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# Final Expansion of Plaster

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*The onset, duration, rate, and magnitude of setting expansions of one gypsum product were compared under different conditions of restraint. Specimens were set normally or hygroscopically in a mercury bath or in tinfoil- or plastic-lined troughs. The final setting times were the same for all combinations. Both internal and external restraints altered the rates, and thus the magnitude, of expansion during all stages of setting. Conditions affecting the rate of restraint, in decreasing order, were tinfoil, plastic film, and mercury.*

It has been reported<sup>1-6</sup> that the external dimensional changes during the "normal" setting process of dental gypsum products comprise an initial contraction followed by an expansion. Although it is known that external restraints reduce the magnitude of expansion,<sup>5,7-9</sup> it is not clear whether this reduction takes place by masking<sup>10</sup> the initial contraction or occurs throughout the entire process. The aim of the present study, therefore, was to determine the onset, duration, and rate of expansion of one commercial plaster product under conditions of different minimal external restraints that do not mask the initial contraction.<sup>6</sup>

It has been shown that the normal amount of evaporation influences the magnitude of normal setting expansion,<sup>4</sup> so open and sealed specimens were studied.

## Materials and Methods

Two methods were used to measure the linear dimensional changes of the setting plaster specimens: a modified horizontal trough<sup>6</sup> and a rectangular mercury bath.<sup>5</sup> The trough was constructed so that the initial size of the specimen could be standardized (200 mm), and a fixed time (3.5 minutes) was allowed for mixing and manipulating the slurry before beginning the measure-

ments. Restraint on the setting materials was obtained by lining the trough with tinfoil or plastic film.\* For normal conditions, the exposed surface area was left open or was sealed with an extension of the liner. Three tests with each liner were made under both open and closed conditions. For hygroscopic conditions, the lid was closed, and two tests with each liner were made. For the mercury bath (24.0×6.5×3.5 cm), the length of the specimens and the time allocated for mixing and manipulating the slurry were identical to those for the horizontal trough. A scribed pin in an acrylic base was floated on the mercury surface, held at 200 mm ± 1 mm, from one end of the bath. A narrow ribbon of slurry, attached only to the far vertical wall, was spread along the mercury surface and around the scribed pin. Full details of the techniques used are given elsewhere.<sup>6</sup>

A uniform slurry for all tests was prepared from one batch of commercial dental plaster (250 gm of powder to 150 gm of water).† A standardized procedure for mixing was used.<sup>6</sup> Vicat needle setting times (initial time, 5.8 minutes ± 0.5 SD; final time, 13 minutes ± 1.0 SD) were determined on part of the slurry retained for that purpose. Room temperature and humidity were kept constant: The mean temperature was 22C (SD 0.8C), and the mean percentage of relative air humidity was 43% (SD 2.5%).

When the amount of expansion was plotted against the time, typical sigmoidal curves were obtained, except for hygroscopic expansion on mercury. The curves for that intersected and were unclear, so they were replotted with the final setting time as the starting point (Fig 1). However, by plotting

\* Teflon, E.I. du Pont and Co., Inc., Wilmington, Del.

† Gesher (alabaster, plaster of Paris), Israeli Gypsum Co., Haifa, Israel.

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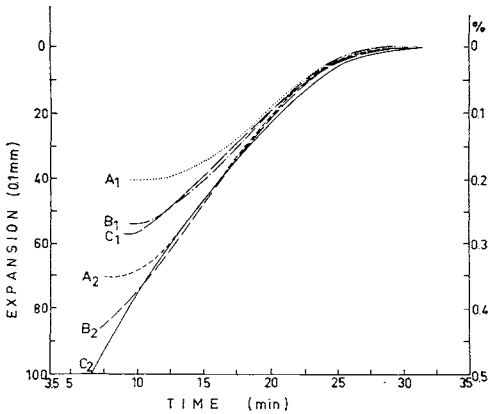


FIG 1.—Effect of restraint on the magnitude of expansion, in order of increasing expansion. Normal setting expansion: *A*<sub>1</sub>, tinfoil-lined trough; *B*<sub>1</sub>, plastic-lined trough; *C*<sub>1</sub>, mercury bath. Hygroscopic expansion: *A*<sub>2</sub>, tinfoil-lined trough; *B*<sub>2</sub>, plastic-lined trough; *C*<sub>2</sub>, mercury bath.

the rate of expansion, a better picture could be obtained to show the stage of setting at which the effect of restraint was noticeable and to show how the restraint influenced the final magnitude of recorded expansion.

Therefore, the average increase in expansion per 0.5 minute is represented as plotted against time (Fig 2).

**Results**

**HORIZONTAL TROUGH.—Normal setting.—**After the initial contraction,<sup>6</sup> which was preceded by a delay, these events took place: A linear expansion progressed at an increasing rate until it reached a relatively uniform plateau, whereupon the rate decreased until expansion stopped (Fig 2). A lag then occurred, the onset and duration of which were similar for all the tests. Subsequent to this lag, there was a small contraction (Table 1).

The increase in rate of expansion, the maximum rate of expansion, and its duration (plateau) varied with the different conditions of restraint. Despite the great difference in exposed surface area for the open and closed troughs, there was not a great difference in the magnitude of expansion (Table 1). However, after about 23 minutes from the start of mixing, the decreasing rates of expansion became similar. In these tests, the times at which expansion stopped ranged

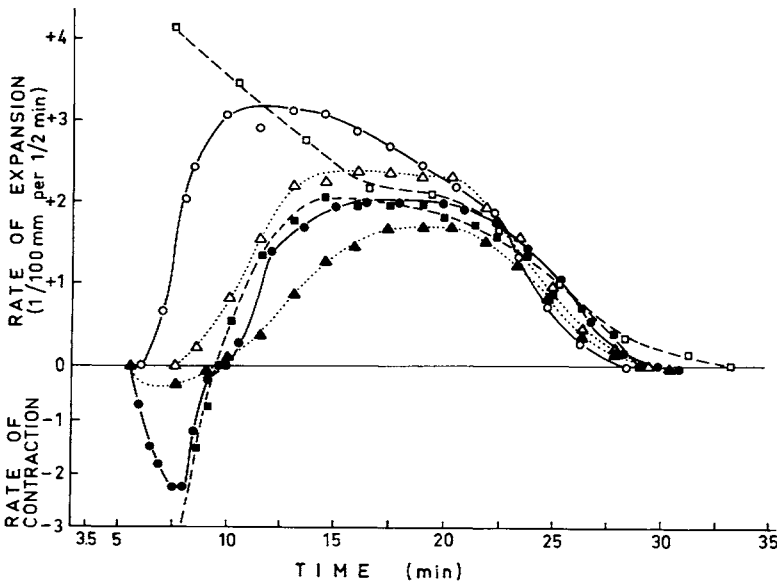


FIG 2.—Effect of restraint on rate of setting expansion of plaster. Mercury bath: *white squares*, hygroscopic expansion; *black squares*, normal expansion. Plastic-lined trough: *white circles*, hygroscopic expansion; *black circles*, normal expansion. Tinfoil-lined trough: *white triangles*, hygroscopic expansion; *black triangles*, normal expansion.

TABLE 1  
ONSET, DURATION, AND MAGNITUDE OF SETTING EXPANSION

Variable	No. Tests	Delay (Minutes) Before Onset of Contraction (Expansion)*	Duration (Minutes) of Initial Contraction	Duration (Minutes) of Expansion	Lag (Minutes) After Expansion	Magnitude (mm) of Expansion	Final Contraction (mm) at 1 Hour (Expansion)†
<i>Normal expansion</i>							
Tinfoil; open	5	2.5	3.5	18.0	12.5	0.407	-0.001
	7	2.5	5.0	19.0	3.5	0.397	-0.005
	12	3.0	4.5	20.0	4.5	0.410	-0.004
Tinfoil; closed	17	3.0	4.5	19.0	4.5	0.407	-0.015
	19	3.0	3.0	18.0	5.5	0.386	-0.013
	21	3.0	3.0	18.5	4.0	0.423	-0.017
Plastic film; open	3	2.5	4.0	20.5	5.5	0.560	-0.001
	9	3.0	3.5	19.5	4.0	0.540	-0.003
	14	3.0	4.5	20.0	9.5	0.562	-0.001
Plastic film; closed	16	3.0	3.5	19.0	3.0	0.561	-0.023
	18	3.5	2.5	18.5	3.0	0.552	-0.022
	20	3.5	2.5	18.5	3.5	0.565	-0.022
Mercury	0	none	6.0	20.0	11.0	0.559	+0.023
	1	none	6.0	18.5	11.0	0.561	+0.031
	11	none	6.0	23.0	4.5	0.616	+0.036
<i>Hygroscopic expansion</i>							
Tinfoil	24	5.5	none	22.0	5.0	0.575	-0.007
	27	4.5	none	21.5	8.5	0.703	-0.003
Plastic film	23	3.0	none	22.0	to 1 hr	0.970	none
	26	4.0	none	22.5	to 1 hr	0.848	none
Mercury	22	none	none	27.5	to 1 hr	1.004	none
	25	none	none	28.5	to 1 hr	0.943	none

\* All measurements were begun 3.5 minutes from start of mixing. Setting on mercury was not preceded by any delay.  
† Normal setting on mercury; subsequent to lag after expansion there was a small expansion.

from 27.5 minutes to 31.0 minutes (Table 1).

*Hygroscopic expansion.*—As previously reported,<sup>6</sup> there was no initial contraction but only a small delay of 6.5 to 9.0 minutes before expansion began under hygroscopic conditions. The sequence of events was then similar to the normal expansion. The increase in the rate of expansion and the maximum rate of expansion (plateau) was greater on plastic film than on tinfoil. The decrease in the rate of expansion started earlier on plastic film than on tinfoil. Expansion stopped at 28.5 to 31.0 minutes.

*MERCURY BATH.*—*Normal setting expansion.*—After the initial contraction,<sup>6</sup> which was not preceded by any delay, the magnitude and rate of expansion were similar to those in the plastic film-lined troughs. Expansion stopped at 28.5 to 30.0 minutes. A lag period lasted longer than in the lined trough. This lag preceded a small expansion.

*Dimensional changes during hygroscopic expansion.*—Readings were begun at 3.5 minutes from the start of mixing. There was no delay. At the first measurement, the plaster was already expanding rapidly. The

rate decreased steadily until no further expansion or contraction was recorded at 31 and 32 minutes.

### Discussion

In the present experiment, the completion of hygroscopic and normal expansion was indicated by a lag, during which no further expansion occurred. This lag was either prolonged or it preceded a small contraction or expansion (Table 1; Fig 1). Similar relatively small dimensional changes have been observed by others.<sup>1,2,4,11</sup>

Significantly, the time at which expansion stopped was similar for all the tests (27.5 to 32.0 minutes). Because a uniform slurry was used throughout,<sup>3</sup> it appears that this final setting time is independent of the different internal restraints<sup>3,4,12</sup> of hygroscopic or normal expansion and of the external restraints imposed by the method of measurement (bath or lined trough), as well as by the liners (mercury, plastic film, and tinfoil). Mahler et al<sup>13,14</sup> have found a similar stage in the setting process, and Ryge and Fairhurst,<sup>15</sup> using diffraction studies, have shown that the normal and hygroscopic hydration

processes are essentially the same. These findings suggest that setting expansion measurements can be used to establish a final setting time for dental gypsum products and that this final setting time need not be arbitrarily related to the setting process, as it is with the Vicat and Gillmore tests.

Combining the results of the mercury bath and lined trough tests (Fig 1, 2) made it possible to follow the setting expansion of one dental gypsum product, under different conditions of restraint, from the stage at which mixing and manipulation of the slurry were completed and until no further expansion was recorded. As would be expected,<sup>5,7-9</sup> the different combinations of internal and external restraints altered the final magnitude of expansion (Table 1). Tinfoil was the most restrictive external restraint. It reduced the magnitude and rate of hygroscopic expansion to values close to that obtained for normal expansion when the same material was setting against mercury or plastic film.

The differences in magnitude of expansion however, could be accounted for not only by the delay that occurred in the lined trough tests, which masked<sup>10</sup> some of the early longitudinal expansion, but in great differences in the rate of expansion during the whole setting process. It was thus concluded that longitudinal setting expansion is sensitive to restraint during all the stages of setting, hygroscopic expansion being more sensitive than normal expansion.<sup>16</sup>

Furthermore, it maybe inferred from the early high rates of expansion and contraction of the slurry setting on the mercury bath, that setting is well advanced by the time to start measurements. Thus, in addition to the external restraint of the liners, any delay in measuring (mixing and manipulating) as well as any delay caused by the measuring system will proportionately reduce the recorded magnitude of the final expansion.

A comparison of the mercury bath and lined trough tests (Fig 1, 2) showed that despite the early high rate of hygroscopic expansion recorded on mercury, its rate then decreased below that for the plastic and tinfoil-lined specimens. Furthermore, the decrease in the rate of expansion started earlier with plastic film than with tinfoil. The decrease in the rate of normal expansion also started earlier in the mercury bath than

in the plastic lined-trough, although the magnitudes of expansion recorded between the time of initial contraction and final expansion were similar. In the present tests, only longitudinal measurements were made.<sup>6,9,17</sup> The specimens all had the same initial length (200 mm), but the mercury bath and lined trough specimens differed in that in the former they were relatively flat and attached only at one end, and in the latter they were confined by the hemicylindrical shape of the trough. Although the present specimens had an apparently simple configuration, it appears that the influence of shape and size<sup>17</sup> on the rate of increase in linear expansion during setting was significant.

### Conclusions

From the present experiment on one plaster product, it can be concluded that internal or external restraints influenced the magnitude of expansion but not the time of final setting. It also was found that the influence of restraint was active throughout the duration of the setting process, but less so during the final stages. Thus, it would not be possible to predict the clinical behavior of this product on the basis of these measurements.

Further studies on other dental gypsum products are needed to verify these findings and to allow general conclusions to be drawn. The effect of size and shape of the specimen on setting expansion measurements should be studied by using the time of the initial contraction and the final setting time as reference points.

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