The current U.S. test for evaluating bond durability of phenolic-bonded particleboard and other wood-based panels subjected to severe exposures is the six-cycle accelerated-aging test in ASTM D 1037 (3). The National Bureau of Standards (NBS) developed this test in the 1930s to determine fiberboard sheathing durability (16). The various exposures used were based on NBS experience with aging of paper; wetting and freezing steps were added because fiberboard sheathing maybe subjected to this type of exposure. No attempts were made to determine how much each exposure step contributed to fiberboard deterioration.

The most often reported problem with the ASTM D 1037 test is that it is much too long to be used as an in-plant quality control check. Each of the six cycles contains six individual exposure steps. The test normally takes 2-1/2 weeks to complete since the cycle can be interrupted only at the freezing step. After accelerated aging, additional time is needed to recondition the specimens before stiffness and strength can be measured.

The two objectives of our study were to 1) evaluate the progressive deterioration of products with each successive exposure cycle in the ASTM D 1037 test; and 2) determine how various steps in the ASTM D 1037 six-cycle test contribute to panel deterioration. Results of this study were used to develop a less time-consuming accelerated-aging test, which will be evaluated in a future study.

Literature review
Two approaches to predicting long-term durability of exposed wood-based panels are mentioned in the literature (6,13):

1. Identify the factors that cause degradation and determine their individual influence. Then, devise a laboratory test that closely approximates actual-use conditions, compressed in time.

2. Select severe laboratory exposures that cause changes in properties that can be correlated reliably with property changes under actual-use conditions. The ASTM D 1037 test clearly represents the second approach; exposures include soaking in 120°F water, steaming at 200°F, freezing at 10°F, and drying at 210°F. These conditions would not be found in the environment. A temperature of 10°F is possible, but the panel would probably not be saturated. Maximum roof sheathing temperatures close to 170°F have been recorded in the United States (14,29).

Some researchers concluded that the 20-hour freezing portion of the ASTM D 1037 test did not significantly af-
However, River et al. (24) found that the relationship between bending strength and stiffness reduction for a soak (OD/VPS) and the ASTM D 1037 test gave essentially the same results as the ASTM D 1037 test for various phenolic-bonded particleboard (Fig. 1). Sleet (27) and Chow and Janowiak (10) found general agreement between the WCAMA test and the ASTM D 1037 test. In addition, Chow and Janowiak found no difference in results after four or six cycles of either test. Carre (7), on the other hand, stated that the effect of freezing depends on whether or not the material is saturated with water. The amount of moisture absorbed during soaking or steaming depends on the makeup of the material. Fiberboards, hardboards, and particleboard will not adsorb the same amount of moisture for a given soaking condition. A vacuum-pressure soak, high-temperature soak, or both types of soak may be the only way to assure complete saturation. Dinwoodie (11) stated that a suitable accelerated-aging test must include a freezing step.

Caster (8) found that 20 cycles of a modified version of the automatic boil test, ASTM D 3434 (2), gave the same general results as the ASTM D 1037 test, but took only 2 to 3 days to complete. Knudson and Rosenberg found good correlation between the ASTM D 1037 six-cycle test and a test consisting of one cycle of 2-hour boil plus 1-hour cold water soak plus 24-hour ovendry. The latter test has been adopted by MacMillan Bloedel as part of their waferboard mill quality control. Jathar (15) suggested a single cycle of 10-minute boil plus 4-minute ice water soak plus 1-hour ovendry as a simple, low-cost, rapid in-plant quality control test for waferboard. He found this test to be somewhat more severe than the ASTM D 1037 test. Lehmann (20) outlined a fast durability test for composite materials that is based on shear testing of specimens after hot-water soaking in a small pressure cooker. In an earlier study, Lehmann (19) had reported that five cycles of 24-hour ovendry plus 2-hour vacuum plus 22-hour pressure soak (OD/VPS) and the ASTM D 1037 test gave essentially the same bending strength and stiffness reduction for a variety of phenolic-bonded flakeboards, but internal bond strength reduction was greater in the ASTM D 1037 test. However, River et al. (24) found that the relationship be-

tween OD/VPS and the ASTM D 1037 test was different for different panel types. In most studies where effects of successive cycles were evaluated, the rate of panel degradation decreased as the number of cycles increased.

Of the standardized accelerated-aging methods, no single method is universally recognized as outstanding (4,12,13). The ASTM Standard E 632 (1) outlines a systematic approach that should be used in developing accelerated tests to predict service life of building materials. In summary, numerous attempts have been made to devise accelerated-aging tests that are shorter and simpler than the ASTM D 1037 six-cycle test, which was developed more than 50 years ago. Most short quality-control tests have been developed for specific phenolic-bonded particle panel products and include cyclic hot-water soaking and ovendrying. The usefulness of a freezing step in cyclic exposure is questionable.

**Experimental procedure**

Our study was conducted in two phases. Phase 1 determined the effects of the number of cycles of the ASTM D 1037 accelerated-aging exposure test on the bending properties of selected wood-based panel products. Phase 2 evaluated how selected steps in the cycle contributed toward panel deterioration. A third phase, the investigation of an abbreviated version of the current cyclic exposure in ASTM D 1037, will be conducted in the future.

Five wood-based panel products were evaluated in the study hardboard lap siding, isocyanate-bonded particleboard, phenolic-bonded laboratory-made flakeboard, waferboard, and oriented strandboard (OSB). All were nominally 1/2 inch thick except for the hardboard, which was 3/8 inch thick.

Ten lengths of 1-foot-wide by 16-foot-long lap siding were obtained. The other materials were obtained in 4- by 8-foot sheets (five sheets each). The laboratory-made flakeboard panels were manufactured in 4- by 8-foot sheets as part of the USDA Forest Service program on structural flakeboard from forest residue (21).

Each panel was cut into ninety 3-inch-wide bending specimens. Half the specimens were cut with their length parallel to the panel length and half with their length perpendicular to the panel length. Except for hardboard, all specimens were 14 inches long hardboard specimens were 11 inches long. All specimens were marked to identify type of material, panel number, location in the panel, and direction relative to panel length.

**Phase 1**

For each material, 20 specimens were randomly selected and tested as controls (5 panels × 2 panel directions × 2 replicates) and 120 specimens were randomly selected and tested after 1, 2, 3, 4, 5, or 6 cycles of accelerated aging (5 panels × 2 panel directions × 2 replicates). All specimens were first conditioned to equilibrium moisture content at 75°F and 64 percent relative humidity (RH), weighed, and measured. Control specimens were tested in static bending according to ASTM Standard D 1037 (3). The remaining specimens were subjected to 1 to 6 cycles of the accelerated-aging exposure specified in ASTM D 1037. Twenty specimens of each product were
removed after 1 cycle, 20 specimens after 2 cycles, and so on through 6 cycles. All aged specimens were reconditioned at 64 percent RH and again weighed and measured prior to testing in static bending. Residual thickness swelling of each aged specimen was determined as a percentage of original thickness.

**Phase 2**

Each cycle in the ASTM D 1037 accelerated-aging test consists of the following six steps:

<table>
<thead>
<tr>
<th>Step</th>
<th>Exposure</th>
<th>Time (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Water soak, 120°F</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Steam, 200°F</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Freezing, 10°F</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>Dry air heat, 210°F</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>Steam, 200°F</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Dry air heat, 210°F</td>
<td>18</td>
</tr>
</tbody>
</table>

In Phase 2 of our study, specimens were tested after being subjected to four or six cycles of the standard exposure (all six steps) and three modified exposures: freezing step (step 3) deleted, steaming steps (steps 2 and 5) deleted, or freezing and steaming steps (steps 2, 3, and 5) deleted. In the latter two exposures, the drying steps (steps 4 and 6) of the accelerated-aging cycle were combined for a total drying time of 21 hours.

Specimens were selected and tested as described for Phase 1 so that 20 specimens of each material were tested after each of 4 or 6 cycles of the modified aging exposures.

**Method of analysis**

For each material, analysis of variance (ANOVA), with panels as a blocking factor, was used to determine if the mean properties of thickness swelling (TS), modulus of rupture (MOR), and modulus of elasticity (MOE) were the same in these test situations: controls, 1 to 6 complete aging cycles, or 4 or 6 modified aging cycles. If the ANOVA indicated that all the means were not the same, Tukey's multiple comparisons were used to determine which means could not be considered statistically equal at the 5 percent level.

**Results and discussion**

**Properties of control specimens**

Average properties of the control specimens are given in Table 1. For all the materials, there were significant differences in bending strength and stiffness between specimens cut parallel or perpendicular to the length of a given panel. For OSB, this difference was due to alignment of the strands parallel to the 8-foot direction on the face and perpendicular to the 8-foot direction in the core. For hardboard, flakeboard, and waferboard, the stronger and stiffer direction corresponded to the forming direction of the panel during manufacture. Some alignment of particles or fibers is common during mat layup. The waferboard was weaker in the 8-foot direction since this corresponds to the “cross-panel” direction of the mat layup during manufacture. The lower stiffness of the particleboard in the 8-foot direction cannot be explained since this corresponds to the mat-forming direction during manufacture.

**Calculation of aged specimen properties**

As specified in ASTM D 1037, MOE and MOR of aged specimens were calculated using both initial thickness and thickness after aging. In this paper, we refer to the MOE and MOR that were calculated using the initial thickness as bending resistance and load-carrying capacity, respectively. Lehmann (18) found that MOE and MOR values based on initial thickness were sometimes greater after aging than before aging. Although aging decreases specimen strength by breaking interparticle bonds and degrading the wood, increased specimen thickness can sufficiently increase resistance to a bending load to more than offset the effects of loss in interparticle bonding. Sleet
(27) suggests that if the effect of TS is removed by calculating MOE and MOR using actual thickness, then comparisons reflect only degradation of the wood and the glue bond.

**Phase 1. Effect of number of cycles**

Residual TS. - Thickness of each specimen was measured again after the accelerated-aging exposure and reconditioning at 64 percent RH. Residual thickness is the difference between this value and the initial thickness, expressed as percentage of initial thickness. Figure 2 shows the steady increase in thickness for individual specimens of the five materials as the number of accelerated-ageing cycles increased. Total residual TS (springback) after six cycles of accelerated aging was least for the particleboard (13%) and greatest for the waferboard (30%). This is characteristic of the behavior of panels made from finer particles (planer shavings, sawdust) compared to those made from large flat flakes (wafer, strands) (22,28).

Bending stiffness and strength. - Figure 3A shows the progressive decrease in bending resistance with successive cycles of accelerated aging, based on initial specimen thickness. Data for parallel and perpendicular orientations of specimens in the panels are combined for hardboard, particleboard, flakeboard, and waferboard, but are presented separately for OSB where directional properties were intentionally built into the panels. Bending resistance decreased steadily, but at a decreasing rate, for each successive cycle of accelerated aging. The character of this decrease was similar for hardboard, particleboard, flakeboard, and waferboard specimens. The change for OSB specimens cut in the parallel direction was more variable, on the average, bending resistance of OSB decreased less than that of the other materials. For OSB specimens cut in the perpendicular direction, most decrease in bending resistance occurred in the first aging cycle.

Data for MOE in Figure 3B are based on actual specimen thickness. As a result, the average MOE of the control specimens was much greater than that of specimens tested after one to six cycles of accelerated aging. This is particularly true for OSB cut in the parallel direction. Average slope of the load-deformation curves for the OSB-parallel specimens after one aging cycle (591 lb/in.) was actually slightly greater than that of the control specimens (545 lb/in.). Therefore, bending resistance showed an increase after one aging cycle (Fig. 3A). However, there was a significant drop in MOE based on actual specimen thickness as a result of an average 12 percent residual thickness swelling of OSB specimens after one aging cycle (Fig. 2). Put another way, Figure 3A indicates that the OSB-parallel specimens retained all their ability to re-
sist deflection under load after one aging cycle (90% retained after six cycles). Figure 3B, on the other hand, indicates a 28 percent degradation of the wood and glue bond in the OSB-parallel specimens after one aging cycle (50% degradation after six cycles). Other materials also showed a much greater decrease in MOE than in bending resistance.

The changes in bending strength, based on initial or actual thickness (Fig. 4), were much like those found for stiffness. Strength retained after six cycles (4A), expressed as a percentage of initial load-carrying capacity, ranged from 55 percent for particleboard and waferboard to 70 percent for OSB when based on initial thickness. When based on actual thickness (4B), retained MOR ranged from 32 percent for waferboard to 50 percent for OSB and flakeboard.

Phase 2. Effect of deleting aging steps

Residual TS. — Figure 5 shows residual TS of individual specimens of the five panel products after four or six cycles of the four aging exposures described in the Methods section.

TS was virtually the same after four or six cycles of accelerated aging. Swelling was slightly reduced when the freezing step was deleted. Reduction is more substantial when the steaming step was deleted. Residual TS with both freezing and steaming steps deleted was essentially the same as when only steaming was deleted. The effect of deleting the steaming step was most evident with hardboard, where average residual TS was reduced from about 18 percent to only 2 percent. The effect was least for waferboard, where residual TS was reduced from 30 percent for the complete exposure to 20 percent with the steaming step deleted.

Bending stiffness and strength. — Deleting the freezing and/or steaming steps from the six-cycle accelerated-aging test had little effect on bending resistance (Fig. 6A). Results were the same whether four or six cycles of accelerated aging were used. When the freezing and steaming steps were deleted, bending resistance of hardboard increased the most (about 20%); particleboard and waferboard increased about 14 percent. Flakeboard and OSB showed no consistent change in bending resistance with deletion of freezing and/or steaming steps.

When actual specimen thicknesses were used to calculate MOE, deletion of the steaming step resulted in a
Four cycles of accelerated aging gave essentially the same results as six cycles.

Deleting the 20-hour freezing step from the exposure cycle did not significantly affect test results.

Deleting the two 3-hour steaming steps did significantly affect results. However, for convenience in conducting the test, it would be advantageous to limit the exposure to simply a hot-water soak and overdrying.

Because of residual TS, interpretation of test results can vary depending on whether calculations of bending strength and stiffness are based on initial specimen thickness or thickness after aging.

The following alternative exposure cycle, and possibly others, will be investigated in a future study:

<table>
<thead>
<tr>
<th>Step</th>
<th>Exposure</th>
<th>Time (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Water soak, 120°F</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Dry air heat, 210°F</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Water soak, 120°F</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Dry air heat, 210°F</td>
<td>16</td>
</tr>
</tbody>
</table>

Cycle repeated X number of times. Specimens tested dry after cooling.

Conclusions

An analysis of the ASTM D 1037 accelerated-aging test for wood-based panel products indicated definite opportunities for shortening total exposure time without significantly altering effects of aging on residual TS and bending strength and stiffness.