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DISTORTION OF WAX PATTERNS AS INFLUENCED BY SETTING AND HYGROSCOPIC EXPANSION OF THE INVESTMENT

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Introduction

The problem of balancing the expansions and contractions which occur during the construction of the gold inlay has been a subject of research and discussion for many years. There is no common opinion on how best to compensate for the contraction of the wax when cooled from mouth to room temperature and the casting shrinkage of the metal or alloy.

About 25 years ago two methods were developed to solve this problem. Both are still in use to-day. The first method makes use of the fact that if cristobalite is incorporated in the investment the thermal expansion can be raised sufficiently to compensate for the contractions, when the thermal expansion of the investment is combined with its normal setting expansion (1). The second method makes use of the hygroscopic expansion of the investment together with a relatively small expansion on heating (2).

Which of these two methods can better be used depends to a great extent on whether serious distortion of the wax pattern will occur when the setting or the hygroscopic expansion of the investment is used. There is evidence that an interaction exists between the investment and the wax pattern (3, 4). The investment, when expanding, may deform the wax pattern while the pattern itself may confine the expansion of the investment. What the final result of these two tendencies will be is difficult to predict but is probably dependent on the following factors:

1. The degree of expansion of the investment (setting versus hygroscopic expansion). This in turn will be influenced by:
   a. the type of investment used
   b. the manipulative factor with the material

2. The strength of the wax pattern. Its strength may be determined by:
   a. the thickness and shape of the pattern
   b. the temperature at which the pattern is invested
   c. the type of wax used.

A water bath at 37°C is often used in the hygroscopic expansion technic. An argument for this procedure is that at this temperature the wax will have more flow and will thus follow more readily the expansion of the investment (2). The question remains, however, whether the wax pattern will follow this excessive expansion in all its details to the same extent.

Since little is known about the interaction between wax pattern and investment and the arguments supporting the technics are to a large extent of theoretical nature and not based on direct measurement, it seems of utmost importance to collect some information on how the wax pattern behaves in an expanding investment. Little research has been done in this area.

Lasater (5) has shown that if wax patterns are placed in a water bath the distortion increases when the temperature rises. Phillips and Biggs (6) combined the effect of temperature with time and found that with increase of storage-temperature distortion occurs sooner. Suffert and Mahler (7) mentioned that distortion of the wax pattern may occur by the expansion of the investment.

Mumford and Phillips published an article (8) on the same subject with results comparable with those described in this publication.

Purpose of this investigation

The purpose of this investigation was to collect information on the distortion in wax patterns as influenced by the setting and hygroscopie expansion of the investment. Comparisons were made between:
a. different degrees of expansion (setting and hygroscopic expansion)
b. thin and thick „M.O.D." shaped wax patterns (1 and 2 mm thick)
c. different temperatures of investing (20° and 37°C).

Methods

Small lead markers were attached to the wax pattern and X-ray pictures were made of the invested wax pattern. In this way changes in the relative position of the leadmarkers could be recorded and measured.

The wax patterns were made on two different dies. The cavities were both of the „M.O.D." type, only the depth of the preparation being different (fig. 1).

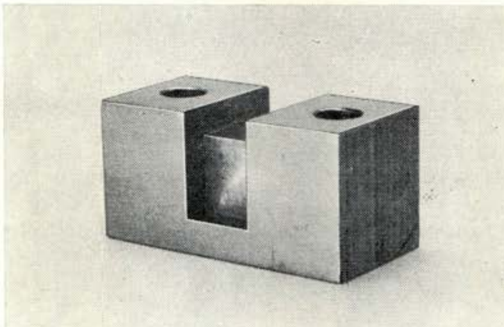
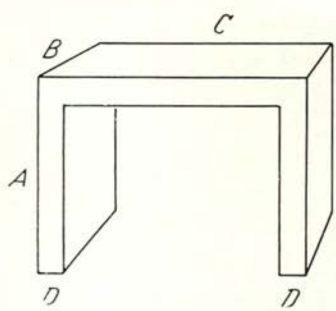


Fig. 1. Die used for making „mod" type wax patterns.



	A	B	C	D
I	7½	5	10	1
II	7½	5	10	2

Fig. 2. Dimensions of the wax patterns in mm.

The dimensions of the wax patterns obtained are shown in fig. 2. The taper of the dies was so small that it could be neglected in comparison with its dimensions. After the die and a stick of inlay wax was heated to 50°C in a thermostatically heated water bath, the wax was formed around the M.O.D. die and forced into the cavity by hand. The wax was held under pressure until cooled to room temperature. The pattern was then carved flush to the surface of the die.

Wax patterns of 2 mm thickness were also made mechanically. The parts shown in fig. 3 were made for this purpose.

Part A fits around the die leaving only the occlusal part of the cavity exposed.

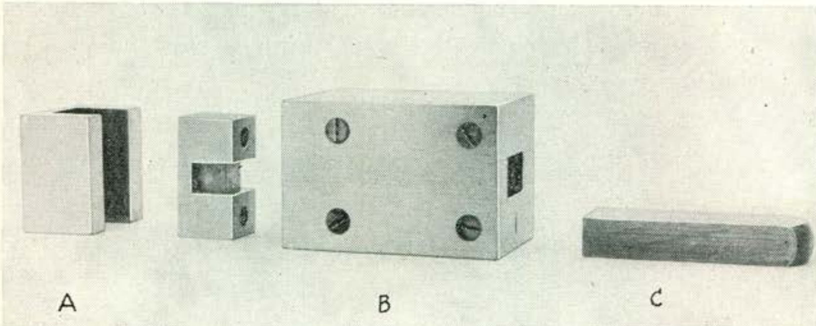


Fig. 3. Apparatus used to make wax patterns mechanically.

To bring the wax under a constant pressure in the cavity, an extension tube with a tight fitting piston was placed on top of the die (Part B and C).

The apparatus was placed in a water bath of 50°C with the opening just above the water level. A constant amount of wax of 50°C was dropped into the extension tube.

The amount of wax was such that it was just sufficient to fill the cavity. After the piston was placed in the extension tube, the apparatus was removed from the bath and placed under a lever which exerted a constant pressure on the piston. At the same moment the cooling started. The time-temperature curve is shown in fig. 4. The temperature was measured with a thermocouple in the wax pattern. After 10 minutes the apparatus was dismounted and the wax pattern carved smooth to the margins. Four lead markers of one square millimeter with a hole of 0.18 mm in diameter in its center were then carefully melted in the wax pattern.

The position of the lead markers are shown diagrammatically in fig. 5. The markers were placed at the center of the width of the pattern. The sprue pin was screwed in a hole drilled in the wax. A metal sprue base was used since rubber would have been too unstable.

The casting ring used had a diameter of 23 millimeters and a length of 53 millimeters. To permit the Röntgen rays to penetrate the casting ring four acrylic windows were made on both sides in the ring corresponding with the place of the four lead markers in the wax pattern (fig. 6). The equipment was kept at a constant temperature by using a thermostatically regulated water bath ($\pm$ 0.1°C) fig. 7. To reduce the absorption of the X-rays in the glass walls of the water bath two rectangular windows were cut and closed on one side with a sheet of plexiglass and on the other side, on account of lack of space, with a microscope cover-glass.

A series of 12 X-ray pictures was made of this assembly on one photographic glass plate (fig. 8). This was accomplished by shielding of the X-ray beam except for a rectangular area corresponding with the window in the water bath with a lead sheet.

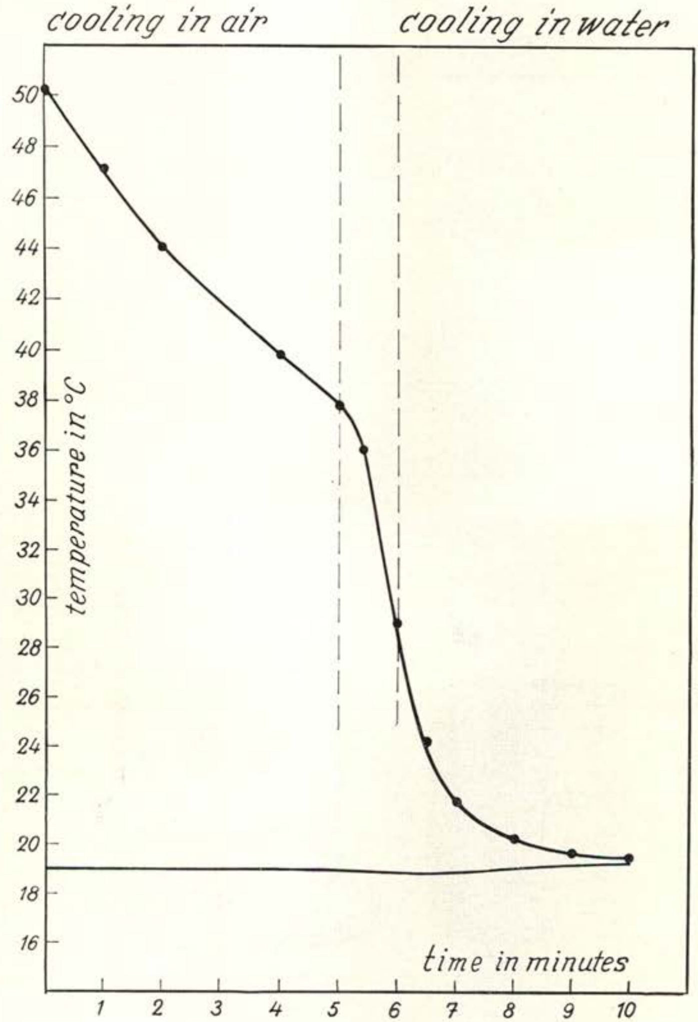


Fig. 4. Cooling curve of the mechanically made wax patterns.

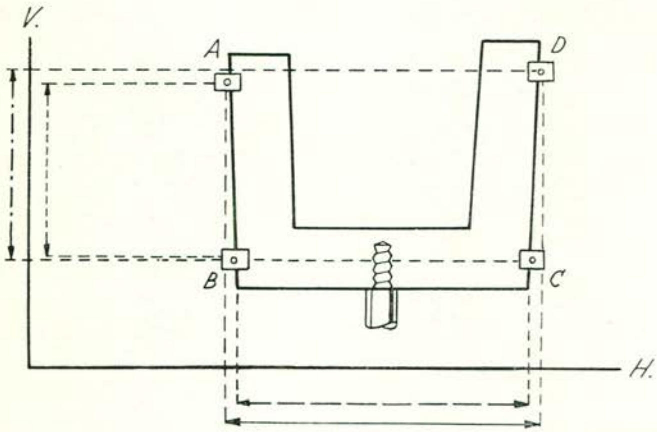


Fig. 5. Diagram of the position of the four lead markers.

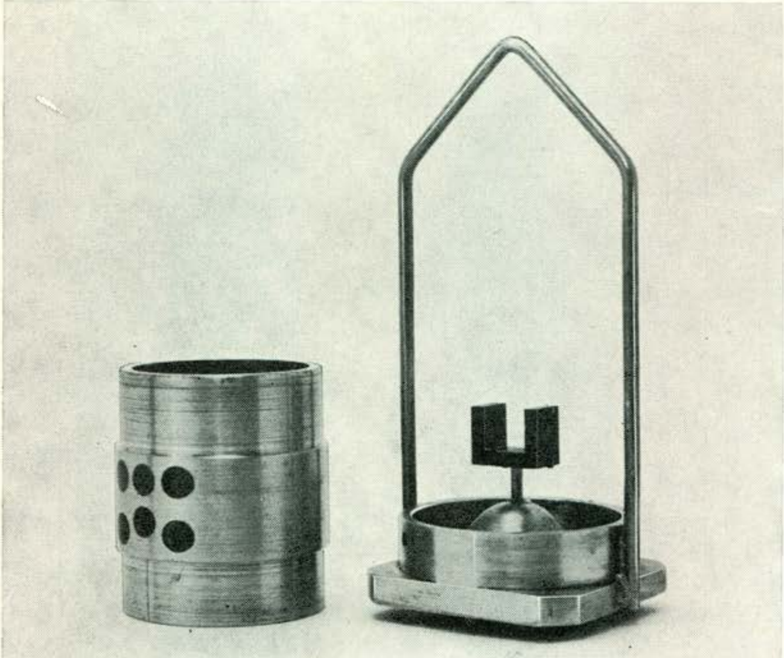


Fig. 6. Sprue base with wax pattern and casting ring with 6 acrylic windows, 4 of which are used.

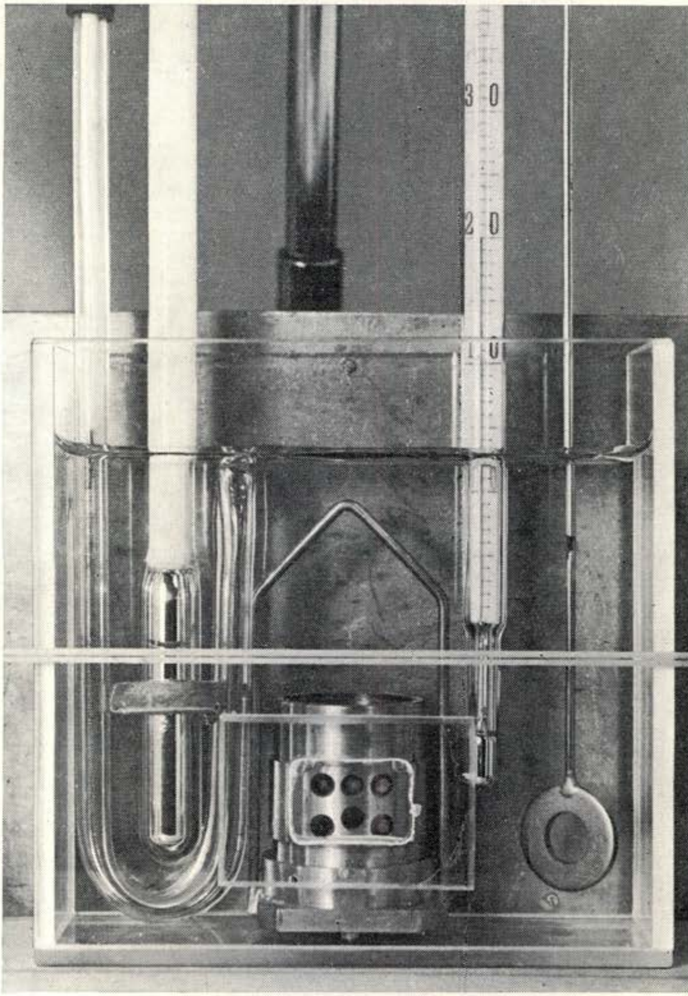


Fig. 7. Thermostatically regulated water bath with casting ring on the sprue base.

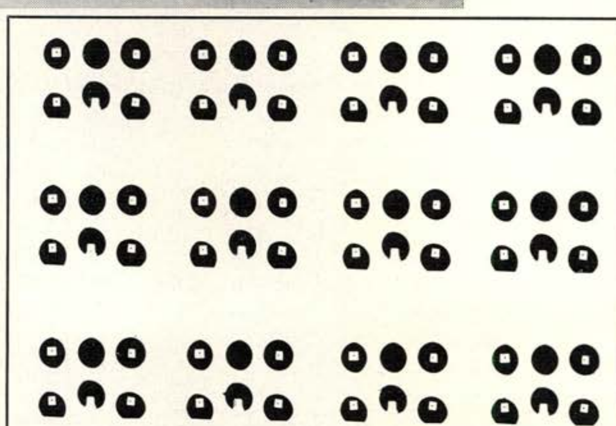


Fig. 8. Example of the 12 X-ray pictures on the photographic glass plate.

Against the lead sheet was placed a piece of plate glass of the same shape to guide the cassette with the photographic glass plate. All parts were stabilized by making contact with each other at three points. It was of the utmost importance that the emulsion of the photographic glass plate be moved exactly parallel with its own surface. This was obtained by attaching three screws of exactly the same length through the aluminum front of the cassette. By sliding these screws over the plate glass, the photographic glass plate could be moved parallel with its surface.

All parts so far described can be found in the diagram represented in fig.9. The distance focus-emulsion was 75 cm while the distance from the wax pattern to the emulsion was 2.8 cm. A Philips Rotalix Röntgen unit

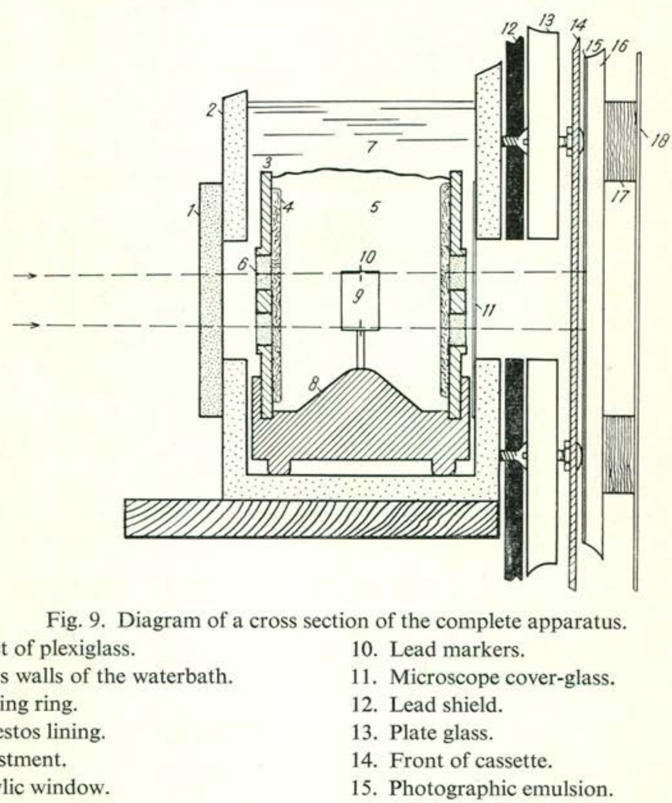


Fig. 9. Diagram of a cross section of the complete apparatus.

1. Sheet of plexiglass.
2. Glass walls of the waterbath.
3. Casting ring.
4. Asbestos lining.
5. Investment.
6. Acrylic window.
7. Water (temperature thermostatically regulated).
8. Sprue base.
9. Wax pattern.
10. Lead markers.
11. Microscope cover-glass.
12. Lead shield.
13. Plate glass.
14. Front of cassette.
15. Photographic emulsion.
16. Photographic glass plate.
17. Felt.
18. Rear of cassette.

was used. The Röntgen tube was operated at 93 kV and 12.2 mA, exposure time 6 seconds. The size of the focal spot was 0.3x0.3 mm (rotating anode).

Kerr's Cristobalite investment and Kerr's hard inlay wax were used throughout this study. (Both meet the specification of the A.D.A.) The water-powder ratio was 0.38. The time interval between the removal of the wax pattern from the die and the commencement of mixing the investment was 3 minutes. During the mixing time of half a minute, approximately 40 revolutions were made with a glass piston in a rubber bowl placed on a vibrator.

Times shown in the graphs are taken from the commencement of mixing. In the tests without investment the same time schedule was used. To obtain hygroscopic expansion the casting ring was lined with one layer of wet asbestos and placed in the water bath. For the evaluation and isolation of only setting expansion, any contact of the investment with water must be eliminated. This was done by lining the casting ring with a uniform layer of vaseline of 0.2 mm thickness (9). A definite amount of vaseline was applied to the ring and placed in a device which rotates the ring with a uniform speed around its axis. When the rotating ring is heated slightly the vaseline melts and then solidifies in a uniform layer on the inside of the casting ring (10). On the top of the ring a rubber cap was placed to prevent any contact of the water with the investment.

Results

1. Reproducibility

First the reproducibility of the image formation and method of measuring was studied on plates of different manufacture. Two leadmarkers were attached to a metal wire at a definite fixed distance. The pictures were made in 3 rows of 4, as far as possible from the border of the plate (11). For each manufacture, two plates were tested, one of which was normalized as described by Cooksey D. and Cooksey C. P. (12, 13). The pictures of the hole in the markers on the photographic plates were recorded in coordinates. This was done by fixing the plates in a very accurate mechanical stage above which a microscope with crosswires was mounted. The coordinates of each marker were measured three times. The wires were centered as accurately as humanly possible on the center of the round black areas. An astronomical comparator was found very useful for these measurements.

The results were in close agreement with those obtained by other investigators (11, 12, 13, 14, 15) (see table 1 and 2).

A comparison between the plates was made by analysis of variance (16, 17).

1. Analysis of the difference between the plates.

Table 1

	Q_{ABC}	Degrees of freedom	$Q_{residual}$	Degrees of freedom	F	P
Kodak/Ilford (both not normalized)	105	11	288	96	3.18	<0.005
Kodak/Ilford (both normalized)	74	11	229	96	2.59	$0.005<P<0.01$
Normalized/ Not normalized (Kodak)	84	11	213	96	3.4	<0.005
Normalized/ Not normalized (Ilford)	53	11	303	96	1.52	>0.05

2. Analysis of the four plates separately

Table 2

	Q_{AB}	Degrees of freedom	$Q_{residual}$	Degrees of freedom	F
Kodak 0800 (not normalized)	120	11	104	48	5.04
Kodak 0800 (normalized)	119	11	110	48	4.73
Ilford H.P. 3 (not normalized)	108	11	184	48	2.56
Ilford H.P. 3 (normalized)	63	11	119	48	2.31

Q = sum of squares
A = values for first and second mark
B = values for the twelve pairs
C = values for the two plates
AB = first order interaction between A and B
ABC = second order interaction between A, B and C
F = variance ratio
P = probability

Conclusions from table 1:

a. There is a significant difference between Kodak and Ilford plates whether normalized or not.

b. There is a significant difference between the Kodak plates before and after normalization.
Ilford plates do not show this effect.

Conclusions from table 2:

a. Normalization improves the Kodak plates sligthly.

b. Ilford plates are better than Kodak plates

ILFORD H. P. 3 plates were used, without normalization. The slight improvement that might be reached by normalization of the plates (no significant difference was found, table 1) was neglected in favor of a less complicated procedure. The method was further studied by making series pictures of a sheet of lead (15 x 15 mm soldered in a metal frame for reinforcement) with four holes of the same diameter and in the same relation to each other as those to be used with the wax patterns.

The metal frame was placed on a sprue pin in the casting ring. The ring was filled with investment and the pictures made during the hygroscopic expansion of the investment.

Fig. 5 gives, schematically, the coordinates of the four markers of one picture.

The plate was fixed in the comparator in such a way that the line BC coincided as nearly as possible with the horizontal axis.

The average of three measurements of the coordinates of each marker was used in the calculations. By subtracting the coordinates of the markers the distances between the markers are found (arrows in fig. 5). In each experiment each distance can be found twelve times (twelve pictures made during 90 minutes). In the following curves are plotted the per cent changes in length with time for each of the four distances. The four curves in each of the figures 10 through 28 have the same line pattern as shown in figure 5. Thus the solid line ——— in each of the graphs represents the distance AD in figure 5 and the broken line of long dashes ------ represents the distance BC and so on. The result is represented in figure 10.

*2. Behaviour of a wax pattern without investment**)

A series of 6 tests was made to study the behaviour of a wax pattern without investment. For conditions and numbers of graphs see table 3. From the graphs it can be seen that no appreciable distortion was detected within 90 minutes after removing a 2 mm thick wax pattern

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*) For an analysis of variance of the results see table 4A and 4B.

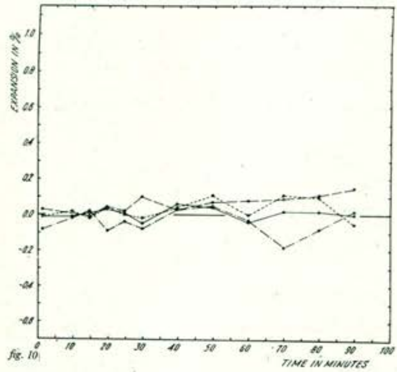


Fig. 10. Per cent change in length recorded from a lead test plate with 4 holes.

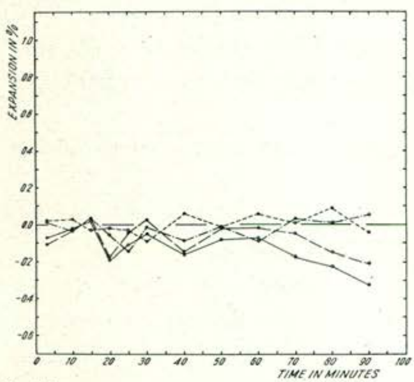


fig. 11

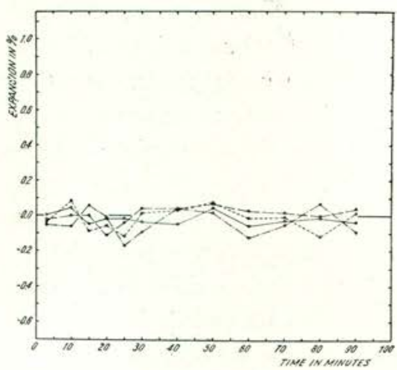


fig. 12

Per cent change in length of four dimensions of a wax pattern in a waterbath of 20° C.

Fig. 11. A hand made wax pattern of 1 mm thickness.

Fig. 12. A hand made wax pattern of 2 mm thickness.

Fig. 13. A mechanically made wax pattern of 2 mm thickness.

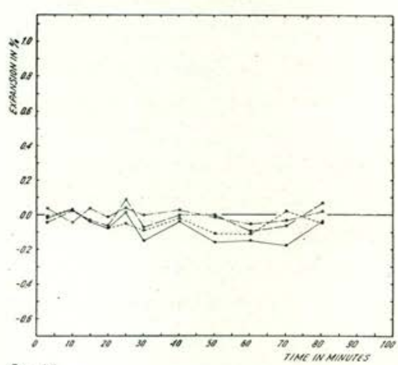


fig. 13

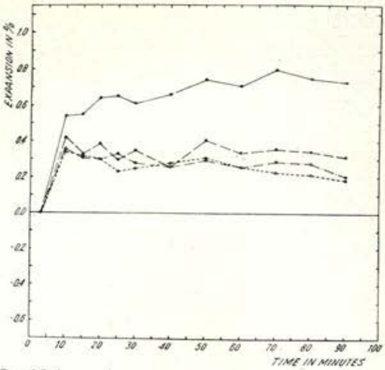


fig. 15A

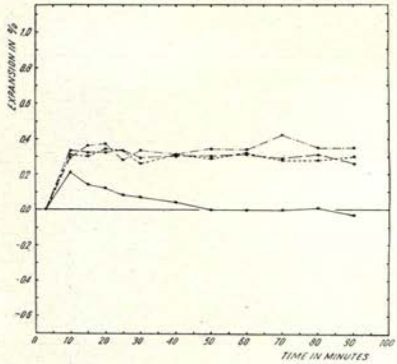


fig. 16A

Fig. 15A. Per cent change in length of four dimensions of a hand made wax pattern of 2 mm thickness in a waterbath of 37° C.

Fig. 16A. Per cent change in length of four dimensions of a mechanically made wax pattern of 2 mm thickness in a waterbath of 37° C.

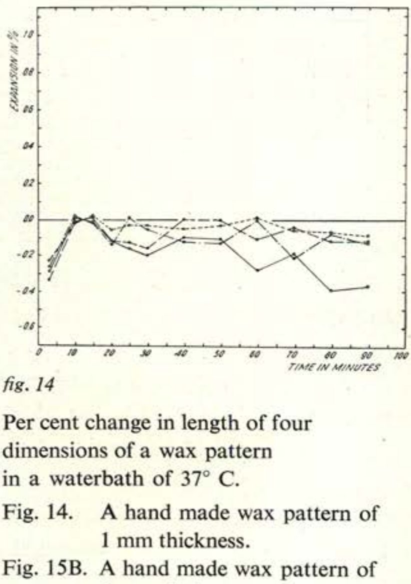


fig. 14

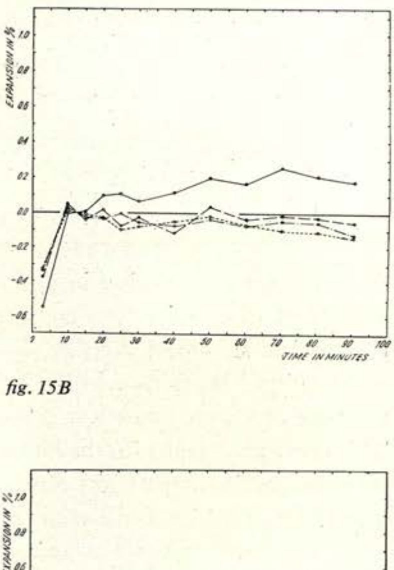


fig. 15B

Per cent change in length of four dimensions of a wax pattern in a waterbath of 37° C.

Fig. 14. A hand made wax pattern of 1 mm thickness.

Fig. 15B. A hand made wax pattern of 2 mm thickness.
Fig. 15B is the same as fig. 15A, except that the curves are shifted as explained in the text.

Fig. 16B. A mechanically made wax pattern of 2 mm thickness.
Fig. 16B is the same as fig. 16A, except that the curves are shifted as explained in the text.

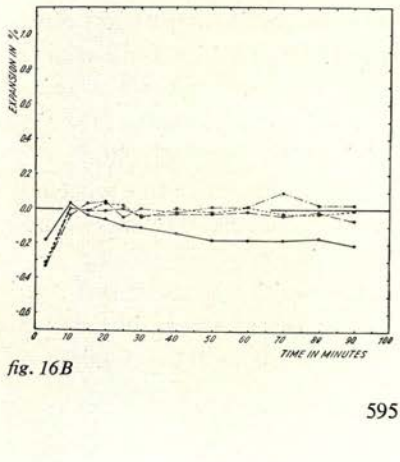


fig. 16B

Table 3

	Condition	WAX PATTERN made by hand thickness 1 mm figure no.	WAX PATTERN made by hand thickness 2 mm figure no.	WAX PATTERN mechanically made thickness 2 mm figure no.	sheet of lead figure no.
20°	water bath	11	12	13	
37°	water bath	14	15 A 15 B	16 A 16 B	
20°	setting expansion of investment	17	18	19	
	hygroscopic expansion of investment	20	21	22	10
37°	setting expansion of investment	23	24	25	
	hygroscopic expansion of investment	26	27	28	

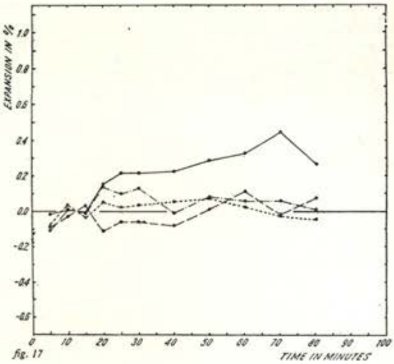
from the die and storing in a water bath of 20°C (fig. 13, 12). A wax pattern of 1 mm thickness, however, shows a change in distance between the cervical shoulders (fig. 11).

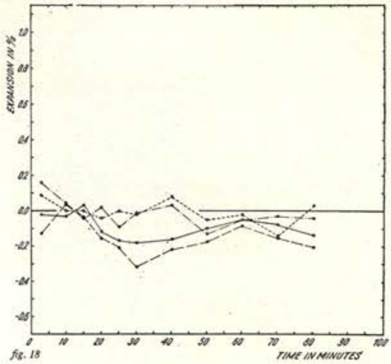
At a higher temperature (37°C) the curves show a thermal expansion of the wax of approximately 0.35% from 20° to 37°C (fig. 16A and 15A). This is in agreement with the information of the physical properties of the wax. To eliminate the effect of temperature change the curves of fig. 16A and 15A were shifted to put the average values of per cent change for 10 and 15 minutes on the zero axis. As a result the curves will intersect the zero axis at 12.5 minutes (The time measured from the commencement of mixing) (fig. 16B and 15B).

The advantage of this procedure is that:

a. the influence of temperature changes in the first 10 minutes are eliminated

b. the position of the curves relative to each other will be more accurate because the errors, included in each point of the curves, are averaged for $t=10$ and $t=15$ minutes. Since the initial setting time of the



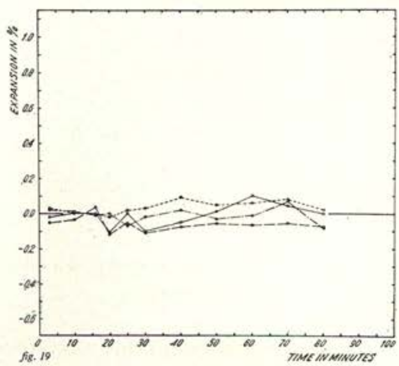


Per cent change in length of four dimensions of a wax pattern as influenced by normal setting expansion of investment at 20° C.

Fig. 17. A hand made wax pattern of 1 mm thickness.

Fig. 18. A hand made wax pattern of 2 mm thickness.

Fig. 19. A mechanically made wax pattern of 2 mm thickness.

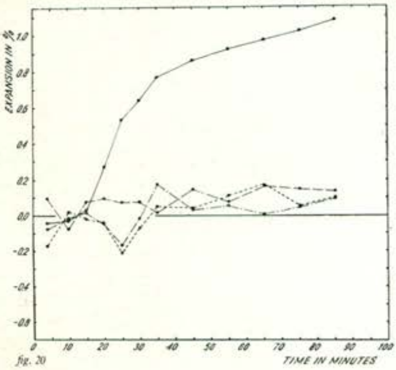


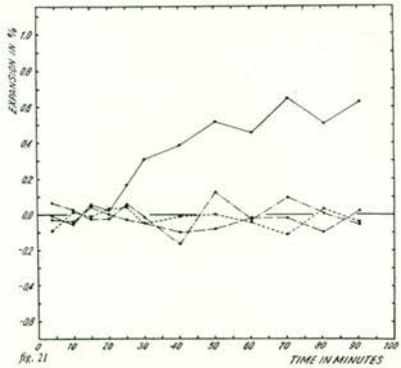
investment is greater than 15 minutes (9, 18, 19) it is not very probable that there will be any effect on the wax pattern before 15 minutes.

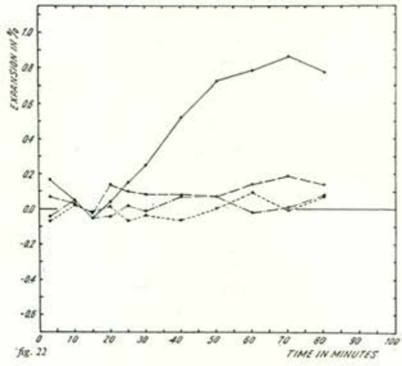
Special attention should be paid to the fact that, as a result of this procedure only the effect of the expanding investment is studied. The distortion of the wax patterns that may occur when heated to 37°C, and before the influence of the investment becomes effective, has been neglected.

At 37°C all wax patterns have a tendency to distort (change in distance between cervical shoulders), fig. 16A, 15A and 14.

The magnitude will be determined by the manipulation of the wax. Since it is difficult to reproduce the exact manipulation each time when a pattern is hand made, the stresses incorporated will vary accordingly. This is particularly important with the wax patterns of 1 mm thickness. We can expect for this reason that thin wax patterns give less reproducible results than thick wax patterns; this was experienced during the investigation.







Per cent change in length of four dimensions of wax pattern as influenced by hygroscopic expansion of investment at 20° C.

Fig. 20. A hand made wax pattern of 1 mm thickness.

Fig. 21. A hand made wax pattern of 2 mm thickness.

Fig. 22. A mechanically made wax pattern of 2 mm thickness.

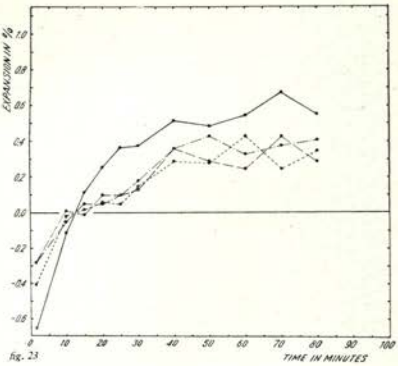
3. Effects of investment and thickness of wax pattern

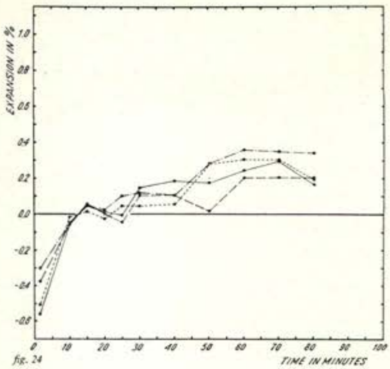
A variety of conditions was studied. Table 3 shows the combination of factors with the corresponding numbers of the figures.

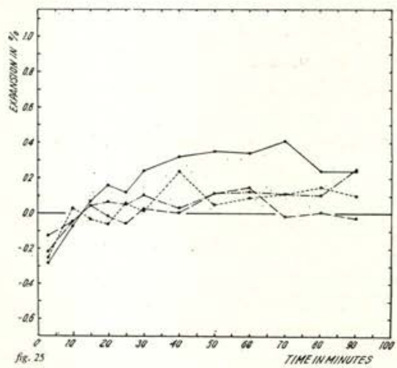
A. Tests at 20°C

From the graphs it can be concluded that wax patterns of 1 mm thickness distort more than the 2 mm thick ones (fig. 17-18 and 20-21). The change in distance between the cervical shoulders is also increased when the investment has a higher expansion. Compare fig. 17, 18 and 19 with fig. 20, 21 and 22.

The difference between the effect of a water bath and setting expansion on the distance between the cervical shoulders is only significant for a wax pattern of 1 mm thickness. A wax pattern of 2 mm thickness shows no distortion when exposed to setting expansion.







Per cent change in length of four dimensions of a wax pattern as influenced by normal setting expansion of investment at 37° C.

Fig. 23. A hand made wax pattern of 1 mm thickness.

Fig. 24. A hand made wax pattern of 2 mm thickness.

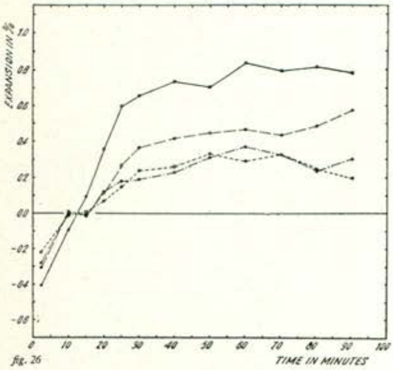
Fig. 25. A mechanically made wax pattern of 2 mm thickness.

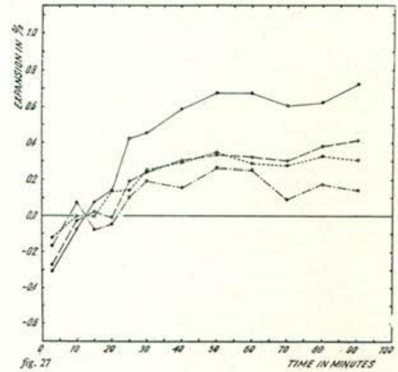
B. Tests at 37°C

Although the data at 37°C are not as conclusive as those at 20°C, some effects can be observed. The curves made at 20°C show an increase in the distance between the cervical shoulders of the wax patterns whereas the other dimensions are not affected by an expanding investment. At 37°C however the other dimensions are also affected to a certain extent, although not as much as the cervical distance. This effect is most pronounced when wax patterns of 1 mm thickness are used. Compare curves 23 and 26 with 24, 25, 27 and 28.

The statistical analysis applied to the distances found between the cervical shoulders permits the following conclusions concerning these distances.

For wax patterns of 2 mm the differences between the effect of a water bath and hygroscopic expansion of investment is significant (fig. 15B-27) as well as the difference between the effect of setting and hygroscopic expansion (fig. 24-27). No significant effect was found when comparing the effect of a water bath and setting expansion of investment (fig. 15B-24).



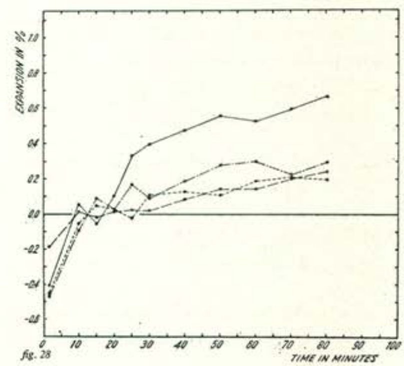


Per cent change in length of four dimensions of a wax pattern as influenced by hygroscopic expansion of investment at 37° C.

Fig. 26. A hand made wax pattern of 1 mm thickness.

Fig. 27. A hand made wax pattern of 2 mm thickness.

Fig. 28. A mechanically made wax pattern of 2 mm thickness.



For wax patterns of 1 mm the difference between the effect of a water bath and both setting and hygroscopic expansion of investment is significant (fig. 14-23 and 14-26). No difference between setting and hygroscopic expansion of investment can be shown in wax patterns of 1 mm (fig. 23-26). There is also no significant difference between the wax patterns of 1 and 2 mm (fig. 23-24 and 26-27). In general it can be said that at 37°C there is an increase in the change in distance between the cervical shoulders by increase of expansion of investment, but not much difference in reaction could be found between wax patterns of 1 mm and 2 mm thickness.

Normal setting expansion of investment has more effect at 37°C than at 20°C, for wax patterns of 2 mm (fig. 18-24). Those of 1 mm show no increased effect statistically (fig. 17-23) although the curves suggest an effect (This will be due to the large residual sum of squares). By comparison of all the curves made of patterns of 1 mm with those of 2 mm thickness we see that the distortion of the thinner wax patterns starts earlier.

Table 4A
An analysis of variance of the results obtained with hand made wax patterns.

Conditions of treatment	figure number	distance	Q treatment	Q residual	F	effect
		D_1	7	42	0.3	—
wax pattern of 2 mm		D_2	2	8	0.5	—
in water bath of 20°C	12	D_3	1	200	0.01	—
		D_4	25	229	0.2	—
		D_1	729	58	25	S
wax pattern of 1 mm		D_2	306	43	14	—
in water bath of 20°C	11	D_3	12.2	32.5	0.7	—
		D_4	6.2	102	0.1	—
		D_1	361	5	144	S
wax pattern of 2 mm		D_2	16	45	0.7	—
in water bath of 37°C	15 B	D_3	81	37	4.3	—
		D_4	156	7	45	S
		D_1	1444	4	722	S
wax pattern of 1 mm		D_2	144	2	144	S
in water bath of 37°C	14	D_3	121	17	13	—
		D_4	64	10	13	—
wax pattern of 2 mm setting exp. of investment at 20°C	18	D_1	121	36	7	—
wax pattern of 1 mm		D_2	1296	100	26	S
setting expansion of	23	D_3	1560	55	56	S
investment at 37°C		D_4	898	60	30	S
wax pattern of 1 mm		D_2	2809	41	137	S
hygroscopic expansion	26	D_3	729	20	73	S
of investment at 37°C		D_4	506	15	67	S
wax pattern of 2 mm		D_2	420	61	14	—
setting expansion of	24	D_3	1190	51	47	S
investment at 37°C		D_4	625	65	19	S
wax pattern of 2 mm		D_2	1600	17	188	S
hygroscopic expansion	27	D_3	256	117	4.4	—
of investment at 37°C		D_4	1024	2	1024	S

Q treatment = sum of squares for the difference between the values for 10 and 15 minutes and those for 80 and 90 minutes; degrees of freedom = 1.
Q residual has 2 degrees of freedom. See also footnotes at bottom of table 4B.

Table 4 B

Conditions of treatment	distance	comparison between	figure numbers	Q comp.	Q residual	F	effect
wax pattern 1 mm 20°C	D_1	setting-hygrosc. expansion	17 – 20	2486	198	50	S
wax pattern 2 mm 20°C	D_1	setting-hygrosc. expansion	18 – 21	2278	169	54	S
setting exp. of investment 20°C	D_1	wax pattern 1–2 mm	17 – 18	1035	199	21	S
hygrosc. exp. of investment 20°C	D_1	wax pattern 1–2 mm	20 – 21	1176	169	28	S
wax pattern 1 mm 20°C	D_1	water bath-setting expansion	11 – 17	1892	224	34	S
wax pattern 2 mm 20°C	D_1	water bath-setting expansion	12 – 18	36	79	2	—
wax pattern 1 mm 37°C	D_1	setting-hygrosc. expansion	23 – 26	171	522	1	—
wax pattern 2 mm 37°C	D_1	setting-hygrosc. expansion	24 – 27	989	289	14	S
setting exp. of investment 37°C	D_1	wax pattern i–2 mm	23 – 24	742	461	6.4	—
hygrosc. exp. of investment 37°C	D_1	wax pattern 1–2 mm	26 – 27	78	347	1	—
wax pattern 1 mm 37°C	D_1	water bath-setting expansion	14 – 23	4950	341	58	S
wax pattern 2 mm 37°C	D_1	water bath-setting expansion	15B– 24	4	130	0.2	—
wax pattern 1 mm 37°C	D_1	water bath-hygrosc. expansion	14 – 26	6959	189	148	S
wax pattern 2 mm 37°C	D_1	water bath-hygrosc. expansion	15B– 27	1177	167	28	S
wax pattern 1 mm setting expansion of investment	D_1	20°–37°C	17 – 23	364	499	3	—
wax pattern 2 mm setting expansion of investment	D_1	20°–37°C	18 – 24	573	161	14	S

D_1 = distance AD (fig. 5)
D_2 = distance BC (fig. 5)
D_3 = distance AB (fig. 5)
D_4 = distance DC (fig. 5)
Q = sum of squares
F = variance ratio

S = significant effect on 5% level
$Q_{comp.}$ = sum of squares for the influence of the factor indicated in column 3 on the difference between the values for 10 and 15 minutes and those for 80 and 90 minutes (1 degree of freedom).
$Q_{residual}$ has 4 degrees of freedom.

Discussion

Method

The representation of the results is based on the assumption that the effects measured are a result of a movement of the leadmarkers parallel with the photographic glass plate.

There is only a speculative basis to justify this assumption.

No proof is given that this assumption is true and a movement of the leadmarkers in any other direction which would produce the same curves as represented can not be denied. This question can only be resolved by further investigation. Likewise there exists also the possibility of a movement in the position of the other parts of the apparatus. To obtain some information about the relative importance of changes in the geometrical variables influencing the image formation, an analysis of the effect of these variables was made. Figure 29 is a schematic drawing of the variables used in the calculations.

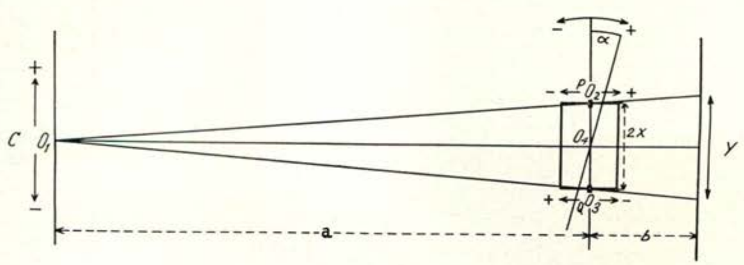


Fig. 29. Diagram of the geometrical variables which influence the image formation. For explanation see text.

a. the distance from the focal spot to the middle of the wax pattern
b. the distance from the middle of the wax pattern to the emulsion of the photographic glass plate
c. the deviation of the Röntgentube from O_1
p. the deviation of the leadmarker from O_2
q. the deviation of the leadmarker on the opposite side of the wax pattern from O_3
α. angle of rotation of the wax pattern with axis O_4
2x the distance between the two approximal parts of the wax pattern
y. the distance recorded.

Table 5

Per cent change in length of distance recorded ($100\frac{dy}{y}$) as influenced by geometrical variables.

Values*) substituted							variation	$100\frac{dy}{y}$
a	b	c	x	p	q	α		
722	28	50	5	0	0	0	da = + 1	— 0.005
				+ 1	+ 1	0	da = + 1	— 0.007
				— 1	— 1	0	da = + 1	— 0.003
				+ 1	— 1	0	da = + 1	— 0.005
				— 1	+ 1	0	da = + 1	— 0.005
722	28	50	5	0	0	0	dc = + 1	0
				+ 1	+ 1	0	dc = + 1	+ 0.03
				— 1	— 1	0	dc = + 1	— 0.03
				+ 1	— 1	0	dc = + 1	0
				— 1	+ 1	0	dc = + 1	0
722	28	50	5	0	— 1	— 1	dp = + 1	+ 0.79
				0	0	— 1	dp = + 1	+ 0.80
				0	— 1	— 1	dp = + 1	+ 0.81
				0	+ 1	0	dp = + 1	+ 0.62
				0	0	0	dp = + 1	+ 0.62
				0	— 1	0	dp = + 1	+ 0.62
				0	+ 1	+ 1	dp = + 1	+ 0.45
				0	0	+ 1	dp = + 1	+ 0.45
				0	— 1	+ 1	dp = + 1	+ 0.45
722	28	50	5	+ 1	0	— 1	dq = + 1	+ 0.93
				0	0	— 1	dq = + 1	+ 0.94
				— 1	0	— 1	dq = + 1	+ 0.94
				+ 1	0	0	dq = + 1	+ 0.76
				0	0	0	dq = + 1	+ 0.76
				— 1	0	0	dq = + 1	+ 0.76
				+ 1	0	+ 1	dq = + 1	+ 0.58
				0	0	+ 1	dq = + 1	+ 0.58
				— 1	0	+ 1	dq = + 1	+ 0.59
722	28	50	5	0	0	0	dα**) = + 0.017	+ 0.12
				+ 1	+ 1	0	dα = + 0.017	+ 0.22
				— 1	— 1	0	dα = + 0.017	+ 0.48
				+ 1	— 1	0	dα = + 0.017	+ 0.12
				— 1	+ 1	0	dα = + 0.017	+ 0.12
722	28	any value					db = + 1	+ 0.13

*) Values in mm except α in degrees.

**) dα in radians 0.017 rad. = 1°.

The relation between x and y is influenced by a, b, c, p, q, x and α and can be expressed as follows:

$$y = (a+b) \quad \frac{(p-q)x + \{2cx - a(p+q)\} \sin\alpha + \{2ax + c(p+q)\} \cos\alpha}{(a + x\sin\alpha + p\cos\alpha)\,(a - x\sin\alpha - q\cos\alpha)}$$

By logarithmic differentiation expressions can be found of the relation between $\frac{dy}{y}$ and da, db, dc, dp, dq, dx, and dα.

Calculations were made with this expression of $\frac{dy}{y}$ for various combinations of the variables.

In the following table $100\frac{dy}{y}$ is given, expressing the per cent change in length of y.

From table 5 it can be concluded that the largest errors are produced by variations in p and q. The magnitude of the errors actually occurring can not be calculated because the values to be substituted are unknown. In table 5 arbitrarily chosen values are used and the table gives therefore only an idea of the relative importance of the different variables.

Effective expansion

Several investigators have measured the normal and hygroscopic expansion of investment. The method they used to measure the expansion contributed greatly to the data secured (9, 18, 19, 20.) Some anticipated however that it would be possible to give a definite point at which the effect of the investment on the wax starts. From this investigation, however, we may conclude that there is no fixed point for the start of the effective expansion and that the magnitude of the effect of the expansion on the wax pattern is variable. Compare curves of wax patterns of 1 mm with those of 2 mm thickness. In some cases it is even impossible to detect where the thermal expansion of the wax ends and where the effect of the expanding investment starts (fig. 23-26).

In the discussion so far, effective expansion has been considered only as it influences the distance between the cervical shoulders. However, to call an expansion effective it must have an effect on all the parts of the wax pattern and to the same degree.

When the dimensions of a wax pattern do increase in length but not in the same magnitude, the result is a partly expanded, partly distorted wax pattern.

Distortion of the wax pattern

Distortion of the wax pattern is evident when the four curves in the graphs do not coincide. In all cases studied distortions can be found except when a 2 mm thick wax pattern was invested with normally expanding investment at 20°C, (fig. 18-19) under the same conditions but at 37°C there is a tendency towards distortion (fig. 24-25).

It can also be concluded that hygroscopic expansion produces less distortion at 37°C than at 20°C (fig. 20-26 and 21-27 and 22-28).

Elimination of distortion

We should therefore, if possible, avoid thin wax patterns and use normally expanding investment preferably at 20°C. The question remains how hygroscopic expansion can be eliminated. This is still a problem as long as an asbestos lining in the casting ring is used and no investments are available which do not show hygroscopic expansion.

Ryge and Fairhurst (21) have shown that not only water but also other fluids may cause the investment to exhibit a „hygroscopic" expansion. To investigate the normal setting expansion casting rings lined with vaseline were used in this study. In view of this report of Ryge and Fairhurst it becomes questionable if the vaseline actually prevented hygroscopic expansion. Measurements made at 20°C do not show any such effect but data at 37°C were somewhat inconclusive.

Conclusion

A method has been described for measuring dimensional changes in wax patterns as influenced by setting and hygroscopic expansion. Distortion of wax patterns from normal setting expansion and hygroscopic expansion could be detected in all cases studied. The only exception was observed when a 2 millimeter thick wax pattern was invested with normally expanding investment at 20°C.

The distortion found increased when the thickness of the wax pattern was decreased or the expansion of the investment was increased.

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Samenvatting

Inleiding

In verschillende fasen van het vervaardigingsproces van inlays treden contracties van de gebruikte materialen op. Deze kunnen op twee wijzen gecompenseerd worden.

1e. Door gebruik te maken van een inbedmassa die sterk expandeert tijdens het verhitten en in geringe mate tijdens het hard worden.

2e. Door tijdens het hard worden van de inbedmassa deze in contact te brengen met water waardoor een sterke expansie optreedt (hygroscopische expansie), en deze te combineren met een relatief geringe thermische expansie.

Door de expansie van de inbedmassa tijdens het hard-worden, bestaat de mogelijkheid dat het waspatroon vervormd wordt. Teneinde een keus te kunnen maken tussen de twee genoemde compensatiemethoden, is het van belang te weten of een distorsie van het waspatroon optreedt en of deze distorsie bij toepassing van de hygroscopische expansie van de inbedmassa groter is dan wanneer van de hardwordingsexpansie gebruik gemaakt wordt.

De mate van de expansie van de inbedmassa wordt bepaald door:

a. de soort inbedmassa

b. de wijze van verwerking

De weerstand van het waspatroon tegen vervorming wordt bepaald door:

a. de dikte en het model van het waspatroon

b. de temperatuur waarbij het wordt ingebed (gangbare technieken 20° en 37° C)

c. de soort was waaruit het bestaat

Doel

Doel van het onderzoek was informatie te verzamelen omtrent vervormingen van het waspatroon. Onderzocht werden de invloed van:

a. hardwordingsexpansie en hygroscopische expansie

b. de dikte van het waspatroon (1 en 2 mm dik)

c. de temperatuur waarbij ingebed wordt. (20° C en 37° C)

Methode

Waspatronen werden uit de hand vervaardigd op een model van het „mod" type (fig. 1, afmetingen zie fig. 2). Op het model met een diepte van 2 mm werden ook mechanisch waspatronen vervaardigd. Fig. 3 toont de hiervoor gebruikte apparatuur:

A: matrix die de „approximale" gedeelten van de caviteit afsluit.

B: opzetstuk waarin een zuiger C past.

Nadat een bepaalde hoeveelheid was in het opzetstuk geplaatst is wordt dit met de zuiger C onder constante druk in de caviteit geperst. De koeling tijdens dit proces verliep volgens de curve van fig. 4. De verkregen waspatronen werden op vier plaatsen (fig. 5) van een loden merkplaatje (1 x 1 mm) voorzien, waarin een ronde opening was aangebracht met een middellijn van 0.18 mm.

De inbedring heeft vier met kunsthars gevulde vensters (fig. 6) die corresponderen met de localisatie van de loodmerken in het waspatroon. Hierdoor is het mogelijk röntgenopnamen van de loodmerken in het waspatroon te maken terwijl deze zich in de inbedring met inbedmassa bevinden.

Door de procentuele verandering in afstand tussen de vier merkpunten tijdens het hardworden van de inbedmassa te vergelijken, is na te gaan in welke mate het waspatroon vervormt. (fig. 5, zie de pijlen)

Nemen alle vier de afstanden met hetzelfde percentage toe dan betekent dit een vergroting van het waspatroon (expansie); nemen de lengtes in verschillende mate toe dan betekent dit een vervorming (distorsie).

Op verschillende momenten tijdens het hardwordingsproces werden opnamen gemaakt. (In totaal twaalf op één fotografische glasplaat, zie fig. 8).

Om de juiste temperatuur (20° of 37° C) te handhaven stond de ring in een thermostatisch geregeld waterbad. (fig. 7). Hardwordingsexpansie van de inbedmassa werd verkregen door de inbedring van een dunne laag vaseline van uniforme dikte (0.2 mm) te voorzien. Op de ring werd een rubber dop geplaatst om contact met het omgevende water te voorkomen.

Resultaten

1. De reproduceerbaarheid van de methode werd nagegaan door opnamen te maken van een loodplaat met twee openingen op ongeveer dezelfde afstand van elkaar als in het waspatroon. Hierbij spelen verschuivingen van de emulsie van de fotografische plaat, die op kunnen treden tijdens het ontwikkelproces, een belangrijke rol. Nagegaan werd in hoeverre deze fout verkleind kon worden.
2. Om zeker te zijn dat de gevonden distorsies door de inbedmassa waren veroorzaakt, werden controle opnamen gemaakt van waspatronen die zich in een inbedring zonder inbedmassa bevonden (eveneens in het waterbad 20° of 37° C).

   Het blijkt dat bij 20° een waspatroon van 2 mm dikte geen merkbare distorsie vertoont, terwijl een waspatroon van 1 mm dikte (zie fig. 11-12-13) dit wel doet. Bij 37° C treedt eerst een thermische expansie van de was op, deze gaat over in een distorsie van het waspatroon (fig. 14-15A-16A).

Om de thermische expansie te elimineren en beter vergelijkbare resultaten te verkrijgen werden de curves zodanig verschoven dat ze de O as sneden bij 12,5 min. (fig. 15A-15B, 16A-16B).

3. De invloed van de inbedmassa.

   De combinaties van factoren die werden bestudeerd zijn inTabel 3 weergegeven (met de nummers van de corresponderende figuren).

Uit de proeven genomen bij 20° C blijkt, dat de distorsie van het waspatroon toeneemt indien de expansie van de inbedmassa groter wordt (hardwordings-hygroscopische expansie). Ook is de distorsie groter indien het waspatroon dunner is (2 – 1 mm dikte).

Alleen de combinatie dik waspatroon (2 mm) met hardwordingsexpansie van de inbedmassa vertoonde geen meetbare distorsie.

Bij 37° C treedt, in tegenstelling tot de resultaten verkregen bij 20° C, behalve een distorsie een toename in lengte van al de gemeten dimensies op. (Het waspatroon vertoont de neiging de expansie van de inbedmassa meer in zijn geheel te volgen). De distorsies die optreden vangen in een vroeger stadium aan dan bij 20° C. Het verschil in reactie tussen de waspatronen van 1 mm en 2 mm dikte wordt geringer.

Discussie

De geregistreerde veranderingen kunnen eveneens ontstaan door geringe veranderingen in de geometrie van de opstelling. De invloed van een aantal variabelen in deze opstelling werd nagegaan.

Conclusie

Distorsies van het waspatroon onder invloed van de expansie van de inbedmassa treden steeds op. Als enige uitzondering werd geen distorsie gemeten wanneer een waspatroon van 2 mm dikte de invloed van de hardwordings-expansie van de inbedmassa onderging.

Het is daarom raadzaam er voor te zorgen dat de waspatronen niet te dun zijn en dat hygroscopische expansie van de inbedmassa wordt uitgesloten.

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