THE BEHAVIOR AND MEASUREMENT OF HYGROSCOPIC EXPANSION OF DENTAL CASTING INVESTMENT

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SINCE the discovery of the phenomenon of hygroscopic expansion of dental casting investments when subjected to an environment of water, there has been considerable work carried out to investigate its behavior. The ultimate goal is to develop a technic based on this property capable of compensating for the casting shrinkage of dental gold alloys. The result of these efforts has been the establishment of two technics which involve the introduction of water to the investment by a surrounding wet asbestos liner or by immersion of the entire inlay ring into a water bath. Results obtained with these technics have indicated that a successful casting is dependent on an almost overwhelming number of variables.

Previous investigators have used various methods of measuring hygroscopic expansion which afford different results in accordance with the restriction offered to the expansion, as well as other less significant factors. Degni,[1] Docking and Chong,[2] Landgren and Peyton,[3] and Delgado and Peyton[4] have summarized, commented on, and investigated these methods. The general conclusion is that hygroscopic expansion is affected by the method of measurement and test when initial readings are made as soon as possible after mix. When measured from the initial set time, the expansion values of the various methods are more closely in agreement with each other. It has been felt that these latter values are more indicative of the actual enlargement of the mold cavity, since they are recorded when the investment is more rigid and can hold its shape. Accordingly, the term ''effective'' expansion has been applied. However, for lack of further, more conclusive, information, it is difficult to accept a starting point of such arbitrary nature. In addition, the methods for measurement of hygroscopic expansion designed to determine its compensating abilities as well as its behavior as influenced by these variable factors have been based on linear changes as measured in one direction. These measurements, as well, are dependent on factors whose effects are manifest in a significant variability of test results.

As a result of these difficulties, a different approach to the problem was initiated. It was postulated that the amount of water taken up by the investment might be related to the subsequent expansion, and a procedure for adding a measured or controlled quantity of water was devised. Furthermore, since the previous methods of measurement have been based on changes occurring in only one direction, consideration was given to measuring the expansion in three directions simultaneously. It was felt that this measure would establish a more

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comprehensive value of hygroscopic expansion. The two established technics of introducing water to the investment, based on this three-dimension procedure of hygroscopic expansion measurement, were analyzed.

CONTROLLED WATER ADDITION

Originally, a measured quantity of water was added to the investment to establish a means of controlling or eliminating some of the many variables which influence hygroscopic expansion. It was reasoned that if the specific amount of water available to the investment determined the expansion, a controlled amount, added to the investment at less than the maximum capacity of the investment to take up water, would give rise to an exact reproducible expansion. This was found to be true.

It was considered desirable that all measurements be made on the investment held in an inlay ring so as to duplicate the conditions of the casting procedure. To control the amount of water available to the investment, it was necessary to dispense with a surrounding asbestos liner, since some of the added water would be absorbed by the asbestos. However, if a solid inlay ring were used, with no liner, the expansion would be restricted in the diametric or lateral direction. To resolve these difficulties, a four-section ring was designed, permitting lateral expansion with a minimum amount of resistance and without an asbestos liner. This ring consists of four sections, positioned by means of small locating pins (Fig. 1). Two light springs hold the assembly in place and offer insignificant resistance to extension.

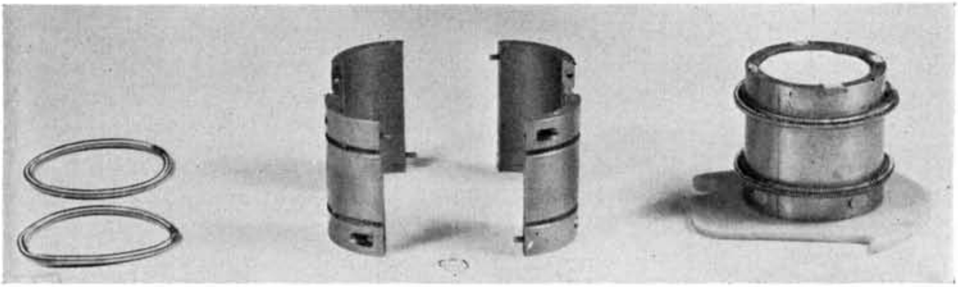

Fig. 1.

Method of Measurement.—The expansion was measured by determining the dimensional changes which occurred in the axial or vertical direction of the four-section inlay ring, as well as in the lateral or diametric directions. The axial expansion was measured by a cathetometer, which recorded the movement of a fine wire placed on top of the investment, similarly to the method described by Docking.[2] The lateral expansion was measured by photographing the before and after positions of four crossed marks painted on the four sections of the ring, diametrically opposed and positioned at ninety degrees with respect to each other. The negatives (microfilm used because of its fine grain size) were then measured using a comparator microscope. The fine wire can be seen in Fig. 1. Fig. 2 shows a print made from a sample negative used for measuring lateral expansion. In this manner, initial and final readings of axial and lateral expansion could be made simultaneously. These values were combined to yield "volumetric hygroscopic expansion." This consists of the addition of one axial measurement and two lateral measurements. The accuracy of measurement was ± 0.02 per cent in the axial direction and ± 0.06 per cent in the lateral direction.

Since it has not been definitely established when the mold cavity experiences enlargement, it was decided to measure the expansion from the time that the external dimensions of the investment began to increase. This was accomplished by recording fiducial readings at the time when the fine wire began to move upward. The results of preliminary tests indicated that this point corresponded to an opening of the four-section ring, so that a photograph of the lateral cross-marks was taken at the same time. Thus, the expansion values as reported in this paper can be summarized as representing changes in the outer dimensions of the investment mass when confined by an easily expansible inlay ring.

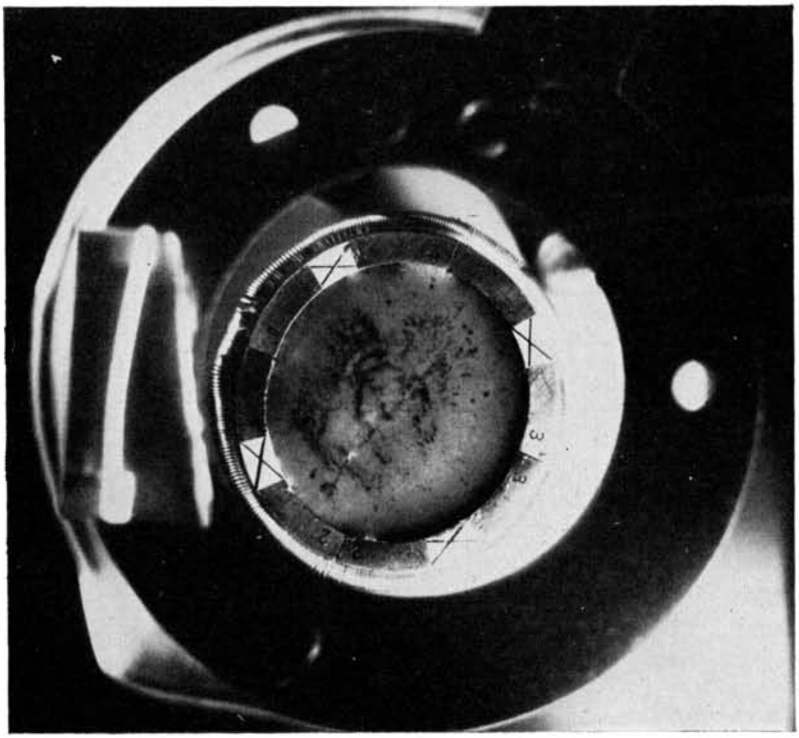

Fig. 2.

Method of Test.—The water:powder ratio of mix was controlled by carefully weighing the investment and adding it to the mixing bowl, into which had been placed an amount of water measured by use of a burette. The mix was mechanically spatulated at a constant rate after having been hand spatulated for ten seconds. The particular investment used for all tests in this study was

Ransom and Randolph Hygroscopic Investment. After the mixed investment was placed into the four-section ring, specific quantities of water were added using a hypodermic syringe having an accuracy of 0.05 c.c. This water was added to the top of the investment in the ring, three minutes after the start of the mix. The time of three minutes was chosen since an early water addition was found to be desirable for maximum expansion, and all manipulative procedures could be accomplished within this time interval. As soon as the fine wire placed on top of the investment began to rise, an initial reading of expansion was recorded, and at thirty minutes a final reading was recorded. This final point for measurement was chosen since little expansion occurs after thirty minutes.

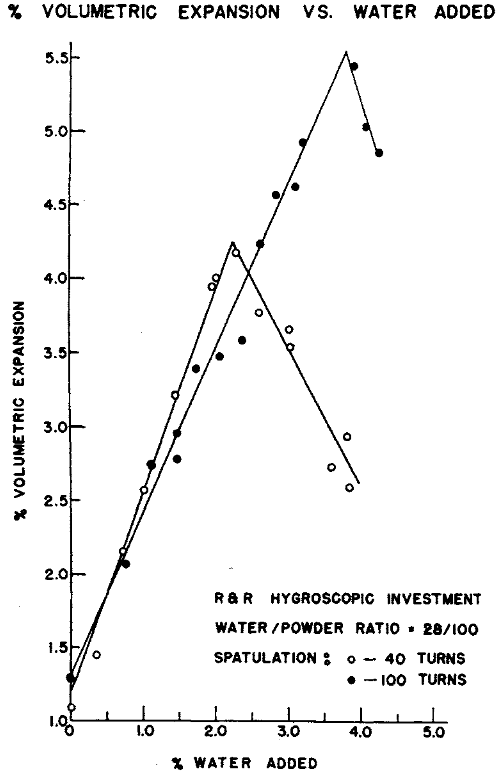

Fig. 3.

Results and Discussion.—In Figs. 3, 4, and 5 are shown the relationship between volumetric hygroscopic expansion at thirty minutes after mix and the specific quantity of water added to the investment for water:powder ratios of 28:100, 30:100, and 36:100. These ratios represent a thick mix, average mix, and thin mix, respectively, for the investment studied. The percentage of water added is based on the initial volume of the investment mass.

There appears to be a critical point to these curves beyond which further water addition results in a decrease in the expansion. This inhibiting situation may prove to be of importance in the analysis of the basic mechanism of hygroscopic expansion. Its physical significance is that for a given set of conditions, the capacity of the investment to pick up water and subsequently expand is limited. In using a technic based on controlled water addition, it would be wise to operate below this critical point where a direct proportionality exists between expansion and water added. For the 36:100 mix, the critical points were too difficult to establish due to loss of added water from the bottom of the inlay ring.

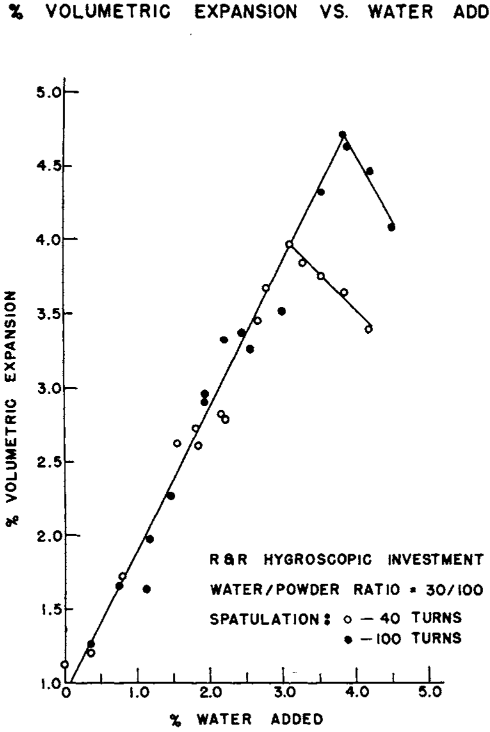

Fig. 4.

Changing the number of spatulations is shown to affect only the position of the critical point for the water:powder ratio of 30:100. An increase in the number of spatulations elevates the critical point or increases the capability of the investment to pick up water and expand. However, the curves for the two indicated spatulation conditions are synonymous below the lower critical point. This is also true for a water:powder ratio of 36:100, but deviates slightly when a water:powder ratio of 28:100 is used.

Although the number of spatulations was varied, the rate of spatulation was kept constant for the plotted results. Some preliminary work carried out on the effect of rate of spatulation indicated that an increase in rate would lower the critical point markedly. This may be due to the increase in rate of setting which decreases the time interval over which the hygroscopic expansion can effectively take place.

In Fig. 6 is shown the effect of varying the water :powder ratio for a spatulation condition of 100 turns. The 30 :100 ratio and the 36 :100 ratio are very similar, while the 28 :100 ratio has a slightly different slope and a different intercept on the expansion axes. Furthermore, these curves are drawn to the critical point, and the effect of decreasing the water :powder ratio is to advance the critical point, or increase the capacity of the investment mix to pick up water and expand. The significance of these curves is that for water :powder ratios of 30 :100 and greater, the same expansion may be expected if the water added is kept below the critical points. This was also observed, in part, by Landgren and Peyton[3] when using Ransom and Randolph Hygroscopic Investment.

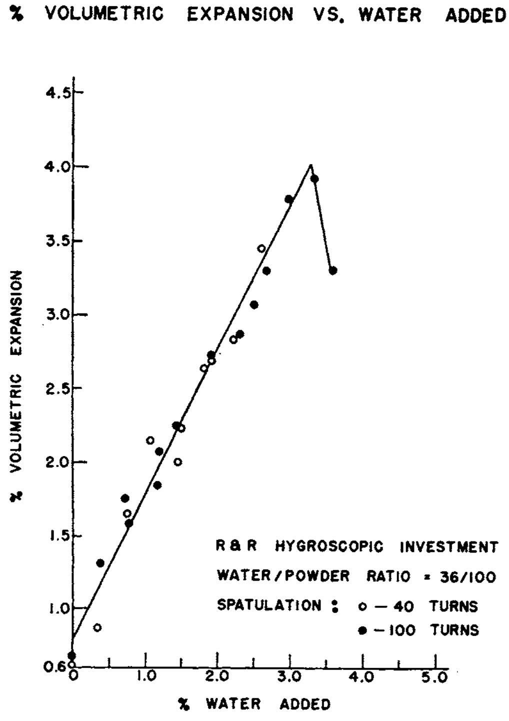

Fig. 5.

There has been some evidence to indicate that different batches of investment and investment which has been on hand over extended periods of time exhibit different values of hygroscopic expansion when the two established technics are used. To investigate the influence of these variables on the controlled water addition procedure, test runs were made using six different batch numbers and also on a batch of investment which had been stored at laboratory conditions after having been used two years previously. As long as the water added was kept below the critical points for these conditions, the data did not deviate from the established proportionality. The position of the critical points varied, however, and was extremely low for the aged investment.

ANALYSIS OF HYGROSCOPIC TECHNICS USING THE VOLUMETRIC MEASUREMENT PRINCIPLE

The criteria for a successful technic of gold inlay casting must include not only adequate compensation for casting shrinkage, but also reproducibility within desired practical limits of accuracy. However, some basis for judgment must be set forth since the necessary accuracy of an inlay fit has never been quantitatively defined. It appears that a difference of fit of 0.2 per cent linearly can be detected when the restoration is placed into the cavity preparation. For lack of any other criteria, this accuracy was chosen as the basis for analysis of the technics under discussion. It should be emphasized, however, that the recorded measurements represent changes of the outer dimensions of the investment mass rather than the actual changes in the mold cavity. Conclusions drawn as to the practical significance of these measurements should be moderated by the knowledge of this test condition.

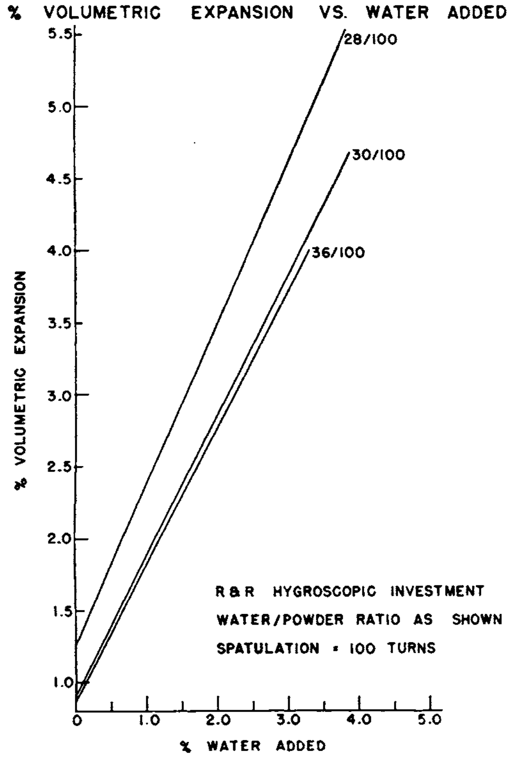

Fig. 6.

The methods of measurement and test were similar to those used for the controlled water addition technic. The lateral measurements, however, were achieved by observing the movements of four posts imbedded into the investment and having crossed marks painted on the ends. The reason for this modification was to allow for the taking of lateral measurements in a solid ring. In Fig. 7 is shown a print made from a sample negative which was taken in the same manner as previously described. The diametric distances between the posts were measured, as before, using a comparator microscope.

The technics of the saturated asbestos liner alone and the complete water immersion were investigated. In addition, the results of the controlled water addition technic were also included for comparative purposes.

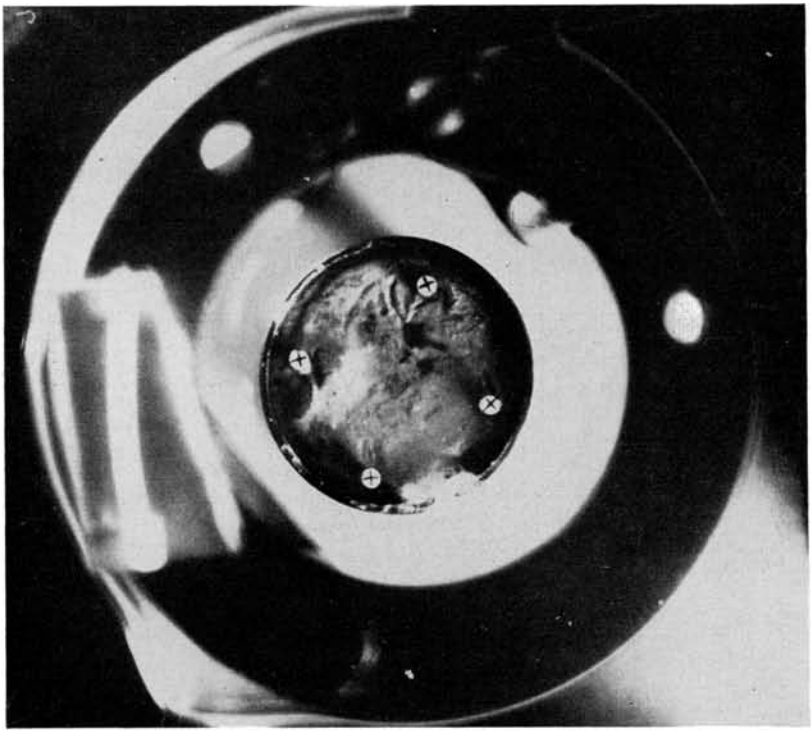

Fig. 7.

Results and Discussion.—In Tables I, II, and III are shown the results of nine test runs made at constant conditions for the three technics studied. These conditions included a W:P ratio of 30:100 and a mechanical spatulation condition of 100 turns. The variation between the runs for each individual technic is clearly shown, and to illustrate the discrepancies still further, average deviations and maximum deviations (without regard to sign) were calculated and are summarized in Table IV. These indices are indicative of the reproducibility of the three technics. Furthermore, the average and maximum differences (without regard to sign) between the two lateral expansion values and the axial and average lateral expansion values were calculated. These factors are indicative of the isometric nature of the expansion when using these technics. To evaluate the significance of this analysis, the practical accuracy of inlay fit is also included in Table IV. It is of utmost importance to state that no test runs were discarded.

It is apparent that the reproducibility and isometric nature of the wet asbestos liner and complete immersion technics leave much to be desired as far as accurate compensation is concerned, while the controlled water addition procedure appears to have some merit in this respect. As an example of reproducibility, attention is drawn to the maximum deviation of the lateral expansion values. For the wet asbestos liner, complete immersion, and controlled water addition, the maximum deviations are 0.63 per cent, 0.62 per cent, and 0.11 per cent, respectively, while the accuracy desired is 0.20 per cent. The other results in Table IV reaffirm these comparisons.

On the basis of the results of the controlled water addition tests, these results could have been anticipated. Examination of Fig. 5 indicates that a change of 0.2 per cent linear expansion or 0.6 per cent volumetric expansion (assumed practical limits) will require a change of water addition of about 0.5 per cent or, on the basis of an initial volume of 27 c.c. of investment, approximately 0.15 c.c. of water. This, in turn, is about three drops of water from an average medicine dropper. In order to yield the practical accuracy stated, the amount of water incorporated in the asbestos liner for the wet asbestos liner technic would have to be reproducible within three drops. There is a reasonable doubt as to whether this can be accomplished.

Since the complete immersion technic produces an environment of an unlimited supply of water, the points representing this technic would be past the critical point at the extreme end of the curve illustrated in Fig. 5. It has been shown that both the critical point and the curve beyond the critical point are affected by almost every conceivable variable. Consequently, this technic could not be expected to be successfully reproducible.

It should be restated that these measurements indicate changes in the external dimensions of the investment mass, rather than the actual changes in the mold cavity. Some work directed toward the accuracy of the casting procedure by measuring the difference between the wax pattern and the subsequent casting has established the practical significance of these results.

SUMMARY

The results of the controlled water addition experiment can be summarized as follows:

1. The hygroscopic expansion is directly related to the specific amount of water picked up by the investment.

2. Hygroscopically expanding investments have limiting capacities to pick up water and expand. This limit has been called the critical point and is affected by water :powder ratio, manipulative procedures, and the condition of the investment. Other variables which may affect the critical point, but which were not specifically investigated at this time, include setting time and the nature of the investment.

3. Although variations in spatulation, water :powder ratio, batch number, and age do not significantly affect the value of the expansion below the critical points established for these variables, a slight deviation exists for thick mixes.

TABLE I

HYGROSCOPIC EXPANSION (PER CENT) (WET ASBESTOS LINER—SOLID RING)

RUN NO.	AXIAL EXPANSION	DEVIATION FROM AVERAGE	LATERAL$_1$ EXPANSION	LATERAL$_2$ EXPANSION	LATERAL$_1$ −LATERAL$_2$	AVERAGE LATERAL	DEVIATION FROM AVERAGE	AXIAL −AVERAGE LATERAL	VOLUMETRIC EXPANSION	DEVIATION FROM AVERAGE
1	1.06	−0.12	2.06	1.72	0.34	1.89	0.39	−0.83	4.84	+0.67
2	1.83	+0.65	2.23	2.03	0.20	2.13	0.63	−0.30	6.10	+1.93
3	0.97	−0.21	1.11	1.07	0.04	1.09	0.41	−0.12	3.15	−1.02
4	1.16	−0.02	2.08	1.93	0.15	2.01	0.51	−0.85	5.18	+1.01
5	0.84	−0.34	1.75	0.73	1.02	1.24	0.26	−0.40	3.32	−0.85
6	1.01	−0.17	1.25	0.95	0.30	1.10	0.40	−0.09	3.21	−0.96
7	0.98	−0.20	1.40	0.72	0.68	1.06	0.44	−0.08	3.10	−1.07
8	1.36	+0.18	2.06	0.94	1.12	1.50	0.01	−0.14	4.37	+0.20
9	1.39	+0.21	1.49	1.38	0.11	1.43	0.07	−0.04	4.26	+0.09
Average	1.18	0.23	1.71	1.27	0.44	1.50	0.34	0.32	4.17	0.86

TABLE II

HYGROSCOPIC EXPANSION (PER CENT) (COMPLETE IMMERSION—SOLID RING)

RUN NO.	AXIAL EXPANSION	DEVIATION FROM AVERAGE	LATERAL$_1$ EXPANSION	LATERAL$_2$ EXPANSION	LATERAL$_1$ −LATERAL$_2$	AVERAGE LATERAL	DEVIATION FROM AVERAGE	AXIAL −AVERAGE LATERAL	VOLUMETRIC EXPANSION	DEVIATION FROM AVERAGE
1	2.08	+0.27	2.37	2.13	0.24	2.25	+0.62	−0.17	6.58	+1.50
2	1.64	−0.17	2.17	1.63	0.54	1.90	+0.27	−0.26	5.44	+0.36
3	1.19	−0.62	1.59	1.38	0.21	1.49	−0.14	−0.30	4.16	−0.92
4	2.30	+0.49	1.85	0.86	0.99	1.35	−0.28	−0.95	5.01	−0.07
5	1.71	−0.10	1.47	1.39	0.08	1.43	−0.20	+0.28	4.57	−0.51
6	1.70	−0.11	1.40	1.22	0.18	1.31	−0.32	+0.39	4.32	−0.76
7	1.67	−0.14	1.94	1.36	0.58	1.65	+0.02	+0.02	4.97	−0.11
8	1.90	+0.09	1.28	1.03	0.25	1.15	−0.48	+0.75	4.21	−0.87
9	2.14	+0.33	2.28	2.03	0.25	2.15	+0.52	−0.01	6.45	+1.37
Average	1.81	0.25	1.81	1.44	0.37	1.63	0.32	0.35	5.08	0.72

TABLE III

HYGROSCOPIC EXPANSION (PER CENT) (0.9 C.C. WATER ADDED—FOUR-SECTION RING)

RUN NO.	AXIAL EXPANSION	DEVIATION FROM AVERAGE	LATERAL$_1$ EXPANSION	LATERAL$_2$ EXPANSION	LATERAL$_1$ –LATERIAL$_2$	AVERAGE LATERAL	DEVIATION FROM AVERAGE	AXIAL –AVERAGE LATERAL	VOLUMETRIC EXPANSION	DEVIATION FROM AVERAGE
1	1.24	–0.13	1.55	1.53	0.02	1.54	–0.10	–0.30	4.32	–0.33
2	1.50	+0.13	1.80	1.55	0.25	1.67	+0.03	–0.17	4.85	+0.20
3	1.44	+0.07	1.57	1.54	0.03	1.55	–0.09	–0.11	4.55	–0.10
4	1.13	–0.24	1.65	1.43	0.22	1.54	–0.10	–0.41	4.21	–0.44
5	1.64	+0.27	1.75	1.59	0.16	1.67	+0.03	–0.03	4.98	+0.33
6	1.40	+0.03	1.81	1.70	0.11	1.75	+0.11	–0.35	4.91	+0.26
7	1.48	+0.11	1.74	1.71	0.03	1.73	+0.09	–0.25	4.94	+0.29
8	1.23	–0.15	1.57	1.57	0.00	1.57	–0.07	–0.34	4.37	–0.28
9	1.27	–0.10	1.74	1.72	0.02	1.73	+0.09	–0.46	4.73	+0.08
Average	1.37	0.14	1.69	1.59	0.09	1.64	0.08	0.27	4.65	0.25

TABLE IV

REPRODUCIBILITY AND ISOMETRIC NATURE OF HYGROSCOPIC EXPANSION

Reproducibility

	AXIAL EXPANSION		LATERAL EXPANSION		VOLUMETRIC EXPANSION	
	AVE. DEV.	MAX. DEV.	AVE. DEV.	MAX. DEV.	AVE. DEV.	MAX. DEV.
A	0.23	0.65	0.34	0.63	0.86	1.93
B	0.25	0.62	0.32	0.62	0.72	1.50
C	0.14	0.27	0.08	0.11	0.25	0.44
D	0.20	0.20	0.20	0.20	0.60	0.60

Isometric Nature of Expansion

	AXIAL – LATERAL$_{ave}$		LATERAL$_1$ – LATERAL$_2$	
	AVE. DIFF.	MAX. DIFF.	AVE. DIFF.	MAX. DIFF.
A	0.32	0.85	0.44	1.12
B	0.35	0.95	0.37	0.99
C	0.27	0.46	0.09	0.25
D	0.20	0.20	0.20	0.20

A—Wet asbestos liner—solid ring.
B—Complete immersion—solid ring.
C—Controlled water addition—split ring.
D—Practical accuracy desired of inlay fit.

The three technics of wet asbestos liner, complete immersion, and controlled water addition were investigated with respect to the reproducibility and isometric nature of their hygroscopic expansions. The results of this analysis indicate that accurate compensation by the established technics is an elusive entity and that a method of controlled water addition may serve as a basis for resolving this difficulty.

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