Technical report

Dental Materials Journal 19(3) : 307−316, 2000

New Partition Technique for Two-chamber Pressure Casting Unit for Titanium

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Received February 14, 2000/Accepted June 8, 2000

Although titanium has been widely used in prosthetic appliances, such as cast removable partial denture frameworks, high quality castings are still difficult to obtain. This study proposes a new partition technique using a metal foil for improving castability of a two-chamber pressure casting unit. The metal foil was formed beforehand to bring it in contact with the mold crucible wall so that no clearance was left behind it. Using this formed foil, the mold cavity can be completely isolated from the upper chamber and can be maintained in a vacuum even after the rupture of the foil. Accordingly, a large casting force is generated very quickly, and as a result, castability is expected to be significantly improved. This expectation was confirmed by the experiments using wax patterns including thin plate and mesh plate.

Key words : Titanium casting, Two-chamber pressure unit, Partition foil

INTRODUCTION

Dental titanium casting has been developed since its beginning of two decades ago, and has been widely applied to prosthetic appliances, including partial denture frameworks[1]. This is due to titanium's attractive properties, such as its low density, high corrosion resistance and excellent biocompatibility[2]. However, its high melting point (1,943°K) and high reactivity at higher temperatures require a particular casting system and complex procedures, which increase the cost of fabricating dental titanium castings. In addition, the low success rate[3] of quality castings increases the cost significantly.

The Cyclarc system uses a two-chamber pressure casting apparatus[4]; the upper chamber houses a copper crucible to melt a titanium ingot, and a mold is placed in the lower chamber. When the mold is set under the pipe passage between both chambers, they are isolated from each other. The typical operation recommended by the manufacturer is as follows: After both chambers are evacuated, argon gas is introduced into the upper chamber and the titanium ingot is arc-melted. When the melt drops down onto the mold crucible, the casting force increases gradually with the decrease in pressure in the mold cavity.

Although this casting unit has been improved, insufficient castability of complicated patterns, such as partial denture frameworks[3], is one of serious misgivings of this system. The importance of proper control of the argon pressure on castability has been studied by Syverud *et al.*[5] Concerning mold permeability, Watanabe *et al.* theoretically investigated the behavior of the casting force and proposed a choice of investment appropriate for this system[6]. Since these all are partial improvements, however, the problem has not been completely resolved.

The procedure needed to overcome this problem is probably a partition technique. To isolate the mold cavity from the upper chamber, Togaya *et al.* proposed two techniques using a flat metal sheet called diaphragm[7,8]. One cannot be applied to a typical mold because a special crucible is required for each mold[7]. The other can be applied easily[8], but the moment the diaphragm is fused and ruptured by the melt, the argon gas flows into the cavity prior to the drop of the melt. As a result, this diaphragm was not so effective as had been expected.

To make the separation complete, we designed in a new partition technique that involves a metal foil formed in a cone shape. Due to this shape, there is no clearance between the foil and the crucible wall, and, thus, the mold cavity is maintained in a vacuum when the foil fuses due to the liquid titanium.

The purpose of the present study was to confirm the hypothesis that by using an appropriate partition technique, the casting force increases very quickly and as a result the castability is remarkably improved.

MATERIALS AND METHOD

To demonstrate the difference in castability between the typical and the new techniques, three types of wax pattern were adopted: a relatively thick plate, a very thin plate and a complicated mesh plate (Grids round RN Ⅲ, DENTAURUM, Ispringen, Germany). We adopted round sprues with smaller diameters than those used in the conventional titanium casting. Each sprue was flattened to enable a smooth connection to each pattern. The dimensions of these patterns and the corresponding sprues are shown in Table 1. As shown in Fig. 1, the three types were attached to one crucible former and invested using a $MgO-Al_2O_3$ based investment material (Titavest CB, Morita, Kyoto, Japan). The mold was burnt out according to the manufacture's instructions and then cooled in a furnace. Casting was made into the mold maintained at room temperature using a two-chamber pressure unit (Cyclark, Morita, Kyoto, Japan).

The casting procedures were carried out using two techniques:

(1) One was the typical technique recommended by the manufacturer.

Table 1 Three types of wax pattern used in the present study

(mm)

	pattern size	sprue size
thick plate	20 × 23 × 1.4	2.0 ϕ × 8
thin plate	20 × 23 × 0.45	2.5 ϕ × 5
mesh plate	27 × 29 × 0.76	2.5 ϕ × 5

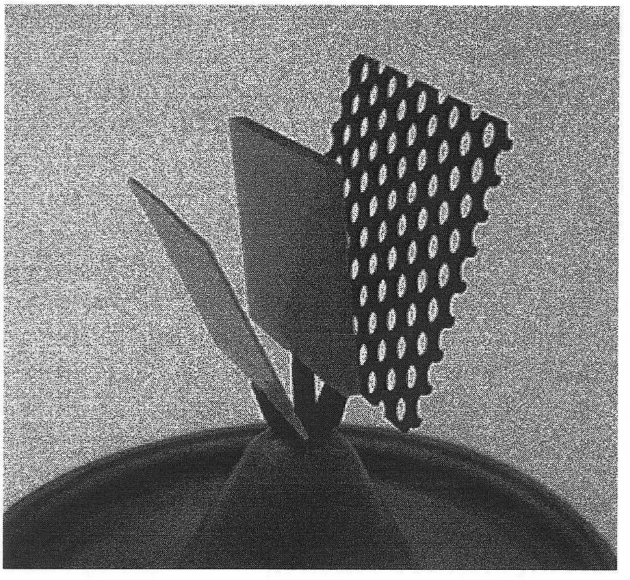

Fig. 1 Three types of wax pattern used in the present study.

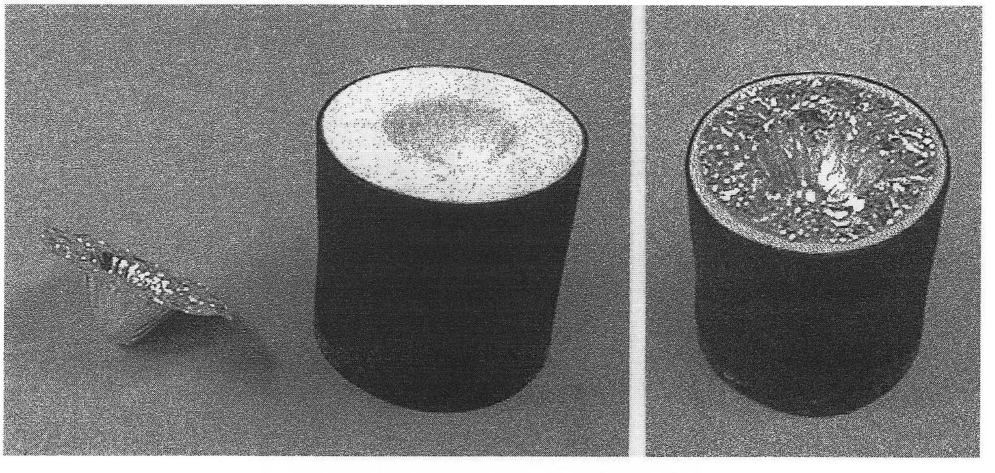

Fig. 2 Invested molds and partition foils: an individual state (left) and a combined state (right).

(2) The other was the new technique that contained the additional step of putting the partition foil on the crucible before the mold was set in the casting unit. Other steps are the same as those of (1).

For the partition foil, two sheets of commercial aluminum foil of 0.020 mm in thickness were formed to bring them in contact with the mold crucible wall so that no clearance was left behind them (Fig. 2). Then, a ceramic packing was placed on the mold and the mold was set in the casting unit as shown in Fig. 3. The arrowhead in Fig. 3 indicates the partition foil. Argon gas at 240 kPa was supplied from a cylinder to the upper chamber. The pressure is represented as the absolute value in this study. The pressures of both chambers were checked by the pressure gauge incorporated in this casting unit. Commercially pure titanium (cp-Ti: grade 2) was cast in five molds for each technique.

After sandblasting the surface with glass powder, each casting was weighed, and its volume was calculated based on the density of the metal. Castability was determined as the percentage of metal volume filled divided by the total volume. The findings obtained were analyzed using ANOVA and Students' test.

The obtained castings were examined using an X-ray transparent instrument (MBR-1505TV, Hitachi, Tokyo, Japan) under a tube voltage of 70 kV, a tube current of 1 mA and an appropriate exposure time depending on the thickness of each cast-

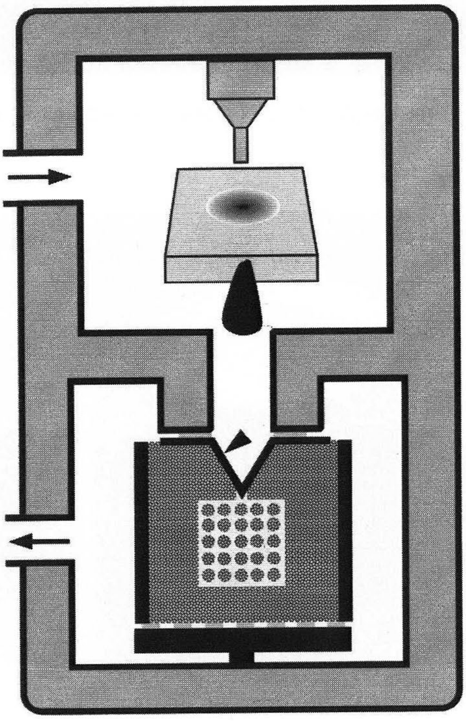

Fig. 3 Schematic diagram of the two-chamber casting unit including a partition foil proposed in the present study.
The arrowhead indicates the partition foil cone, the thickness of which has been represented after magnification. Each arrow indicates the flow direction of argon gas.

ing. To check the existence of small as well as large pores, ultra-fine industrial X-ray film (IX 80, FUJI PHOTO FILM, Tokyo, Japan) was used.

RESULT

In the typical technique, the pressures in the upper and lower chambers were 200 ± 7 kPa and 25 ± 3 kPa, respectively. These measurements were means and standard deviation of 5 repeated tests. When the partition foil was used, they were approximately 230 ± 3 kPa and 3 ± 1 kPa. That is, the lower chamber was maintained at a rough vacuum. The pressure in the mold cavity was also maintained at a rough vacuum because equilibrium was achieved between the lower chamber and the mold cavity.

Photographs of typical castings obtained with the usual technique (upper side) and with the partition foil technique (bottom side) are shown in Fig. 4. In this figure, the left side and right side are the results of thin, and mesh plates, respectively.

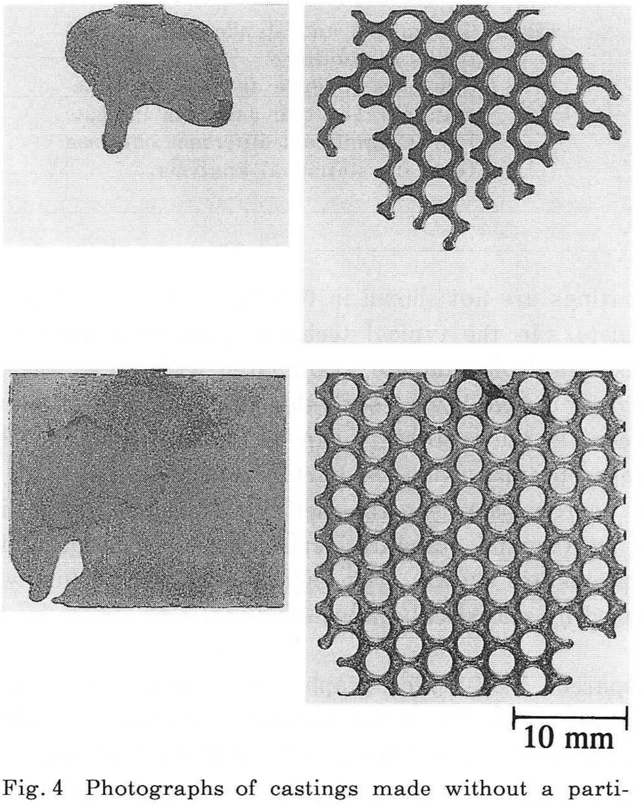

Fig. 4 Photographs of castings made without a partition foil (upper side) and with a partition foil (bottom side).
The left side and right side indicate the thin and mesh plates, respectively.

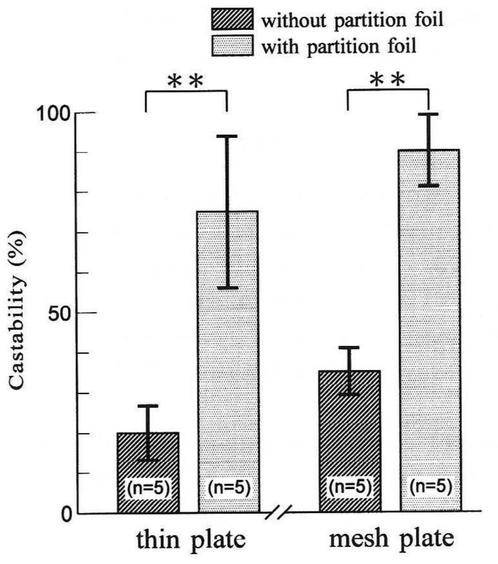

Fig. 5 The means and standard deviations of the castability.
The bars indicate the standard deviations. The two asterisks indicate higher significant difference obtained from the statistical analysis.

The thick plate castings are not shown in this figure because in both techniques, each casting was complete. In the typical technique, the thin plate and the mesh plate castings were considerably incomplete. Compared with these, the partition technique significantly improved castability of both thin plates and mesh plates. In particular, a significant increase in the castability can be recognized in the thin plate castings. In the mesh castings obtained using the partition technique, despite the sprue followed by only two very narrow passages, the melt filled almost the entire area.

In Fig. 5, the means and standard deviations for the castability values of thin plates and mesh plates are shown. For each casting shape, highly significant differences were confirmed by statistical analysis indicated as shown by two asterisks (Fig. 5).

Typical transparent X-ray photographs of castings obtained using the typical technique (upper) and the partition foil technique (bottom) are shown in Fig. 6. The left side, middle, and right side are the results of thick, thin, and mesh plates, respectively. In the partition technique, a slight increase in small pores can be observed in the thick plate and the thin plate.

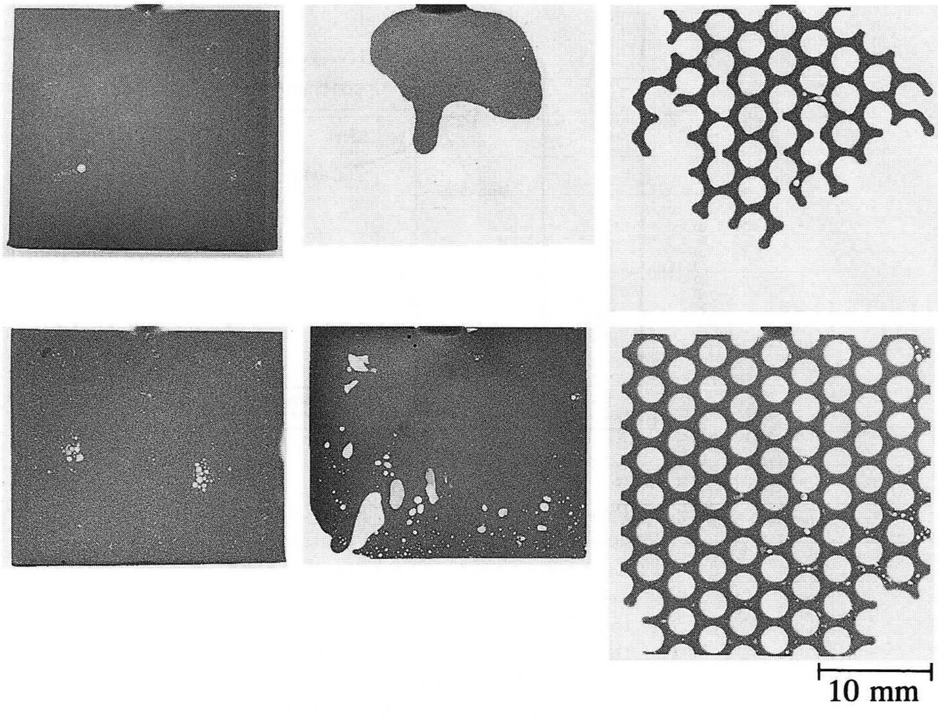

Fig. 6 Typical X-ray transparency photographs.
The upper and bottom photographs indicate the castings obtained without the partition foil and with a partition foil, respectively. The left, middle and right indicate the thick, thin and mesh plates, respectively.

DISCUSSIONS

For dental titanium casting, one of the most important properties is good castability to obtain good-quality castings because dental casting requires replication of complex shapes with high fidelity. Castability has been used as the fluidity that is the power of the mold filling and is influenced by many factors, such as casting force, mold temperature, and mold permeability[5]. Above all, the casting force is the essential factor because a too speedy solidification tends to occur due to the large temperature difference between the melt and the mold. Therefore, a sufficient force acting on the melt is an indispensable condition for complete castings.

The casting force of the pressure casting unit is identical to the pressure difference between the upper and lower surfaces of the melt on the mold crucible. In this two-chamber unit[9], each casting step is described as follows, with reference to Fig. 7. In these steps, the typical technique and the partition foil technique were also discussed.

(1) First both chambers are evacuated simultaneously to 1 kPa.

(2) Then, high pressure argon gas was introduced into the upper chamber while

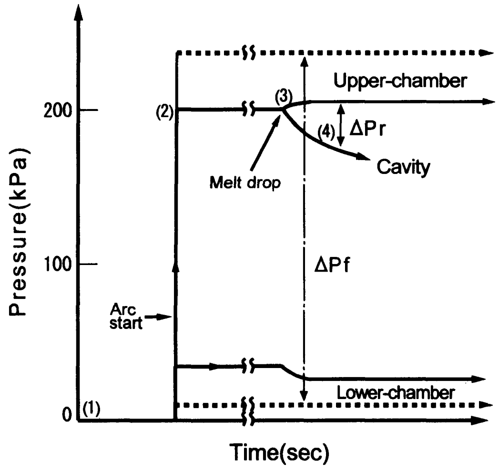

Fig. 7 Pressure changes at each casting step of the two-chamber casting unit. Each step, represented by the number in the bracket, corresponds to that in the text. After the arc starts, the processes of the typical technique and of the partition foil technique are shown with a solid line and a dotted line, respectively. The symbols, ΔP_r and ΔP_f, indicate pressure differences (casting forces) of the typical technique and of the partition foil technique, respectively.

the lower chamber was maintained at a low pressure. Both pressure values are dependent on the mold permeability even if the supplied pressure is the same. The pressures in the upper and the lower chambers were 200 kPa and 25 kPa in the present study, respectively. At this time, the pressure of the mold cavity is identical to that of the upper chamber (200 kPa) because the cavity is connected to the upper chamber through the sprue. In the partition technique, the pressures of the upper chamber and the lower chamber were 230 kPa and 3 kPa, respectively. The pressure in the mold cavity was almost equal to that of the lower chamber because the mold cavity was completely separated from the upper chamber. That is, the pressure in the cavity was 200 kPa in of the typical usual technique and 3 kPa in the partition foil technique.

(3) When the melt drops down and plugs the sprue inlet, the mold cavity is completely isolated from the upper chamber. The pressures in the upper and the lower chambers become larger and smaller, respectively.

(4) As the argon gas in the mold cavity leaks into the lower chamber through the porous media of the mold, the pressure of the mold cavity starts to drop. As a result, the pressure difference, ΔP_r in Fig. 7, between the upper and lower surfaces of

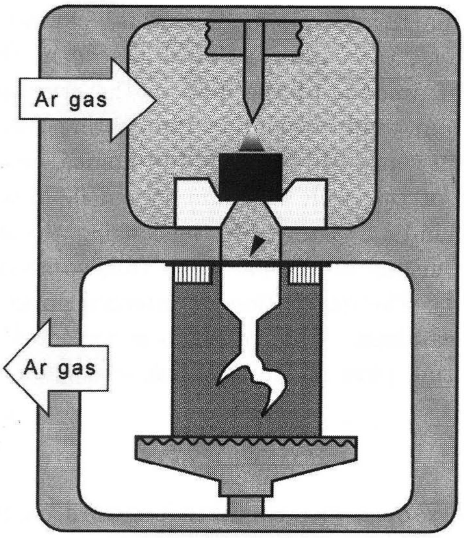

Fig. 8 Schematic diagram of a pressure casting unit and the diaphragm technique proposed by Togaya *et al.*[8].
The arrowhead indicates the diaphragm, the thickness of which has been represented after magnification. Each arrow indicates the flow direction of argon gas.

the melt increases. In the partition technique, the moment the partition foil is fused by the dropped melt, a large pressure difference, ΔP_f in Fig. 7, is exerted on the melt very quickly.

Accordingly, there are two important differences between the typical technique and the partition foil technique; one is the sharpness of the casting-force rise, and the other is the pressure in the mold cavity at the start of the melt filling. The value is 200 kPa in the typical process or 3 kPa in the partition foil process. The former effect can be clearly demonstrated as an improvement in the castability was shown in Figs. 4 and 5. However, the influence of the latter effect was unclear in this study.

The idea of cavity mold-upper chamber separation was first proposed by Togaya *et al.*[7,8] approximately ten years ago. As shown by the arrowhead in Fig. 8, they used a flat sheet called a diaphragm[8] for this purpose. With the help of this diaphragm, the cavity was completely separated from the upper chamber and maintained a vacuum. However, when the liquid titanium fuses the diaphragm, high pressure argon gas passes through the perforated hole more quickly than the melt. The reason is that the melt drops according to the gravity, while the speed of the average argon molecules is comparable to the speed of sound.

In the partition foil technique proposed in the present study (Fig. 3), when the liquid titanium fuses the partition foil, the argon gas cannot pass the hole perforated by the melt. This is because the partition foil is placed in close contact with the crucible wall and a sufficient amount of the melt in the crucible can cover the hole instantly. Thus, a significant improvement in the casting force can be achieved.

The aluminum foil may not be suitable for clinical use since pure titanium is slightly alloyed. Instead of this foil, titanium foil of 0.015 mm thickness was used in a trial. The result was similar to that obtained using the aluminum foil.

As seen in Fig. 8, by means of the partition foil, some increase in the number of small pores was observed. The generation of internal pores is another serious problem for dental titanium castings. This problem is expected to be solved by further improvements of the casting plan including sprue condition.

CONCLUSION

To improve the castability of a two-chamber pressure casting unit for titanium, a new partition technique was proposed. The partition, metal foil was formed and placed in contact with the mold crucible wall so that no clearance was left behind it. Using this partition foil, complete separation of the two chambers was achieved and this was verified by means of the pressure gauges attached to this unit. Significant improvement in the castability was confirmed by the experimental findings using two types of wax pattern. Therefore, the partition foil proposed in this study has been shown to be a very valuable accessory.

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