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# Setting Expansion of Plaster of Paris: The Initial Contraction

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Docking, Chong, and Donnison,[1] Jørgensen,[2] and Earnshaw,[3] using the mercury bath method (horizontal specimens), and Earnshaw,[3] using a modification of Fusayama's method (vertical specimens), have all shown that the "normal setting expansion"[4] of gypsum products is preceded by an initial contraction. A careful review of the literature produced only one study on the nature of this phenomenon.[4] The aim of the present study, therefore, was to investigate the early dimensional changes during the setting of gypsum products and the effect of any restraint imposed by the boundary conditions on this initial contraction.

## Materials and Methods

Two methods, a modified horizontal trough method (Fig. 1) and a mercury bath method, were used to measure the linear dimensional changes of the setting plaster specimens.

The horizontal glass* trough, closed at one end, had a piston joined to a dial gauge micrometer (springs removed) at the opposite end. The piston, sliding freely in the trough, responded to the dimensional changes (linear contraction and expansion) of the setting material. The inertia of the unloaded system was 7.5 Gm. in the scale range used. A clamping device (Fig. 1) screwed through the piston bearing. The clamp was locked to predetermine the initial trough length (200 ± 0.001 mm.). Three and a half minutes was allowed for mixing and manipulating the slurry into the trough (Table 1), after which the clamp was released. This procedure separated the time required for mixing and manipulating the slurry from that for setting expansion.

Restraint on the setting material was varied by lining the trough (Fig. 1) with tinfoil (0.03-mm. sheet) or plastic film (0.12-mm. sheet).* Uniform specimens were obtained by filling the trough to the margins. The calculated area of liner in contact with the specimens was 5,654 mm.$^2$ The exposed surface area was 3,500 mm.$^2$ and was either left open or closed with an extension of the liner (Fig. 1). Three tests were carried out for each condition with both liners (Table 2).

On the mercury bath, a scribed pin in an

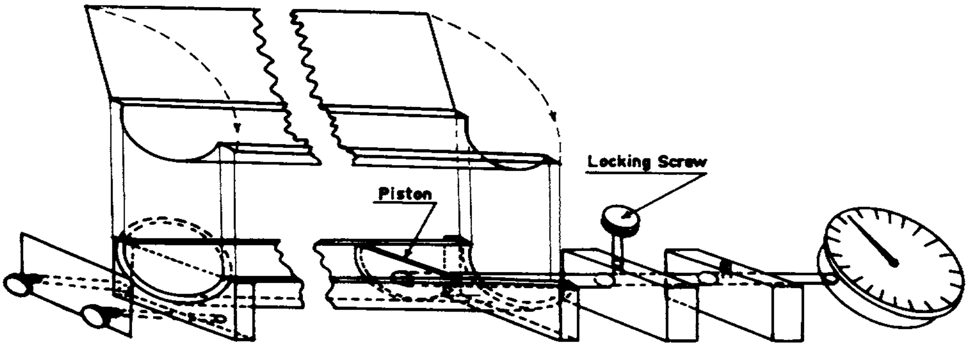

FIG. 1.—Exploded view, showing horizontal glass trough apparatus and liner (open or closed). (Cross-sectional region of piston and specimen: chord, 19 mm.; radius, 10 mm.)

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* Pyrex 22-mm. tube, Corning Glass Works, Corning, N.Y.

* Teflon, E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.

TABLE 1
PREPARATION OF SLURRY

| Manipulation | Vibration (Seconds) | Vacuum (Seconds) | Spatulation (Seconds) | Time Progression (Seconds‡) |
|---|---|---|---|---|
| Addition of powder to water and handmixing, all on vibrator* | 40 | none | ? | 0–40<br>(40) |
| Lid containing spatula and vacuum hose readied | none | none | none | 40–50<br>(10) |
| Vacuum and vibration | 30 | 30 | none | 50–80<br>(30) |
| Readied under drive spindle† | none | 10 | none | 80–90<br>(10) |
| Spatulation and vacuum | none | 15 | 15 | 90–105<br>(15) |
| Loading trough or bath | .... | .... | .... | 105–210<br>(105) |
| Totals | 70 | 55 | 15 | 210 |

*Vac-U-Mixer, 350-Gm. capacity bowl and matching lid with built-in mechanical spatula and vacuum connection, Whip-Mix Corp., Louisville, Ky.
†Low-speed drive spindle at 425 rpm=106 revolutions of the double-bladed spatula.
‡Programmed tape recorder.

acrylic base was set at 200 mm. ± 1 mm. by a clamping device. The same time (3 minutes, 30 seconds) was allowed for mixing and manipulating the slurry, after which the pin was released. Three tests were carried out.

The effect of hygroscopic conditions on the initial contraction was studied with both methods, by adding water before releasing the clamping devices. Two tests were carried out with each liner with the lid in the closed position, and two more tests were done with the mercury bath.

A uniform slurry (composition and ma-

TABLE 2
NORMAL SETTING IN THE LINED TROUGH TESTS: PHASES OF INITIAL CONTRACTION

| No. | First Lag Period (Minutes)* | Maximum Contraction |  | Duration of Plateau (Minutes) |
|---|---|---|---|---|
|  |  | mm. | Plateau Period (Minutes) |  |
| *Tinfoil (Open)* |  |  |  |  |
| 5 | 3.5 to 6.0 | −0.011 | 8.0 to 9.5 | 1.5 |
| 7 | 3.5 to 6.0 | −0.016 | 9.0 to 11.0 | 2.0 |
| 12 | 3.5 to 6.5 | −0.011 | 9.0 to 11.0 | 2.0 |
| *Plastic Film (Open)* |  |  |  |  |
| 3 | 3.5 to 6.0 | −0.073 | 9.0 to 10.0 | 1.0 |
| 9 | 3.5 to 6.5 | −0.058 | 9.5 to 10.0 | 0.5 |
| 14 | 3.5 to 6.5 | −0.073 | 10.0 to 11.0 | 1.0 |
| *Tinfoil (Closed)* |  |  |  |  |
| 17 | 3.5 to 6.5 | −0.004 | 9.0 to 11.0 | 2.0 |
| 19 | 3.5 to 6.5 | −0.007 | 8.5 to 9.0 | 1.0 |
| 21 | 3.5 to 6.5 | −0.006 | 8.0 to 9.5 | 1.5 |
| *Plastic Film (Closed)* |  |  |  |  |
| 16 | 3.5 to 6.5 | −0.031 | 9.5 to 10.0 | 0.5 |
| 18 | 3.5 to 7.0 | −0.018 | 9.0 to 9.5 | 0.5 |
| 20 | 3.5 to 7.0 | −0.035 | 9.0 to 9.5 | 0.5 |

*All times are given from start of mix, time zero.

nipulation) was prepared for all tests, using one batch of dental plaster (P/W of 250 Gm. powder and 150 Gm. water), and a standardized procedure for mixing was employed (Table 1). Vicat needle setting times (initial and final) and time of loss of gloss were determined on part of the slurry retained for that purpose. Room temperature and humidity were kept constant: The mean temperature was 22°C. (SD 0.8°C.), and the mean percentage relative air humidity was 43 percent (SD 2.5 percent).

The sequence of testing was varied so that no two similar conditions were repeated consecutively. Normal setting expansion tests were completed before the hygroscopic tests.

## Results

Initial and final vicat needle setting times (means, 5.8 minutes ± 0.5 SD and 12.0 minutes ± 1.0 SD, respectively), as well as the times for the loss of gloss, (mean, 8.0 minutes ± 0.25 SD) were similar during all the tests.

HORIZONTAL TROUGH.—*Dimensional changes during normal setting.*—An analysis of the results in this series indicated that there was a lag, during which no changes took place, an initial contraction that maintained its maximum for a certain period (plateau) and, finally, an expansion. The duration of the initial lag was similar in all tests. The rate and magnitude of the initial contraction varied with the different conditions of restraint, as did the duration of the plateau (Table 2; Fig. 2). The plateau in all lined trough tests centered around 9.5 minutes from the start of mixing.

*Dimensional changes during hygroscopic setting.*—Under hygroscopic conditions, a lag similar to that during normal setting was followed immediately by expansion. Specimens in plastic film-lined troughs had a shorter lag and a faster rate of expansion than specimens in tinfoil-lined troughs.

MERCURY BATH.—*Dimensional changes during normal setting.*—On release of the clamp, the specimens were found to be already contracting. This contraction reached a peak 9.5 minutes after mixing, from which time expansion began. There was no plateau effect.

*Dimensional changes during hygroscopic setting.*—The plaster was already expanding at the first measurement and continued to do so.

## Discussion

The potential for expansion of gypsum products seems to depend on composition and manipulative factors,[4] modified by temperature[5] and humidity.[6] The first two factors were rigidly controlled in this experiment (Table 1). Temperature and humidity were also kept constant. The constant vicat needle setting times prove, furthermore, that no aging of the plaster took place. The mixes made at different times are comparable, therefore, and should have the same potential for expansion.

HYGROSCOPIC EXPANSION.—Mercury, plastic film, and tinfoil all exerted restraint on the hygroscopically expanding plaster. With mercury, however, the amount of restraint seems to have been so minimal that no indication of this could be found in the readings (straight lines and immediate onset, Fig. 2). These findings disprove the general graphic demonstration made by Mahler and Ady[4] that hygroscopic expansion necessarily must have a lag period before its onset. Rather, it appears that the lag is due to the experimental method of measuring this hygroscopic expansion, as evidenced by the mercury versus the lined trough tests.

Plastic film seems to restrain the plaster more, as indicated by a lag in the onset of expansion and a shallower curve; whereas, tinfoil was the most restrictive, as evidenced by the longest lag and the shallowest curve. These findings are in agreement with those of Skinner and Degni,[7] who observed that hygroscopic expansion is sensitive to confinement by either pressure or friction. Shell[8] has also shown that longitudinal restrictive forces delay the onset of hygroscopic expansion and reduce its rate. The external restraint of liners appears to play a significant role in reducing linear hygroscopic expansion in horizontal specimens during the early stages of setting.

NORMAL SETTING EXPANSION.—The findings of this experiment proved the existence of an initial external contraction that so far has received only cursory treatment in the literature.[1–3,9,10] Furthermore, it seems that the onset and demonstration of this initial contraction is dependent to a large extent on the methods used for measuring setting expansion.[9,11,12] Thus, on the mercury bath, the initial contraction took place immedi-

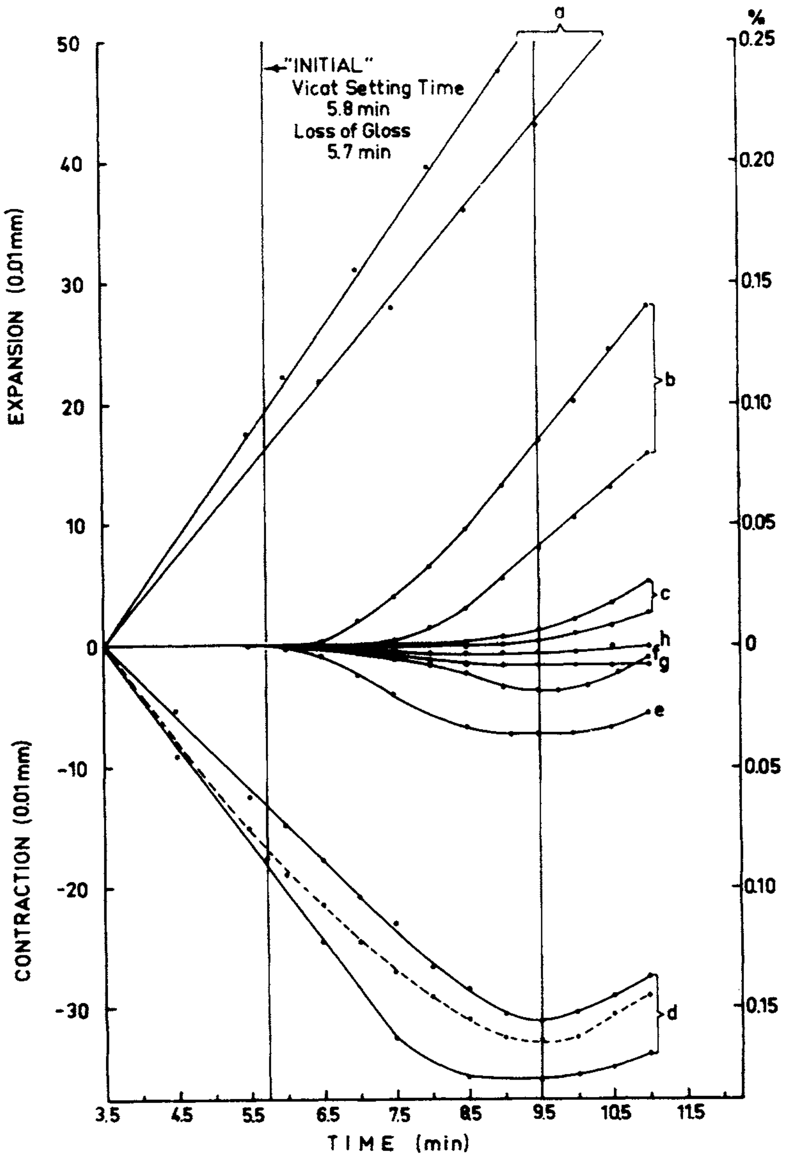

FIG. 2.—Effect of restraint on setting expansion of plaster of paris. Hygroscopic expansion: a = mercury bath; b = plastic film-lined trough; c = tinfoil-lined trough. Normal setting expansion: d = mercury bath (open); e = plastic film-lined trough (open); f = plastic film-lined trough (closed), g = tinfoil-lined trough (open); h = tinfoil-lined trough (closed).

ately, whereas in the lined trough, there was a lag before the onset of contraction. The extent of the lag did not vary, however, irrespective of the methods of external restraint used. This is probably because the growing crystals need a certain time to interact,[2,4,9,13,14] draw air into the mass, and attain sufficient strength before a linear contraction begins. This onset of contraction corresponded to the externally observed loss of gloss. This is in agreement with the work of Earnshaw and Marks,[14] who have shown loss of gloss to be an indication of the time at which the setting slurry loses its fluidity. Interestingly, the initial vicat needle setting time also occurred at that critical time.

The magnitude of initial contraction as well as the duration of the plateau varied with the method of restriction used, in the same order as for hygroscopic expansion. The relative influence of the means of external restraint was similar to that described for hygroscopic conditions. Mercury offered the least restraint, followed by plastic film and tinfoil, respectively. The time at which the maximum contraction was reached was the same, however, irrespective of the method or liner used. Thus, the time at which the initial contraction of plaster reaches its maximum can be used as an initial reference point for measuring normal setting expansion, irrespective of the method used. This statement is corroborated by similar findings made by Earnshaw[3] who used a mercury bath, a vertical cylinder, and a horizontal trough. This is the point at which the internal forces of the outwardly growing or expanding crystals, the decreasing fluid phase, the porosity, and concomitant capillary or surface tension forces or both, are all in equilibrium.[2,4,13] Since normal expansion is invariably preceded by an initial contraction, one wonders if this term is really appropriate.

## Summary

The early dimensional changes on setting (ambient temperature, 22°C., and relative humidity, 43 percent) of one gypsum product was studied under different conditions of restraint. Restraint was varied by allowing the material to set against tinfoil, plastic film, and mercury. Further variation was produced by altering the conditions of the normally free or exposed surface. This surface was (1) exposed to the air (open setting), (2) sealed with tinfoil or plastic film (closed setting), or (3) water was added (hygroscopic setting).

Specimens of uniform composition and manipulation, of the same length (200 mm.), were prepared in a horizontal hemicylindrical glass trough (lined with tinfoil or plastic film) and on a mercury bath.

Contraction and expansion (normal setting expansion, open and closed) or only expansion (hygroscopic expansion) was recorded soon after mixing; both methods (a piston sliding within the trough or a scribed marker in the plaster moving on the mercury) responded to the linear dimensional changes of the setting slurry.

External restraint on the setting material altered the magnitude of the initial contraction linearly but did not alter the time at which the contraction reached a maximum (or setting expansion began), provided that ambient temperature and humidity did not vary. This time of maximum contraction, with small variations, appeared independent of the method of measurement. The time of the externally observed loss of gloss, initial vicat needle setting time, and the onset of the initial contraction in the lined trough occurred at the same time.

During a period comparable to the initial contraction, only a linear expansion was observed when additional water was available to the setting mass against mercury, plastic film, and tinfoil, but the onset and rate of the early linear expansion varied. Mercury offered the least restraint, followed by plastic film and tinfoil, respectively.

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