Technical report

Labor Reduction for Mold Preparation of a Commercial Titanium Cast Denture System Using a Heat-shock Method

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The purpose of this study was to investigate the application of a heat-shock method to fabricate titanium cast plates. Duplications of a maxillary model were prepared using DM under different firing schedules. Molds with patterns on the duplications were made by an outer investment (D), followed by heat shock at 850°C. Duplications heat shocked at 850°C after 30 min from mixing exploded within a few minutes. This explosion was successfully avoided by a drying procedure prior to the heat-shock. The molds were available for the heat shock at 850°C when the duplicate models were prepared by firing either using the conventional method and the heat shock above method described. Therefore, we could reduce the preparation time from about 16 hr with the conventional method to about 10 hr at the longest with the heat-shock method. These results suggested that the heat-shock method was labor-saving for fabricating titanium cast denture plates when controlling preliminary conditions prior to use.

Key words: Heat-shock method, Titanium, Investment

INTRODUCTION

Titanium has high potential as a metal for dental prostheses because of its excellent biocompatibility and mechanical properties1–3). Although titanium has been difficult to cast due to its high melting temperature and reactivity, some problems have already been solved by recent improvements in materials, devices and technology. Currently, there are several types of commercial investments available on the market specially for titanium casting. Since most of these are of the phosphate-bonded type, the reaction between molten titanium and the mold material deteriorates the quality of precision casting4).

A commercial titanium casting system without phosphates and silica was recently developed to produce high quality titanium castings5). However, this system requires much more preparation time for the mold because of the unique preparation of the duplicate models advised by the manufacturer.
Recently, many gypsum-bonded and phosphate-bonded investments for quick heating (heat-shock) have been introduced\(^6\)\(^{–}\)\(^1\(^2\)\) and are labor-saving when fabricating prostheses. However, there are no reports on the application of a heat-shock method to the preparation of molds for titanium casting. The purpose of this study was to evaluate the possibility of using the heat-shock method for titanium cast plates when using a commercial casting system without phosphate-bonded investments.

**MATERIALS AND METHODS**

A commercial titanium casting system (Selecast system\(^\circ\), Selec Co., Osaka, Japan) was used in this study. Two kinds of investments were used in this system, one was a duplicate model (SelevestDM\(^\circ\), Selec Co., Osaka, Japan, Code: DM), and the other was used as a secondary investing to form a mold (SelevestD\(^\circ\), Selec Co., Osaka, Japan, Code: D).

The heat-shock method in this study involved putting the mold in a furnace pre-heated to 850°C after 30 min from mixing as the maximum heating temperature for D and DM was designed to be 850°C. To evaluate the fundamental properties of both investments, compressive tests after 30 and 120 min from mixing, and after heating at 850°C, were done using universal testing machine (Instron 1125, Instron Japan Co., Tokyo, Japan). The size of each cylinder-shaped specimen was \(\phi\) 10 mm x 20 mm. These data were statistically evaluated by student’s t-test (n=10). After 24 hr from preparing the cylinder-shaped specimens (\(\phi\) 5 mm x 12 mm) for both D and DM, thermal expansion curves from room temperature to the maximum firing temperature at 850°C were recorded on a thermodiffractionmeter (Thermo plus TMA8310, Rigaku, Tokyo, Japan). Then another thermal expansion curve when re-heating for DM was also recorded as a conventional procedure. In addition, EDX analyses were performed to check powder components and their ratios with an energy-disperse X-ray microanalysis device (Rayny EDX-700/800, Shimadzu, Tokyo, Japan).

The procedure for titanium cast denture fabrication using this system is summarized in Fig. 1. This system has an original concept involving a duplicate model ex-

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![Diagram](image-url)

Fig. 1 Working time and procedure for the Selecast system selected in this study. Three procedures indicated with bold rectangles were reduced using the heat-shock method.
panded by almost the same firing schedule of the secondary investment prior to the preparation of wax patterns. Therefore, there were two opportunities to test the heat-shock method in this system. Duplicate models of a maxillary edentulous model using DM were prepared under two types of heat treatment (gradual heating, rapid heating), and no treatment after 30 min from mixing (Table 1). After completing the conventional wax patterns for a full denture plate on a duplicate model (Fig. 2), the secondary investment (D) followed by heat shock was embedded into a ring to form the mold. Duplicate models were prepared under different conditions (Table 2). Three molds were prepared under each condition for these experiments. The molds were taken as being available for casting if they exploded or suffered crack propagation.

Table 1  The heat-shock conditions tested in this study

<table>
<thead>
<tr>
<th>Duplication</th>
<th>Heat-starting time (min)</th>
<th>Preheated temp. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>With heat treatment</td>
<td>30</td>
<td>850</td>
</tr>
<tr>
<td>Without heat treatment</td>
<td>30</td>
<td>850</td>
</tr>
<tr>
<td>With heat treatment*</td>
<td>30</td>
<td>850</td>
</tr>
</tbody>
</table>

*Duplication treated by the heat shock

Fig. 2  Wax pattern preparation for a cast full denture.

Table 2  Conditions for the heat shock of DM

<table>
<thead>
<tr>
<th>Factors</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat-starting time (min)</td>
<td>30  60  90</td>
</tr>
<tr>
<td>Preheated temp. (°C)</td>
<td>500  600  700  850</td>
</tr>
</tbody>
</table>
RESULTS

The results of the compressive test are shown in Figs. 3 and 4. There were significant differences between DM and D on green strength using the t-test (p<0.01). The values of DM and D after 30 min from mixing were $1.40 \pm 0.23$ MPa, $0.51 \pm 0.06$ MPa, respectively. The difference between the two materials became large with the passage of time. Especially, the green strength of DM after 120 min from mixing was $8.56 \pm 0.51$ MPa and was approximately six times higher than that after 30 min from mixing. Although the fired strength was lower than green strength in the case of DM, D became strong with firing. The values of DM and D after firing were $1.96 \pm 0.54$ MPa and $1.85 \pm 0.74$ MPa, respectively, and there was no significant difference between them.

DM and D showed different thermal behaviors, as shown in Fig. 5. DM showed a large thermal expansion after approximately 500°C. However, it linearly expanded on re-heating. On the contrary, D curve showed no such unique expansion on the DM chart during heating.

Fig. 3 Compressive strength of each investment.

Fig. 4 Fired strength of each investment.

Fig. 5 Thermal behavior of both investments.
The results of powder components in each investment are shown in Table 3. The compounds composed of Al and Ca in DM were less than those in D. DM also contained more Zr.

The viability for heat shock on DM is summarized in Table 4. The duplicate model heat-shocked at 850°C after mixing 30 min exploded in the furnace within a few minutes. Explosion of the duplicate models was successfully prevented when the

Table 3 Elemental analyses of investments

<table>
<thead>
<tr>
<th>Investment</th>
<th>Mg (at%)</th>
<th>Al (at%)</th>
<th>Ca (at%)</th>
<th>Zr (at%)</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM</td>
<td>18.4 (0.4)</td>
<td>20.3 (0.1)</td>
<td>31.0 (0.4)</td>
<td>30.2 (0.1)</td>
<td>0.1</td>
</tr>
<tr>
<td>D</td>
<td>21.4 (0.3)</td>
<td>29.8 (0.3)</td>
<td>48.6 (0.6)</td>
<td>0.2 (0.1)</td>
<td>0.0</td>
</tr>
</tbody>
</table>

unit: at%, ( ): SD

Table 4 Heat-shock conditions arranged for DM

<table>
<thead>
<tr>
<th>Heat-starting time</th>
<th>Preheated temp.</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 min from mixing</td>
<td>850 (°C)</td>
<td>×</td>
</tr>
<tr>
<td></td>
<td>700</td>
<td>△</td>
</tr>
<tr>
<td></td>
<td>600</td>
<td>△</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>△</td>
</tr>
<tr>
<td>60 min from mixing</td>
<td>850</td>
<td>×</td>
</tr>
<tr>
<td>90 min from mixing</td>
<td>850</td>
<td>×</td>
</tr>
<tr>
<td>120 min from mixing</td>
<td>850</td>
<td>×</td>
</tr>
<tr>
<td>30 min from mixing + Dry (100°C, 30 min)</td>
<td>850</td>
<td>○</td>
</tr>
</tbody>
</table>

×: Mold explosion, △: Crack appearance, ○: Acceptance for cast

Fig. 6 Cracks expanding on the duplicate while cooling.

Fig. 7 Mold damaged by the expansion of the duplicate without heat treatment during heating.
Table 5 Heat shock for molds made under different conditions

<table>
<thead>
<tr>
<th>Preparation</th>
<th>Mold</th>
<th>Heat-start (min)</th>
<th>Furnace (°C)</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM without H</td>
<td>D</td>
<td>30</td>
<td>850</td>
<td>○</td>
</tr>
<tr>
<td>DM with H</td>
<td>D</td>
<td>30</td>
<td>850</td>
<td>×</td>
</tr>
<tr>
<td>DM with HS</td>
<td>D</td>
<td>30</td>
<td>850</td>
<td>○</td>
</tr>
</tbody>
</table>

H: Heat treatment, HS: Heat treatment by heat shock
○: castable, ×: uncastable

The preheated temperature was dropped to 700, 600 and 500°C. However, since a lot of cracks extended during cooling until room temperature as shown in Fig. 6, they were not available for casting. On the other hand, it was also useless to delay the heat-starting time. Finally, the duplicate model dried for 30 min in the furnace at 100°C after 30 min from mixing was ready for the heat-shock and casting.

The readiness for heat shock of the final mold after preparing the duplicate models under different conditions is summarized in Table 5. The heat-shock method was not possible on molds using the duplicate models without heat treatment. They had severe cracks, as shown in Fig. 7. On the other hand, the heat shock was possible on molds using the duplicate models fired using the conventional method. Furthermore, heat-shock was also possible on molds using the duplicate models prepared by heat shock after drying for 30 min in the furnace at 100°C.

DISCUSSIONS

There are few reports on the application of the heat-shock method to Co-Cr cast plates. We took only 1.5-2 hr from investing to cast plates. On the other hand, we usually need more time for the mold preparation for titanium cast plates than Co-Cr plates, because the mold for titanium must be cooled. If the heat-shock method is viable for titanium, it will be very beneficial for operators. Therefore, in this study we investigated the possibility applying of the heat-shock method to a popular casting system.

The titanium casting system developed by Togaya comprised two special types of calcium aluminate (CA)-bonded investments (DM and D). The difference in the mold components of DM and D, except for additional Zr powder, has not been recorded in previous reports. The ratio of refractory (Mg) and binder (Al and Ca) in DM and D was obviously different as shown in Table 3. Especially, the difference in the amount of binder may influence the mechanical strength at setting.

When fabricating cast denture plates using this casting system, we have to expand the duplication by firing before the wax pattern preparation to obtain a casting fit. As shown in Fig. 1, according to the manufacturer’s instructions, it takes approximately 16 hr for the casting procedure, since both DM and D must be gradually heated to 850°C and cooled down to room temperature, or casting temperature in the furnace.
Initially, we investigated applying the heat shock at 850°C for fresh specimens from DM and D, and found that D was stable but that DM exploded. Fig. 3 shows that the compressive strength of DM was higher than that of D because of the amount of binder in DM, as shown in Table 3. Therefore, the mechanical properties of the mold were not a key factor in avoiding mold explosion. Therefore, we assumed that gas release from the wet molds may be linked to mold explosion during the heat-shock procedure because the explosion occurs within a few minutes after heat shock.

In addition, we further investigated the conditions to prevent explosions during the heat-shock process using DM. Prolonging the heat-starting time clearly improved the compressive strength, but it showed little influence on the tolerance for heat shock. Furthermore, molds stored in an air atmosphere for one day were unacceptable to the purpose of this study, even if the conditions were acceptable for the heat-shock method.

On the other hand, molds heat shocked with temperatures below 850°C did not explode, but formed small cracks on the surface which expanded during cooling to casting temperature and were not viable for casting.

We found that drying the mold for 30 min in the furnace at 100°C prevented the explosion of the mold under heat shock at 850°C; the mold was available for casting. We think that mechanical strength is not a criterion for judging the prevention of mold explosion. We rather suspect that gas pressure produced by rapid evaporation from the hydrated set products exploded the mold during the heat-shock process.

Subsequently, we applied the heat-shock method to a mold prepared by investing a duplicate model with a secondary investment (D). The mold was stable under heat shock when the duplicate model was prepared by firing following the manufacturer’s instruction. When using a duplicate model without heat treatment, there was no remarked change in the mold directly exposed at 850°C for the initial 15 min, but deep cracks violently appeared on the mold after 30 min. We suspect this phenomenon was based on the large expansion of the duplicate model due to the oxidized expansion of the additional Zr powder contained, as shown in Fig. 7 and Table 3. For prefired duplication, a large internal stress was not produced inside the mold, because the re-heated thermal expansion curve of DM was linear. Finally we could reduce the mold preparation time by combining a heat-shocked duplicate model and a heat-shocked secondary mold.

The molds must be cooled after firing to a temperature instructed by the manual in the furnace, even if using the heat-shock method. Thus, this cooling process could not be shortened. However, compared to the schedule recommended by the manufacturer, the total labor indicated by bold rectangles in Fig. 1 is expected to be reduced to around 5.5 hr. The preparation time from mixing to heat-starting, and the heating time for both the duplication and the mold, were greatly shortened.
CONCLUSION

Judging from the results obtained in this study, we made the following conclusions.

1. The heat-shock method was applicable to the selected titanium casting system and was effective at reducing the labor time. However, some preparations were necessary for heat shock duplication.

2. There were large differences between DM and D in the powder components and fundamental properties, but their effects on heat shock viability were inconclusive.

3. The dry process used on the mold prior to heat-shock was useful and effective.

4. The heat-shock method reduced the total labor time needed for the titanium casting system selected in this study to around 5.5 hr.

REFERENCES


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