ABSTRACT

Flexural-creep testing of composite products has been performed by numerous researchers using a myriad of methods. The creep behavior of these composite panels, such as flakeboards and particleboards, is dependent on a wide variety of processing, testing, and environmental influences. The lack of a consistent test method makes interpretation and comparison of creep-testing information from one study to another quite difficult. The great

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amount of time and expense invested in performing these various tests is justification for the establishment of a standardized test method.

This paper begins with a review of the world literature on creep-testing methods, results, and analyses for structural composite panels. Establishing the need for a test standard with this literature review, a proposal is made for the creation of a standard method of testing and reporting creep information. Use of this standard by other researchers will provide the opportunity for a consistently-derived database on creep behavior of panel products.

INTRODUCTION

The need for engineering data on wood-based panel products extends beyond the determination of static strength and stiffness properties. The emergence of reliability-based design methods requires an adjustment of strength and stiffness values obtained from short-term laboratory condition tests to values which will assure a given level of structural reliability under the loads and environments encountered during the life of the structure. That is, to accurately establish design procedures requires knowledge of the materials' mechanical properties and the effects of load history, thermal, and moisture conditions on these properties.

The deflection of a structural product due to the long-term application of load is termed creep. Why is creep important? Reconstituted panel products produced from wafers and strands are expanding rapidly as replacements for traditional materials such as plywood and boards. These new products have spawned a number of performance-based standards to support them in traditional markets. One of the few performance parameters not prescribed, as yet, is that of creep or behavior under long-term loading.

This paper describes what research has been done in the study of creep and presents a proposal for a creep standard for structural panels. This information is intended to serve as a precursor for publication of the results of a large test program currently being conducted at the U.S. Forest Products Laboratory, Madison, WI, (Figure 1) and at Forintek Canada Corporation's Western Laboratory in Vancouver, B.C., Canada. The program will provide a baseline of information, gathered on a consistent basis, for understanding creep and creep-rupture in structural composite panels as well
as plywoods. This program is being supported by the Forest Services of both Canada and the United States, as well as the American Plywood Association and the Waferboard Association (Laufenberg, 1986). Results from the test program will, however, not be complete until mid-year 1988, with publication of the results expected in 1989.

Literature Review of Creep of Structural Panels

Creep is defined as the inelastic strain caused by the stressing of a material for any period of time. Creep is always associated with an inelastic condition because the stress level remains constant (or nearly so with small cross-section dimension changes) while the strain increases. The rheological (or time-dependent deformation) properties of wood are influenced intimately by the moisture and temperature environments. A particularly interesting aspect of creep in wood is that cycling of the moisture environment tends to cause much larger creep strain than a constant moisture content condition. A review of the rheological behavior of wood and wood-based materials is presented by Schniewind (1968) for those desiring a broader background on this subject. Research conducted on particleboard and flakeboard products will be discussed in detail here.

Lehmann, et al., (1975) studied the bending creep characteristics of three types of particleboards, three types of structural particleboards, and three plywoods. A relationship between higher creep resistance and longer flake lengths was observed. Alignment of flakes on the board faces also improved creep resistance. Several regressions were determined which relate the initial elastic stiffness of the panel products to their creep deflection at 65% relative humidity (RH). These regressions were:

a) for heavy (3x design) loads for 14 days
\[ \gamma_c = 153.61(EI)^{-1.73} \]

b) for light (design) loads for 6 months
\[ \gamma_c = 19.65(EI)^{-1.43} \]

with correlation coefficients \( r^2 \) between 0.74 and 0.87, where,
\[ \gamma_c = \text{creep deflection (in.)} \]
\[ EI = \text{stiffness (10}^3 \text{ lb-in.}^2/\text{ft}) \]
Figure 1. -- View of large test program underway at U.S. Forest Products Laboratory, Madison, WI. (a) Small specimen creep tests and (b) large specimen creep and creep-rupture tests.
Cyclic humidity changes from 30% to 90% relative humidity were found to produce two to four times the creep deflection produced by a constant 65% relative humidity condition.

Haygreen, et al., (1975) studied creep of particleboard and plywood under various humidity regimes. About the same flexural creep was noted for cycling the RH between 50% and 70% or between 55% and 65% (96 hour cycle) as for a constant 60% RH, but creep was much greater for cycling between 40% and 80% RH. On absorbing from a 50% RH condition, flexural creep increased with the level of adsorbing RH. Creep was much greater at 80% RH than at the lower adsorbing RHs. Under a concentrated load, panel creep was greater at a constant 85% RH than for cyclic 50 - 85% RH. Linear viscoelastic behavior was reported for loads less than 20% of the bending ultimate.

Armstrong and Grossman (1972) studied bending creep of hardboard and particleboard subjected to moisture content cycling between 6% and 18% moisture content (MC) (initially adsorbing) or 18% and 6% MC (initially desorping). Creep deflections were substantial for the first cycles of moisture content change whether adsorption or desorption. Following the first half cycle, subsequent adsorption cycles produced less additional creep deflection than desorption cycles. Precycling of the specimens from 6% to 18% back to 6% MC prior to loading did not change their creep behavior upon loading. Application of a correction factor which reduced material stiffness to the appropriate value at high moisture contents was presented to support the observed apparent creep recovery upon absorption.

Hall, Haygreen, and Neisse (1977) studied creep of particleboard and plywood as floor panels under concentrated loads while under various humidity regimes. Creep was somewhat greater for cycling RH between 45% and 65% (96 hour cycle) than for a constant 50% RH and considerably greater for cycling between 45% and 85% RH. Creep under indoor ambient conditions (temperature range 68° - 90°F, RH range 8 - 80%) for one year was on the same order as creep under 45 - 85% RH cycling after about 400 hours. The authors noted that creep of both particleboard and plywood was accelerated during adsorption, but leveled off or recovered during desorption. The authors indicated this was consistent with some other studies on particleboard, but contrary to studies on solid wood. In a followup report, Hall and Haygreen (1978) reported little or no creep during the second year
the panels were under load in ambient conditions. There appeared, however, to be much less variation in temperature and humidity in the second year compared to the first year. Additionally, creep results were presented for one type of particleboard protected by a vapor barrier on either the top face or the bottom face during the 2-year monitoring period. Creep tended to be greater with a top face barrier than with a bottom face barrier, and there was a tendency for increased deflection during adsorption with a top face barrier and during desorption with a bottom face barrier.

Perkitny and Perkitny (1966) compared the creep of wood, particleboard, and fiberboard at 20% and 40% of ultimate bending load. Three moisture content levels (0, 10, and 20%) were included in the 10-day duration bending tests. Within each load level, the particleboard and fiberboard exhibited higher deflection and the solid wood deflected less at each higher MC level. It must be remembered that the bending stresses were different for each MC level in proportion to the bending strength at each MC. The bending stiffness to bending strength ratio, therefore, increases at increased MC for solid wood and this ratio decreases for increased MC of particleboard and fiberboard. The 20% and 40% load levels were found to produce proportionately larger creep deflections. In summation, the Perkitny's found the creep deflections for solid wood, particleboard, and hardboard were, on the average, ratios of 1:4:5, respectively, for the test conditions used.

Halligan and Schniewind (1972) studied the creep behavior of urea-bonded particleboards subjected to relative humidity conditions from 30 - 97%. Creep during adsorption was found to be highly variable between board types. Creep was found to be correlated directly to thickness swelling. Both creep and thickness swelling were found to be reduced by a steam post-treatment.

A comprehensive study by Gressel (1972) on the creep behavior of solid wood, plywood, and particleboard included the effects of sorption, temperature, gluing, and stress. Sample dimensions were found to have a great influence in the tests on sorption contributions to creep. Several different particleboard adhesives were studied and conclusions were drawn to indicate that actual creep of the different binders was not the cause of the differing creep rates. Each binder was found to impart a different hygroscopicity to the particleboard which caused different equilibrium moisture conditions at each temperature and relative humidity climate.
Clad and Schmidt-Hellerau (1981) conducted long-term bending tests on particleboards with different adhesives loaded at 20% of static strength which were exposed to exterior humidity and temperature conditions for 600 days. Panel deflections were greatest for phenol-formaldehyde resin-bonded boards followed by phenol-isocyanate, urea, with the least deflection being for melamine-bonded boards (Table 1). Moisture content monitored during the testing showed the phenolic boards have higher moisture content at any point in time than the other boards.

Table 1.--Average creep values for particleboards with different resin systems

<table>
<thead>
<tr>
<th>Panel Adhesive</th>
<th>Relative Creep</th>
<th>Irrecoverable Creep</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(creep deflection/elastic deflection) (%)</td>
<td>(creep set/initial elastic deflection) (%)</td>
</tr>
<tr>
<td>Phenol-formaldehyde</td>
<td>620</td>
<td>470</td>
</tr>
<tr>
<td>Surface layer--phenol formaldehyde; core layer--isocyanate</td>
<td>340</td>
<td>240</td>
</tr>
<tr>
<td>Urea</td>
<td>292</td>
<td>185</td>
</tr>
<tr>
<td>Melamine</td>
<td>190</td>
<td>126</td>
</tr>
<tr>
<td>Modified melamine</td>
<td>104</td>
<td>63</td>
</tr>
</tbody>
</table>

Morze and Struk (1980) investigated the effects of various temperature and moisture cycles on the viscoelastic properties of urea-formaldehyde (UF) and phenol-formaldehyde (PF) particleboards. Dynamic modulus of elasticity and damping were measured by nondestructive means as indications of bonding failures and board integrity. The specimens were conditioned through five cycles of 95% RH, 50°C for 40 days, and dried for 2 days. Reduction of dynamic modulus averaged 31% (UF) and 12% (PF) particleboard; while there was an increase in damping of 62% (UF) and 26% (PF).

Niemz (1982, 1983) investigated the influence of particle dimensions, specific gravity, resin, and wax content as well as load level on the physical and mechanical properties and the rheological behavior of particleboard. Simplified regressions for the creep characteristics as functions of the processing and load conditions were obtained from studies performed by Jensen (1977).

Ikeda and Takemura (1979) studied the effect of flake length on the creep properties of particleboards. Flakes of 1, 3, 4, and 8 cm were used to
make particleboards with 0.50, 0.65, and 0.80 specific gravity. No influence of density on relative creep was observed in this study. Flake lengths longer than 1 cm were similar in relative creep performance. Expressions for creep deformation were of this form,

\[ \gamma_c = at^n \]

\( \gamma_c \) = creep deformation  
\( t \) = time (min)  
\( a, n \) = constants determined from data

The parameter, a, like Young's modulus, was found to depend on flake length and specific gravity. The parameter, n, was found to be nearly constant regardless of flake length or specific gravity. An average value was found to be \( n = 0.29 \).

Elmendorf and Etzold (1969) measured long-term creep deflections of plywood and oriented particleboards at 33% of ultimate bending stress after 80 weeks under load (Table 2). Ambient conditions in the laboratory resulted in cyclic fluctuations in deflections attributed to changing humidities.

Table 2.--Creep deflection of structural panels at 33% of estimated ultimate for 80 weeks

<table>
<thead>
<tr>
<th>Load (lb)</th>
<th>3-Ply Plywood</th>
<th>X-Aligned Core</th>
<th>Random Core</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness (in.)</td>
<td>0.38</td>
<td>0.36</td>
<td>0.38</td>
</tr>
<tr>
<td>Creep deflection (in.)</td>
<td>0.10</td>
<td>0.083</td>
<td>0.083</td>
</tr>
</tbody>
</table>

Lyon and Barnes (1978) evaluated interior and exterior particleboard decking under constant bending loads. Relative creep (creep deflection/initial elastic deflections) of surviving specimens at any given time was found to be independent of the stress level. Relative creep (RC) was relative to time under load for both particleboard types.

\[ \text{RC (exterior)} = 5.23 + 4.82 \log_{10} t + 1.23 (\log_{10} t)^2 \]

\[ \text{RC (interior)} = 7.26 + 6.63 \log_{10} t + 0.99 (\log_{10} t)^2 \]

Extrapolation of these relations to a 10-year bending load provided estimates of the relative creep of 93% and 96% for the exterior and interior panels,
respectively. Thus, the authors' findings supported the rule of thumb for wood, whereby elastic deflections are doubled for long-term (lo-year) load duration.

McNatt and Hunt (1982) conducted creep tests of a thick, structural flakeboard, and of plywood material designed for use as roof decking. Samples were subjected to design bending loads while in a constant 65% RH condition or cycled between 25% and 85% RH for 90 days. Constant humidity conditions produced creep deflections of 44 - 69% of the initial (elastic) deflections. Cyclic conditions produced relative creep (creep deflection /elastic deflection) of 145% - 276%. Under both sets of conditions, the plywood exhibited the least creep. Retained bending strengths and stiffnesses were 74 - 99% of control specimens with no significant difference between the plywood and flakeboard retentions. Long-term loading under cyclic humidity conditions did not result in any greater loss of strength retention than specimens under constant conditions.

Yang and Haygreen (1971) studied the possibility of producing long-term flexural behavior by short-term, high temperature tests. The two applications of rate theory tested were,

\[ K' = T \left( C + \log t \right) \]

and

\[ K'' = \frac{T}{T_0 - t} \left( C + \log t \right) \]

where

- \( K \) = rate parameters
- \( T \) = absolute temperature of the process (Kelvin)
- \( T_0 \) = absolute temperature at which the material has no strength (Kelvin)
- \( C \) = a material constant
- \( t \) = time

The prediction theories proved to provide good predictions of deflection for stress levels of 10 - 20% of ultimate, but deflections from load levels above that were not predictable. Application of these rate parameters is not feasible for cycles of changing moisture/temperature conditions once the master rate curves are established.

Chow (1979) studied the creep of veneer-overlaid particleboard for 30-day durations of bending load at three humidity levels (30, 65, and 90% RH).
Two creep-time expressions were seen to give accurate predictions for creep deflections, $y_C$. 

\[
\begin{align*}
\text{for } t \leq 10 \text{ minutes}, & \quad y_C(t) = A' \left( t - 1 \right)^{1/b'} \\
\text{for } t \geq 10 \text{ minutes}, & \quad y_C(t) = y_C(10) + A'' \left( t - 1 \right)^{1/b''}
\end{align*}
\]

where $A'$, $b'$ and $A''$, and $b''$ are obtained from data.

Pierce, et al., (1977, 1979) investigated the utility of three- and four-parameter models (Figure 2) to predict the creep behavior of particleboards in bending. The models used were:

\[
y = \beta_1 + \beta_2 \left[ 1 - \exp(-\beta_3 t) \right] + \beta_4 t
\]

where

- $y =$ deflection
- $\beta_1 =$ parameters which describe the spring and dashpot components of the model, fitted by least squares to the data
- $t =$ time

Experimental tests of five commercial particleboards were used to assess the models. Depending upon the amount of time included in the prediction and the stress level used during the test, the parameters ($\beta_1$) were found to be variable, not constants, as intended when the model was developed. It was found also that the use of longer time under test load provided a better fit of the experiment to the model, as expected.

Niemz (1979) provided his view of particleboard creep. The conclusions and recommendations for research direction offered still seem relevant at this writing:

Systematic investigations of the influence of material structure on creep behavior have not, or only to an insufficient extent, been previously available. The essence of creep deformation, i.e. especially the processes occurring in the material during creeping, have as yet been inadequately explained. This also holds true for a quantitative identification of the contribution of wood particles
and adhesive to the total creep deformation. In order to be able to influence effectively the creep behavior of wood particle materials, fundamental investigations of the influence of structure and of the nature of creep deformation are necessary.

Figure 2. -- Mechanical spring and dashpot analogs with three and four components used to model the creep behavior of particleboard in bending (Source: Pierce, et al., 1977, 1979)

A Proposed Creep Test Standard

After reviewing the world literature it is quite obvious that a standard method of testing and assessing creep performance is needed badly. Within all the reviewed literature, there is no basis for directly comparing one data set with another. Even though all of the reviewed literature deals with flexural creep behavior, there are a number of "creative" methods to load the panel materials in flexure, a wide spectrum of geometries for the specimens, and various constant and cyclic environments in which to run the tests. Additionally, there is no consensus on load levels, time periods, and formats for presentation and analysis of the creep data.
In order to make significant improvements in the understanding of creep of wood-based panel products, a standard flexural creep test technique is proposed. This would allow consistent evaluation of materials over a useful range of load levels and environmental conditions.

Specimen Geometry and Loading

The basic method of test should be to produce a uniform moment over the area of the specimen such as is created in third-point loading. This uniform-moment "span" should be twenty times the specimen thickness, and the panel specimen should have a width of twenty times its thickness. Rollers used to load the panel should have a diameter of three times thickness. The method of inducing the uniform moment is irrelevant and whatever means a researcher chooses will suffice. The primary creep deflection measurement is to be the relative deflection between the loading rollers and the center of the uniform moment span.

Sampling and Short-term Strength

Sample sizes for the creep tests cannot be dictated clearly, but if a median creep performance expectation is to be acquired, three specimens are needed. No fewer than ten specimens should be used if the intent is to examine the distribution of creep performance. Flexural testing of at least one side-matched specimen for each creep test specimen is required to measure the short-term "static" strength and modulus of elasticity of the material. A one-minute ramp to failure is recommended. For each sample set, the average strength of the short-term tests will be used to dictate the presumed load carrying capacity of the creep specimens.

Baseline Environment and Loading

The proposed baseline environment for both the short-term static tests and the creep tests is 68°F (20°C) and 50% relative humidity (RH). Proposed creep stress levels are 15% and 30% of the short-term specimens' failure strength. These creep loads should be applied to the specimens in a consistent and smooth fashion to yield the full stress within 15% or 30% of one
minute. Quantities to be measured are the no-load deflection, deflection at the termination of the uploading of the specimen, and from then at 1 minute, 10 minutes, 30 minutes, 10 hours, 1 day, 2 days, and every 2 days until unloading. Zero time is defined as the initiation of the uploading part of the test. This monitoring should be performed through an eight-week period in the loaded state, the specimen is then unloaded and can be monitored optionally for rebound by the same time schedule for an additional 3 weeks.

A Second Environment

When a second climatic condition is to be addressed, 85% RH should be used. The load levels applied at the 85% RH should be identical to those for the 50% RH (i.e., 15% and 30% of the average one minute short-term strength for specimens conditioned at 50% RH). Short-term static strength and stiffness tests should also be performed on side-matched specimens conditioned to the 85% RH.

Cyclic Environment

When cyclic variation of the environment is considered, the cycle should start at the 50% RH condition and provide 24 hours at each environmental condition for each thickness up to 0.5 in. (12.5 mm). Thus, for panels with a thickness between 0.5 in. (12.5 mm) and 1.0 in. (25 mm) in thickness, each environmental condition should be held for two days. These cycles should be continued for a period of time as close to eight weeks as possible along with the optional unloading and rebound measurement for three weeks (i.e., for panels up to 0.5-in. thickness with one day at each condition, 28 full cycles can be achieved under load with 10 cycles rebounding). Deflection measurements should be made by the schedule defined for steady-state environments with a measurement just prior to each climate change.

Additional Measurements

Control specimens need to be monitored for moisture content and thickness swell during the course of the creep tests to allow some interpretation of the physical condition of the specimen under test. Also, the
creep specimens' residual short-term strength should be tested after reconditioning back to 50% RH.

Data Presentation

For each sample set, averages, and in the case of large sample sets, variances, should be calculated for the following values:

- $E_s$ - side-matched "static" specimen modulus of elasticity
- $E_i$ - initial (uploading) modulus of elasticity
- $E_R$ - rebound (uploading) modulus of elasticity
- $MOR_s$ - "static" specimen strength
- $MOR_R$ - creep specimen residual strength

Relative creep (RC) is a good parameter to use for presenting basic creep data. It is defined as the creep deflection at a point in time divided by the elastic deflection, which is measured immediately after uploading. RC values should be reported for one week, three weeks, and eight weeks for steady-state environments and cyclic environments. In the cyclic case, the portion of the cycle closest to the target time that produces the largest deflection should be reported.

Irrecoverable creep (IC) is a parameter that has been used to describe the permanent deflection induced by sustained loads. IC is the deflection remaining after load removal divided by the elastic deflection. These IC values should be reported at the time of unloading, one week after unloading, and three weeks after unloading.

Additionally, the data on moisture content and thickness swell should be reported at loading, one week, three weeks, eight weeks (with the optional rebound measurements), nine weeks, and eleven weeks. The equilibrium moisture content of the creep specimens at 50% RH prior to residual static strength should be reported also. With all these data reported, any researcher can reproduce the actual data of the experiment if they would like or can use the parameters to compare results.
CONCLUSION

The literature review of existing creep information vividly points out the reason that the creep phenomenon is not well understood. There has been no consistent method of testing or assessing the creep of simple structural panel components under a fairly simple flexural loading situation. By implementing the proposed standard into a consensus test standard, other researchers performing creep tests will be able to add to a data base by using this systematic approach. With a consistently derived data base, the industry may be in a good position to derive fundamental relationships which will further reduce the testing requirements needed to characterize the creep behavior of structural panels and other wood-based products.

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