Measuring corrugated box performance

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Performance differences between corrugated containers stored in a warehouse were not detected by the standard compression tests, but static load tests did reveal these differences when a changing environment was part of the evaluation.

In addition to being a supplier to the corrugating industry, our company is also a box user. It is in this capacity that we have become involved with the questions of box design, construction, performance, economics, and so forth. In discussing ways to reduce costs on one of our purchased box types, a question was raised. Could the currently specified 161.1-g/m² (33 lb/1000 ft²) corrugating mediums be replaced by less expensive 126.9-g/m² (26 lb/1000 ft²) corrugating mediums without sacrificing container performance?

The best way to answer the question was to test two sets of boxes, one set with the standard 161.1 g/m² corrugating mediums and the other with the proposed 126.9-g/m² replacement. The box is used for shipping hot melt adhesives. It is a doublewall, regular slotted container of B/C flute construction, 34.3 cm × 34.3 cm × 47 cm high, consisting of three 185.5-g/m² liners.

For this test series, these boxes were made on the same corrugator, with the same adhesive and glue settings. They were passed through identical finishing equipment so that all machine variables could be kept to an absolute minimum. The only deliberate variable was the basis weight of the two corrugating mediums.

Our plan was to evaluate these containers using the following test methods:

1. Edge crush test (ECT) and top-to-bottom box compression
2. Actual warehouse observation of the stacked boxes
3. Static loading in both constant and changing environments.

Standard compression tests

Soon after these boxes were made, ECT corrugated board samples were cut from them (5 cm × 5 cm with waxed edges), were conditioned, and were tested according to TAPPI T 811 in a 22.2°C, 50% RH environment. As the results in **Table I** show, we should expect no statistically significant performance difference between the two box types.

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I. ECT and extrapolated values for compression for both mediums

	Conditions		*Corrugating medium*	
	Temp., °C	*RH, %*	*161.1 g/m²*	*126.9 g/m²*
Edge crush test	22.2	50	11.7 kN/m (±1.54)	12.1 kN/m (±1.14)
	32.3	90	5.3 kN/m (±0.67)	5.6 kN/m (±0.47)
Extrapolated whole box compression	22.2	50	6.4 kN	6.5 kN
	32.2	90	2.8 kN	3.0 kN

Additional ECT samples were conditioned and tested in a 32.2°C, 90% RH environment to determine how the more adverse environment would effect the results. As expected, the values were lower because of the high humidity, but these results also indicated that there should be no performance difference.

Whole box top-to-bottom compression tests were planned but could not be run because our remaining boxes were inadvertently damaged. However, Table I shows the corresponding compression values obtained from the simplified McKee formula:

$$P = 5.87\, P_m\, h^{1/2} z^{1/2} \quad (1)$$

where

P = compression strength of the box

P_m = ECT value

h = caliper of the corrugated board

z = perimeter of the box.

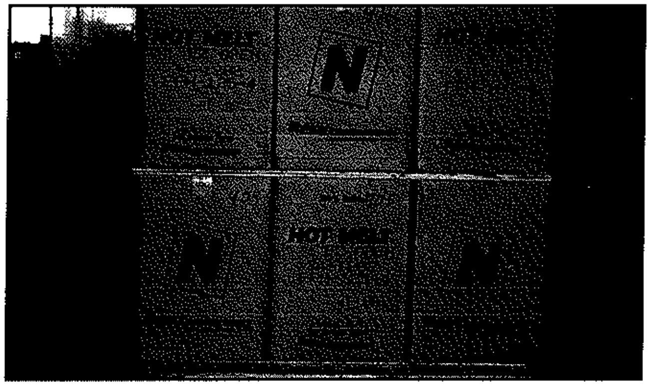
Before making the proposed switch to the 126.9-g/m² corrugating mediums, however, we proceeded with the additional planned tests.

Warehouse evaluation

Standard handling procedures were followed for the warehouse test. The boxes, filled with 27.7 kg (50 lb) of hot melt adhesive, were placed on pallets, 18 boxes to a pallet (nine on nine). The pallets were stacked four high and were placed in our warehouse, as shown in **Fig. 1**. In this

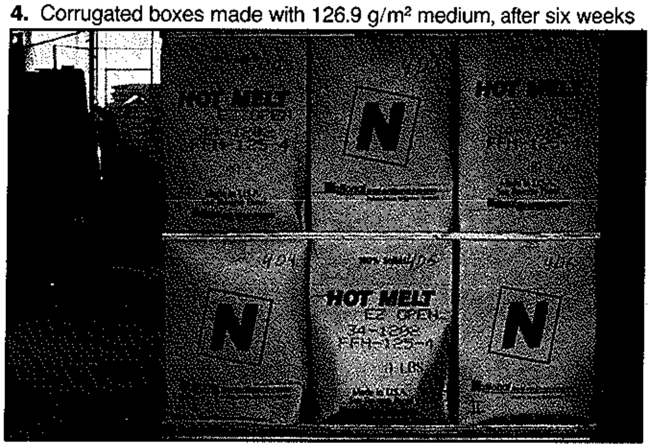
1. Warehouse stacks

2. Corrugated boxes made with 126.9 g/m² medium, at the start of the test

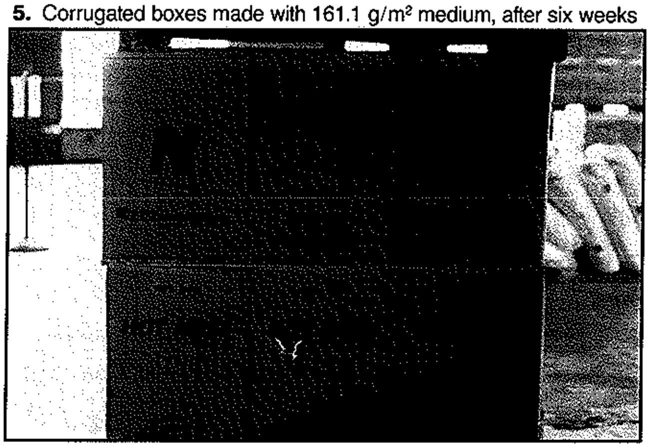


3. Corrugated boxes made with 161.1 g/m² medium, at the start of the test

4. Corrugated boxes made with 126.9 g/m² medium, after six weeks



5. Corrugated boxes made with 161.1 g/m² medium, after six weeks

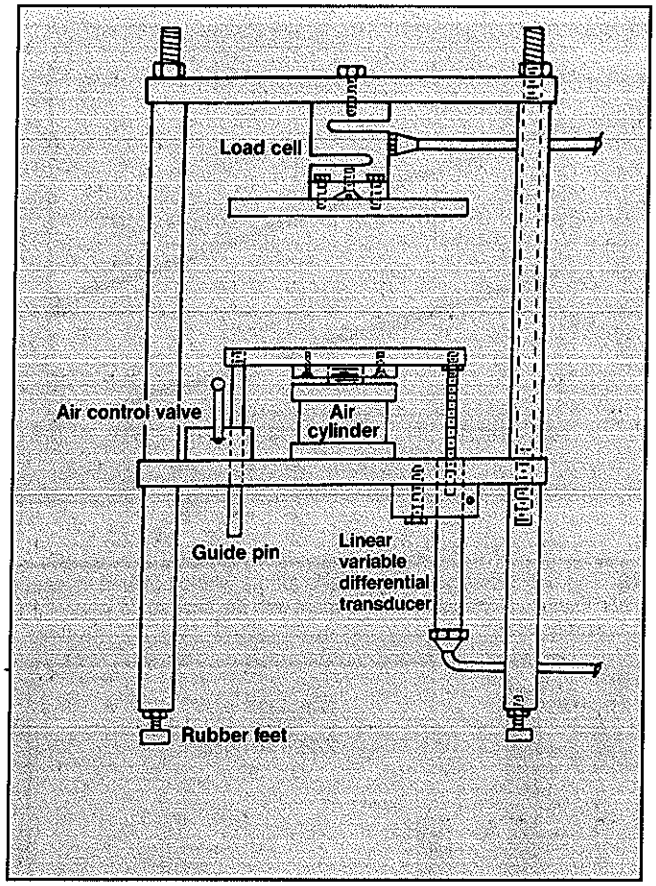


configuration, including pallet weight, the bottom box supports a dead load of 169 kg (372 lb) (**Figs.** 2 and 3).

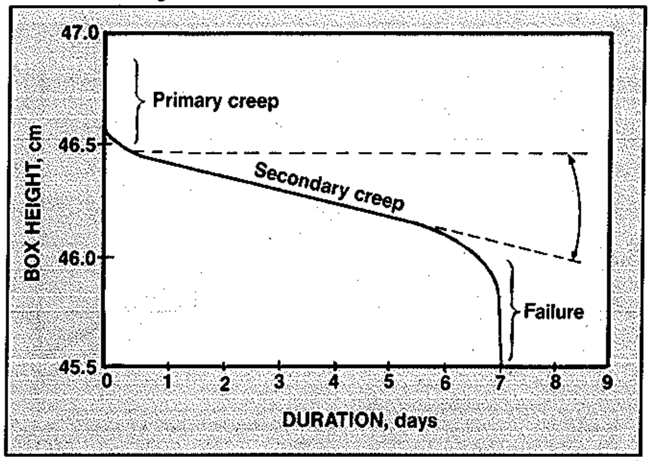
The stacks of boxes, two columns of each box type, were continuously observed during the next two months. After only a few weeks, the boxes made with the 126.9-g/m² corrugating medium showed evidence of weakening, while the ones made with the 161.1-g/m² corrugating medium remained essentially as first stacked. After approximately six weeks, the 126.9-g/m² corrugating medium boxes on the bottom pallet had weakened to the point where total box failure was imminent (**Fig.** 4), causing these columns of stacked containers to lean to such an extent that the top pallets had to be removed for safety reasons. The boxes of 161.1-g/m² corrugating medium remained in relatively good shape. Even those boxes located at the bottom of the stack showed virtually no sign of weakening (**Fig.** 5), which allowed us to leave the stacked pallets in an upright position.

These observations showed that the boxes made with the 126.9-g/m² corrugating medium were inferior to those made with the 161.1-g/m² corrugating medium and that we should not make the proposed change. These results were in direct conflict, however, with the results for the edgewise crush test. The question was, why? To try and

6. Device for measuring static load



7. A time curve showing the compression of corrugated container with three distinct regions



answer this question, static load evaluations were conducted.

Static load test

There are few references to static load testing in the literature, and most of what has been done (*1–5*) has come out of the Forest Products Laboratory in Madison, Wis. The concepts established by these works were used throughout our static load evaluations. We believe that we have reinforced the validity of these concepts and that we have added some new dimensions to them.

Our two box types and their corresponding corrugated board samples (5 cm × 5 cm with waxed edges) were both tested in static loading devices designed and built on our premises (**Fig. 6**). The larger, full box unit consists of a rigid bottom platen and a swivel top platen. The smaller unit, used for testing corrugated board samples, has both a rigid top and bottom platen. The load, measured by a load cell, is applied pneumatically through the use of an air cylinder located under the bottom platen. A linear variable differential transducer measures lower platen movement caused by the weakening and the eventual collapse of the box or corrugated board sample to the nearest 0.025 mm (0.001 in.).

The Forest Products Laboratory had found that the stacking service life of containers could be predicted by using short-term creep rate values (*3*). According to the FPL, when a load is placed on a corrugated container, a compression time curve can be drawn, as **Fig.** 7 shows. Three distinct regions are formed:

1. A primary region which shows rapid deformation caused by the initial load
2. A secondary region which shows the more gradual deformation of a container that occurs over a period of time before the actual onset of failure
3. A final section, or tertiary region, which shows the rapid deformation that signals the onset of failure.

This gradual deformation of the secondary region occurs at a much slower pace than that which occurs either in the primary or tertiary regions. This secondary portion of the curve can be used to predict how long a container will last without taking the container to the actual failure point. The slope of the secondary creep portion of this curve is directly related to the life span of the container.

To establish the exact relationship between this slope and time to failure (*3*), we divided the slope of the secondary portion of our creep curves by the box height and defined this value as the creep rate. Next, we plotted the creep rate against the corresponding applied static load on log-log paper. The resulting line of best fit for this series of tests was determined using the least squares method. The equation of this line was:

$$D = 3707 / R^{0.957} \qquad (2)$$

where

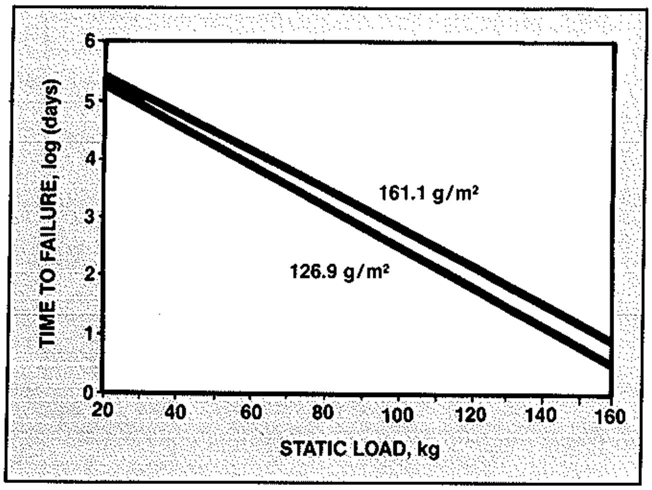
D = duration of load or life span of the container

R = secondary creep rate defined as the slope of the secondary creep divided by the container height.

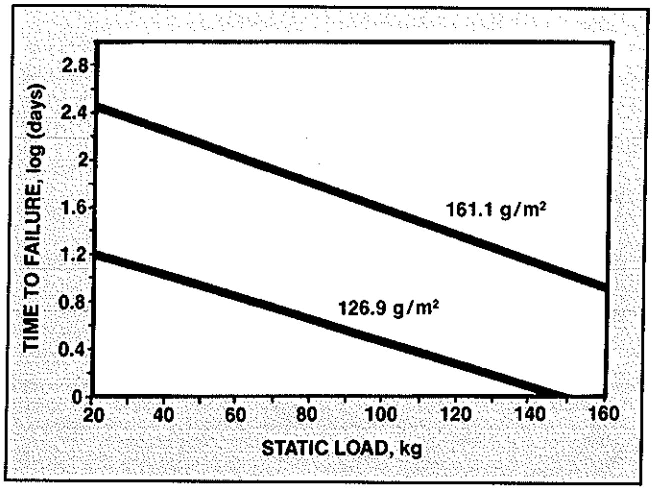
Having established the relationship between creep rate and box life, there was no longer a need to wait for complete failure to occur to determine the life span of a container. By using our static load units and these techniques established at the Forest Products Laboratory, the time required to generate meaningful life span data is greatly shortened, and the procedure becomes more practical.

For this static load evaluation, the two box types were conditioned and tested on the static load equipment in the

8. Duration for the whole box under static loads (constant environment)



9. Duration for the whole box under static loads (changing environment)



same environment, 32.2°C and 90% RH. This environment was chosen instead of 22.2°C and 50% RH because of the greater demands the higher temperature and humidity make on box performance. If differences were to be seen, we felt they should occur in this environment.

The results of this work are shown in **Fig. 8**, where the semilog relationship of the static loads vs. the time to failure are plotted. Both of these plots are quite similar, indicating that, as with the standard dynamic ECT results, there are virtually no significant performance differences between the two box types. Both box types lasted an equivalent length of time at any one particular static load before collapsing.

Static load test in a changing environment

The warehouse evaluation had shown that the two box types performed differently, yet both the dynamic ECT and the full box static load results were indicating that the boxes should perform the same. What was the difference between the actual field results and these two laboratory test results?

The answer turned out to be: *a changing environment.* Including this factor in the static load test proved to be the ingredient needed to realistically evaluate performance.

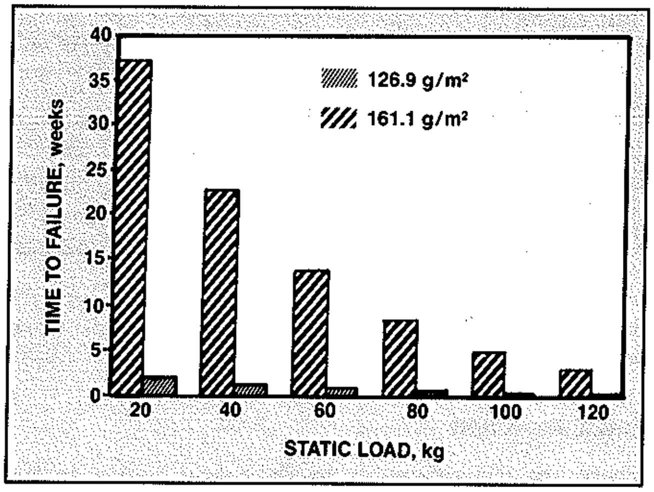
These same two box types were now conditioned and dead loaded in 22.2°C and 50% RH. After loading, the environment was changed to 32.2°C and 90% RH. This test was limited to this one environmental change.

Once again, creep rates generated for this changing environment were plotted against the corresponding static loads on log-log paper. The equation for the best straight-line fit of this data was:

$$D = 26{,}817 / R^{1.121} \tag{3}$$

By introducing an environmental change into the test procedure, differences in box performance were seen. **Figure 9** shows the semilog relationship of the static loads vs. the time-to-failure of these boxes. The results of this static load test showed that the containers made with the 126.9-g/m² corrugating medium were inferior to those

10. The direct life span comparisons for the whole box under various static loads in a changing environment with the time scale in weeks



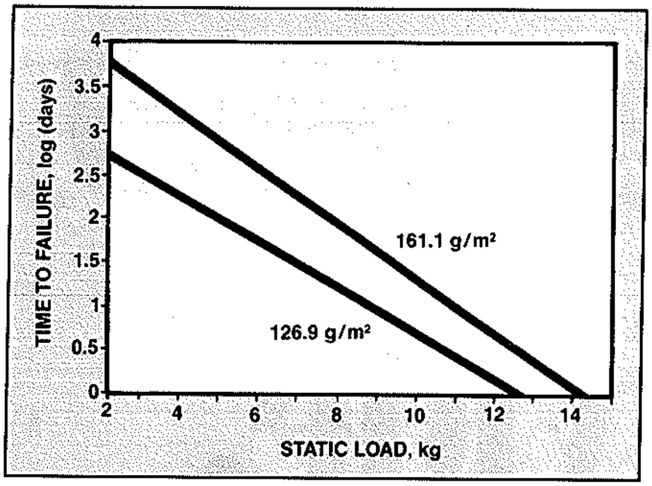
made with the 161.1-g/m² corrugating medium, meaning that they would weaken sooner. Not only did the change in environment reveal a performance difference, but the overall life spans for *both* boxes were shorter than when tested in a constant, unchanging environment.

These results can be better appreciated in **Fig. 10**, where the semilog relationship between specific applied loads and the respective box life spans have been translated to a normal time scale.

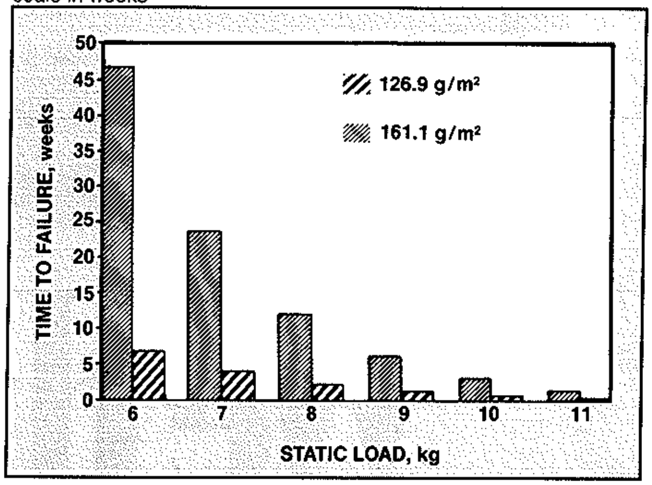
These same relationships between creep rates and life spans held, not only for these whole containers, but also for 5 × 5-cm corrugated board samples when they were subjected to static loads in the same changing environment. **Figure 11** shows the semilog relationships between static load and life span for these corrugated board samples, and **Fig. 12** illustrates the direct life span comparisons at various static loads.

The magnitude of the performance difference between box types may be somewhat different for these laboratory static load tests than that seen in the warehouse. Nevertheless, the conclusion is the same: The containers

11. Duration for the corrugated board samples under static loads (changing environment)



12. The direct life span comparisons for the corrugated board samples under various static loads in a changing environment with the time scale in weeks



made with the 126.9-g/m² corrugating medium are inferior to those made with the 161.1-g/m² corrugating medium. This performance difference between box types had *not* been revealed by either the industry-accepted edgewise crush test or by the static load test performance on the whole box in a constant environment. The difference was revealed, however, by a static load test performed on both whole boxes and on corrugated board samples when a *changing* environment was a part of the test.

Summary

In the first static load test, the environment was the same during conditioning and during the test period. In the warehouse, however, the containers were stacked under the specific environmental condition of that day. The environment then changed, humidities and temperatures fluctuated, and the boxes either absorbed or gave up moisture as the conditions directed.

The environmental changes that occur while the container is not being subjected to a load will have no permanent effect on the box. If the box is brought back to its original environment and then loaded, it will perform as it did initially. If, however, the environment changes *while* the container is under load, even greater stresses are imparted to the paper and to the bonds holding the corrugating medium to the linerboard, causing an increase in the creep rates (*2*, *4*, *5*). As the container tries to equilibrate to the new conditions while under this load, permanent, irreversible weakening occurs. These stresses not only accelerate the weakening process but serve to reveal actual performance differences between boxes. A box will not experience these same destructive stresses if it has been conditioned in the *same* environment as that in which it is later dead loaded.

Actual performance differences may not be detected by the standard dynamic tests nor even by the use of a static test. The evaluation must include a changing environment. This same phenomenon was seen by Byrd and Koning (*4*), where the edgewise compression creep rates generated in a constant environment were similar for corrugated board made from several types of pulp but were notably different in a changing environment.

Additional remarks

Our experience shows that there may be other box parameters that effect a container's performance that the current test procedures are not revealing. We contend that the combining adhesive is one such parameter.

A number of years ago, we specified that a water-resistant combining adhesive be used on our hot melt boxes as a means of improving box performance. The reason for this change was simply the subjective feedback from other box users who told us that a switch to water-resistant adhesives had improved the performance of their containers. On the research front, Koning and Stern indicated that water-resistant adhesives should be used in humid environments (*3*). Furthermore, Byrd (*5*) had shown that the combining adhesive can influence the creep rates and therefore the stacking life of paperboard.

Additional hard evidence and quantification of such evidence is still needed, however. One objective of our continuing static load program is to expand on this work, to quantify the effect that the combining adhesive can have on box performance and to show that the choice of adhesive is one means of improving that performance.

Literature cited

1. Kellicutt, K. Q. and Landt, E. F., Fibre Containers 36(9):28 (1951).
2. Byrd, V. L., Tappi 55(11): 1612(1972).
3. Koning, J. W., Jr. and Stern, R.K., Tappi 60(12): 128(1977).
4. Byrd, V. L., and Koning, J. W., Jr., Tappi 61(6): 35(1978).
5. Byrd, V. L., Tappi 69(10): 98(1986).

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