Repeated recycling of corrugated containers and its effect on strength properties

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One method of extending the United States’ timber supply is to reuse the fiber from such products as used corrugated fiberboard containers. This practice is increasing because of the high quality of the fiber and its availability in concentrated areas such as shopping centers, supermarkets, and industrial plants. The amount will also increase as more balers and compactors are installed at places of such concentration and as new concepts, such as truck-mounted balers for use in collecting segregated, used corrugated containers from dispersed locations, are perfected. The recovery of used corrugated containers also reduces the problem of solid waste disposal for municipalities. Thus, the recycling of used corrugated containers into new corrugated fiberboard containers is expected to increase.

But what happens to the strength properties of containers made from repeatedly recycled fiber? Although there are many articles on the use of recycled fibers, only a few (1–4) deal with recycling unbleached kraft fiber. McKee (3) reported the effect of repeated recycling, but his work was limited to hand-sheets and did not include the effects of conversion of the paperboard and corrugated or the subsequent performance of the container.

Thus, this study determined (a) the effect of repeated recycling of uncontaminated fibers on the compressive strength, scoring, and impact resistance of corrugated fiberboard containers, and (b) the effect on those same properties of repeated recycling with refining to a burst level of approximately 100 for each facing (to meet the carrier requirements of a burst level of 200 for the combined board.)

The approach was to use virgin southern pine unbleached kraft pulp for the linerboard and mixed hardwood neutral sulfite semichemical (NSSC) pulp for the corrugating medium. These components were combined into corrugated fiberboard, and then the combined board was converted into containers. Performance of the corrugated containers was evaluated by tests simulating actual service conditions. After the containers were evaluated, the corrugated board was recycled. One-third was made into a 42-lb linerboard without refining so the drainage on the paper machine would be as good as possible; one-third was made into 26-lb corrugating medium; and the last third made into a 42-lb linerboard with refining to achieve a burst value of approximately 100. Components were combined (Fig. 1) and again converted into containers for evaluation. After evaluation, the corrugated board made with the linerboard from unrefined fiber was divided—half recycled into linerboard and the other half into corrugating medium. The same procedure was followed with the corrugated board made with the linerboard from refined fiber. After evaluation of containers made from these components, the process was repeated for a total of four complete cycles.

RESULTS AND DISCUSSION

The study encompassed the production process from raw pulp to finished
Fig. 1. Sequence of recycling starting with virgin fiber in control material.

container, under controlled laboratory conditions. Predictive and production quality control tests were performed on the component materials, and tests considered indicative of in-service performance were run on the completed containers.

This was a limit condition study in that it was designed to study containers made with 100% virgin fiber and 100% recycled fiber, rather than blending various percentages of recycled fiber with virgin fiber, as is typically done in industry. What is presented here is an estimate of the maximum effect on strength properties that can be attributed to the repeated recycling of fiber. Other factors such as contaminants, production processes, or severe contaminant removal processes (5) may result in additional degradation.

Paperboards in this study were made on a 13-in.-wide experimental fourdrinier paper machine. Recycled fiber has been successfully used for many years as the principal furnish for paperboard made on cylinder machines; however, cylinder linerboard differs in physical properties from fourdrinier linerboard, so any effects of recycling would likely be masked by the inherent differences in the paperboard manufacturing processes. Therefore, it is desirable that an evaluation of the effects of recycling utilize the fourdrinier papermaking process.

It would be highly desirable to correlate container performance tests and predictive material component tests for production quality control. Though a full analysis of correlation is beyond the scope of this report, a limited analysis of the data indicates that no one test adequately characterizes container performance; a number of separate tests are required to determine different performance qualities. For example, some of the better correlations were machine-direction tensile or burst strength with impact resistance of containers, and ring crush or edgewise compression with container compressive strength.

**Component Properties**

The properties of nominal 42-lb linerboard and 26-lb medium from the various cycles are listed in Table 1.

**Linerboard.** Results indicate a reduction in linerboard burst and tear strength, folding endurance, ring crush, machine-direction tensile strength, and stretch, regardless of whether the material was unrefined or refined when compared to the virgin material.

Each time the pulp was recycled, a sample of the stock was recovered for drainage evaluation. The drainage time of the virgin fiber average 12 sec using a 42-lb/1000 ft² weight handsheet made in a standard TAPPI sheet mold. Drainage time of unrefined recycled material was 17 sec after the first cycle, 25 sec after the second, and 30 sec after the third, for an increase of over 100% in drainage time. For the refined recycled fiber, the increase in drainage time was even more dramatic, going to 26, 29, and then on the third cycle to 65 sec, indicating a more than five-fold increase in drainage time.

The drainage on the paper machine followed the trend of sheet-mold drainage. A considerable reduction in machine speed was necessary to make a 42-lb linerboard with the recycled refined fiber. The results indicate that one of the most serious problems with using recycled fibers in the reduction in drainage on the paper machine wire and the corresponding decrease in production rate.

**Corrugating medium.** Between the virgin fiber and the first recycle, strength properties of the corrugating medium generally improved. With repeated recycling, burst strength was reduced on each succeeding cycle, but all the recycled corrugating medium burst values were higher than the virgin NSSC.

During the corrugating process, the recycled corrugating medium tended to fracture, and corrugating speed and web tension had to be reduced to complete the runs. Thus, the use of recycled fiber results in conversion problems at the corrugator, as well as manufacturing problems on the paper machine.

**Combined Corrugated Fiberboard Properties**

**Burst.** The effect of recycling on the burst characteristics of the combined board made from the unrefined fiber was greater than in the case of the refined fiber (Table II). Between the virgin material and unrefined corrugated, burst strength was reduced 35% on the first cycle, 44% on the second cycle, and 37% on the third cycle. The refined material showed reductions of 19, 18, and 18%. These results indicate that the loss in burst strength can be reduced with refining, but the refined material drains more slowly on the wire. Repeated recycling had less effect than the initial recycle of the virgin fiber.

**Edgewise compressive strength.** In edgewise compressive strength, a most important property of the combined
hoard, the unrefined material lost 15% on the first and second cycles and 17% on the third cycle. The refined material dropped 7, 11, and 1%. Thus it appears that repeated recycling may not be significantly detrimental to edgewise compressive strength if sufficient refining is employed.

Flat crush. Flat crush resistance was lowered by 10, 7, and 14% for the three recycles of the unrefined material. For the refined material, losses were 15, 29, and 12%.

Scoring. Tests of horizontal scores (perpendicular to flutes) made with a three-point roller score indicated no visible cracking. This was true regardless of material, number of recycles, atmospheric condition in which scoring took place (30, 50, or 90% RH), or whether the material was refined or unrefined.

Tests of vertical scores (parallel to the flutes) indicated that atmospheric conditions and refining affected scoring. Scores made at 80°F, 90% RH conditions showed no visible cracking. At 80°F, 30% RH and 73°F, 50% RH, scoreline cracking increased. The refined material showed a greater tendency to crack than did the unrefined.

Apparently the moisture conditions wider which the recycled corrugated board is scored are critical. The effects of recycling on score-line cracking are much less significant than are the effects of moisture conditions. If the moisture content of the board is low, a board made from refined stock will have a greater tendency to crack than a board made from unrefined material.

### Container Properties

After the corrugated fiberboards were converted into containers, they were evaluated for compressive properties and impact resistance.

**Top-to-bottom compression.** Because the mode of failure varies with height of containers, two sizes were evaluated; the shorter containers were 3¼ in. high and the taller ones 8 in. (Table II).

In the case of the short containers made from the unrefined material and tested at 80°F, 30% RH or 73°F, 50% RH, recycling reduced compressive strength approximately 10%, regardless of the number of recycles. Under 80°F, 90% RH conditions, there was no significant change. The refined material reacted similarly, except the reductions were not as great. Therefore, for short containers, where the mode of failure is primarily by crushing, recycling reduced compression parallel to the flutes by 10% or less.

The taller containers usually failed by a combination of buckling and crushing. These containers showed a re-
duction in compressive strength of 8\% on the first recycle for the unrefined material and 24 and 22\% for the next two recycles. For the refined material, the reduction was 12, 18, and 1\%. Comparing these results with those of the shorter containers indicates that, when a combination of buckling and crushing occurs, repeated recycling significantly affects compressive strength; however, refining can partially offset this loss.

Higher compressive loads were recorded for the 8-inch containers than for the 3\(-\frac{1}{2}\)-in. containers because of the difference in the deformation at which maximum loads were determined.

Side-to-side compression. Recycling reduced the side-to-side compressive strength of the unrefined material by 27, 8, and 10\% from the virgin material for the three recycles. This compares with reductions of 17 and 2\% and an increase of 8\% for the refined material. The first recycle showed the greatest loss; however, repeated recycling indicated an improving trend for the refined material.

End-to-end compression. Containers of unrefined recycled material tested in end-to-end compression lost 15, 18, and 20\% of their compressive strength for the three recycles when compared to the control. For the refined material, strength increased 11\% on the first recycle, decreased 9\% on the second, and decreased 6\% on the third. These results indicate a significant reduction in end-to-end compression with unrefined material, but not with refined material.

Impact resistance. The shorter containers were filled with cans (case-load, 12 lb), conditioned at 73°F, 50\% RH, and dropped on edge using a single-drop procedure. The results indicate impact resistance was reduced 16, 25, and 26\% for the unrefined material and 15, 9, and 17\% for the refined material when compared to the virgin material.

CONCLUSIONS

A comparison of 100\% virgin kraft and NSSC material with 100\% contaminant-free, recycled material and repeatedly recycled material indicated that:

1. Recycling generally lowers the strength properties of the recycled paperboard and corrugated containers. These reductions can be overcome to a large extent with refining, but with a possible decrease in attainable production rates.

2. In general, the greatest loss in strength properties occurred with the first recycle; part of this loss in strength may be attributed to the presence of NSSC fibers in the linerboard and part to recycling. Losses between subsequent recycles were less.
3. This recycling fiber will drain progressively more slowly on the paper machine wire with each cycle, particularly if the stock is refined between cycles to develop more of its potential strength.

4. Recycling corrugated fiberboard results in significantly lower values for the linerboard in burst and tear strength, folding endurance, machine-direction ring crush, machine-direction tensile strength, and stretch, though the reductions were less with the refined material.

5. Repeated recycling causes the corrugating medium to be more susceptible to cracking on the corrugator, which tends to reduce the rate of production.

6. Recycling corrugated fiberboard results in reductions of at least 35% in burst strength of combined board for unrefined fiber and 18% for refined.

7. The moisture conditions under which the combined board in scored are more important than the material (recycled, refined, or unrefined). In general, for combined board made from four-drinier linerboard, the vertical score linen (scores parallel to the flutes) are more sensitive to cracking than are horizontal scores. Also, the refined material is more sensitive to humidity conditions than the unrefined.

8. Top-to-bottom compressive strength of containers is reduced approximately 10% if failure is primarily by crushing (shorter containers). The difference between unrefined and refined is slight; considering the drainage problem, an unrefined stock would be preferable. For taller containers, the effect of recycling is more significant (up to 24% reduction) due to the influence of the buckling and crushing modes of failure. However, refining can partially offset this loss.

9. Under conditions of 73°F, 50% RH, recycling reduced impact performance up to 26%, with the refined material being better than the unrefined.

LITERATURE CITED

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