CIB-W18/40-12-5

INTERNATIONAL COUNCIL FOR RESEARCH AND INNOVATION
IN BUILDING AND CONSTRUCTION

WORKING COMMISSION W18 - TIMBER STRUCTURES

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MEETING FORTY
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AUGUST 2007

Creep and Creep-Rupture Behaviour of Structural Composite Lumber Evaluated in Accordance with ASTM D 6815

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Abstract

Structural composite lumber (SCL), as defined in accordance with ASTM D 5456, *Standard Specification for Evaluation of Structural Composite Lumber Products,* includes laminated veneer lumber (LVL), parallel strand lumber (PSL), laminated strand lumber (LSL), and oriented strand lumber (OSL). As there is no consensus-based national or international manufacturing standard for SCL, mechanical properties of SCL products manufactured in North America are proprietary and normally derived following ASTM D 5456. One of the qualification requirements for SCL is the evaluation of its creep and creep-rupture behaviour in accordance with the 90-day long-term bending tests specified in ASTM D 6815, *Standard Specification for Evaluation of Duration of Load and Creep Effects of Wood and Wood-Based Products*.

According to ASTM D 5456, the performance of SCL is affected by many factors, such as wood species, wood element size and shape, adhesive, and manufacturing parameters. As a result, SCL products produced by each individual manufacturer are required to be evaluated separately, regardless of the similarity in product characteristics with other manufacturers. This means each SCL manufacturer is required to evaluate the creep and creep-rupture behaviour of its products individually even though the components of the finished product is similar.

Since the publication of ASTM D 6815 in 2002, APA – The Engineered Wood Association has evaluated the creep and creep-rupture behaviour of many SCL products in accordance with this standard. Therefore, there is a wealth of information in this area. This paper studies the creep and creep-rupture behaviour of SCL products manufactured with a variety of wood species, and SCL types and grades. This information may be used by SCL manufacturers, third-party inspection agencies, regulatory bodies, and standard developers in determining generic creep and creep-rupture effects on SCL products.

1. Introduction

Structural composite lumber (SCL) is a generic term used to describe a family of engineered wood composites. By the definition of ASTM D 5456 [1], *Standard Specification for Evaluation of Structural Composite Lumber Products,* SCL consists of laminated veneer lumber (LVL), parallel strand lumber (PSL), laminated strand lumber (LSL), and oriented strand lumber (OSL). The difference between these SCL products lies mostly in the type and size of the substrates, and the manufacturing processes used to manufacture the finished products.

This SCL classification system by ASTM is a physical differentiation among the subgroups of SCL, but is not necessarily based on product performance. For example, the difference between the relatively new wood composites of LSL and OSL is simply the strand dimension. The strands used in LSL and OSL are defined by the ASTM D07.02 Subcommittee on Lumber and Engineered Wood Products as having an average length of at least 150 times and 75 times, respectively, the least dimension (usually the strand thickness). This ASTM definition is by no means scientific, but reflects the practical limitations of commercially available products at the time of the standard development. While it is true that LSL typically has higher mechanical properties than OSL, some higher grades of OSL may have higher performance characteristics than the lower grades of LSL.

Just like wood I-joists, there are no national or international manufacturing standards in existence today for SCL. However, ASTM D 5456, which was originally published in 1993, has become the basis for product qualification and code recognition in both the US and Canada. In the last 14 years, ASTM D 5456 has evolved through numerous revisions. One of the most recent changes was the adoption of ASTM D 6815 [2], *Standard Specification for Evaluation of Duration of Load and Creep Effect of Wood and Wood-Based Products*, as a requirement for evaluating the long-term performance of SCL.

It is very important to recognize that ASTM D 6815 was not developed for evaluating the true load duration and creep effects on SCL products. Instead, the procedures prescribed in ASTM D 6815 are intended to demonstrate the engineering equivalence to the duration of load and creep effects of solid-sawn lumber when used in dry service conditions. The development of product-specific duration of load or creep factors, or the long-term product performance due to a combination of load duration and changing environmental conditions is considered beyond the scope of ASTM D 6815.

According to ASTM D 5456, the performance of SCL is affected by many factors, such as wood species, wood element size and shape, adhesive, and production parameters. As a result, SCL products produced by each individual manufacturer are required to be evaluated separately, regardless of the similarity in product characteristics with other manufacturers. This means each SCL manufacturer is required to evaluate the creep and creep-rupture behaviour of its products individually even though the components of the finished product is similar.

Since the publication of ASTM D 6815 in 2002, APA – The Engineered Wood Association has evaluated the creep and creep-rupture behaviour of many SCL products as part of the ASTM D 5456 product qualification requirements. Therefore, there is a wealth of information in this area. This paper studies the creep and creep-rupture behaviour of SCL products manufactured with a variety of wood species, and SCL types and grades. This information may be used by SCL manufacturers, third-party inspection agencies, regulatory bodies, and standard developers in determining generic creep and creep-rupture effects on SCL products.

2. Materials and Test Methods

2.1 Products Description

For the purpose of this study, LVL products made with Douglas fir, Southern pine, Spruce, Maritime pine, Eucalyptus, or a mixture of these species, and LSL and OSL products made with Aspen or mixed Aspen and Poplar were conducted. These products were manufactured using a variety of manufacturing equipment and press parameters. All LVL products were manufactured with phenolic adhesives meeting the requirements of ASTM

D 2559 [3], *Standard Specification for Adhesives for Structural Laminated Wood Products for Use Under Exterior (Wet Use) Exposure Conditions*. The LSL and OSL products were made with an MDI binder system. APA does not have data on PSL, which is only produced by one manufacturer in North America. Table 1 describes the materials reported in this study.

Table 1. Product description

Test Series	Product Type	Species	Grade E [(a)]		Adhesive
			MPa	10^6 psi	
A	LVL	Maritime pine	18620	2.7	Phenolic
B	LVL	Eucalyptus/So. Pine (55:45)	17240	2.5	Phenolic
C	LVL	Spruce/D. fir (50:50)	15860	2.3	Phenolic
D	LVL	Douglas fir	15170	2.2	Phenolic
E	LVL	Southern pine	13790	2.0	Phenolic
F	LSL	Aspen	11030	1.6	MDI
G	OSL	Aspen/Poplar	10340	1.5	MDI

[(a)] Mean value from short-term bending tests using matched specimens

2.2 Test Methods

To evaluate the long-term performance of SCL products, ASTM D 6815 requires the applied load for the long-term (90-day) specimens to be based on 55% of the 5th percentile parametric point estimate of the short-term bending load using matched specimens. This load level was selected based on the review of long-term performance of solid-sawn lumber. It should be noted that the choice of the 5th percentile parametric point estimate, as opposed to the 5th percentile with 75% confidence that is commonly used for the design value derivation, was meant to be conservative because the point estimate gives a higher value (i.e., higher applied load on the long-term specimens) than the characteristic value with 75% confidence. Also, it is noted that the applied load for the long-term specimens was based on the ultimate load (i.e., the moment capacity of the specimens), instead of the bending stress, of the short-term specimens. This may be critical to specimens that would experience significant dimensional changes (e.g., thickness swell) due to fluctuations in surrounding environments.

The short-term specimens were tested edgewise in a universal testing machine using the third-point loading method, as shown in Figure 1, with an on-centre span of 1143 mm (45 inches) or 1372 mm (54 inches). The specimen depth was mostly 63.5 mm (2-1/2 inches), resulting in a span-to-depth ratio ranging from 18:1 to 27:1. The higher span-to-depth ratio (i.e., 27:1) helped to reduce the dead weight required for creep tests, but is still in compliance with ASTM D 6815. The load rate for the short-term tests was set to fail the specimen in approximately 1 minute. All specimens were preconditioned at the indoor laboratory conditions for at least 30 days prior to the long-term tests.

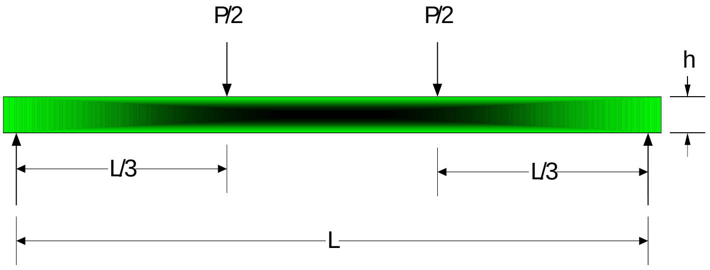

Figure 1. Bending test configuration (L/h = 18 to 27)

Long-term bending tests were performed on the specimens that were side-matched with the short-term specimens from the same production billets using a test frame designed and fabricated by APA staff. The test span and loading configuration were identical to the short-term specimens. Figures 2 and 3 are simplified schematic diagrams of the creep test frame. The dead load was independently applied to each individual specimen through a third-point loading harness. An adjustable weight was attached to a lever to magnify the load to achieve the desired dead load. Deflection was measured with a linear potentiometer mounted on a tripod placed on the top of the specimens. Deflection was continuously measured with a computerized data acquisition system.

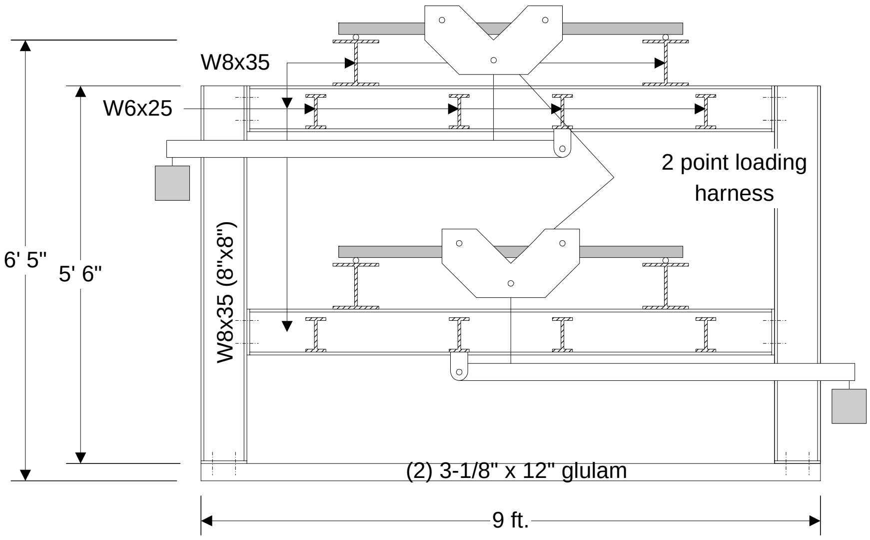

Figure 2. Schematic diagram of long-term bending frame in end elevation
(1 inch = 25.4 mm; 1 foot = 305 mm)

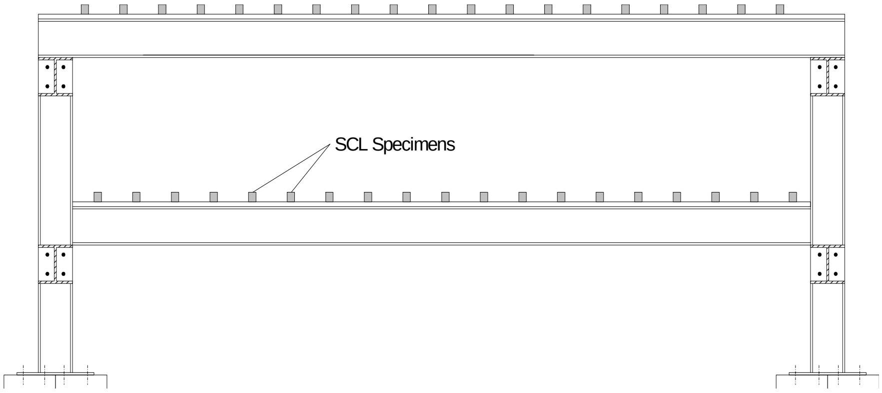

Figure 3. Schematic diagram of long-term bending frame in side elevation

The dead load was individually adjusted until the desired load was achieved on each specimen. Each weight was checked by measuring the applied load through a load cell located on the reaction of each individual specimen. Once all of the weights were adjusted, the weights were fixed to the levers and load was applied to the specimens over a 1-minute time period. All long-term tests were conducted in uncontrolled indoor laboratory conditions, which had a fluctuation of temperature between 18 and 29°C (65 to 85°F) and relative humidity between 40 to 70%. A data logger was used to measure the environmental conditions of the area where the creep tests were conducted throughout the entire long-term test period.

Each test series is required by ASTM D 6815 to contain a minimum of 28 specimens for side-matched short-term and long-term tests (minimum 56 specimens total). However, the test results reported below are based on 28 to 32 long-term specimens. The additional specimens beyond the minimum were intended to provide a safety net in case there was a malfunction of any individual linear potentiometers during the long-term test period. Table 2 shows the specimen dimensions and test details.

Table 2. Specimen dimensions and test details

Test Series	Product	No. of Spc.	Width, b (mm)	Depth, h (mm)	Applied Load, P (kN)	Span, L (mm)	L/h	Estimated Initial Strain (mm/mm)
A	2.7E LVL	30	38.1	63.5	5.4	1372	21.6	0.0026
B	2.5E LVL	30	44.5	63.5	6.5	1143	18.0	0.0024
C	2.3E LVL	31	44.5	63.5	5.3	1372	21.6	0.0026
D	2.2E LVL	31	44.5	63.5	5.3	1372	21.6	0.0027
E	2.0E LVL	32	44.5	50.8	2.7	1372	27.0	0.0024
F	1.6E LSL	31	38.1	63.5	3.4	1143	18.0	0.0023
G	1.5E OSL	28	44.5	63.5	3.7	1143	18.0	0.0023

Assuming the bending strain at the extreme fibre of the specimen remains elastic on the application of load (55% of the 5th percentile point estimate), Table 2 also shows the estimated initial bending strain at the extreme fibre, as calculated using elastic engineering mechanics. It is interesting to note that the estimated initial bending strains for all 7 products were in the range of 0.2 to 0.3%.

3. Results and Discussions

Figures 4 through 10, as provided in the end of this paper, show the creep deflections of the LVL, LSL, and OSL products throughout the test duration. As noted from these figures, these products follow a similar trend as solid-sawn lumber under long-term loading. ASTM D 6815 prescribes the following 3 acceptance criteria for a product to demonstrate the engineering equivalence to the duration of load and creep effects on solid-sawn lumber:

1. No specimen shall be allowed to fail if the minimum sample size is 28,
2. Fractional deflection at the 90th day for each individual specimen shall not be greater than 2, and
3. All specimens shall show a decreasing creep rate over the 90-day test period.

None of the specimens failed in any of the 7 products reported in this study, which satisfied the first criterion.

3.1 Initial Deflection

ASTM D 6815 defines the initial deflection as the deflection that is measured 1 minute after the application of load. Table 3 compares the calculated deflection based on an elastic beam equation and the measured deflection at 1 minute after the application of load for Series A, B, F, and G (the calculated deflection data for Series C, D, and E are not available because the modulus of elasticity of the long-term specimens, which is not required by ASTM D 6815, was not tested). Results shown in Table 3 suggest that the measured initial deflection per ASTM D 6815 is in good agreement with the calculated elastic deflection.

Table 3. Comparison of calculated and measured initial deflections

Test Series	Product	Mean Calculated Deflection [(a)] (mm)	Measured Initial Deflection [(b)]		Ratio [(c)]
			Mean (mm)	COV	
A	2.7E LVL	15.9	16.5	0.030	1.04
B	2.5E LVL	12.3	11.6	0.051	0.94
F	1.6E LSL	9.7	9.8	0.054	1.01
G	1.5E OSL	9.9	9.5	0.050	0.95

[(a)] Calculated based on the dimensions and MOE of each specimen for long-term loading

[(b)] Measured at 1 minute after the application of load

[(c)] The mean measured initial deflection divided by the mean calculated deflection

3.2 Fractional Deflection

Fractional deflection is defined by ASTM D 6815 as the ratio of the deflection at a test duration and the initial deflection measured 1 minute after the application of load. In the US timber design code, *National Design Specification for Wood Construction* (NDS) [4], the time-dependent deflection (creep) factor is limited to no greater than 1.5 and 2.0 times the elastic deflection due to long-term loading in dry and wet service conditions, respectively. Due to the relative high dead load specified in the standard, ASTM D 6815 prescribes the fractional deflection of each individual specimen (not the average of all specimens in a test series) to be no greater than 2.0 at a 90-day test duration. Table 4 shows the fractional deflection at the 90-day test duration for all 7 products evaluated in this study. As shown, the maximum fractional deflection for these products at the 90-day test duration was 1.38, which is lower than 1.5.

Table 4. Factional deflection at the 90-day test duration

Test Series	Product	Fractional deflection at the 90-day test duration			
		Maximum	Mean	Minimum	COV
A	2.7E LVL	1.31	1.23	1.18	0.024
B	2.5E LVL	1.21	1.19	1.16	0.013
C	2.3E LVL	1.20	1.16	1.13	0.015
D	2.2E LVL	1.20	1.15	1.11	0.020
E	2.0E LVL	1.32	1.26	1.21	0.023
F	1.6E LSL	1.31	1.26	1.23	0.013
G	1.5E OSL	1.38	1.34	1.32	0.013

3.3 Diminishing Creep Rate

It is obvious that the purpose of specifying the diminishing creep rate in ASTM D 6815 is to avoid the acceptance of a product from the tertiary creep. A typical evaluation of diminishing creep rate is to divide the test duration into 3 thirty-day periods and show that the creep deflection at the second period (30 to 60 days) is less than the first period (0 to 30 days), and the third period (60 to 90 days) is less than the second period. While this is simple, there are cases when the creep deflections in the second and third periods are both very small and therefore, it is not unusual that this criterion is violated due to the temperature and relative humidity fluctuations in the uncontrolled test environment, as previously mentioned. In such cases, ASTM D 6815 permits the test duration to be extended for additional 30 days (total 120 days).

Among all 7 products evaluated in this study, all specimens meet the diminishing creep rate requirements except for the 2.7E LVL (Test Series A), which had a maximum creep deflection of 0.50 mm (0.020 inch) during the second period and 0.58 mm (0.023 inch) during the third period due to a significant relative humidity fluctuation in the third period. As a result, the test series was extended to 120 days and the fourth period (90 to 120 days) had a maximum creep deflection of 0.33 mm (0.013 inch), which satisfied the requirement of ASTM D 6815.

3.4 Residual Bending Strength and Modulus of Elasticity

While ASTM D 6815 does not require the residual bending strength and modulus of elasticity of each specimen be measured at the end of the long-term testing, some selected products were tested to destruction after the 90-day (120-day for the 2.7E LVL) loading using the same test setup as the matched short-term specimens. This information is helpful for the evaluation of the strength and stiffness degradation, if any, due to the long-term loading. Table 5 shows the residual MOR and MOE ratios of the 2.7E LVL, 1.6E LSL, and 1.5E OSL.

Table 5. Ratios of the mean bending strength and modulus of elasticity between the long-term and matched short-term specimens

Test Series	Product	Ratio of the Mean Residual Properties [(a)]	
		MOR	MOE
A	2.7E LVL	0.99	0.99
F	1.6E LSL	0.96	0.99
G	1.5E OSL	1.06	1.03

[(a)] The ratio between the long-tern specimens after the test duration and matched short-term specimens

In reviewing the data provided in Table 5, it should be recognized that the comparison was based on matched specimens, but not exactly the same specimens (the same specimen could not be tested to destruction twice), and therefore, the between-specimen variations should be considered. Besides, the moisture conditions were apparently not the same in the 90-day test period. With these considerations in mind, it seems reasonable to conclude that there was a negligible long-term loading effect on the bending properties of the SCL products reported in this study.

4. Conclusion

Based on the evaluation of creep and creep rupture behaviour of 7 SCL products that covered a wide range of elastic properties, product types (LVL, LSL, and OSL), and manufacturing parameters in accordance with the procedures of ASTM D 6815, it is reasonable to conclude that the SCL products, if properly manufactured, have demonstrated the engineering equivalence to the duration of load and creep effects of solid-sawn lumber when used in dry service conditions. There is strong evidence that the LVL products (5 out of 7 products evaluated in this study) manufactured with today's technology have a similar creep and creep rupture behaviour as solid-sawn lumber. In fact, there has not been a single instance, as far as APA is aware, when an LVL product failed to meet ASTM D 6815 requirements in the last 10 years. Therefore, an opportunity exists for standardizing the creep and creep rupture factors for LVL products without the expensive and time-consuming long-term tests, provided that the LVL product is manufactured with an adhesive, wood species, and manufacturing parameters typical of those evaluated.

On the other hand, the newer generation of SCL products, such as LSL and OSL, tends to be more innovative than LVL in the use of adhesive binder systems, wood species, strand geometry, and other manufacturing parameters. Therefore, more long-term test data are needed for LSL and OSL to gain the same confidence as the LVL products on their creep and creep rupture behaviour.

At this point, ASTM D 6815 is a go-no-go standard that does not provide an alternative if a SCL product fails to meet the prescribed acceptance criteria. This may pose a challenge for the market access of newer products. In recognizing this need, the ASTM D07 Committee on Wood, which has jurisdiction over the ASTM D 5456 and D 6815 standards, has initiated the dialogue among its key members for the development of a standard that would allow the establishment of unique creep and creep rupture factors for the new generation of structural composite lumber in the future.

5. References

1. ASTM International. 2006. *Standard Specification for Evaluation of Structural Composite Lumber Products.* ASTM D5456-06. West Conshohocken, PA.

2. ASTM International. 2006. *Standard Specification for Evaluation of Duration of Load and Creep Effects of Wood and Wood-Based Products*. ASTM D6815-02a. West Conshohocken, PA.

3. ASTM International. 2006. *Standard Specification for Adhesives for Structural Laminated Wood Products for Use Under Exterior (Wet Use) Exposure Conditions*. ASTM D2559-04. West Conshohocken, PA.

4. American Forest & Paper Association. 2005. *National Design Specification for Wood Construction*. Washington, D.C.

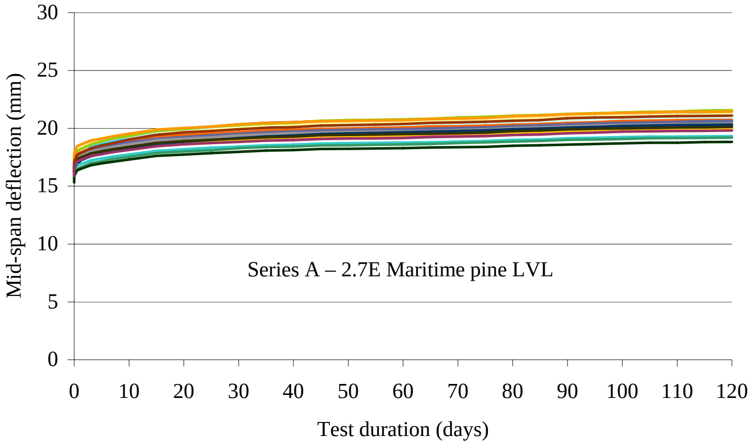

Figure 4. Series A – 2.7E Maritime pine LVL

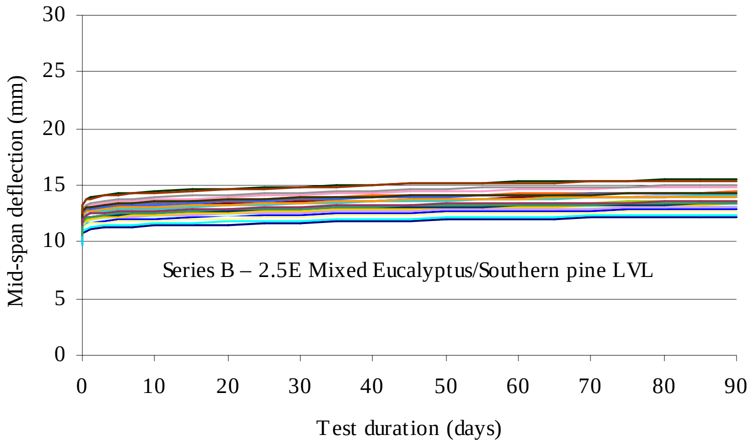

Figure 5. Series B – 2.5E Mixed Eucalyptus/Southern pine LVL

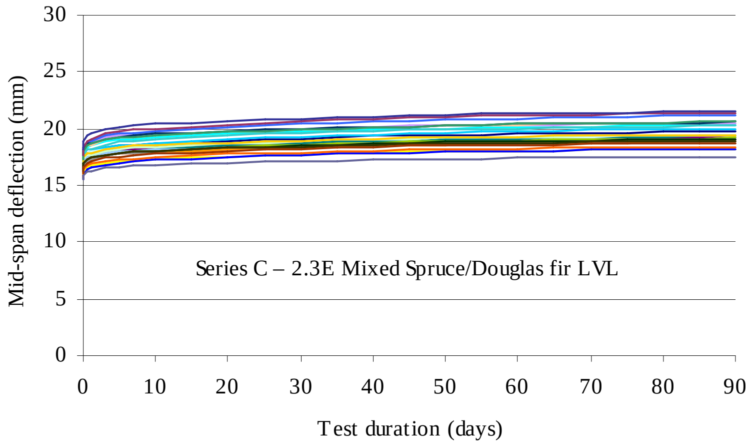

Figure 6. Series C – 2.3E Mixed Spruce/Douglas fir LVL

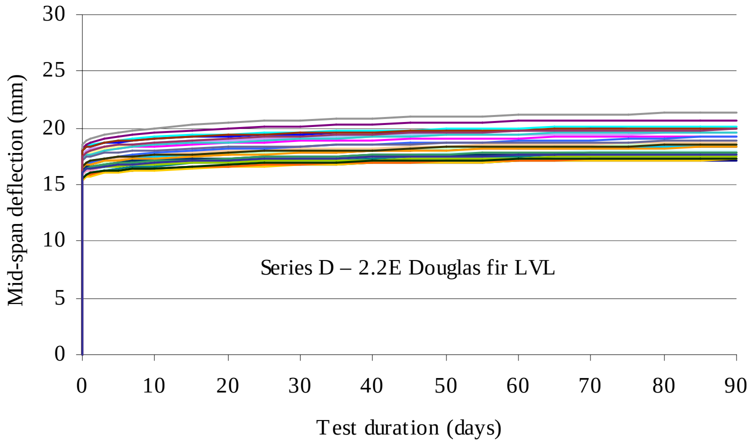

Figure 7. Series D – 2.2E Douglas fir LVL

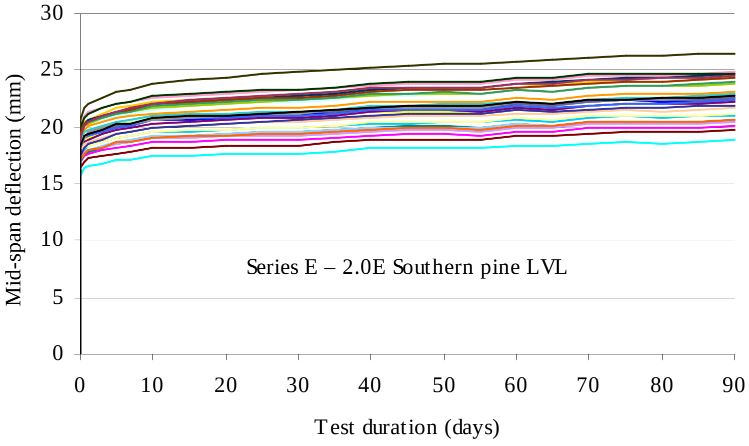

Figure 8. Series E – 2.0E Southern pine LVL

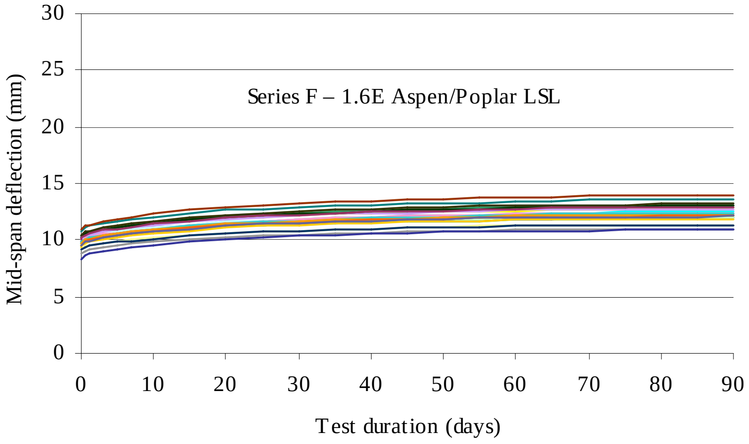

Figure 9. Series F – 1.6E Aspen LSL

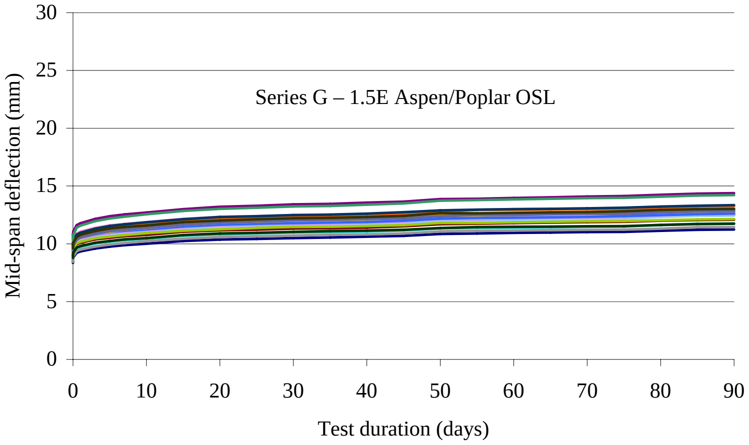

Figure 10. Series G – 1.5E Aspen/Poplar OSL