Soda-lime glass as a binder in reusable experimental investment for dental castings

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In this study, different glasses were investigated to improve reusable investments. Borosilicate glass (BSG) powder and soda-lime glass (SLG) powder were prepared by milling broken beakers and microscope slides, respectively, and used in experimental investments (I-BSG, I-SLG) by blending glass powder (10wt%) with cristobalite (90wt%). Some properties and casting fits were evaluated with commercial gypsum-bonded investment as the control. Both BSG and SLG were mainly composed of Si, but SLG had a large Ca content. The glass transition temperatures were approximately 800°C (BSG) and 700°C (SLG). Experimental investments with heating showed the significantly (p<0.05) higher expansion than that of the control. The compressive strength of I-SLG was higher than that of I-BSG, and increased with temperature. The MOD inlay obtained from I-SLG had a significantly smaller gap than that from I-BSG, and was comparable to the control. These results suggest SLG could be applied clinically as a reusable dental investment.

Keywords: Investment, Reuse, Glass, Cast

INTRODUCTION

The quantity of industrial waste produced increases each year, and this has become a major environmental issue1. Reuse of casting metal is common2-4) in dental laboratory works. For example, unnecessary parts of precious alloy castings, such as the sprue, vent or bottom of the casting, have been melted and reused. However, most of the ceramic materials, such as gypsum and the investment, are discarded5). Although dentistry is not a major contributor to industrial waste, it would be beneficial to reduce this waste.

We previously investigated reuse of mold materials, and found that phosphate-bonded investments could be recycled6). We also developed a new type of dental casting investment consisting of only refractory materials without binder, which could also be reused7). We crushed broken laboratory glassware with a milling machine to prepare glass powder8). When this powder was included in dental investments instead of traditional binders, such as gypsum or phosphate, the investments could be reused and showed excellent performance in casting of dental precious alloys. A mass fraction of 10% glass powder was effective in clinical use9). The glass tested had a glass transition temperature of 800°C, and the maximum heating temperature was set to be higher than this at 900°C. In dental laboratories, gypsum-bonded investment is generally heated at up to 700°C9). Therefore, glass with a lower glass transition temperature is required so that the maximum heating temperature of the mold can be set closer to that used in dental laboratories. Fujioka10) examined a number of glass powders when evaluating investments for titanium, and found that the transition temperature varied greatly with the type of glass.

Soda-lime glass is a component of microscope slides, and is prepared by melting a ceramic powder blend of SiO2, Na2CO3, K2CO3 and CaCO3. Its glass transition temperature is lower than that of the heat-resistant glass described in Aida’s report6). Therefore, soda-lime frit could be used as binder in reusable investments. The objective of this study was to prepare reusable investments with different glass compositions and evaluate their usefulness in conventional dental castings.

MATERIALS AND METHODS

Preparation of experimental reusable investment

Two different glass powders were examined in this study. Borosilicate glass (BSG) powder was prepared from a beaker (500 mL, Pyrex®, IWAKI Houseware, Co. Ltd., Chiba, Japan), and soda-lime glass (SLG) powder was prepared from a microscope slide (Micro Slide Glass, Matsunami Co., Ltd., Osaka, Japan). The beakers and microscope slides were individually powdered for 2 min using a ball mill (P-10, Fritsch Japan Co. Ltd., Yokohama, Japan) as shown in Fig. 1.

Silicon dioxide (cristobalite, average particle size 9.1 µm, Tatsumori Co., Ltd., Tokyo, Japan) was selected as the refractory material. Experimental investments I-SLG and I-BSG were prepared by mixing cristobalite with SLG or BSG powder, respectively. The mass fraction of glass powder (BSG or SLG) sieved with 200 mesh pass in each experimental investment was determined to be 10%. For testing, all of the investments were manually mixed with distilled water at a water/powder ratio of...
0.30 for 30 s, and then automatically mixed for 30 s more under vacuum using a commercial mixing machine (NEW-MIX, Yoshida Comp., Tokyo, Japan). To simulate reuse, the experimental investments were initially set in molds, then heated to 900°C and crushed to a powder again before examination. A commercial gypsum-bonded investment (Crist PF, Shofu Inc, Kyoto, Japan) was examined as a control.

**Fundamental properties**
The experimental investments used in this study are never hardened by a chemical reaction. The poured investments certainly contract when becoming a mold. However, it is merely evaporation of excess water added for the suitable slurry. Therefore, the setting properties were not examined.

**Elemental analysis**
Elemental analysis of the prepared BSG and SLG powders was performed by energy dispersive X-ray fluorescence spectrometry (Rayny, Shimadzu Corp., Kyoto, Japan) in the range of Na-U. The results are the average of triplicate measurements.

**Thermal analysis**
Using a thermomechanical analysis equipment (TMA) (Thermo plus TMA 8310, Rigaku Corp., Tokyo, Japan), TG-DTA analysis was performed on each of the prepared powders (30 mg) in a Pt-pan to determine glass transition temperature. TMA was conducted at up to 1000°C with a heating rate of 10°C/min. Changes in the mass of the samples were monitored along with the exothermic or endothermic nature of the reaction. Glass transition was automatically specified from the arbitrary temperature before and after the peculiar behavior on the drawn curve. Measurements were repeated three times for each glass and their average values were calculated.

**Compressive strength measurements**
Green compressive strengths for each investment (ø 10 mm, height 20 mm) after 24 h of mixing were measured using a universal testing machine (Instron MD-1125, Instron Japan Co. Ltd., Kawasaki, Japan) with a crosshead speed of 1.0 mm/min.

Fired strengths were tested after firing the green samples (ø 10 mm, height 20 mm) to either 700, 800, or 900°C at a heating rate of 10°C/min, holding for 1 h at maximum temperature, and then cooling to room temperature in the furnace. Five samples were fired for each investment.

**Thermal expansion measurements**
TMA (Thermo plus TMA 8310, Rigaku Corp., Tokyo, Japan) was used to prepare thermal expansion curves. Specimens (ø 6 mm, height 12 mm) were heated to 900°C at a rate of 10°C/min and then cooled to room temperature. Measurements were repeated five times for each investment. Because differences were not apparent in the data obtained for the five repeat measurements according to Aida’s report, an investigation of the repetition was limited in this study.

**Casting application**

**Preparation of wax patterns**
To evaluate the fit of dental castings using the experiment investments, a MOD type stainless steel die recommended by the American Dental Association was selected. Figure 2 shows the MOD metal die and the points for measurement of the marginal gap according to Aida’s report, an investigation of the repetition was limited in this study.

**Casting procedures**
Because the experimental investments were not strong enough to be removed from a ready-made rubber crucible former, a handmade crucible was prepared using paraffin wax (GC Co., Ltd., Tokyo, Japan). A single cast liner
(Fitting liner, Shofu Co. Ltd., Kyoto, Japan) was placed inside the ring (ø 30 mm, height 35 mm). Twenty-four hours after preparing the molds, they were gradually heated up to 300°C at a rate of 5°C/min and held at this temperature for 30 min. Then they were heated again to 900°C at 10°C/min. After holding at 900°C for 30 min, the molds were cooled to 700°C.

A commercial Au-Ag-Pd alloy (Castwell M.C., 12% Au, 46% Ag, 20% Pd, 20% Cu, and 2% other metals, GC Co., Ltd., Tokyo, Japan) was then cast into the mold using a commercial spring-type centrifugal casting apparatus (Centrifico Casting Machine, SDS Kerr Japan, Tokyo, Japan). The spring was wound twice before casting. After cooling the mold, each casting was carefully removed from the mold, scrubbed under running water, and cleaned in water using an ultrasonic cleaner. Other surface treatment methods, such as acid cleaning or sandblasting, were not used. Three castings were performed for each investment.

Each cast MOD inlay was replaced on the steel die, and the gap between the margin of the MOD inlay and the die at both the mesial and distal side was measured using a digital microscope (Motic Images 2000, Shimadzu Corp., Kyoto, Japan). The distance at each point was measured three times and an average value was calculated.

Statistical analysis

The data were statistically evaluated by one-way ANOVA and Tukey’s post-hoc test at a significance level of α=0.05.

RESULTS

The elemental analysis results are shown in Table 1. BSG and SLG contained similar elements, but the distribution of these elements was different. Silicon was the main component in both glasses, but SLG had higher calcium content than BSG. No sodium and potassium were detected from BSG.

Figures 3 and 4 show typical thermogravimetric-differential thermal analysis (TG-DTA) curves of BSG and SLG, respectively. TG of both BSG and SLG showed an almost straight line, and there was no variation in the weight loss during heating. The glass transition temperature was calculated using any two arbitrary points before and after the inflection temperature of the DTA curve. The average glass transition temperatures of BSG and SLG were 799.4±6.5°C and 723.2±4.7°C, respectively.

The compressive strengths of the experimental investments were determined before and after heating at 700, 800 and 900°C (Fig. 5). The green strength of the control was 5.5 MPa, but this decreased to 0.7 MPa after firing at 700°C. The compressive strength increased at higher firing temperatures. I-SLG had higher compressive strength than I-BSG at all temperatures. This was particularly apparent at 900°C where the

<table>
<thead>
<tr>
<th>Element</th>
<th>BSG</th>
<th>SLG</th>
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<tbody>
<tr>
<td>Si</td>
<td>99.0 (0.8)</td>
<td>79.0 (9.5)</td>
</tr>
<tr>
<td>Ca</td>
<td>0.6 (0.0)</td>
<td>15.7 (5.3)</td>
</tr>
<tr>
<td>Na</td>
<td>–</td>
<td>7.7 (0.8)</td>
</tr>
<tr>
<td>K</td>
<td>–</td>
<td>2.5 (0.9)</td>
</tr>
<tr>
<td>S</td>
<td>0.5 (0.2)</td>
<td>2.8 (2.3)</td>
</tr>
<tr>
<td>Fe</td>
<td>0.2 (0.1)</td>
<td>0.5 (0.2)</td>
</tr>
<tr>
<td>Ti</td>
<td>0.2 (0.1)</td>
<td>0.5 (0.4)</td>
</tr>
</tbody>
</table>

The number in the parenthesis is a standard deviation.

Fig. 3 TG-DTA curve of BSG. Arrow indicates the glass transition temperature.

Fig. 4 TG-DTA curve of SLG. Arrow indicates the glass transition temperature.
compressive strength of I-SLG reached 9 MPa, which was the highest value obtained in this study. The compressive strengths of I-SLG with heating at 900°C were significantly different among all the specimens tested.

The thermal behavior of the investments is shown in Fig. 6. The graphs were constructed using average values at each temperature. Both experimental investments showed higher expansion than the control at 700°C and there are significant differences among them. The average expansion rate of I-SLG at 700°C was approximately 1.8%, which was significantly about 0.3% larger than that of I-BSG.

Figure 7 shows the gap measurement results for the investments, and images of the fit are shown in Fig. 8. The castings from I-BSG had significantly larger average gaps than those from I-SLG or the control. Significant differences were not found between I-SLG and the control for the gap with the fit of the casting.

**DISCUSSION**

It is widely known that traditional dental porcelain technique is typically formed by sintering the glass component during firing\(^1\). In the present study, glass powder prepared by milling broken glass containers for the experiments or the observation on the microscope was used as a dental mold material for a casting process in place of conventional binder such as gypsum and phosphate. The BSG has excellent heat resistance and a glass transition temperature of about 800°C. Because the maximum mold firing temperature for dental castings is usually around 700°C, different glass powders were needed with glass transition temperatures lower than the firing temperature of the mold.

In this study, SLG obtained from crushed microscope slides was investigated for use in experimental investments. Both I-BSG and I-SLG were fired at temperatures up to 900°C to evaluate the differences in their castings. Since thermal analysis revealed that the glass transition temperature of SLG was close to 700°C,
SLG could be used to decrease the maximum firing temperature of the mold. The compressive strength of I-SLG after heating at 800°C was greater than that of the control. Therefore, SLG could be used as a binder in molds fired at 800°C or higher. However, the maximum firing temperature of both glass-mixed molds was set at 900°C to compare the casting precision of I-SLG with I-BSG by this experiment. The fired strength of I-SLG at 900°C was excellent and was comparable to that of commercial phosphate-bonded investment. However, because the main aim is reuse of the mold, firing at 900°C is too high.

Thermal expansion of I-BSG and I-SLG depended on the cristobalite content. In this study, the mass fraction of cristobalite was fixed at 90% for both the experimental BSG and SLG investments. However, the glasses have different specific gravities because the glass is classified in some types by components. It is known that the specific gravity of SLG is about 2.5 g/cm³ and larger than that of BSG. Consequently, the volume of BSG added to the cristobalite should be more than that of SLG. In this case, the content of SLG with cristobalite was advantageous to the expansion compared with that of BSG.

Fitting tests with the MOD inlay castings (Fig. 8) showed how this specific gravity difference affected the cast inlay. The cast inlay obtained from I-SLG had a better fit to the die than that obtained from I-BSG, which was loose on the occlusal side even without the MOD cap. The larger gap with I-BSG was probably because of insufficient expansion. MOD inlays obtained from the control showed the smallest gap, but there was no significant difference between the gaps produced with the control and I-SLG. The control can compensate for cast inlay shrinkage because both setting expansion and thermal expansion of the mold material occur. By contrast, only thermal expansion occurs with the experimental investments, and no dimensional change occurs on setting. Hence, the combination of refractory material in the experimental reusable investments needs to be considered to increase the fit of cast inlays. On the other hand, it is known that the fit of castings which is greatly influenced by not only the expansion of the mold but also the surface conditions of them. In order to clarify some problems on the fit of castings, more investigations will be continued.

These results suggest that SLG powder could be used in reusable dental investments. Since Aida has already proven the efficacy of adding the glass powder to increase reusability of the mold, more detailed examinations were not conducted in the present study. However, the influence of repeated reuse should be investigated in future, because SLG has a low glass transition temperature. In conclusion, the experimental reusable investment with SLG was obviously more effective than that with BSG in dental fabricating technology by casting.

REFERENCES