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# More Rapid Edgewise Crush Test Methods

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**ABSTRACT:** The use of paraffin wax to reinforce the loading edges of corrugated fiberboard edge-crush specimens requires that the specimens be reconditioned after waxing. The traditional practice employing a 24-h reconditioning period is a conservative approach based on the moisture response rate of corrugated containers. An interlaboratory study was conducted to determine the effect of reconditioning time on edgewise compressive strength of waxed specimen prepared by standard test methods. Results showed that reconditioning time can be reduced from 24 h to 2 h with no significant change in test values. The results apply to flexible-beam and rigid-platen loading machines, but at conventional loading speeds. the flexible-beam machine yielded higher overall strength values. Other tests were conducted to evaluate the performance of an edge-clamping fixture for use with unwaxed specimens. When tested with heavy basis weight materials, the fixture did not yield equivalent results compared to those obtained with lighter grade waxed specimens.

**KEYWORDS:** paper testing, corrugated containers, packaging, compression, laboratory methods, procedures, specimen preparation, strength

Research has shown that the edgewise compressive strength of corrugated fiberboard in combination with the flexural stiffness relates to the top-to-bottom compressive strength of corrugated fiberboard boxes [*1*]. The edgewise compression test (ECT), performed on a rectangular short column of combined corrugated fiberboard, can be used to determine strength.

One method for preparing short column specimens and determining strength is specified in the former ASTM Test Method for Compressive Strength of Corrugated Fiberboard (Short Column Test, D 2808). A technically identical method, except that specimen size is a function of flute construction, is specified in the TAPPI official test method on Edgewise Compressive Strength of Corrugated Fiberboard (Short Column Test, T 811) [*2*]. A common feature of these two methods is that the edges of the short column specimen in contact with the compression machine platens are reinforced with paraffin wax to centrally direct the location of failure. Both methods specify a conditioned test environment of 23°C (73°F) and 50% relative humidity (RH) in which the moisture content of specimens is raised to an equilibrium level from a dryer, preconditioned environment.

The sequence of steps specified for preparing the test material is to cut the specimens, dip the ends in molten paraffin, precondition the specimens, and condition them. The conservative assumption is that moisture loss resulting from the hot paraffin affects the strength of an already conditioned specimen. Users have reported that in practice they normally cut, precondition, and condition the specimens, then wax and recondition them for 24 h.

Other ECT methods have been proposed around the world [*3*], with each method offering unique advantages with regard to specimen shape, preparation, and edge reinforcement. In one alternative method recently advocated [*4*], the rectangular shape is retained but an edge-clamping test fixture, marketed by the Sumitomo Corp.[5] of Japan, is used instead of wax reinforcement. The test fixture grips the ends of the short column specimen in a pair of spring-loaded clamps; the fixture plus the specimen are loaded as an integrated assembly.

One advantage of the Sumitomo fixture is that once a corrugated fiberboard sheet has been conditioned to an equilibrium moisture content, specimens can be cut from the sheet and immediately tested, provided all operations remain within the conditioned environment. The Sumitomo fixture yielded results in agreement with TAPPI Method T 811 when used in tests on single-wall and double-wall corrugated fiberboard specimens, with bursting strength ranging from 22 to 51 kPa (nominal 150 to 350 lb/in.$^2$) and cut with a dual-blade Billerud cutter (Lorentzen and Wettre, Inc., Fairfield, NJ) [*4*].[6]

The compression machine specified by Methods D 2808 and T 811 has a flexible lower platen that acts like a spring, with a known spring rate, and yields force. When the upper and lower platens are in contact and moving at 38.1 mm/min (1.5 in./min), the rate of force increase is 110 N/s (25 lbf/s). When a specimen is inserted, the speed of the lower platen becomes a function of specimen stiffness. Method T 811 additionally specifies an alternative rigid-platen machine augmented with a force trans-

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[5] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

[6] Bursting strength values in this report are the nominal material grades in English units according to the motor freight and rail classification system.

ducer. Data reported in [4] showed that the flexible-beam machine yielded strength valves about 2.5% higher than those yielded by the rigid-platen machine.

## Objective and Scope

It was proposed to ASTM Committee D-10 on Packaging that the Method D 2808 Task Group address current issues concerning more rapid ECT procedures. The Task Group recognized that the specified conditioning requirement of Method D 2808 came about as a conservative approach as a result of insufficient knowledge about how wax dipping affects specimen moisture content and short column strength. The Task Group further recognized that the merits of using the Sumitomo fixture could not be fully assessed without data on heavy grades of double-wall corrugated fiberboard. The fixture cannot accommodate triple-wall fiberboard. The Task Group therefore decided that a pilot interlaboratory study was needed.

The primary objectives of the study were twofold: (a) to measure the effects of reconditioning time after waxing on edgewise compressive strength of wax-dipped specimens. using various grades of corrugated fiberboard and conditioned short column specimens. and (b) to compare the strength of wax-dipped short column specimens cut and tested in accordance with the ASTM D 2808 Method to the strength of unwaxed specimens cut by the same method but held in the Sumitorno test fixture.

The Task Force further agreed that the study should address the increasing use of rigid-platen loading machines. A secondary objective of the study was therefore to compare the performance of the flexible-beam loading machine with that of the rigid-platen machine.

The minimum preconditioning and conditioning times determined for corrugated fiberboard containers to reach an equilibrium moisture content have also come to be accepted as the requirements for short column specimens. An additional interest of the Forest Products Laboratory (FPL) was to determine if these requirements are too conservative and if short column conditioning can be accelerated. Therefore, the FPL conducted an exploratory test to determine how rapidly fiberboard short column specimens absorb moisture.

Four interlaboratory study participants representing five participating laboratories contributed to the study. The breakdown of laboratory by type of loading machine and machine speed is shown in Table 1.

## Test Material and Procedure

The test plan was divided into two elements. test elements A and B, according to the two primary study objectives. Two laboratories supplied corrugated fiberboard in eight bursting strength and flute combinations (Table 2).

**TABLE 2** — ***Nominal bursting strength and flute type of test fiberboards.***

| Fiberboard Type | Bursting Strength. kPa (lb/in.$^2$) | Flute Type |
|---|---|---|
| Single-wall | 22 (150) | C |
| | 29 (200) | C |
| | 40 (275) | C |
| Double-wall | 40 (275) | CB |
| | 73 (500) | CB |
| | 87 (600) | CB |
| Triple-wall | 160 (1 100) | AAA |
| | 189 (1300) | AAA |

One of the five laboratories cut the single-wall and triple-wall specimens for both test elements using a no-set circular saw blade in accordance with Method D 2808. Another laboratory cut the double-wall specimens for both test elements using a band saw deemed to be equivalent to the circular saw. For test element A, specimens were cut 31.8 mm (1.25 in.) high by 50.8 mm (2 in.) wide. with height in the axis direction of the flutes. The Sumitomo specimens for test element B were cut 50.8 by 50.8 mm (2 by 2 in.).

Each of the five laboratories received an equivalent batch of the cut test specimens to condition. wax. and test in accordance with a specified test plan. For test element A. specimens of all eight materials were first preconditioned in a dry environment below 35% RH, followed by conditioning at 23°C (73°F) and 50% RH in accordance with ASTM D 685. Method for Conditioning Paper and Paper Products for Testing. The loading edges of the conditioned specimens were then dipped in molten paraffin. Once treated with wax. the specimens were retained at 23°C (73°F) and 50% RH until tested for compressive strength. The time between waxing and testing was 1, 2, 3, 5, or 24 h.

For test element B, specimens of four materials (275 C, 275 CB, 500 CB, and 600 CB, Table 2) were preconditioned and conditioned as in test element A. The compressive strength of each specimen was then measured using the Sumitomo test fixture to support the specimen in the loading machine.

Laboratories 1, 4, and 5 tested ten replicates of each material in rapid succession. Laboratories 2 and 3 tested one replicate of each material in succession such that all replicates were still tested in accordance with the time duration test plan. but over multiple testing periods.

## Interlaboratory Results

Five interlaboratory participants are fewer than the minimum of six required for a valid ASTM reproducibility analysis. Never-

**TABLE 1** — ***Test conditions at study laboratories.***

| | | Machine Speed | | | |
|---|---|---|---|---|---|
| Laboratory | Machine Type | N/s | lbf/s | mm/min | in./min |
| 1 | Flexible-beam | 110 | (25) | | |
| 2 | Flexible-beam | 110 | (25) | | |
| 3 | Rigid-platen | | | 0.5 | (0.02) |
| 4 | Rigid-platen | | | 10 | (0.39) |
| 5 | Rigid-platen | | | 12.5 | (0.49) |

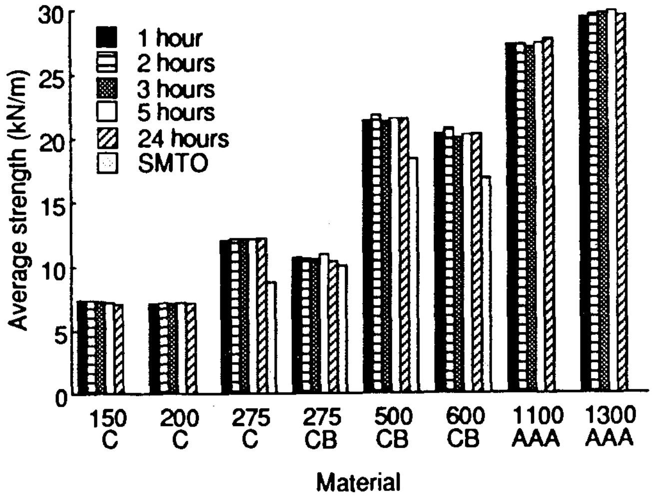

**FIG. 1** — *Average edgewise compressive strength of eight materials after various postwaxing reconditioning times (test element A) and of four materials in Sumitomo (SMTO) fixture (test element B). For materials, number is bursting strength (lb/in.$^2$) and letter designates flute type. (Note: 1 lb/in.$^2$ = 6.89 kPa.)*

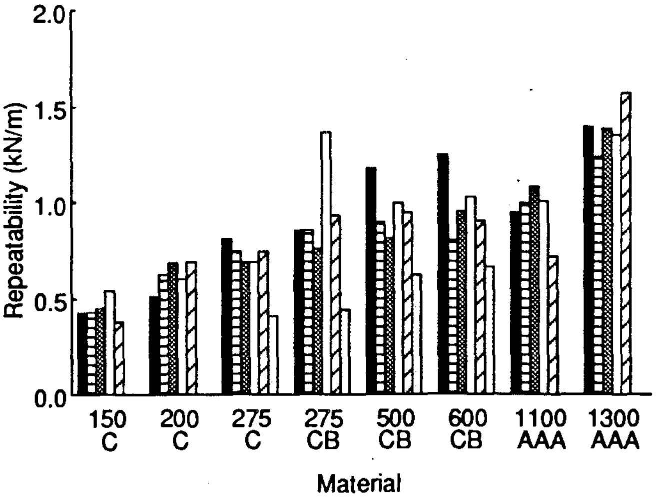

**FIG. 2** — *Repeatability standard deviation (Sr) for eight materials after various postwaxing reconditioning times and for four materials in Sumitomo fixture.*

theless, the data[7] were subjected to a precision analysis following the procedures in ASTM E 691, Practice for Conducting an Interlaboratory Test Program to Determine the Precision of Test Methods. The precision analysis was applied to uncorrected data. Then, the data were corrected for loading rate to compare loading machines. A summary of the statistical analysis results is included with the test data. Among the results are the repeatability standard deviation (*Sr*) and the reproducibility standard deviation (*SR*) for evaluating within-laboratory and between-laboratory precision, respectively.

The results of the laboratory tests are summarized in Figs. 1 through 5. No significant strength differences were apparent among the test element A specimens as a result of difference in reconditioning time after waxing. Figure 1 compares average overall

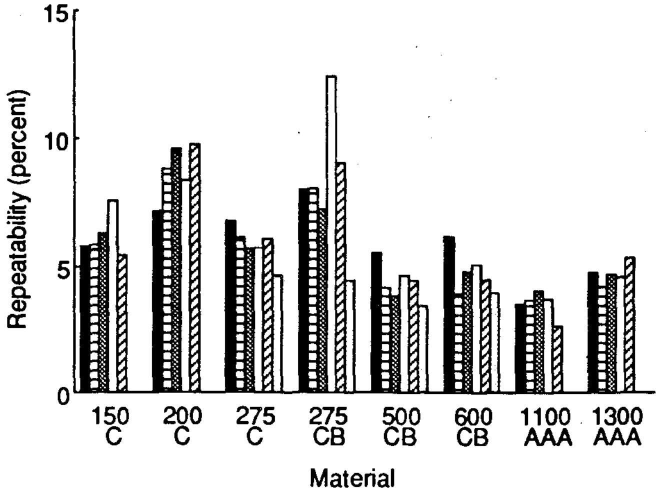

**FIG. 3** — *Repeatability coefficient of variation for eight materials after various postwaxing reconditioning times and for four materials in Sumitomo fixture.*

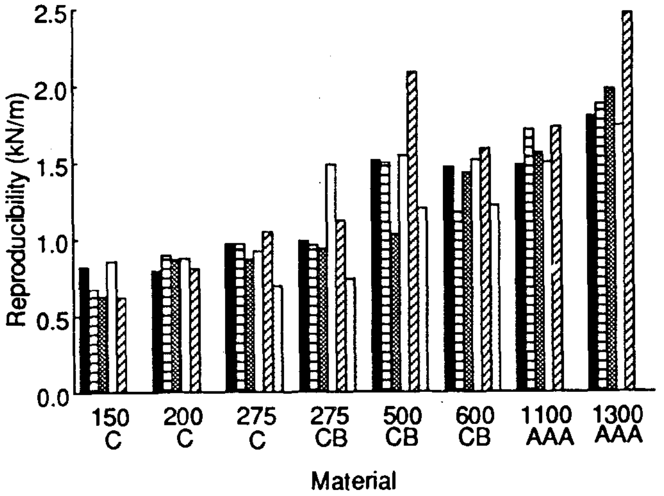

**FIG. 4** — *Reproductibility standard deviation (SR) for eight materials after postwaxing reconditioning times and for four materials in Sumitomo fixture.*

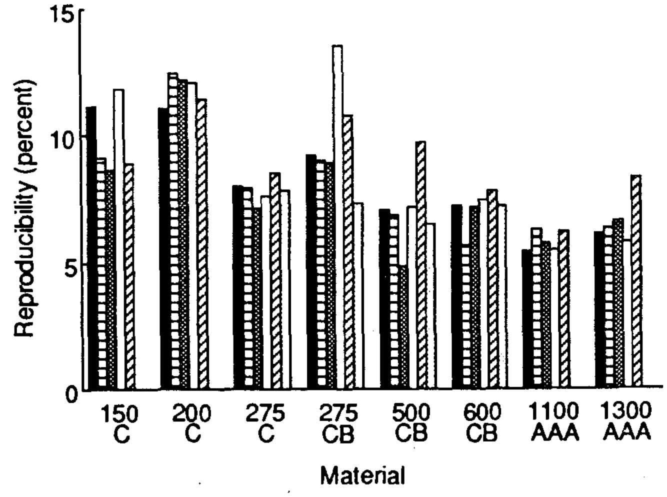

**FIG. 5** — *Reproductibility coefficient of variation for eight materials after various postwaxing reconditioning times and for four materials in Sumitomo fixture.*

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[7] The interlaboratory test data are obtainable from American Society for Testing and Materials. Philadelphia.

strengths of test element A and B materials. The effect of reconditioning on average strength of materials by laboratory is shown for the 2-h and 24-h postwaxing times in Fig. 6. The results for the two reconditioning times are statistically the same.

Figure 7 compares strength of specimens held in the Sumitomo fixture to strength of waxed specimens reconditioned for 24 h. The low strength correlation results from the fact that the ordering of materials by strength as determined by the Sumitomo fixture (that is, 275 C, 275 CB. 600 CB, 500 CB) is not consistent with the order determined by the test element A methods (275 CB, 275 C, 600 CB, 500 CB) (Fig. 1). The Sumitomo fixture yielded less variable within-laboratory results, as determined by *Sr* on an absolute scale (Fig. 2). However, the difference in variability is not as obvious when variation is evaluated between laboratories by *SR* on a relative scale (Fig. 5).

The effect of flexible-beam loading compared to rigid-platen loading on strength is shown in Fig. 8. The figure shows an overall average of all data obtained 1 h through 24 h after waxing. The strength levels shown for the flexible-beam data were determined by averaging data from Laboratories 1 and 2. The strength levels for the rigid-platen data were determined by averaging the data from Laboratories 3, 4, and 5 after first correcting for loading machine speed.

The results of Moody and Koning [*5*] can be used to predict the strength $P_1$ determined at loading rate R, when the strength $P_2$ determined at rate $R^2$ is known. The average effect of loading rate on the strength of A-, B-, and C-flute specimens is shown in Fig. 4 of the report by Moody and Koning. For each tenfold increase in loading rate from a reference rate of $R_0$ = 25.4 mm/min (1 in./min), strength was found to increase approximately 7.5%. An equivalent statement in equation form that can be applied to other arbitrary rates is given by

$$\frac{P_1}{P_2} = 1 + \frac{0.075 \log R_1/R_2}{1 + 0.075 \log R_2/R_0}$$

Thus, the Laboratory 3 strength values determined at 0.5 mm/min (0.02 in./min) were multiplied by 1.11 to predict the strength values determined at 10 mm/min (0.4 in./min). Likewise, Laboratory 5 strength values determined at 12.5 mm/min (0.5 in./mm) were multiplied by 0.99.

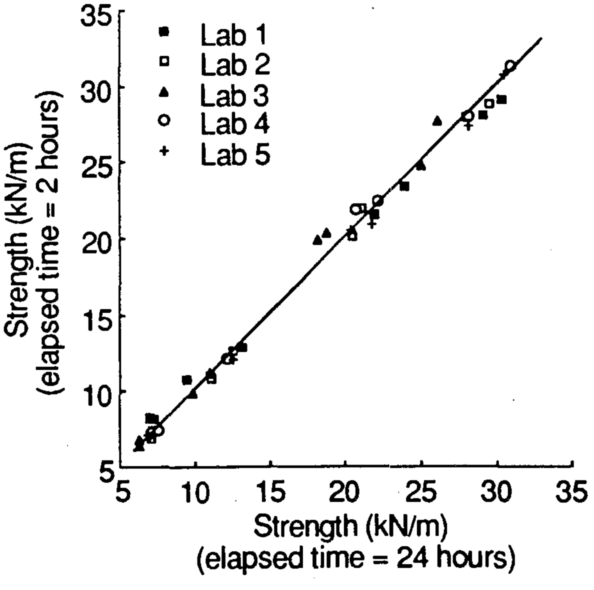

**FIG. 6** — *Edgewise compressive strength of waxed reinforced specimens 2 and 24 h after waxing. Points represents data. Line is plot of equality;* $r^2$ *= 0.9937.*

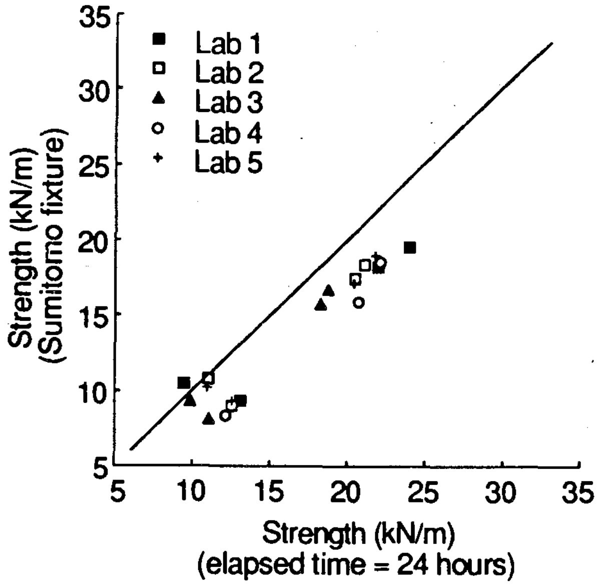

**FIG. 7** — *Edgewise compressive strength of waxed reinforced specimens tested in Sumitomo fixture compared to strength of waxed reinforced specimens reconditioned for24 h. Points represent data. Line is plot of equality;* $r^2$ *= 0.9218.*

A comparison of all the reconditioning time data showed that. with the exception of double-wall materials 275 CB and 500 CB tested 2 h after waxing, double-wall material 275 CB tested 24 h after waxing, and triple-wall material 1300 AAA tested 1 h through 24 h after waxing, the flexible-beam machine was found to yield higher strength values. Flexible-beam values were on average 2.6% higher than rigid-platen values. Although the rigid-platen averages were corrected for differences in machine speed, the general trend of higher flexible-beam values is consistent with the results observed in Fig. 3 of Schrampfer and Whitsitt [*4*].

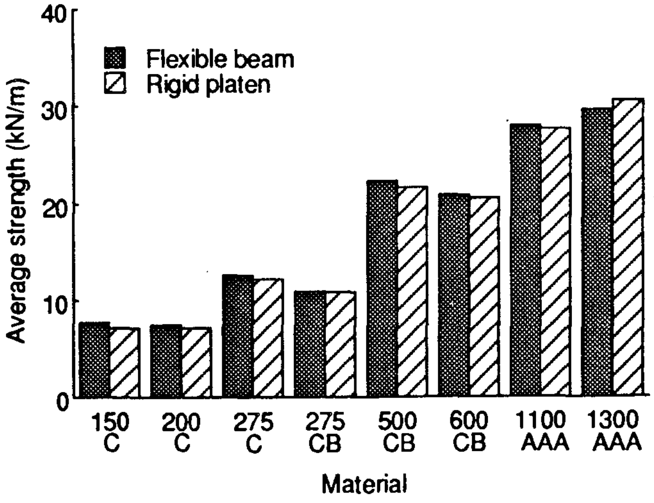

**FIG. 8** — *Average observed edgewise compressive strength of eight materials tested in flexible-beam loading machine and predicted average strength of materials tested in rigid-platen machine.*

## Moisture Absorption Test

The FPL measured the weight of corrugated fiberboard as a function of time and the variation following wax dipping for comparison with the results of test element A. The tests involved short column specimens cut from commercially purchased, 51 kPa (nominal 350-lb/in.$^2$), double-wall corrugated fiberboard. The specimens were first preconditioned in a dry environment at 27°C (80°F) and 30% RH. Then, a batch of six specimens was taken into a 23°C (73°F), 50%-RH conditioned room and placed on an electronic scale. Specimens were positioned surface-to-surface to induce a conservative exposure to penetrating air. A digital oscilloscope connected to the scale continuously recorded weight as the specimens absorbed moisture. Because the room was equipped with circulation fans, the scale was positioned away from direct air disturbances. However, it was not isolated within any enclosure. Fig. 9 records the results of this initial test.

For the next test, equilibrated specimens were wax dipped in the same conditioning room according to Method D 2808 specifications and, as soon as possible, returned to the electronic scale. About 15 min elapsed between wax dipping and weighing. Figure 10 shows the resulting weight change with moisture reabsorption. The difference between the initial weight (Fig. 10) and the terminal weight (Fig. 9) was due to the weight of wax gained minus the weight of moisture lost through waxing.

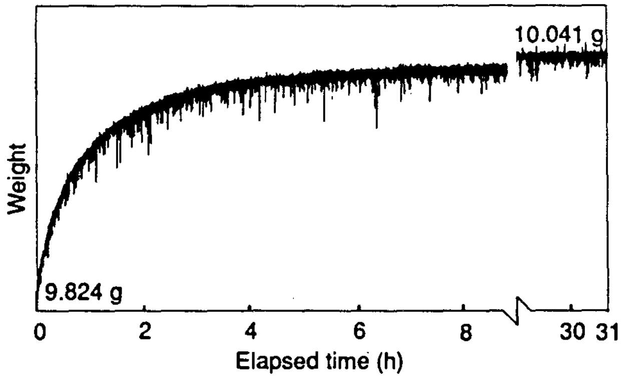

**FIG. 9** — *Weight of corrugated fiberboard short column specimens as a function of time in a 23°C (73°F), 50% RH conditioned room without forced air curculation after removal from a 27°C (80°F), 30% RH preconditioning room. Spikes resulting from analog-to-digital data conversion can be ignored.*

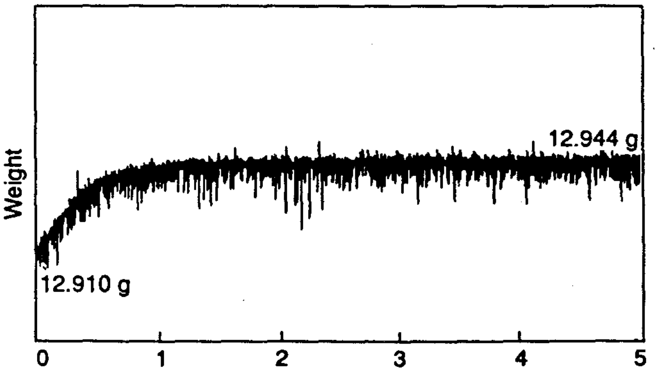

**FIG 10.** — *Weight of corrugated fiberboard short column specimens as a function of time in a 23°C (73°F), 50% RH conditioned room after conditioning and waxing in the same room.*

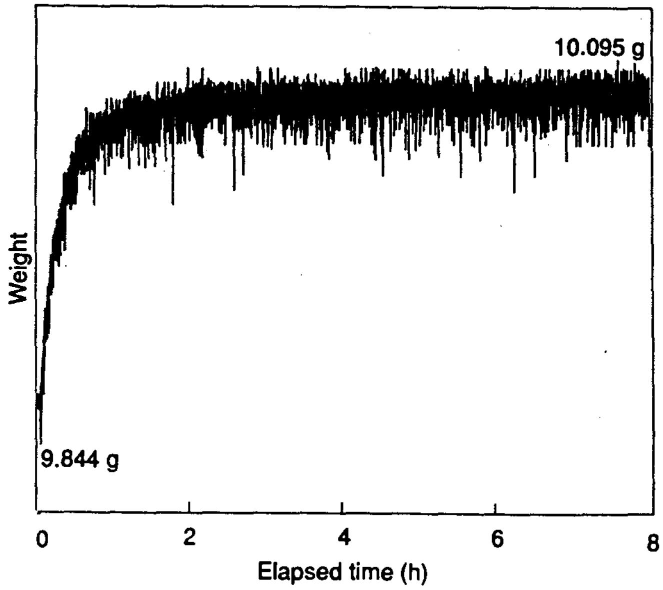

**FIG. 11** — *Weight of corrugated fiberboard short column specimens as a function of time in a 23°C (73°F), 50% RH conditioned room with forced air circulation after removal from a 27°C (80°F), 30% RH preconditioning room.*

Some trial tests revealed that equilibrium rate is sensitive to the air speed and direction that vary with specimen arrangement and horizontal as opposed to vertical positioning. The first test was therefore repeated with a new batch of specimens, using a fan to draw a slight draft across the specimens (Fig. 11).

The material represented by the postwaxing weight as a function of time curve in Fig. 10 had returned to an equilibrium moisture content between 1 and 2 h after waxing. The conservative surface exposure implies that equally rapid reconditioning could be achieved with triple-wall material. This independent experiment further corroborates the results of Figs. 1 and 6, from which we can infer that 2 h is a sufficient postwaxing reconditioning period.

## Conclusions

Our results indicate that the procedures for edge crush testing of corrugated fiberboard should be changed to permit testing of conditioned specimens 2 h after waxing. Heavy-grade specimens cut with a saw and tested in the Sumitomo test fixture were found to yield lower strength values compared to those of waxed Method D 2808 specimens. Previous research had indicated that light-grade Sumitomo specimens cut with a Billerud knife yielded equal values to those of waxed Method T 81 1 specimens. Therefore, additional tests are needed to determine if heavy-grade materials cut with a Billerud knife perform equally to Method T 811 specimens. A comparison of flexible-beam data and corrected rigid-platen data seems to indicate that a rigid-platen machine driven at 10 mm/min (0.4 in./min) yields lower strength values compared to those obtained with a flexible-beam machine driven at 110 N/s (25 lbf/s). More tests are needed to establish a loading rate that yields equivalent results.

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