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Mold filling and dimensional accuracy of titanium castings in a spinel-based investment

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ABSTRACT

Objectives. Aim of the study was to analyze the mold filling capacity and the dimensional accuracy of a spinel-based investment for titanium castings.
Methods. Expansion of the investment in dependence of the preheating temperature was measured in a dilatometer. The degree of transformation of MgO and Al_2O_3 to spinel ($MgAl_2O_4$) was evaluated by means of X-ray powder diffraction. Mold filling capacity was assessed by casting a grid and calculating the percentage of completed segments. Dimensional accuracy was analyzed by casting a hollow cylinder and measuring the difference between the inner diameter of the resin pattern and the resulting titanium casting.
Results. Spinel formation starts at 819 °C. Diffraction patterns prove the formation of spinel from MgO and Al_2O_3. The amount of spinel increases with increasing preheating temperature. The final expansion of the investment at the end of the preheating cycle at 450 °C shows a linear correlation to the maximum preheating temperature. The degree of mold filling is reciprocal to the preheating temperature. The dimensional accuracy shows a linear correlation to the amount of spinel. Best dimensional accuracy was obtained at about 900 °C. After a preheating temperature of 884 °C, as recommended by the manufacturer, the cast specimens showed a slightly lower inner diameter as compared to the resin patterns.
Significance. The results suggest that with the spinel investment analyzed an excellent accuracy of titanium castings may be obtained.

1. Introduction

Casting of titanium is demanding. The strong affinity of Ti to elements such as O, N, or C and its high melting point of 1668 °C lead to reactions with the investment surface. Thus, a brittle surface layer is formed which affects the surface properties of titanium castings [1]. To reduce the formation of this so-called alpha-case, Ti has to be cast at a comparatively low

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mold temperature of about 400–450 °C. Hence, mold filling and dimensional accuracy in titanium castings are a concern [2]. In fact, the margin quality of titanium reconstructions is significantly lower as compared to high-gold alloys [3,4].

For dimensional accuracy the metal shrinkage during crystallization and cooling must be compensated. That is accomplished by an appropriate expansion of the investment prior to casting [5]. Silica-based phosphate-bonded investments have been commonly used for casting high temperature melting noble and base metal alloys in dentistry. Since Ti is highly reactive at high temperatures, effort has been made to replace silica with thermally more stable refractory materials such as MgO or Al_2O_3 [5].

Current investments for titanium casting use the formation of spinel ($MgAl_2O_4$) from MgO and Al_2O_3 to generate an expansion of the investment [6]. From crystal data [7–9] it can be calculated that the crystallization of spinel from MgO and Al_2O_3 is associated with an increase in volume of 8.04%. Hence, by the degree of transformation of MgO and Al_2O_3 to spinel the expansion of the investment can be controlled.

To the knowledge of the authors no data are available concerning the properties of the investments based on spinel. Aim of the present study, therefore, was to measure the expansion of a spinel-based investment and to evaluate the mold filling and the dimensional accuracy of titanium castings in dependence of the thermal treatment of the investment.

2. Materials and methods

The investigation was performed with the spinel investment Biotan Vest C&B (Schütz Dental, Rosbach, Germany). For all specimens a powder/liquid ratio was chosen according to the manufacturers instructions (18 g powder/100 ml liquid). The powder was weighed to a precision of 0.01 g (PL1200, Mettler Toledo, Nänikon, Switzerland). The liquid volume was measured with a 25 ml pipette with a graduation of 0.25 ml. Mixing was done in a vacuum mixer (Smart-Mix, Amann Girrbach, Pforzheim, Germany) with a reduced pressure of −845 mbar for 60 s and the investment was poured into the appropriate mold on a vibrator (Vibrator 7032, Leleux, Oberhausen, Germany) using a frequency of 6000 Hz. Setting was allowed for 45 min as recommended by the manufacturer. A heating temperature of 884 °C is recommended to achieve a precise fit, but a temperature range of 850–940 °C is allowed in order to adjust the expansion. The appropriate heating cycles for these three preheating temperatures are shown in Fig. 1. According to the manufacturer's instructions a heating rate of 5 K/min was chosen. There are hold-times for 30 min at 300 °C, at the preheating temperature, and at the end of the preheating cycle at 450 °C.

2.1. Setting expansion

To measure the setting expansion an extensometer according to ISO 9694:1996 was used, consisting of a V-shaped trough with a length of 50 ± 0.1 mm and a width of 25 mm. At one side a movable plate was mounted, which was connected to a micrometer. The mixed investment was poured into the V-shaped trough and 2 min after starting the mixing, the micrometer was read every 5 min for 2 h.

2.2. Thermal expansion

For the measurement of the linear thermal expansion cylindrical samples with dimensions of 25 mm in length and 5 mm in diameter were produced using a separable polyacetal mold. Thermal expansion was measured in a dilatometer (DIL 402C, Netzsch, Selb, Germany), performing a complete heating cycle according to Fig. 1 with maximum temperatures of 850, 884, and 940 °C, respectively. A mean curve of 6 measurements for each temperature was calculated. In addition the final expansion at 450 °C was calculated as mean of the 6 samples.

2.3. X-ray diffraction analysis

Powders of the investment after heating to 850, 884, or 940 °C were investigated by powder diffraction (STADI-P, STOE, Darmstadt, Germany) and analyzed by means of the software WinXPow [10]. Assignment of phases via the powder diffraction data base PDF-2 was performed using the software Match! (Crystal Impact, Bonn, Germany). Relative amounts of phases in the samples were determined by Rietveld analysis using EXPGUI/GSAS [11,12].

2.4. Dimensional accuracy and mold filling

In purpose to measure the dimensional accuracy after casting, polyacetal hollow cylinders with a height of 5 mm, an outer diameter of 8 mm and an inner diameter of 5 (±0.03) mm were milled fine mechanically according to Fig. 2A. The inner diameters of the cylinders were measured with a calibrated three-point micrometer screw (Futuro, Brütsch-Rüegger AG, Zurich, Switzerland) with a precision of ±0.02 mm. These cylinders were attached to wax sprues with a diameter of 5 mm. A second part of the specimens consisted of a polyethylenterephthalat grid (Sefarpetex 07-1410/49, Sefar, Rüschlikon, Switzerland) with 10 × 10 meshes to measure the mold filling (Fig. 2B) [13]. The mesh size was 1.4 mm, the diameter of the filaments 0.6 mm. This grid was attached to a Y-shaped wax sprue with a diameter of 2.5 mm. Both the cylinder and the grid were attached together in an angle of 60° and invested in

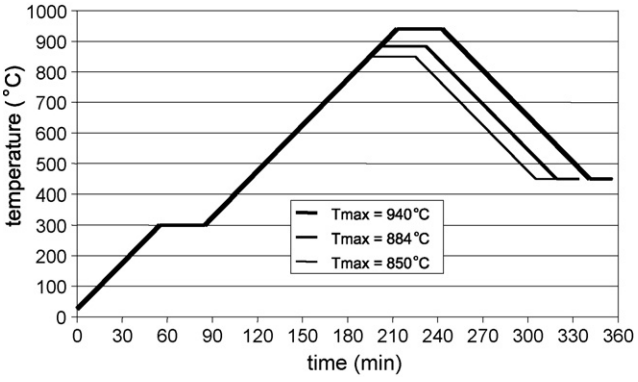

Fig. 1 – Heating cycles for the investment.