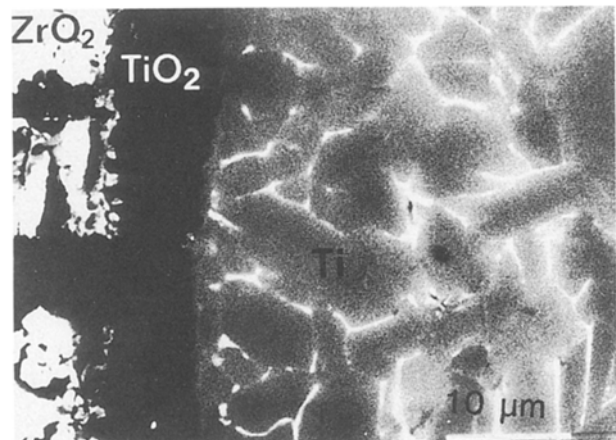

Figure 4 SEM micrograph of a cross-section showing a thin oxide film on the surface and precipitated particles in the Ti.

found by using a micrometer to decrease the outer diameter by 0.02 mm, i.e. a 0.01 mm layer was removed.

SEM investigations of cross-sections of the cast crowns made without a ZrO_2 coating on the wax model displayed an approximately 10 μm-thick oxide film on the surfaces before sandblasting. Applying such a coating reduced this oxide film. A sample in which this oxide layer is present is shown in Fig. 4.

The expansion of the investment subsequent to firing and cooling to room temperature using the 25 mm wax cylinders is shown in Table II. The investment inside the cavity expanded by 2.3%, whereas the expansion was 1.5% for the outside diameter of the wall cavity.

4. Discussion

The present photographic technique for measuring the inner marginal diameter eliminates the uncertainty

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TABLE II Expansion of the investment subsequent to firing and cooling to 20 °C

| | Experiment no. | Diameter of wax cylinder (mm) | Diameter of cold mould cavity (mm) | Difference (= expansion of the investment) | |
				mm	%
Inner diameter	1	22.26	22.74	0.48	
	2	21.96	22.46	0.50	2.3%
	3	21.88	22.40	0.52	
Outer diameter	1	25.45	25.82	0.37	
	2	25.48	25.88	0.40	1.5%
	3	25.48	25.85	0.37	

due to unremoved positive bubbles on the internal conical surface of the castings before placing them on the model die [9] or the need for sectioning the crown luted on a stone die [6, 10].

The diameters measured by the photographic technique were not dependent on the ZrO_2 coating. This clearly shows that the coating adheres to the investment and follows its movements. The measurements of the investment expansion outside the mould cavity [11] (Table II) show that it is reduced by the steel ring.

Data published by the manufacturer claim that with no water added to the mixing liquid the expansion of the investment is 1.9% after setting, firing at 800 °C and subsequent cooling to room temperature. This is higher than for most other phosphate-bonded investments. Accordingly, the inner diameter of the mould increases from 6.02 to 6.13 mm, which is the same as the observed inner diameter of the cast crown (Table I). The expansion data in the present experiments, however, show that the diameter of the mould should increase to as much as 6.16 mm. The shrinkage of the casting due to thermal contraction from the melting point to room temperature is about 0.07 mm, assuming the coefficient of thermal expansion for Ti to be 8.6×10^{-6} °C^{-1} [12]. This brings the calculated inner diameter of the casting at room temperature to 6.09 mm, whereas the observed value was 6.13 mm. This indicates that the actual shrinkage of the casting during cooling is smaller than expected. Careful sandblasting to remove the oxide film increases the inner diameter by 0.02 mm. Thus, the spacing between the die and the crown is about 55 μm (6.13–6.02 mm diameter difference). This is close to the desired gap of 25–50 μm to provide some space for the cement. The addition of water to the mixing liquid, however, can reduce the expansion of the investment according to the manufacturer.

The application of a ZrO_2 coating did not make any significant difference to the observed diameter, since the thickness of the oxide film on the surface of the

present thin-walled casting was only 10 μm without such a coating. However, this oxide film has been found to increase with the wall thickness of the casting [13]. The presence of air in the mould can also be expected to increase the oxide film. Furthermore, a preheated mould to improve the mould filling capacity may also cause an increase in the thickness of the oxide layer. In such cases the removal of the oxide film is likely to reduce the dimensional accuracy.

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