Dimensional Changes of Ring-shaped Pattern

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Ring shaped wax patterns, having the same outside diameter and different inside diameters, were invested with a gypsum-bonded cristobalite investment. The wax pattern was eliminated in an electric furnace at 120°C. A fusible alloy with a melting point of 47°C was cast at room temperature. The dimensional deviations between the fusible alloy casting and the wax pattern were calculated using the inside diameter, ring width and outside diameter. On the other series, a gold alloy casting of the same size was fabricated in the usual manner of the dental precise casting procedure, and the dimension was compared with that of the wax pattern.

In the comparison of 2 types of patterns, dimensional change by setting expansion was different. Dimensional change of the small inside diameter specimen differed at 3 portions measured, but that of the large inside diameter specimen was comparable at 3 portions. Concerning the resultant gold alloy casting, dimensional change at the outside diameter differed from each other, but those at ring width and inside diameter were comparable to each other. The difference in the inside diameter influenced dimensional change by setting expansion as well as that of the resultant casting.

Key words : Cristobarite Investment, Ring-shaped Patterns, Dimensional changes of Mold Cavity

INTRODUCTION

In a precise dental casting, expansion of an investment is utilized to compensate for shrinkage of a casting alloy. Expansion of the investment causes dimensional changes of the mold cavity during the setting and thermal processes. Concerning the setting expansion, a space occurs outward around the pattern at an external site, and a wax pattern is extended at an internal site^{1,2)}. The behavior of the mold cavity during thermal expansion is not well understood, due to the difficulty of an experimental set-up. The casting alloy generally shrinks, mainly during the process of cooling to room temperature from the solidifying temperature. At this time, the alloy would shrink freely inward apart from a mold wall at an external site, but instead the shrinkage of the alloy would be hampered by the core portion of the investment at an internal site. Thus, analysis of dimension changes of the resultant casting becomes complicated.

In order to investigate the dimensional changes of the mold cavity caused by setting expansion, the fusible alloy was utilized^{2–6)} which has a very low melting point of 47°C and negligible solidifying shrinkage (less than 0.001%), the so-called U-alloy⁷⁾. Thus, the dimension of casting fabricated with this alloy would represent the dimension of the mold cavity. Here, it became easy to analyze dimensional changes of the mold cavity caused by setting expansion.

In the previous study⁵⁾, dimensional change of the mold cavity was studied, investing a ring-shaped

wax pattern with a 6 mm inner diameter, 12 mm outer diameter, 3 mm ring width and 3 mm thickness. As a result, dimensional changes of the mold cavity caused by the setting expansion were not uniform, showing different amounts of expansion when compared with the 3 portions measured. The resultant gold alloy casting also distorted, showing different amounts of dimensional changes at the 3 portions measured.

In this study, two types of ring-shaped wax patterns were used which had the same outside diameter and a different inside diameter. The effect of the difference in inside diameter on dimensional changes of the mold cavity after setting expansion and the resultant casting was studied.

MATERIALS AND METHODS

Preparation of wax pattern

Two types of metal split molds were prepared for fabrication of wax patterns. These metal molds had the same outside diameter (OD) of 12 mm and a thickness of 3 mm. However, they had a different inside diameter (ID) of 3 or 9 mm, respectively. The wax pattern with an inside diameter of 9 mm was thereafter named L-ID and that having 3 mm was named S-ID. A width of ring portion was 1.5 mm for L-ID and 4.5 mm for S-ID, respectively. The width of the ring portion was thereafter named RW.

The press molding technique⁸⁾, using an indirect inlay wax (Violet Inlay Wax, 030891, GC, Japan) was employed to fabricate the wax patterns. But, the RW of L-ID (1.5 mm) was too narrow to be

filled adequately, so the defective parts of wax patterns were repaired with molten wax. The finished patterns were left in the mold overnight to release any internal stress. Then, the fiducial line was drawn on the surface of the wax pattern.

Measurement of dimensions of the wax pattern

A travelling microscope equipped with a digital counter (MM-11, Nikon, Japan) was employed to measure the dimensions of the wax pattern. Heat production by the light source of the microscope was considered to be small enough not to cause any dimensional changes of the wax pattern during measurement. The positioning of the wax pattern on the microscope stage was performed under X10 magnification, standardizing the fiducial line on the wax pattern. The dimensions of each portion were determined under X50 magnification.

The measured portions were illustrated in Figure 1, that is, 1) RW (X_1 , X_2 , Y_1 and Y_2), 2) ID (X and Y). OD was not measured directly but calculated from $[RW ({}_1+{}_2)+ID]$. Measurement was repeated twice and the mean dimension was determined.

Casting with fusible alloy

1) Investing and casting

A steel casting ring, 29 mm in inner diameter and 38 mm in height, was lined with two sheets of ceramic liner (Ceramic Ribbon, 99Y04, Noritake Corp. Japan). The liner, measuring 0.7 mm in thickness, was trimmed to 175 mm in length and 35 mm in width. One end of the casting ring, a crucible former side, was not lined to provide a grasp between the casting ring and the investment. A wax spure (Ready Casting Wax, 111251, GC, Japan), measuring 2 mm in diameter, was attached at Y_1 . A gypsum-bonded cristobalite investment (Cristobarite Micro, 011061, GC, Japan) was mechanically mixed for 45 sec. with a W/P ratio of 0.33. The mixture was poured into the casting ring and the pattern was inserted into the slurry.

The casting ring was transferred into an electric furnace (accu-THERM, Jelenko, USA) at 2 hours after investing. Temperature inside the furnace was regulated at 120°C and the molds were kept for 3 hours to eliminate the wax pattern from the mold⁹⁾. Then, the switch was turned off and the mold was cooled down in the furnace to room temperature.

A fusible alloy (U-alloy, Osaka Asahi Metal MFG., Japan) with a melting point of 47°C was used to fabricate the casting. The alloy was melted in a pan dipped in a hot water bath and poured to the crucible of the mold. A centrifugal-type casting machine was used. The mold was broken into small pieces with stone pliers and the casting was taken out carefully.

Fig.1 Measured portions of the ring-shaped pattern.

2) Measurement of fusible alloy casting

The dimension of the U-alloy casting was measured in the same manner as mentioned for the measurement of wax pattern, standardizing the fiducial line reproduced on the surface of casting. The dimensional deviation between the casting and the wax pattern was calculated. Each group contained 10 specimens.

3) Dimensional changes of fusible alloy casting

Dimensional deviation of each portion between the fusible alloy casting and the wax pattern was calculated. Then, by dividing this by the dimension of each wax pattern, dimensional changes of the fusible alloy casting were determined.

Casting with gold alloy

The same procedures were performed as mentioned above until investing. The mold was heated up to 700°C with a heating rate of 10°C/min and kept in the furnace for at least 20 min. Casting was performed in the conventional manner with the dental blow pipe and a gold alloy (Casting Gold MC, Type III, GC). After pickling the surface oxide, the dimension of the gold alloy casting was determined, and dimensional change of the casting was calculated in the same manner mentioned above. Each group had 10 specimens.

Statistical treatment

Statistical analysis was performed by a computer system (Stat View, Abucus, $p=0.05$) using ANOVA or an un-paired t-test.

RESULTS

Dimensional changes of fusible alloy casting

The upper part of Table 1 shows dimensional deviations and dimensional changes of fusible alloy castings. As the shape of specimen is a symmetric form, the same named portions exist at the X and Y axes,

Table 1 Dimensional deviations (μm) and changes (%) of fusible alloy casting

	S-ID		L-ID	
	(μm)	(%)	(μm)	(%)
X axis (Wall direction of casting ring)				
RW _{X1}	15 (9)	0.33 (0.20)	11 (7)	0.73 (0.45)
RW _{X2}	14 (7)	0.31 (0.15)	13 (6)	0.87 (0.37)
ID _X	33 (10)	1.09 (0.32)	76 (10)	0.84 (0.11)
OD _X	62 (9)	0.51 (0.07)	100 (13)	0.83 (0.11)
Y axis (Axis direction of casting ring)				
RW _{Y1}	14 (7)	0.31 (0.16)	11 (6)	0.71 (0.41)
RW _{Y2}	15 (8)	0.34 (0.17)	12 (6)	0.81 (0.39)
ID _Y	28 (8)	0.93 (0.27)	73 (12)	0.81 (0.13)
OD _Y	57 (13)	0.47 (0.11)	96 (14)	0.80 (0.12)
RW	14 (7)	0.32 (0.17)	12 (6)	0.81 (0.39)
ID	30 (9)	1.01 (0.30)	75 (11)	0.83 (0.12)
OD	59 (11)	0.49 (0.09)	98 (13)	0.82 (0.11)

Mean (S.D.)

i.e. 4 portions of RW (x_1 , x_2 , y_1 and y_2), and 2 portions of ID and OD (x and y). The mode of dimensional change is understood readily if the data of the same named portions are summed up into one segment. Thus, the statistical treatment was performed on the determined dimensional deviations and no significant differences were found at each segment. Then, 40 portions of RW, 20 portions of ID and OD were summed up into 3 segments, respectively (Table 1, lower part).

1) S-ID specimen

Dimensional change of RW, ID and OD was approximately 0.3%, 1.0% and 0.5%, respectively. Statistical significant difference was found among 3 segments. ID, which had the smallest original dimension, showed the largest dimensional change.

2) L-ID specimen

Dimensional changes of 3 segments (RW, ID and OD) were comparable to each other, showing approximately 0.8% expansion. This type of pattern, L-ID, exhibited a more uniform setting expansion than that of S-ID.

3) Comparison with S-ID and L-ID specimen

Comparing dimensional change of 2 types of specimens (Fig. 2, left side), statistical significance was found at 3 segments (RW, ID and OD, respectively). Differences in the diameter of ID influenced dimensional change of the mold cavity caused by setting expansion.

Dimension of gold alloy castings

The upper part of Table 2 shows the dimensional deviations and dimensional changes of resultant gold

Fig. 2 Dimensional change of fusible alloy and gold alloy castings.

Table 2 Dimensional deviations (μm) and changes (%) of gold alloy castings

	S-ID		L-ID	
	(μm)	(%)	(μm)	(%)
X axis (Wall direction of casting ring)				
RW _{X1}	9 (7)	0.19 (0.16)	4 (6)	0.26 (0.40)
RW _{X2}	8 (6)	0.18 (0.14)	1 (9)	0.08 (0.62)
ID _X	24 (13)	0.78 (0.43)	61 (9)	0.68 (0.10)
OD _X	41 (15)	0.34 (0.13)	67 (9)	0.51 (0.07)
Y axis (Axial direction of casting ring)				
RW _{Y1}	9 (12)	0.19 (0.27)	0 (6)	0.01 (0.41)
RW _{Y2}	12 (13)	0.26 (0.28)	4 (7)	0.29 (0.46)
ID _Y	17 (9)	0.57 (0.28)	57 (11)	0.63 (0.12)
OD	37 (11)	0.31 (0.09)	61 (8)	0.51 (0.07)
RW	8 (9)	0.20 (0.21)	3 (6)	0.16 (0.48)
ID	20 (11)	0.68 (0.37)	59 (10)	0.66 (0.11)
OD	39 (13)	0.33 (0.11)	64 (9)	0.51 (0.07)
Mean (S.D.)				

alloy castings. The same statistical treatment was performed as mentioned above and no statistical significance was found among RW and between ID and OD, respectively. Summed up data was listed in lower part of Table 2.

1) S-ID specimen

Dimensional change of RW, ID and OD was approximately 0.2%, 0.7% and 0.3%, respectively. Dimensional change of ID was significantly larger than the other 2 segments.

2) L-ID specimen

Dimensional changes of RW, ID and OD were approximately 0.2%, 0.6% and 0.5%, respectively. Dimensional change of RW was significantly smaller than the other 2 segments.

3) Comparison of S-ID and L-ID specimens

Comparing dimensional changes of S-ID and L-ID specimens (Fig. 2, right side), a statistical significant difference was found at OD. No statistical significant difference was found at RW and ID. Differences in the diameter of ID also influenced the dimensional change of OD in the resultant casting.

DISCUSSION

Utilizing the fusible alloy

The fusible alloy with a very low melting point of 47°C, called a U-alloy by the manufacturer, was employed to detect the dimensional changes caused by the setting expansion. According to the manufacturer's instruction⁷⁾, it has a negligible solidification shrinkage (less than -0.001% , thermal expansion coefficient of $26 \times 10^{-6}/^\circ\text{C}$). Thus, the dimension of the fusible alloy casting could represent the dimension of the mold cavity induced by the setting expansion. Originally, this fusible alloy was introduced by Ohno *et al.*¹⁰⁾ to detect dimensional changes in the mold,

investing a quartz tube.

Davis *et al.*⁹⁾ used bismuth-tin alloy (melting point 138°C) to investigate the dimensional changes of MOD wax pattern in the mold. They found a large difference in the determined values at the axial direction between the xeroradiographic method and the fusible alloy casting method. And, they stated the formation of a void at the gingival wall during the setting reaction, meaning that the space arose outward from the wax pattern at the gingival site by the setting expansion. The same occasion would arise around OD in this study. Thus, it is considered that usage of the fusible alloy is a suitable method to investigate the dimensional changes of the mold containing the pattern.

Dimensional changes induced by the setting expansion

Concerning ID, the wax pattern was enlarged by the setting expansion of the investment, and RW would become thinner than the original dimension. Nevertheless, RW expanded, meaning that the space arose outward around RW^{2,9)}.

In comparison with the dimensional change of S-ID and L-ID, it differed completely. The dimension of OD would be regulated by (RW₁+RW₂+ID). Dimensional deviations of RW of both specimens were comparable to each other. However, the dimensional deviation of L-ID was 2.5 times larger than that of S-ID, as the original diameter of L-ID was 3 times larger than that of S-ID. This would cause the difference in dimensional change at OD. Dimensional change at the small portion in the original dimension seems to be larger than that at the large portion.

Compared to the former report⁵⁾ in which the ring shaped pattern with 6 mm in ID, 12 mm in OD and 3 mm in RW was invested, the mode of dimensional change of L-ID was close to that of the former report.

Shibuya *et al.*⁶⁾ invested a quartz tube and cast a fusible alloy into the space around the quartz tube which was induced by the setting expansion of investment. Consequently, the alloy thickness was almost uniform when the simple shaped-pattern was invested. In this experiment, no statistical difference was found when the same-named portions at the X and Y axes were compared. But, comparing one segment with another segment, dimensional changes differed from each other, especially at the S-ID specimen. It was indicated that setting expansion was not uniform when the pattern of a complicated form was invested.

Dimensional changes of the gold alloy casting

The dimensions of the gold alloy castings became smaller than those after setting expansion. The thermal shrinkage of the gold alloy (approximately 1.6%) is usually larger than the thermal expansion of the gypsum-bonded cristobalite investment

(approximately 1.3%).

Compared to the former report⁵⁾ in which the ring shaped pattern with 6 mm in ID, 12 mm in OD and 3 mm in RW was invested, the mode of dimensional change of L-ID resembled that of the former report. Concerning the OD, the dimension of OD would be regulated by $(2 \times RW + ID)$. Dimensional change of OD at S-ID was significantly smaller than that of L-ID in the resultant casting. As RW of S-ID in original dimension was much wider than that of L-ID, casting alloy shrunk far apart from the mold wall at the external site. On the other hand, the dimensional changes at ID of two specimens were comparable to each other. The core portion hampered the thermal shrinkage of the casting alloy. Another study¹¹⁾ also reported that dimensional change of the internal surface of a cast crown became larger than that of the external surface. This tendency is preferable for the dental cast restoration which is luted onto the abutments with cements, providing a cement space. That is, the inaccuracy of resultant casting contributes to easy seating of restorations onto the abutment.

The ring shape is considered to be a model pattern of the full coverage restoration cut horizontally. Considering the clinical condition, the dimensional deviation of ID became smaller when RW was thicker, resulting in insufficient cement space. The same tendency was found in another study¹²⁾, indicating the need for a die-spacer technique¹³⁾.

REFERENCES

- 1) Mahler DB, Ady AB. The influence of various factors on the effective setting expansion of casting investments. *J Prosthet Dent* 1963; 13: 365-373.
- 2) Ohsawa M, Hayashi Y. Dimensional changes of MOD mold cavity corresponding to the degree of setting expansion. *Dent Mater J* 1998; 17: 213-219.
- 3) Ohsawa M, Shibuya M, Ikeda T, Matsumoto H. Study on casting dimension Part 5. The setting and the thermal expansion of the mold containing a wax pattern. *Japan J Conserv Dent* 1993; 36: 347-354.
- 4) Ohsawa M, Shibuya M, Ikeda T, Matsumoto H. Study on casting dimension Part 6. Dimensional changes of a mold cavity of U-shape and MOD pattern. *Japan J Conserv Dent* 1993; 36: 1342-1349.
- 5) Ohsawa M, Shibuya M, Shiraishi C, Ikeda T. Dimensional changes of ring-shaped casting Part 1: Effect of setting expansion and thermal expansion/alloy shrinkage. *Japan J Conserv Dent* 1996; 39: 889-895.
- 6) Shibuya M, Ohsawa M, Matsumoto H, Hisatsune K, Yasuda K. Anisotropic expansion in gypsum-bonded cristobalite investment mold. *Dent Mater J* 1997; 16: 48-59.
- 7) U-alloy series, Osaka Asahi Metal MFG.CO., LTD. P.3, 6.
- 8) Fusayama T. Factor and technique of precision casting part 1. *J Prosthet Den* 1959; 9: 468-485.
- 9) Davis DR, Kennedy MP. Xeroradiographic determination of effective setting expansion of cristobarite investment. *Dent Mater* 1990; 6: 29-34.
- 10) Ohno H, Miyakawa O, Watanabe K, Nakano S, Shiokawa N. A new method to determine setting and thermal expansions in a casting ring. *Jpn Soc Dent Appar Mater* 1974; 15 (Special Issue 27): p 31.
- 11) Tamura A., Yoshida T. Dimensional accuracy of the internal and external surface of the casting crown. *Shigaku* 1988; 75: 1117-1134.
- 12) Finger W, Ohsawa M. Accuracy of cast restorations produced by a refractory die-investing technique. *J Prosthet Den* 1984; 52: 800-803.
- 13) Jorgensen KD, Finger W. Die spacing technique by diffusion precipitation, *Scand J Dent Res* 1979; 87: 73-78.