Gypsum Bonded Investment Moulds for Microcasting of Gold Alloy Using for Inlay Dental Applications

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Abstract: In this paper, microcasting has been attended to investment casting process. The investigation carried on characterization of gold alloy cast by vacuum pressure casting process gypsum bonded investment moulds. The thermal behavior of gypsum bonded investment moulds was illustrated. Macrostructure and microhardness of cast microparts are also presented. Dehydration of investment occurs in a double step process. The generation of sulfur dioxide may result in deterioration of the casting due to gas bubbles in the near-surface region.

Keywords: Gold alloy, gypsum bonded investment moulds, vacuum pressure casting, inlay dental application.

1. INTRODUCTION

Traditional process of preparing investment shell mould uses colloidal silica binder. The working temperature of the investment powder and liquid are critical factors in determining the setting time, expansion, surface roughness and consequently the final fit of the castings [1-10]. The correct positioning of the wax/resin patterns is important in order to ensure sufficient thickness of investment material around the objects to withstand the casting forces and provide sufficient expansion [11-21]. The investment casting is proven casting technology for variety of products [22-25]. Micro-sized investment shell moulds with complex configurations cavity can be prepared with phosphate-bonded investments [26]. Gypsum bonded investment (GBI) casting is widely used in jewellery and dental casting and the investment usually consist of refractory material and a binder. The compressive strength of GBI was between 4–5 MN/m^2 which had been found adequate to withstand casting pressure.

Pure gold is too soft to be used alone in dentistry and to achieve adequate mechanical properties it must be alloyed with other elements [27-29]. Copper is the principal hardener. It is necessary for heat treatment and is usually added in concentrations of greater than 10%. Silver lowers the melting temperature and also modifies the red color produced by the combination of gold and copper. It also increases ductility and malleability. Palladium raises the melting temperature, increases hardness and whitens the gold, even in very small concentrations. It also prevents tarnish and corrosion and acts to absorb hydrogen gas which may be released during casting causing porosity. Zinc acts as an oxygen scavenger and prevents the formation of porosity in the finished alloy. It also increases fluidity and reduces the surface tension in the molten state improving the casting characteristics of the alloy.

In dentistry, an inlay is usually an indirect restoration consisting of a solid substance fitted to a cavity in a tooth and cemented into place. This technique involves fabricating the restoration outside of the mouth using the dental impressions of the prepared tooth, rather than placing a soft filling into the prepared tooth before the material sets hard. An onlay is the same as an inlay, except that it incorporates a replacement for a tooth cusp by covering the area where the missing cusp would be [29]. Crowns cover all surfaces of the anatomical tooth crown.

When casting microparts, a great difficulty is the removal of the investment. For gold base alloys, phosphate bonded investment can be removed by acid owing to the higher chemical resistance of the metal compared with the investment [26], but for base alloys this procedure is not applicable. Hence, special investments which are easily soluble are required. This is achieved by using plaster as binder. Therefore, the purpose of this investigation was characterization of gold alloy cast by vacuum microcasting process in gypsum bonded investment shell moulds.

2. MATERIALS METHODS

The microcasting process requires a lost plastic pattern to be mounted on a gate and feeding system made of wax. The pattern assembly was completely embedded in ceramic slurry. For cost-effective microcasting, the assembly of single patterns was built up into tree-from as shown in figure 1. In microcasting, single polymer patterns are normally fixed with wax. Patterns for microcasting should be constructed according to the well-known design rules for casting. In order to produce faultless patterns, different wall thicknesses and sharp edges should be avoided. The cross-sectional thickness of the sprue system should increase

in the direction of the sprue bottom, because solidification must begin in the microparts and end in the bottom of the tree (figure 1). The best GBI mixture consists of cristobalite, POP and water were mixed until a creamy and thick slurry was obtained. The water/powder (w/p) ratio was 0.40. Then the slurry was poured into the flask and permitted to solidify by chemical reaction forming a block mould. After six hours, the moulds were placed in the furnace for plastic patterns and preheating process. Initially, it was heated at 250^{o}C with a rate of 2.0^{o}C/min and held at this temperature for 3 hours. Then the temperature was increased to 750^{o}C with a rate of 2.5^{o}C/min and held at this temperature for 5 hours. At this stage, burn-out process was expected to occur in order to ensure that all the plastic in the mould was completely eliminated. After the burn-out process the mould was cooled in the furnace to the desired casting temperature. In this study, the mould pouring temperature was set at 600^{o}C.

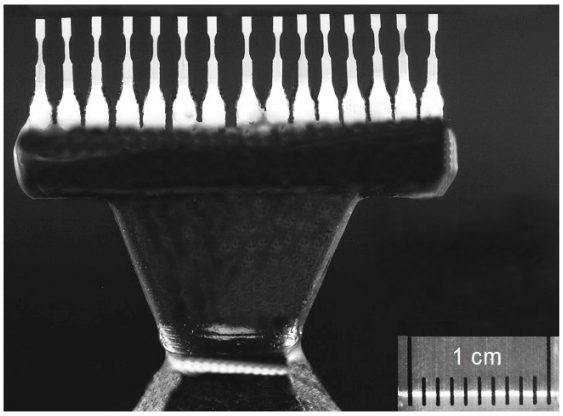

Figure 1: Pattern assembly.

Owing to the much higher surface to volume ratio in microchannels compared with macrostructures and the distinct influence of surface roughness, the occurrence of turbulent flow needs to be taken into account. Another aspect is the extremely high cooling rate and therefore extremely fast solidification in the small structures, which hinders form filling much more than in macrostructures. For vacuum pressure casting of microparts, dental casting machines are used. Figure 2 shows a scheme of the process. The gold alloy was melted in the graphite crucible. On top of the crucible the open mold is fixed upside down. After evacuation, the machine turns itself upside down. As a result, the melt flows into the mold by gravity. Complete form filling even of small cavities is achieved by subsequent application of pressure to the melt. The composition of gold alloy is given in table 1.

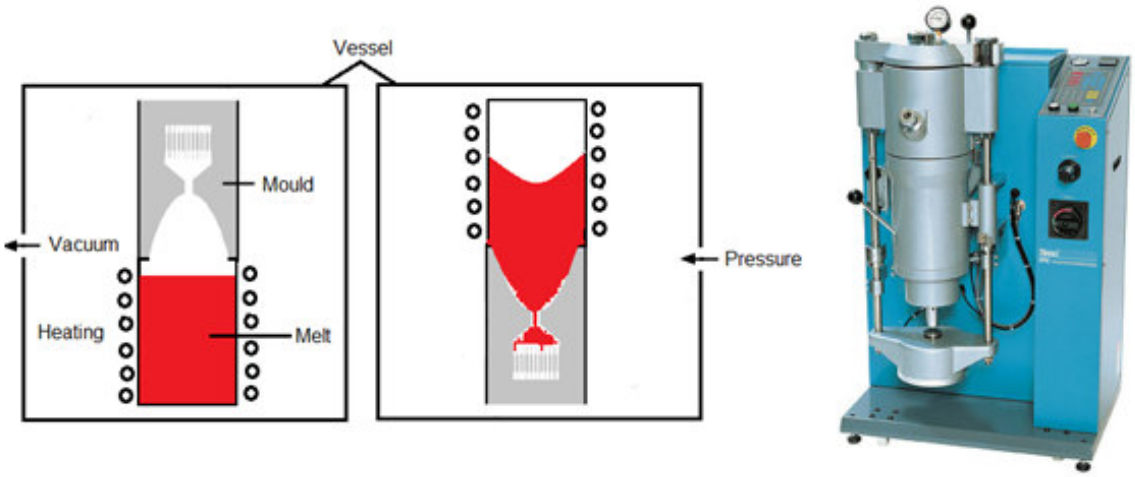

Figure 2: Vacuum pressure casting process.

Table 1: Chemical composition gold alloy

Alloying element	Gold	Silver	Copper	Palladium	Zinc
% wt	75	10	10	3	2

3. RESULTS AND DISCUSSION

Cristobalite also undergoes an expansion in the range 240-275°C. For silica, these transformations are reversible. Gypsum also undergoes phase transformations, but these are not reversible. Varying the percentage of gypsum to silica can change the expansion profile of the investment material. The thermal expansion profiles of two percentage mixes are shown in figure 3. During setting, the plaster shows a change in volume. Although the real volume will decrease by 7% when the starting substances are mixed together, the apparent volume will increase owing to the feeding by the slurry during the solidification of the mold. Gypsum, or calcium sulfate, going from room to glass casting temperature and beyond, undergoes a number of phase transformations that all result in irreversible contractions. Dehydration of investment occurs in a double step process.

When mixing the slurry for embedding, the chemical reaction of α-semihydrate with water results in calcium sulfate dehydrate

$$CaSO_4 \cdot \frac{1}{2}H_2O + \frac{3}{2}H_2O \rightarrow CaSO_4 \cdot 2H_2O$$

This rehydration is an exothermic process. Stoichiometrically, 18.7 ml of water are needed to rehydrate 100 g of plaster. The idealized structure of pure gypsum consists of lattice planes of calcium sulfate molecules weakly bonded to alternating layers of water. The bond is an ionic one between the oxygen atoms and the hydrogen atoms in water – very easily broken. Water thus weakly bonded is often called the water of crystallization.

During burning, the crystal water is released and the anhydrite of calcium sulfate for the mold is obtained.

$$CaSO_4 \cdot 2H_2O \rightarrow CaSO_4 + 2H_2O$$

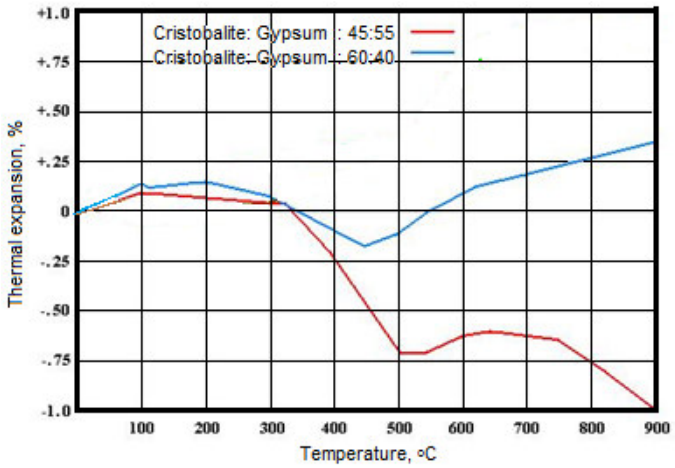

Figure 3: Thermal expansion of gypsum bonded investment.

Above 750°C, calcium sulfate decomposes as follows:

$$2CaSO_4 \rightarrow 2CaO + 2SO_2 + O_2$$

The generation of sulfur dioxide may result in deterioration of the casting due to gas bubbles in the near-surface region if the gas cannot be dissipated through the porous mold. Another problem with plaster bonded investments is the decomposition of the investment between 500 and 600°C if carbon is present.

$$CaSO_4 + 4C \rightarrow CaS + 2CO_2$$

The microstructure of gold alloy is shown in figure 4. Pin-hole porosity is observed in the microstructure. Zinc acts as an oxygen scavenger during melting to minimize the oxidation of the other elements in the alloy. Zinc prevents oxygen from forming gas porosity in the casting. AuCu phase is very strong. The lattice distortion is increased in the inter-phase boundaries of the various phases. The fine inter-phase boundaries between the product phases must have contained large amounts of internal strain by lattice distortion. In microcasting, the side bands that appeared in both sides of the main AuCu phase on account of rapid atomic diffusion by spinodal decomposition. A fine block-like structure is also appeared between the dendrite structures.

Because of Zn content a fine block-like structure is also revealed in the microstructure. The microhadness was 140 VHN. A typical application of this gold for dental inlays is shown in figure 5.

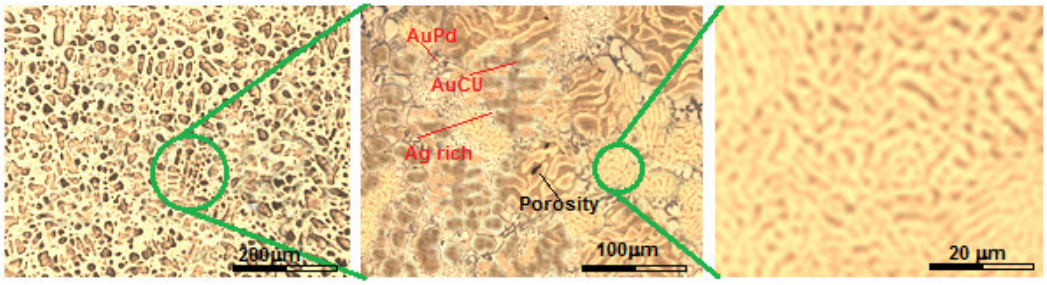

Figure 5: Microstructure of gold alloy.

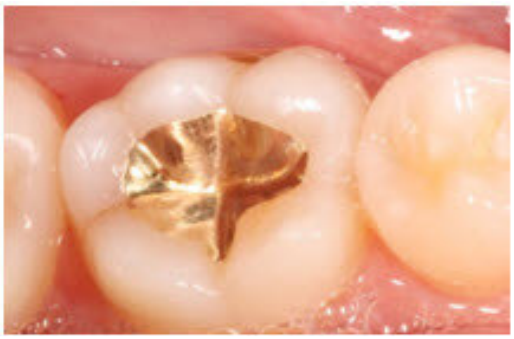

Figure 5: Typical application of gold alloy.

4. CONCLUSIONS

This paper proves that the microcasting is an ideal casting process for metal parts in micro-dimensions. Gypsum investment casting is a suitable technique for the manufacture of gold microparts. The gas bubbles were formed at the mould –metal interface due to generation of sulfur dioxide. The hardened layer thickness appears to be roughly 100–150 mm for gold alloy.

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