Mold filling of titanium castings using a 45° marginal edge angle

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Purpose: The objective of the present study was to investigate the mold filling of pure titanium and titanium alloys using a wedge-shaped mold with a marginal edge angle of 45°.
Materials and Methods: The metals tested were commercially pure Ti, Ti-6Al-7Nb, and Ti-6Al-4V; they were cast using an Ar-arc centrifugal casting machine. The castings were cut into four pieces parallel to the triangular surface. An optical microscope was used to evaluate mold filling as the distance between the tip of the cast wedge and the theoretical tip of the triangle. The data gathered for the 45° marginal edge angle in this study and for the 30° angle in a previous study were compared.
Results: The mold filling of the 45° angle was superior to that of the 30° angle for all three cast titanium metals.
Conclusion: Proper mold filling of titanium metals can be achieved with the 45° marginal edge angle compared with the 30° angle. **(Int Chin J Dent 2004; 4: 67-71.)**

Clinical Significance: Wide marginal edge angles are strongly recommended when titanium is used to fabricate dental appliances.
Key Words: casting, margin, mold filling, titanium.

Introduction

Pure titanium and titanium alloys could be excellent candidates for the production of dental appliances because of characteristics that are similar to those of dental gold alloys, i.e., outstanding biocompatibility,[1] high corrosion resistance,[2,3] good mechanical properties,[4] and good machinability.[5,6] However, several problems associated with titanium casting prevent it from being widely used. One of the requirements of a dental alloy is a superior capacity to fill a mold completely.[7-12] The results in our previous study[11] showed that the mold filling of the marginal edges of the titanium alloy castings having a 30° wedge angle was within the acceptable level for dental appliances, but these values were significantly inferior to those for conventional gold alloy.

It is hypothesized that increasing the edge angle should improve the mold filling. Therefore, in this study, we used a wider wedge angle (45°) to attempt to obtain more acceptable mold filling for titanium and titanium alloys. The purpose of the present study was to investigate the mold filling of pure titanium and titanium alloy castings made with a marginal edge angle of 45º.

Materials and Methods

The three metals tested in this study were commercially pure (CP) titanium (ASTM Grade 2, Titanium Industries, Grand Prairie, TX, USA) and two commercial titanium alloys (Ti-6Al-7Nb, 5.5-6.5% Al, 6.5-7.5 Nb, T Alloy Tough, GC Corp., Tokyo, Japan; Ti-6Al-4V, 6.10% Al, 3.97% V, Titanium Industries, Grand Prairie, TX, USA).

A wedge-shaped pattern with an edge angle of 45° was prepared using an acrylic plate. The shape and dimensions of the pattern are given in Fig. 1. Every edge of the pattern was examined with an optical microscope (Zeiss H-PI, Oberkochen, Germany) to select good patterns with high-quality edges. Three patterns were attached to the sprue former using a wax sprue. A sprue rod (about 3 mm diameter and 8 mm long) was connected to the flat bottom end of the smaller cross section of the wedge pattern. The open end of the sprue was attached directly onto the sprue former. The three patterns were placed horizontally at equal intervals. The patterns were vacuum-invested in a mold ring with a magnesia-based investment material (Selevest CB, Selec Inc., Osaka, Japan). The distance from the top of the pattern to the top rim of the casting ring was approximately 30 mm. The invested mold was allowed to bench-set at room temperature for 120 minutes. After the investment had set, the molds were burned out in a furnace (Accu-Therm III 6000, Jelenko, Armonk, NY, USA) in accordance with the manufacturer's instructions.

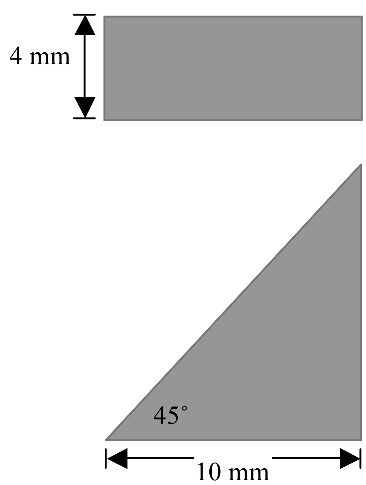

Fig. 1. Shape and dimensions of the pattern used.

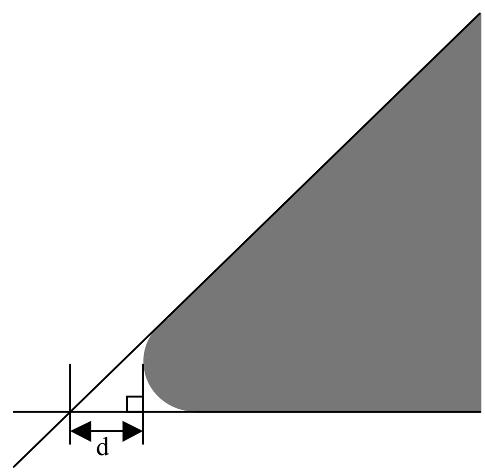

Fig. 2. Definition of mold-filling index (μm).

The three titanium metals were then cast using an arc-melting centrifugal casting machine (Ticast Super R, Selec Inc.). The mold temperature at casting was approximately 200°C. After the sprue rod was cut, each cast wedge specimen was embedded in self-curing resin (Orthodontic Resin, Caulk/Dentsply, Milford, DE, USA) such that the triangular surface appeared on one of the flat surfaces. The embedded specimen was sliced using a diamond wheel (Alpha Resources Inc., Stevensville, MI, USA) into four pieces to make three sectioned surfaces perpendicular to the triangular surface. Each sectioned surface was polished under running water using up to 800 grit silicon carbide paper. Each edge on the polished cross section was photographed using a microscope (Zeiss H-PI) at 68X magnification.

The amount of mold filling was evaluated by determining the missing length (μm) of the partially filled tip of the triangle (mold-filling index) using these photographs (Fig. 2). Fifteen measurements for each titanium metal (three sliced surfaces of each of five castings) and the data for the 30° angle obtained in our previous study[11] were statistically analyzed using two-way analysis of variance (ANOVA). The variables were edge angle and metal. Duncan's new multiple range test was applied when appropriate at a significance level of α=0.05.

Results

Two-way ANOVA and Duncan's new multiple range test revealed that there were significant differences ($p<0.05$) in the mold-filling indexes between the two edge angles. The mold-filling index of each metal for the 45° angle was significantly ($p<0.05$) lower than for the 30° angle. However, there were no significant differences in the indexes due to the metals and their interaction ($p>0.05$). The mean and standard deviations with statistical categories for each metal for the two wedge angles are summarized in Table 1.

Table 1. Mold filling indexes for each metal.

Material	Edge angle (˚)	Mold filling Index (μm)	SD	Duncan grouping	
CP Ti	45	34.7	11.0	a	
CP Ti	30	135.5	27.0		b
Ti-6Al-7Nb	45	32.7	23.3	a	
Ti-6Al-7Nb	30	138.2	46.4		b
Ti-6Al-4V	45	32.9	26.4	a	
Ti-6Al-4V	30	143.9	41.8		b

The data presented here for the 30° wedge angle were obtained from the reference 11. Identical letters indicate that the values are not statistically different ($p>0.05$).

Discussion

The main purpose of the present study was to evaluate the effect of marginal edge angle on mold filling of titanium metals. This investigation using wedge-shaped patterns with two different marginal angles of 45° and 30° provided a mold-filling index range for the titanium metals examined.

Since Brockhurst et al.[7] reported on a castability standard for dental alloys in restorative dentistry, most researchers have used the 30° angle for their molds, including a simulated cylindrical single crown mold, regardless of the dental metal used; titanium casting studies are no exception. However, no information is available about mold filling with angles wider than 30°. The 45° marginal angle used in the present study is the widest angle used in any study of this type.

When a 30° wedge angle was used, the mold filling of the marginal edges of the titanium alloy castings was significantly inferior to that of the conventional gold alloy.[11] However, titanium is still an attractive metal for dental use because it offers many advantages, as described above. The shortcomings of any casting material should be improved if at all possible. The goal of the present study was for titanium to fill a mold as well as conventional gold alloy does.

The results of this study revealed that the three titanium metals tested filled the 45° marginal angle better than the 30° angle. The mold-filling values of the three metals in the 45° marginal angle were at a satisfactory level for dental casting. It should be noted that contrast evaluation revealed that they were even better than that of the gold alloy in the 30° marginal edge angle (71.2±18.5 μm).[11]

A 45° marginal angle is clinically acceptable when abutment teeth are prepared using a torpedo-shaped diamond point or tungsten bur because the appropriate marginal finish for a full veneer crown preparation is what is termed a "135° chamfer".[13] When the 135° chamfer is prepared using the bur parallel to the long axis of the abutment tooth, the marginal edge angle of the wax pattern should be 45° or more. The reason for this configuration is that the profile of the crown of a human tooth is generally convex, since the height of convexity is located closer to the cervix, approximately one-third or one-half of the distance from the cervical line to the marginal ridge. Then, the angle of the prepared surfaces vs. the unprepared surfaces is nearly 28°.[14]

The mold-filling indexes of the three titanium metals used in this study showed no statistical differences at both wedge angles ($p>0.05$). The reason for this finding may be the similar solidification behavior of the three metals. The estimate from the published equilibrium phase diagrams for Ti-Al-Nb and Ti-Al-V alloys[15] at the present alloy chemical compositions suggests that the temperature differences of the liquidus and solidus lines in these two alloys are minimal, indeed almost identical in melting behavior.[11] Even at a 15° wedge angle, the mold-filling indexes of the three metals were statistically same ($p>0.05$),[11] so it is not surprising that no statistical differences were found in marginal filling at a wider angle.

The clinical significance drawn from the present study is that the marginal finish for a full veneer crown preparation should be a 135° chamfer or more, and the marginal finish of the wax pattern should be 45° or more for titanium casting. The standard deviations of mold-filling values of the three metals in the 45° marginal angle were all smaller than those in the 30° angle. This fact indicates that this technique is highly reliable and that there will be less irregularity of the marginal line.

Conclusion

Proper mold filling of titanium metals can be achieved with the 45° marginal edge angle compared with the 30° angle.

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