<Title page>

Casting of MOD Inlay Using Rings With Holes on Both Sides

-12〜18wt%Au-20〜26Pd-14.48〜6.48Cu-40Ag-1.5Zn-0.02Ir Alloys

Hideo Ogura・Kazuo Ohkuma・Miku Kazama・Hideo Ogura

O. Kazuo (✉)・H. Ogura・M. Kazama

Department of Dental Materials Science, The Nippon Dental University, School of Life Dentistry at Niigata, 1-8 Hamaura-cho, chuo-ku, Niigata 951-8580,Japan

Tel. +81-25-267-1500; Fax +81-25-231-7451

e-mail: kazuo@ybb.ne.jp

Key words

Casting ring with openings on both sides・Water-absorbent polymer・Precise MOD inlay・Heterogeneity・Au-Pd-Cu-Ag alloys

<Abstract>

Using a casting ring with openings on both sides and a water-absorbent polymer, heterogeneity is maintained in a single casting and a precise MOD inlay can be produced.

We produced 9 different kinds of gold-silver-palladium (Au-Ag-Pd) alloys by changing the ratio of palladium, gold, and copper and investing them, and changing parameters such as the angulation of the casting ring openings and the water:powder ratios to produce MOD inlay castings. We measured the expansion and shrinkage percentage of the castings in both the buccolingual and mesiodistal directions.

From this experiment, we learned that precise MOD inlay castings can be produced using rings with 240° openings when invested in a thick mix having a standard water:powder ratio or using rings with 200° openings when invested in a thick mix having a water:powder ratio for a 12wt%Au-20～26Pd-20.48～26.48Cu-40Ag-1.5Zn-0.02Ir alloy.

<Text>

Introduction

Dental castings for restorations can be created with precision if the alloy casting shrinkage is compensated for adjusting the setting time and the thermal expansion of the investment.[1-5] Dental casting was first undertaken by Taggart a century ago (1907) to produce gold inlays.[6] Since then, extensive research and development has been performed on investment, heat sources for melting metals, and casting methods. [1,5,7]

Generally speaking, modern casting seems to have reached a high degree of perfection. However, when restoring with an MOD inlay against a proximal tooth that is caries susceptible, there are sometimes margin alignment problems and poor alignment of occlusal surfaces, even though its size is approved for clinical.[8,9] What causes these problems varies depending upon whether there are external restorations such as crowns or internal restorations such as inlays. Furthermore, the luting cements have a certain degree of thickness, that is, external restorations must be made slightly larger. Conversely, internal restorations need to be slightly smaller. It is not currently possible to make a casting expand in one direction and shrink in another (90°) direction using conventional investment methods. According to clinical trial reports, by rearranging the directions of spruing and investment, well-fitting MOD inlays are clinically feasible. M. Yamane,[10] for instance, tried horizontal investment in the mesiodistal direction pointing in the direction of the ring radius, as well as oblique investment with the sprue emanating from the cusp (Figure 1a**).** The other, K. Nakamura, designed a method of investing vertically at a 10° angle from the ring axis (Figure 1b).[11] However, these methods resulted in a slight expansion buccolingually. Therefore, we came up with a method of producing precise MOD inlays using a water-absorbent polymer and casting rings with openings on both sides. Water-absorbent polymer absorbs water in the investment, resulting in a decrease in the water:powder ratio, thus further increasing the setting expansion.[12] Also, when openings are created on both sides of the casting ring,, setting expansion and thermal expansion can occur freely in the investment material abutting the ring opening.[13] On the other hand, both setting expansion and thermal expansion of the investment abutting the remaining steel part of the ring is suppressed. In other words, the part of the casting near the ring openings expands and the part closest to the remaining steel of the ring shrinks. In this experiment, we produced 9 different kinds of Au-Ag-Pd alloys by changing the ratios of palladium, gold, and copper and experimenting with the following: (1) the effect of water-absorbent polymer on setting expansion; (2) the thermal expansion coefficient, melting point, thermal shrinkage; and (3) the expansion and shrinkage of MOD inlay castings.

As a result of these experiments, we discovered that by using casting rings with openings on both sides and water-absorbent polymer, precise MOD inlays can be made with a composition of Au-Ag-Pd alloy in which the degree of opening of the casting rings and the water:powder ratio of the investment are controlled in the manner detailed below.

Materials and Methods

Materials

Investment: Quick-setting cristobalite investment (Noritake F.F.20, Nagoya, Japan) was used, and the water:powder ratio was set at thick (0.32), standard (0.35), and thin (0.38).

Water-absorbent polymer: Sheets containing water-absorbent polymer for pets (BONBIALCON) were used.

Alloys: Nine different kinds of Au-Ag-Pd alloys were produced, whose composition is shown in Figure 2. The nine different Au-Ag-Pd alloys were achieved by changing the content ratio of palladium, gold, and copper by 3%.

Casting rings with openings on both sides: On 50 mm-high stainless steel tubular rings, 40mm diameter, openings were made on both sides. When viewed from the top, the openings measure 160°, 200°, and 240°, respectively, as indicated in Figure 3.

MOD inlay molds: As indicated in Figure 4, the external shape is as specified by ADA standard No.2. The outer frame and apex are removable. Gaps between the shoulder of the mold, after the outer frame was removed, and the MOD inlay castings were measured using a microscope equipped with a sliding caliper to gauge expansion and shrinkage in the mesiodistal direction. Gaps between the outer frames and castings were also measured for expansion and shrinkage in the buccolingual direction.

Methods

The effect of water-absorbent sheets on setting expansion

Water measured according to the 3 water:powder ratios (thick, standard, thin) was poured into rubber bowls; 100 g each of investment was added to the water and mixed for 60 seconds. Then, 90 minutes after mixing and filling the 100-mm long frame of an instrument that measures investment setting expansion,, the length of the test samples was measured using a micrometer gauge. The setting expansion was calculated from the original length of the test sample. We experimented with the setting expansion of the investment under various conditions:

Water-absorbent sheets: 4 different methods were attempted without water-absorbent sheets, with 1 sheet under the investment, with 1 sheet on top of the investment, and with 2 water-absorbent sheets where 1 was under and 1 was on top of the investment. We considered these 4 different applications of water-absorbent sheets as factor A (Figure 5). We used 3 different water:powder ratios: thick, standard, and thin. This was considered factor B.

Thermal expansion coefficient, melting point, and thermal shrinkage

Thermal expansion coefficient: We produced 10mm-high circular castings, 5 mm in diameter, and measured thermal expansion from 50°C to 500°C with a thermal expansion meter (TMA 120, Seiko Electronics, Chiba, Japan**)** We then calculated the coefficient.

Melting point: We produced the same size castings as were used in the thermal expansion coefficient measurements, measured differential calories with a thermogravimeter (DSC method, TG/DTA320, Seiko), and calculated the melting points.

Thermal shrinkage: From thermal expansion coefficients and melting points, thermal shrinkage from melting points to room temperature (25°C) were calculated for each of the alloys.

Expansion and shrinkage of MOD inlay castings

Investment: The center of the openings of the rings was regarded as the

Y-axis, and we waxed the patterns onto the crucible former so that the mesiodistal direction of the wax pattern corresponded to the Y-axis and mounted the casting rings with the openings (Figure 6). We wound a water-absorbent sheet around the rings, filled the opening, and invested it.

Casting: We removed the sprue after the investment hardened and placed the casting mold with the inlay wax patterns into a furnace. The heating rate of the furnace was set at 10°C/min, and the casting molds were heated to 700°C and allowed to cool to room temperature. The castings were later removed from the molds.

Experimental conditions of expansion and shrinkage of the castings are delineated in Table 1.

MOD inlay castings were produced using 3 variables:

A: 9 types of Au-Ag-Pd alloy, B: degree of opening of the casting rings with openings on the both sides, C: water:powder ratios of investment. We measured the expansion and shrinkage of the castings in the buccolingual and mesiodistal directions using the MOD inlay castings and the MOD inlay molds.

Results

Effects of water-absorbent sheets on setting expansion

Regarding the effect of the 4 different water-absorbent sheets on the investment as factor A and the 3 different water:powder ratios as factor B, we measured the setting expansion of the investment and calculated a 2-way layout**.** Though a highly significant difference ($P < .01$) was observed with the main factors A and B, no significant difference ($P > .05$) was observed in interaction effects. The results of this experiment are shown in graphic form (Figure 7). Setting expansion reached 1.87%, the maximum of all the conditions when the 2 water-absorbent sheets were placed on top of and under the investment, respectively, and it was invested using a thick water:powder ratio. This was approximately twice as high as that without water-absorbent sheets and with thin investment.

The thermal expansion coefficient, melting point, and thermal shrinkage of the 9 different Au-Ag-Pd alloys

Results of this experiment are shown in Table 2. Isothermal expansion curves of the 9 alloys are shown in Figure 8. The thermal expansion coefficient of No. 7 is the largest, at 17.88×10^{-6}, and No.9 is the smallest, at 16.89×10^{-6}. The isothermal melting point curves are shown in Figure 9. The melting point of No. 9 is the highest, at 948°C, and the lowest is No.1, at 842°C.

The thermal shrinkage (room temperature assumed to be 25°C) of the 9 Au-Ag-Pd alloys were calculated from the thermal expansion coefficients and melting points. Isothermal shrinkage curves are shown in Figure 10. The largest was No.9, at 1.56%, and the smallest was No.1, at 1.44%.

Expansion and shrinkage of MOD inlay castings

Buccolingual direction

The 9 different Au-Ag-Pd alloys were designated as factor A, the 3 different degrees of opening in the casting rings as factor B, and the 3 different water:powder ratios of investment as factor C. Expansion and shrinkage ratios were calculated using a 3-way layout. No significant difference ($P > .05$) was observed in any of the primary effects or any of the interactions. That is to say, using casting rings with openings on both sides, we obtained precise MOD inlay castings in the buccolingual direction (± 0%).

Mesiodistal direction

Similarly, expansion and shrinkage ratios were calculated using a 3-way layout. For primary effect B, the 3 different degrees of opening in the casting rings; C, the 3 different water:powder ratios of investment; and interaction (A × B), a highly significant ($P < .01$) difference was observed. The results of A × B are shown as a graph in Figure 11. The conditions under which castings expand are when the degrees of opening of the casting rings are 240° and 200° and the water:powder ratios are either thick or standard. Castings expand only with a 160° opening and when the investment has a thick water:powder ratio.

Both factors, degree of opening (160°, 200°, 240°) and water:powder ratio (0.38, 0.35, 0.32), were equally spaced for all alloys to permit an orthogonal analysis of variance and to obtain a regression formula. In this manner, they were orthogonally analyzed by variance of the degrees of opening in the cast rings (factor A) and by water:powder ratios (factor B). The coefficients that became significant by risk factors 0.05 and 0.01 were estimated and an orthogonal polynomial was developed to obtain a regression formula. A graph of this is shown in Figure 12. Almost all the alloys had similar tendencies in ranges of degrees of opening in the rings and water:powder ratios when the castings expanded more than +0.4. In particular, the 9 different kinds of Au-Ag-Pd alloys expanded more than 0.4% in castings when the casting ring openings were 240° and the investment had a thick and standard water:powder ratio, and when the casting ring openings were 200° and the investment had a thick water:powder ratio.

Nos. 1–3 alloys showed expansion exceeding 0.4% in castings when the casting ring openings were 240 ° and the investment had a thick and standard water:powder ratio, and when the casting ring openings were 200 ° and the investment had a thick water:powder ratio.

With the 12wt%Au-20-26Pd-20.48-26.48Cu-40Ag-1.5Zn-0.02Ir alloy produced for this experiment, optimal investment conditions occurred when using the 240°opening of the casting rings and thick or standard water:powder ratios, and using the 200°opening of the casting rings and thick water:powder ratios. This combination produced precise MOD inlays in a single casting that did not expand in the buccolingual direction, but expanded in the mesiodistal direction.

DISCUSSION

The 9 different kinds of Au-Ag-Pd alloys produced

Since the content of palladium in the Au-Ag-Pd alloys is 20%, 23%, and 26%, and that of gold is 12%, 15%, and 18%, as described above, if the factors are equally spaced for all alloys, we can analyze variance orthogonally and get a regression formula. Consequently, expansion and shrinkage were analyzed orthogonally for variance, and a regression formula was obtained. A graph displaying expansion and shrinkage is shown in Figure 13. The investment conditions of MOD inlays expanding 0.4% in the mesiodistal direction were Nos.1–6 (Au12%), 200°, and thick; and 240° and thick,standard. From the regression formula, the alloy to be used, the buccolingual diameter of the abutment teeth, the mesiodistal diameter, and the luting agent to be used are decided and the degrees of opening of the casting rings and the water:powder ratios of the investment required to produce precise MOD inlays become clear. The difference between the maximum and minimum thermal shrinkage is as small as 0.12%, but it is not small when regarded as an error in a precision casting experiment, so it could not be overlooked. Nine different MOD inlay castings produced with the No.1 alloy using three degrees of opening (160°, 200°, and 240°), and thin, standard, and thick water:powder ratios of investment are shown with molds in Figure 14. Thin and standard water:powder ratio investments with 160° openings and thin with 200° openings, as is also indicated when calculated statistically, do not align properly. However, MOD inlay castings produced with thick investment and 240° openings fitted the molds precisely (taking the dental cement layer into consideration).

Using water-absorbent sheets does not require heating expansion

A key reason why we used Noritake F.F.20 investment is that its setting expansion is greater than that of other investments. This investment is quick setting, and it can be placed in a 700°C furnace for 20 minutes after mixing is started. Greater setting expansion is necessary to offset the casting shrinkage that occurs (Fig 13). Plaster is added to the investment as a binder as expansion of the plaster plays an important role in compensating for casting shrinkage. Reducing water:powder ratios, in turn, increases setting expansion; removing water from the investment with water-absorbent sheets increases the setting expansion further. From the results of the experiment, we found that Noritake F.F.20 used as an investment with water-absorbent sheets both on top of and under the investment caused a setting expansion of 1.87%, which was greater than the total expansion of 1.86% (setting expansion after 20 minutes of mixing + thermal expansion) when Noritake F.F.20 was used under normal conditions. Therefore, with water-absorbent sheets and Noritake F.F.20, casting rings can be eliminated from the investment, thus dental cast alloys (with the exception of cobalt-chromium and nickel-chromium alloys) do not require thermal expansion, compensating for casting shrinkage.

What +0.4% expansion in the mesiodistal direction means

Spacing between expansion and shrinkage curves in the mesiodistal direction is set at 0%, 0.2%, and 0.4%, respectively (Figures 12 and 13). The reason for setting +0.4% as the optimum condition for MOD inlay investment is this: The abutment tooth is approximately 10 mm in mesiodistal distance and buccolingual distance, while the thickness of the cement layer is 20 μm (the minimum thickness of zinc phosphate cement, according to the literature), making the sum of the layers of both sides 40 mm. In other words, in order to make precise MOD inlays, the investment must expand 0.4% in the mesiodistal direction and shrink 0.4% in the buccolingual direction. Shrinkage in the buccolingual direction is impossible to measure with the MOD inlay molds used in this experiment. The outer frame and apex, after the MOD inlay mold is taken away, are removable. We tried to measure the gap between the outer frame and the proximal surface of an MOD inlay casting to determine the amount of expansion and shrinkage. However, it is impossible to measure this when the casting shrinks, because the neck of the outer frame cannot be removed, and the result was ± 0% after the castings shrank. For the most part, the castings fit the outer frames of the molds well during actual measurement. Though shrinkage is desirable for castings with the cement layer in the buccolingual direction taken into consideration, ± 0% was considered to be the investment condition wherein it would not expand; it is regarded as the most precise MOD inlay investment condition.

Difficulty in producing precise MOD inlays

In an actual clinical study, some may assert that MOD inlays should be produced under investment conditions in which they are made as large as an external restoration and then the buccolingual part of the casting should be shaved down. However, in casting technology, it is more important to produce castings that cling to the abutment teeth without any modification. Accurate restorations do not come off easily and, as a matter of course, accuracy helps prevent pyorrhea alveolaris. Well-fitting restorations are welcomed by patients, as well. Practitioners who create accurate restorations earn good reputations among patients.

References

1. Tetsuya Kanetake, Fitness of cast crown castings. Journal of Dental

Engineering 1976;36:1-13.

2. Tetsushi Kawai, Mechanism for casting shrinkage. Journal of Dental Technology 1994;22:410-13.

3. Yukio Ida, The outline of dental castings. Quintessence Tokyo 1987;223-34.

4. Tylman SD, Tylman SG, Theory and practice of crown and bridge prosthodontics (5th ed). St Louis: Mosby,1965: 466.

5. Shigeo Takahashi, The precise cast crowns —a way of thinking and the basic method —Journal of Dental Engineering 1993;5:6-15.

6. Taggart WH, A new and accurate method of making gold inlay. Dent Cosmos 1907;49:1117-21.

7. Masahiro Nezumi, Deformation of crowns cast in thermal expansion inhibited investment. Journal of the Japan Prosthodontic Society Prosthodontic Research & Practice 1991;35:432-45.

8. Kengo Nakamura, Precision casting of MOD inlays. Journal of The Japan Society for Dental Apparatus and Materials 1971;12:243-55.

9. Masahiro Ohsawa et al, Study on casting dimension. Part 6. Dimensional

changes of a mold cavity of U shape and MOD pattern. Japanese Journal of Conservative Dentistry 1993;36:1342-49.

10. Masatsugu Yamane, The investing method of setting wax pattern investment –the problem-. Dental Outlook 1970;33-5:889.

11. Kengo Nakamura, Casting accuracy for MOD inlay. Journal of the Japan Society for Dental Apparatus and Materials 1971;12:243-55.

12. Kazuo Ohkuma, Casting of MOD inlay using the rings opened a hole on both sides. Journal of Nippon Academy of Dental Technology 2003;24:27-37.

13. Kazuo Ohkuma. How to make precise MOD inlay –Shrink in the buccal-lingual direction, while expand in the mesial distal direction-. Quintessence of Dental Technology 2002;27:1535-41.

<Table>

Table 1. Experiment conditions

A	No.	1	12.0	20.00	26.48	+40Ag+1.5Zn+0.02Ir
		2	12.0	23.00	23.48	+40Ag+1.5Zn+0.02Ir
		3	12.0	26.00	20.48	+40Ag+1.5Zn+0.02Ir
		4	15.0	20.00	23.48	+40Ag+1.5Zn+0.02Ir
		5	15.0	23.00	20.48	+40Ag+1.5Zn+0.02Ir
		6	15.0	26.00	17.48	+40Ag+1.5Zn+0.02Ir
		7	18.0	20.00	20.48	+40Ag+1.5Zn+0.02Ir
		8	18.0	23.00	17.48	+40Ag+1.5Zn+0.02Ir
		9	18.0	26.00	14.48	+40Ag+1.5Zn+0.02Ir
			1	2	3	
B	Angle of opening		160	200	240	
C	Water:powder ratio		thin	standard	thick	

Table 2. Thermal expansion coefficient, melting point and thermal shrinkage rate

No.	Thermal expansion	Melting point (°C)	Thermal shrinkage
1	1.76	842	1.44
2	1.74	865	1.46
3	1.70	902	1.50
4	1.75	855	1.46
5	1.71	873	1.46
6	1.66	929	1.51
7	1.79	857	1.49
8	1.73	906	1.53
9	1.69	948	1.56

<Figure legends>

Fig.1. Permissible investment methods for practical use

Fig.2. Content ratio of palladium, gold, and copper

Fig.3. Degrees of opening form = 240 °

Fig.4. MOD inlay mold

Fig.5. Four different methods

Fig.6. Casting ring mounted with openings (from above)

Fig.7. Setting expansion

Fig.8. Isothermal expansion curves (10×-6)

Fig.9. Isothermal melting point curves (℃)

Fig.10. Isothermal shrinkage curves (%)

Fig.11. Angles of casting rings

Fig.12. Mounted casting rings with openings

Fig.13. Casting rings mounted with openings

Fig.14. Mounted casting rings with openings

<Figures>

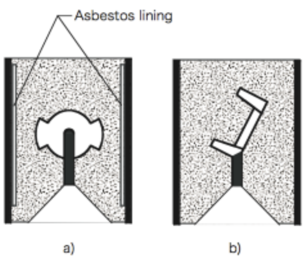

Fig.1.

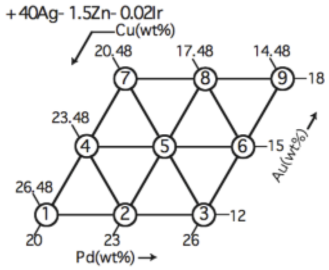
+40Ag- 1.5Zn- 0.02Ir
Cu(wt%)
20.48
17.48
14.48
7
8
9
18
23.48
4
5
6
15
Au(wt%)
26.48
1
2
3
12
20
23
26
Pd(wt%)

Fig.2.

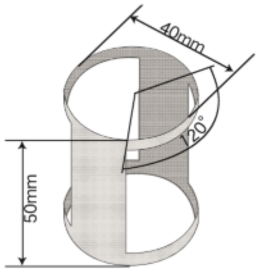

Fig.3.

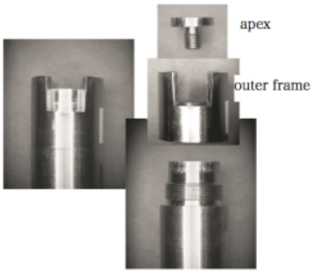

Fig.4.

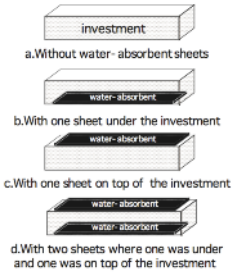
investment
a.Without water- absorbent sheets
water- absorbent
b.With one sheet under the investment
water- absorbent
c.With one sheet on top of the investment
water- absorbent
water- absorbent
d.With two sheets where one was under
and one was on top of the investment

Fig.5.

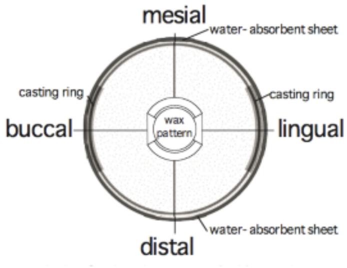
mesial
water- absorbent sheet
casting ring
casting ring
buccal
wax
pattern
lingual
water- absorbent sheet
distal

Fig.6.

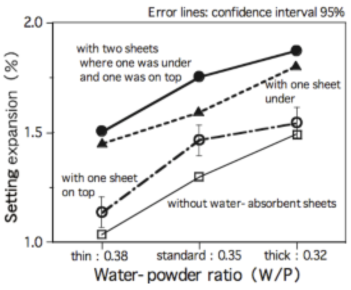
Error lines: confidence interval 95%
2.0
1.5
1.0
Setting expansion (%)
with two sheets
where one was under
and one was on top
with one sheet
under
with one sheet
on top
without water- absorbent sheets
thin : 0.38
standard : 0.35
thick : 0.32
Water- powder ratio (W/P)

Fig.7.

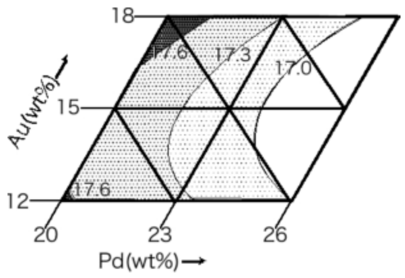

Fig.8.

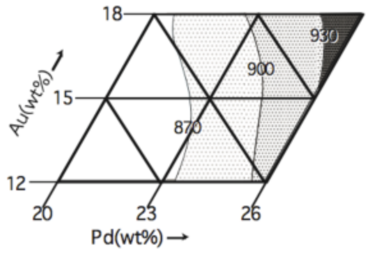

Fig.9.

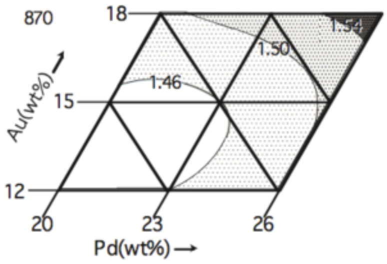

Fig.10.

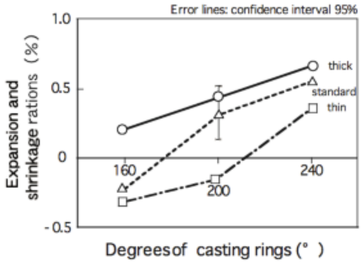
Error lines: confidence interval 95%
Expansion and shrinkage rations (%)
1.0
0.5
0
- 0.5
thick
standard
thin
160
200
240
Degrees of casting rings (°)

Fig.11.

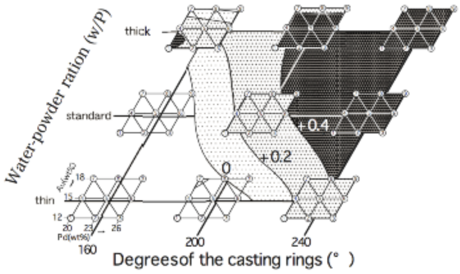
Water-powder ration (w/P)
thick
standard
thin
18
15
12
20
23
26
Pd(wt%)
160
200
240
0
+0.2
+0.4
Degreesof the casting rings (°)

Fig.12.

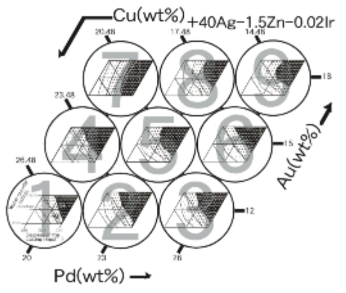
Cu(wt%)
+40Ag−1.5Zn−0.02Ir
20.48
17.48
14.48
23.48
26.48
7
8
9
4
5
6
1
2
3
18
15
12
Au(wt%)
20
23
26
Pd(wt%)

Fig.13.

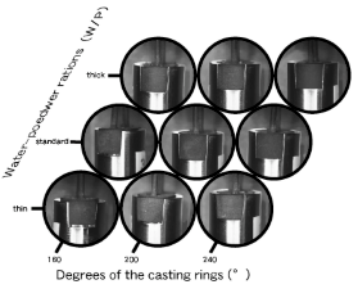
Water-poedwer rations（W/P）
thick
standard
thin
160
200
240
Degrees of the casting rings（°）

Fig.14