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DESIGN ADJUSTMENT FACTORS FOR STRUCTURAL-USE PANELS

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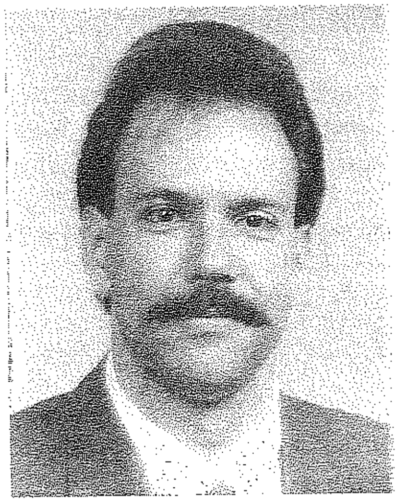
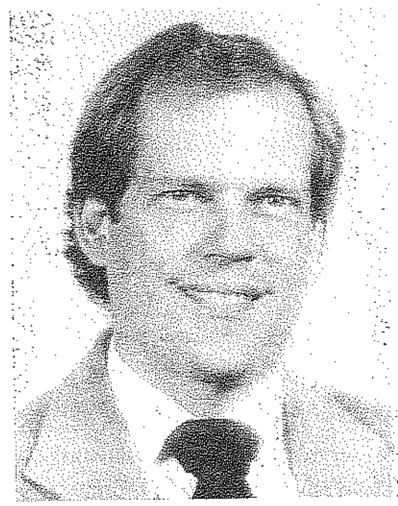

ABSTRACT

Design capacities for wood-based structural-use panels were most recently revised by the American Plywood Association in 1991. Adjustment factors for creep and service moisture conditions are given in the specification. This paper reviews the background for deriving these factors.

Creep adjustment factor was derived from the results of creep studies conducted by the US Forest Products Laboratory and other research institutes. When panels sustain permanent loads without removal up to one-half or more of its design strength capacity, the creep adjustment factor was given as 1/2 for plywood and mat-formed panels at dry (below 16% moisture content) service moisture conditions. When used at wet (16% or higher moisture content) conditions, the adjustment factor should be 1/2 for plywood and 1/6 for mat-formed panels.

To account for various service moisture conditions, test data supported the conclusion that the moisture content adjustment factor of 0.75 was appropriate for interlaminar shear and through-the-thickness shear capacities. For through-the-thickness shear rigidity, the factor was 0.85. Both creep and moisture content adjustment factors are cumulative.

INTRODUCTION

Structural-use panels, including plywood, composite (COM- PLY®), and mat-formed panels such as oriented strand board (OSB), have been used in construction and industrial applications for years. Performance-based standards and span rating systems developed by the American Plywood Association (APA) define the minimum quality of structural-use panels (American Plywood Association 1991a). Based on extensive mechanical testing and product research, APA has published current design specifications for plywood (American Plywood Association 1986) and other APA performance rated structural-use panels (American Plywood Association 1991b).

Current design specification for structural-use panels, *Design Capacities of APA Performance Rated Structural-Use Panels (APA Technical Note TN N375A),* was revised in 1991. Design values in the original 1988 TN N375 were derived based on mechanical test data collected from 1981 through 1986. Methodology used in developing design values for the 1988 TN N375 was documented by Elias and O'Halloran (1988).

In the 1988 TN N375, adjustment factors for panel grade and construction, duration of load, and creep were included. It should be noted, however, that as the effect of moisture on mat-formed panels was not established at the time of publication, design values given in the 1988 TN N375 were limited to dry-use (moisture content below 16%) applications. For creep deflection, it was suggested that calculated deflection should be doubled when panels would sustain permanent loads up to one-half or more of its design strength capacity. Due to the previously mentioned moisture limitation, creep deflection at high relative humidity (RH) conditions was considered out of the scope of the original specification.

Since the publication of the 1988 TN N375, more test data have been collected from APA's quarterly quality assurance program. These data reflected the up-to-date capacity levels of APA-rated panels and offered an opportunity for re-evaluation of the published design capacities. In addition, the effect of moisture on the mechanical properties of structural-use panels was determined as a result of several studies conducted by APA and other research institutes. In combination with the results of creep studies reported by McNatt and Laufenberg (1991) of US Forest Products Laboratory (FPL), the emerging knowledge in the behavior of structural-use panels ultimately allowed the establishment of moisture content and creep adjustment factors at high RH conditions.

Two APA studies investigating the effect of one-sided wetting (W1S) on the bending and shear properties of structural-use panels served as the basis for the moisture content adjustment factor given in the 1991 TN N375A. Results obtained from the studies will be discussed in the following sections.

MOISTURE CONTENT ADJUSTMENT FACTOR

In evaluating the effect of moisture on the mechanical properties of structural-use panels, studies were conducted by APA. These studies placed emphasis on bending stiffness, interlaminar shear, shear through-the-thickness, and shear rigidity through-the-thickness.

Bending Stiffness

In engineering applications, panel bending stiffness represents the capacity to resist deflection under load and is customarily expressed as EI with units of lb-in^2 per foot of panel width, where E is the modulus of elasticity and I is the moment of inertia (American Plywood Association 1986). Limited data are available to quantify the effect of moisture on E and, especially, EI of structural-use panels. Most studies reported in the past were conducted at constant equilibrium moisture content (EMC) conditions. The steady-state moisture content (MC) conditions did not reflect actual conditions in field construction, such as one-sided wetting due to rain.

Material

Eight OSB and two plywood plants were pre-selected to cover a wide range of geographical locations and manufacturing processes in the United States. Four panels from each of the 10 plants were sampled randomly by APA Auditors. The panels were manufactured with various wood species and had been qualified previously as APA Rated Sheathing 32/16 (15/32 in. or 1.19 cm thick) or 24/16 (7/16 in. or 1.11 cm thick) for plywood and mat-formed panels, respectively. From each panel, two specimens with a dimension of 48 by 12 in. (122 by 30 cm) were cut either parallel or perpendicular to the major panel axis direction. Due to damages in some panels, a total of 35 and 40 specimens was tested in the parallel and perpendicular directions, respectively.

Procedures

The 75 specimens prepared for W1S exposure were tested according to the following W1S exposure cycle:

$$\text{oven-dry} \rightarrow 3 \rightarrow 7 \rightarrow 9 \rightarrow 24 \rightarrow 47 \rightarrow 60 \rightarrow 83 \text{ hours} \rightarrow \text{VPS} \quad [1]$$

where VPS is the vacuum-pressure-soak cycle used to determine the maximum changes in panel properties (APA 1991a).

The W1S exposure was performed in a water tank equipped with water sprayers. The specimens were held within 30° of vertical and subjected to continuous one-sided water spray for a specific duration of time. The back of the specimens was not subjected to direct water spray, but was free to adsorb water vapor. At the end of each stage in equation 1, the weight and dimension of the specimens were measured, followed by a nondestructive flexural test to a constant loading level using the pure moment method (American Society for Testing and Materials D3043 1991a).

Results and Discussion

Ratios of panel EI at various duration of W1S exposure to that at oven-dry conditions are shown in Table 1 and Figure 1. Every plywood data point given in this table represents the average of 7 and 8 observations in the parallel and perpendicular directions, respectively. For mat-formed panels, every data point is the average of 28 and 32 observations in the parallel and perpendicular directions, respectively.

Variation shown in Figure 1 for plywood in the perpendicular direction may be partly attributed to the relatively small number of samples tested in this study. Overall, it could be noted that panel EI decreased slightly with increasing duration of W1S exposure. Increase in panel dimensions and the moment of inertia with increasing duration of W1S exposure apparently offset the more severely decreased panel MOE.

As noted from Table 1, the highest reduction in panel EI due to W1S effect was 20% for both plywood and mat-formed panels. However, as it is unlikely for panels to experience such severe VPS conditions in service, the moisture content adjustment factor for panel EI was determined to be 0.85.

Shear Properties

In engineering applications, panel shear properties include interlaminar (rolling) shear, shear

Table 1. — Ratio of panel EI at various duration of W1S exposure

Duration (hours)	Plywood		Mat-Formed	
	Parallel	Perpendicular	Parallel	Perpendicular
		Ratio of EI		
0 (OD)	1.000	1.000	1.000	1.000
3	1.011	0.908	0.935	0.888
7	1.014	0.999	0.933	0.908
9	1.003	1.003	0.913	0.888
24	1.042	1.076	0.918	0.895
47	1.023	0.892	0.942	0.903
60	0.997	0.867	0.963	0.939
83	0.967	0.997	0.931	0.838
VPS	0.946	0.847	0.863	0.808

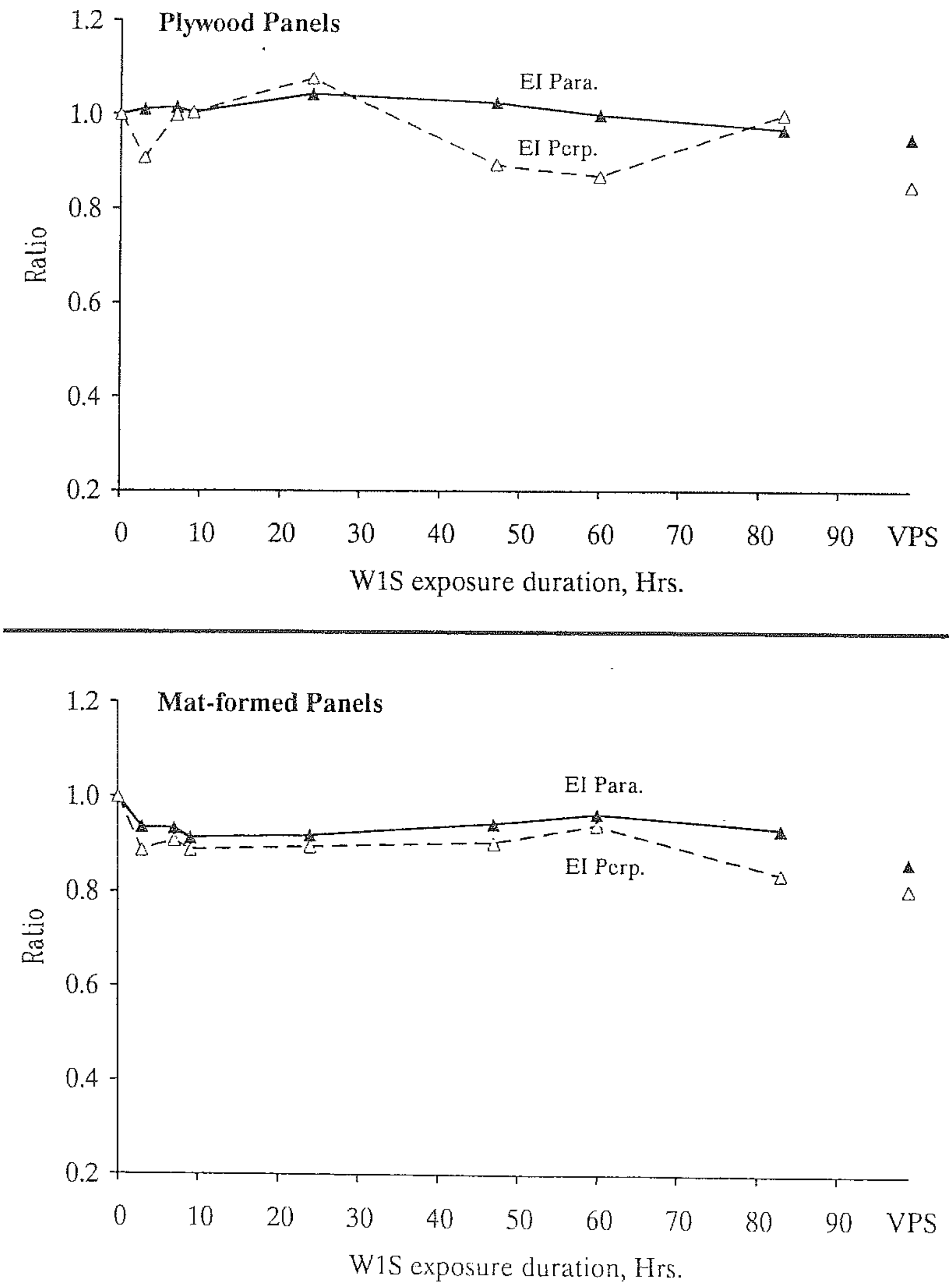

Figure 1. — *Ratio of panel EI at various W1S duration to ovendry conditions*

through-the-thickness, and shear rigidity through-the-thickness. Interlaminar shear and shear through-the-thickness capacities are customarily expressed as $F_S(Ib/Q)$ with units of lb/ft of panel width and $F_V t_V$ with units of lb/in. of shear resisting panel length, respectively, where F_S is the allowable interlaminar shear stress, Ib/Q is the cross sectional shear constant, F_V is the allowable through-the-thickness shear stress, and t_V is the effective panel thickness for shear (American Plywood Association 1986). For shear rigidity through-the-thickness, the expression is $G_V t_V$ with units of lb/in. of panel depth (for vertical applications), where G_V is the modulus of rigidity through-the-thickness (American Plywood Association 1986).

Material

Five OSB plants covering a wide range of geographical locations in the United States and Canada were preselected for collecting test panels. The panels were manufactured with various wood species and had qualified previously as APA Rated Sheathing 24/16 (7/16 in. or 1.11 cm thick). From each plant, five full size OSB panels were randomly sampled. Two of the five panels were used to prepare the specimens for interlaminar shear tests and the remaining three panels were used for through-the-thickness shear tests.

Specimens with a nominal dimension of 16 by 6 in. (41 by 15 cm) and 24 by 16 in. (61 by 41 cm) were prepared from the collected panels for interlaminar and through-the-thickness shear tests, respectively. Long dimension of the specimens was parallel to the major panel axis. From each panel, 30 interlaminar shear specimens were cut, resulting in a total of 300 specimens (5 plants by 2 panels/plant by 30 specimens/panel). For through-the-thickness shear, 12 specimens were prepared from each panel, giving a total of 180 specimens (5 plants by 3 panels/plants by 12 specimens/panel).

Procedures

Three environmental conditions were applied in this study: dry conditions (control), 72 hour W1S exposure, and redry after W1S conditions. Dry conditions were defined in this study as 65% relative humidity (RH) and 68°F (20°C). The W1S exposure and redry conditions were as previously discussed in the bending stiffness study. Test specimens were divided equally into three groups for these three conditions based on source plants and panels.

Two-rail shear method given in ASTM D2719 (1991b) was applied to through-the-thickness shear tests with a uniform loading rate of 0.04 in./minute (0.10 cm/minute) until failure, giving a loading duration of about 5 to 7 minutes. For interlaminar shear tests, the five-point loading method was employed (Bateman et al. 1990) using a span to depth (L/d) ratio of about 16. This ratio has been shown to be adequate for breaking most specimens in interlaminar shear rather than in bending. During testing, a uniform loading rate of 0.1 in./minute (0.25 cm/minute) was applied to fracture the specimens in about 5 to 7 minutes. For both W1S and redry specimens, the directly wetted surface was always placed in the loading side.

Results and Discussion

Interlaminar Shear — Results for interlaminar shear tests are given in Table 2, excluding the 38 specimens that failed in a bending mode. Percentage of shear failure was 87%, which was higher than 72% reported by Bateman et al. (1990) using the L/d ratio of 20.6 to 25.1 for the same panel thickness at about 5% MC. Three-parameter Weibull distribution was used to evaluate the 5th percentile point estimates.

Figure 2 shows the ratios of mean and 5th percentile $f_S(Ib/Q)$. As shown in Table 2 and Figure 2, the 5th percentile interlaminar shear capacity decreased 21% from dry to W1S and 7% from dry to redry conditions. Based on the results, the moisture content adjustment factor of 0.75 was estimated for interlaminar shear capacity.

Shear Through-the-Thickness — Results for shear through-the-thickness tests are shown in Table 3. It should be noted that due to temporary malfunction of the data acquisition system, test data for a dry specimen was lost. Therefore, only 59 test data were available for dry conditions.

Figure 3 shows the ratios of mean and 5th percentile f_{vt}, and mean G_{vt}. As seen from Table 3 and Figure 3, the 5th percentile through-the-thickness shear capacity decreased 28% from dry to W1S and 19% from dry to redry conditions. The decrease was 27 and 12% for mean shear rigidity through-the-thickness. Based on the results, the moisture content adjustment factor for shear through-the-thickness capacity was estimated to be 0.75. However, as a high load factor for G_{vt} (higher than 1.5) was used previously in the 1988 TN N375, the moisture content adjustment factor for panel rigidity through-the- thickness was estimated to be 0.85.

Table 2. — Results of interlaminar shear tests for mat-formed panels

Condition	N	MC (%)	SG*	Ratio of Mean f_s (Ib/Q)	Ratio of 5th Percentile f_s (Ib/Q)
Dry	88	7.8	0.62	1.00	1.00
W1S	81	31.6	0.63	0.77	0.79
Redry	93	10.2	0.64	0.91	0.93

* Based on ovendry weight and volume at dry conditions

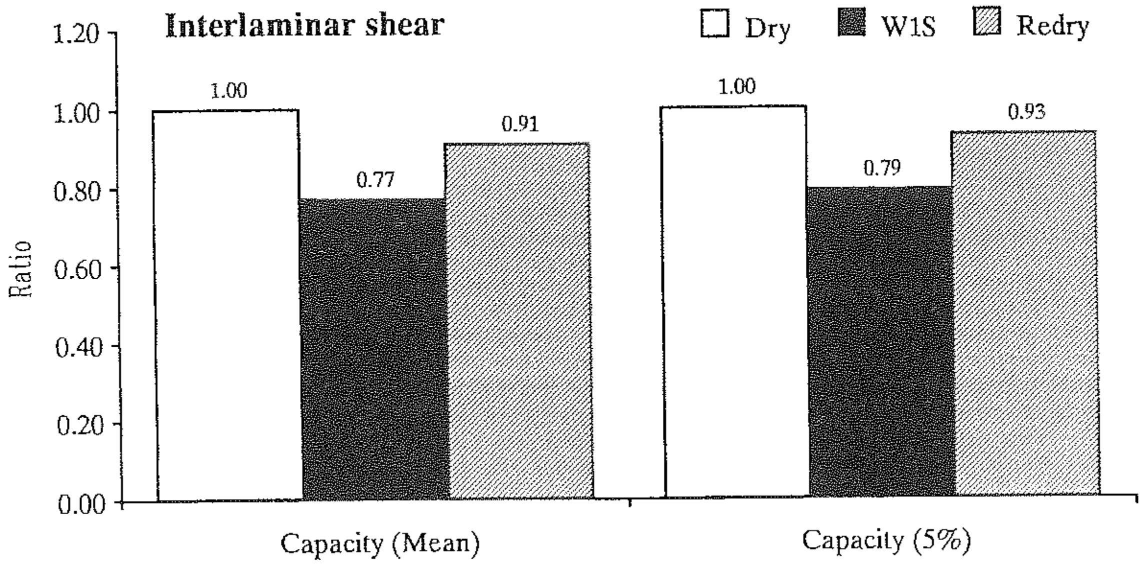

Figure 2.—*Ratio of interlaminar shear properties for mat-formed panels at various test conditions*

Table 3. — Results of through-the-thickness shear tests for mat-formed panels

Condition	N	MC (%)	SG*	Ratio of Mean f_{vt}	Ratio of 5th Percentile f_{vt}	Ratio of Mean G_{vt}
Dry	59	7.9	0.65	1.00	1.00	1.00
W1S	60	27.7	0.64	0.75	0.72	0.73
Redry	60	11.6	0.65	0.85	0.81	0.88

* Based on ovendry weight and volume at dry conditions

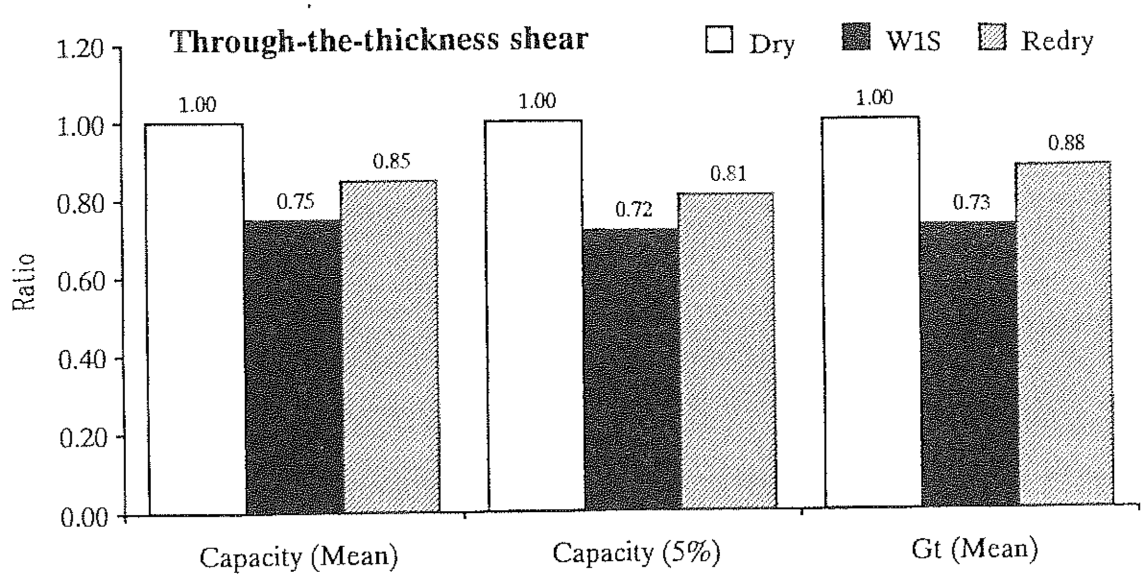

Figure 3.—*Ratio of through-the-thickness shear properties for mat-formed panels at various test conditions*

CREEP ADJUSTMENT FACTOR

When panels sustain permanent loads without removal up to one-half or more of its design strength capacity, it was suggested in the 1988 TN N375 that calculated elastic deflection should be doubled to account for creep deflection. This recommendation, however, was based on limited data available at the time of publication. As design capacities given in the 1988 TN N375 were limited to dry service conditions, the use of doubling calculated elastic deflection was not necessarily applicable to high RH conditions.

In order to characterize creep behavior of structural-use panels, particularly at constantly high and cyclic RH conditions, APA cooperated with the US Forest Products Laboratory (FPL), Forintek Company, and the Waferboard Association (now the Structural Board Association) of Canada in conducting a creep and creep-rupture study. Results obtained from the FPL tests were reported by McNatt and Laufenberg (1991). Table 4 shows the average fractional creep, defined as the ratio of total deflection to initial elastic deflection, for six months of constant loading at the 30% stress level.

At dry service moisture conditions, results given in Table 4 supported the use of the creep adjustment factor of 1/2 for panel EI when calculating deflections. While the same creep adjustment factor could also be applied to plywood at high RH conditions, it was clear that a more restrictive factor was needed for mat-formed panels at such conditions. It should be noted that although the average total deflection for mat-formed panels at high (85%) RH conditions was given as 4.4 times the average elastic deflection in Table 4, test data indicated that the fractional creep for mat-formed panels at such severe environmental conditions could virtually reach the magnitude of 7.1 (Laufenberg and McNatt 1991). Yeh et al. (1988, 1990) reported an even higher fractional creep at cyclic humidity conditions.

Table 4. — Average fractional creep* as adopted from McNatt and Laufenberg (1991)

Condition	Plywood	Mat-Formed
50% Relative Humidity	1.3**	1.5
85% Relative Humidity	1.9	4.4
Cyclic 50-85%	2.1	4.7

* Ratio of total deflection to initial elastic deflection.

** Every data point represents the average of 11 specimens.

In light of the above mentioned results, when panels sustain permanent loads without removal up to one-half or more of its design strength capacity, the creep adjustment factor for plywood was determined to be 1/2, irrespective of service moisture conditions. For mat-formed panels, the factor was 1/2 and 1/6 for dry (below 16% MC) and wet (16% MC or higher) service moisture conditions, respectively. It should be noted that as the creep adjustment factor is cumulative with the moisture content adjustment factor, the actual adjustment on panel EI under long-term loading equal to or higher than 1/2 of design capacity and at wet service moisture conditions becomes 1/2.4 for plywood, and 1/7.1 for mat-formed panels.

SUMMARY

Panel design capacities given in the current APA design specification require adjustments for special end-use conditions. General design adjustment factors include panel grade and construction, duration of load and creep, and service moisture conditions. This paper reviews the research results for deriving the moisture content and creep adjustment factors given in the current APA specification.

Based on research results, the moisture content adjustment factor for interlaminar shear and through-the-thickness shear capacities was given as 0.75. For through-the-thickness shear rigidity, the factor was 0.85. When panels sustain permanent loads without removal up to one-half or more of its design strength capacity, the creep adjustment factor for plywood and mat-formed panels was 1/2 at dry service moisture conditions. When used at wet conditions, the factor was 1/2 for plywood and 1/6 for mat-formed panels. Both creep and moisture content adjustment factors are cumulative.

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