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Creep Behavior of Structural Insulated Panels (SIPs)

Results from a Pilot Study

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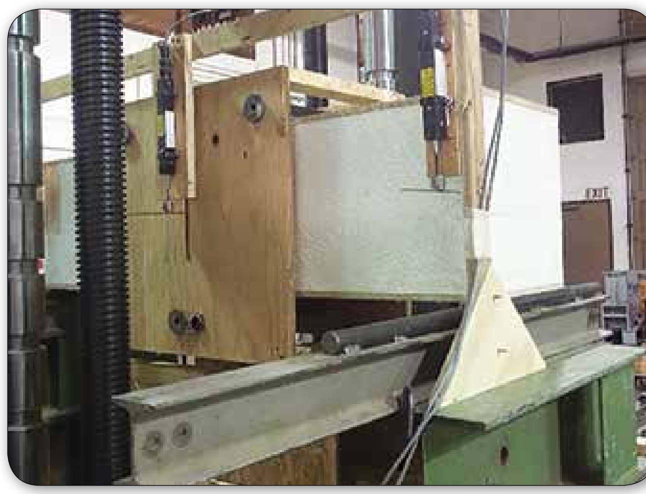

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Abstract

Structural insulated panels (SIPs) have been recognized as construction materials in the International Residential Code (IRC) since 2009. Although most SIPs are used in wall applications, they can also be used as roof or floor panels that are subjected to long-term transverse loading, for which SIP creep performance may be critical in design. However, limited information on creep performance of SIPs under transverse loading is available. Collaborative pilot studies were undertaken by the USDA Forest Products Laboratory and APA–The Engineered Wood Association to explore the creep behavior of SIPs under bending- and shear-critical configurations. Results from these pilot studies will serve as the basis for more comprehensive future studies. This paper provides detailed test results from these pilot studies.

Keywords: creep, structural insulated panels

Conversion Table

English unit	Conversion factor	SI unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
pounds per cubic foot (lb/ft^3)	16.018	kilograms per cubic meter (kg/m^3)
pounds per square foot (lb/ft^2)	47.880	pascal (Pa)
pound force (lbf)	4.448	newton (N)
Temperature (°C) = [Temperature (°F) – 32] / 1.8		

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Results from a Pilot Study

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Introduction

The USDA Forest Products Laboratory (FPL) and cooperators such as APA–The Engineered Wood Association have a long history of researching the properties and performance characteristics of sandwich-type products. Structural insulated panels (SIPs) are a commercially available product that has evolved from early FPL sandwich material research. SIPS are now in wide use throughout both residential and nonresidential construction industries, with over 70 million square feet produced on a yearly basis. Several in-service concerns have arisen related to the use of SIPs, and answers to these concerns would greatly enhance the growth of the SIP industry. For example, limited data are available for the creep performance of SIPs under in-service conditions. This paper summarizes results of a pilot study designed to investigate the creep characteristics of SIPs under indoor environmental conditions.

Background

Structural insulated panels are a composite building material. They consist of a sandwich of two layers of structural facers with an insulating layer of foam plastic insulation adhered between. The facers can be sheet metal, oriented strandboard (OSB), or other materials, and the foam plastic insulation is usually expanded polystyrene (EPS), extruded polystyrene (XPS), or polyurethane foam.

Structural insulated panels have structural properties similar to those of an I-beam or I-column. The rigid insulation core of the SIP performs as a web, and the facers perform as flanges. Structural insulated panels replace several components of conventional buildings, such as studs and joists, insulation, vapor barrier, and air barrier. As such they can be used for many different applications, such as exterior wall, roof, and floor systems.

Structural insulated panels are most commonly made of OSB panels sandwiched around a foam core made of EPS, XPS, or rigid polyurethane, but other materials can be used, such as plywood, steel, aluminum, cementitious panels, and even exotic materials such as stainless steel, fiber-reinforced plastic, and magnesium oxide. Some SIPs use fiber-cement or plywood for the panels, and agricultural fiber, such as wheat straw, for the core. This study considered only SIPs made with OSB facings and an EPS core.

Creep is the tendency of a solid material to deform slowly under the influence of sustained load. It occurs as a result of long-term exposure to levels of stress that are below the yield strength of the material. Creep increases with higher temperatures.

The rate of creep deformation is a function of material properties, exposure time, exposure temperature, moisture, and applied structural load. Depending on the magnitude of the applied load and its duration, deformation may become so large that a component can no longer perform its intended function.

Structural insulated panels are frequently used in both floor and roof application. Historically, determination of transverse load capacities of SIPs for these applications has been conducted using ASTM E 72, which is a short load duration test. Limited data are available describing the creep performance of SIPs under long-term loading conditions that are likely to occur during in-service use. The purpose of the pilot test program described here was to investigate the long-term creep performance characteristics of SIPs used in horizontal loading applications based on a relatively small sample size. This pilot test program is intended to lead to a larger scale test program based on ASTM D 6815 to develop specific design recommendations for SIPs with respect to creep deformation.

Materials and Methods

Material Selection and Specimen Preparation

The test specimens were sampled from a regular production run and are representative of the product under evaluation. Two matched paired test groups were selected, one for short-term bending tests, and one for long-term creep-rupture bending tests. Forty-eight 12-in.-wide by 12.25-in.-deep by 20-ft sections were manufactured by a Structural Insulated Panel Association (SIPA) member for testing, each with 11.25-in.-thick nominal 1.0-lb/ft^3 density ASTM C 578, Type 1 expanded polystyrene (EPS) foam cores. Twenty-foot-long sections were delivered to the FPL, and matching 4-ft-long sections were delivered to APA. The panel facings consisted of APA-rated, 7/16 Performance Category, Exposure 1, 24/16 span rated OSB sheathing on both sides. The OSB complied with the requirements contained in ANSI/APA PRS 610.1-2013. The test samples were constructed with the OSB strength axis parallel with the panel length. The core and the OSB facings were bonded with an approved adhesive conforming to ICC-ES AC05 requirements. Hem–Fir, No. 2 and better nominal 2- by 12-in. lumber was purchased locally for end blocking. For the end blocking, the International Residential Code (IRC) detail was followed, and 8d common (0.131 by 2.5 in.) nails were hand-driven at 6 in. on center.

Table 1 shows specimen and test configuration details, and Figure 1 shows the end conditions for SIP specimens, as noted in Table 1. The relatively long-span (span-to-depth ratio of 18:1) and short-span (span-to-depth ratio of 4:1) tests at the FPL and APA, respectively, are intended for evaluation of bending and shear creep performance.

Test Methods

All testing was conducted using ASTM D 6815 as the basis. Testing conducted at FPL was in a controlled environment of 70 °F and 50% relative humidity (RH). The testing conducted at APA was at indoor laboratory ambient conditions, which were monitored throughout the creep tests. All test specimens were simply supported and loaded by two equal concentrated forces spaced a distance of one-third the total span from the end supports. The loading rate for the short-term test was such that the target failure load was achieved in approximately 1 min. The creep test specimens were loaded such that the average time to attain the preselected constant stress level did not exceed the average time to failure of the short-term tests. The specimens were subjected to three long-term test loads (33%, 22%, and 11% of the average maximum short-term failure load) for a minimum period of 90 days. During this period, midspan deflection readings were taken for each specimen until the 90-day time period has elapsed. At a minimum, deflection readings were taken at approximately once per second after the application of the constant load (initial deflection), and every minute for the first hour, then every 30 min for the next 120 days, including a 30-day creep recovery.

The test loads was removed after 90 days, and the midspan deflections continued to be monitored for the remaining 30 days. After the creep recovery period, all specimens were tested in the same manner as the short-term (control) tests to determine the residual strength of each specimen after the 90-day creep loading.

Test results obtained from the short-term (control) and 90-day creep tests and residual strength after the creep tests, are provided in Tables 2 to 11.

Results and Discussion

The FPL testing was performed as outlined in Figures 2 to 5, and the APA testing was performed as outlined in Figures 6 and 7. All test specimens from both FPL and APA survived the 90-day constant loads without a bending failure. Based on the equations in X2.3 of ASTM D 6815, the creep rate and fractional deflection were calculated and are summarized in Tables 10 and 11. Deflection plots and creep values are shown in Figures 8 to 11. Typical failure modes from the short-term (control) and creep recovery tests are shown in Figures 12 to 14. No significant strength loss was observed after 90 days of loading (see the average P_{Max} in Tables 2 to 9).

Conclusions and Recommendations

The next phase of testing will attempt to develop creep factors for this specific product with statistical factors in accordance with ASTM D 6815. A wood or wood-based product that meets the criteria of ASTM D 6815 would be one that exhibits duration of load performance that is characteristic of structural lumber in its dry-use condition.

Table 1. Specimen and test configuration details[a]

Test number	End condition	Load level	Number of samples	Duration
1	Foam flush	Average maximum load of short term bending tests	3	1 min
1a	Foam flush	(Test no. 1 load) × 1/3	3	90 days
1b	Foam flush	(Test no. 1a load) × 2/3	3	90 days
1c	Foam flush	(Test no. 1a load) × 1/3	3	90 days
2	2× end block	Average maximum load of short term bending tests	3	1 min
2a	2× end block	(Test no. 2 load) × 1/3	3	90 days
2b	2× end block	(Test no. 2a load) × 2/3	3	90 days
2c	2× end block	(Test no. 2a load) × 1/3	3	90 days

[a]Specimens were 12 in. wide by 12.25 in. deep. Test spans for FPL and APA were 18 ft and 4 ft, respectively.

Table 2. FPL short-term bending, foam flush ends[a]

Sample ID	*EI* (×10^6 lbf-in^2)	Max *M* (×10^3 lbf-in.)	Slope (lbf/in.)	Ext P_{Max} (in.)	P_{Max} (lbf)
1A	150.5	72.4	841.70	2.610	2,011
13A	148.5	44.5	830.38	1.538	1,237
16A	144.4	72.7	807.60	2.755	2,021
22A	150.4	44.1	840.81	1.505	1,226
23A	161.3	45.5	901.65	1.476	1,264
24A	159.5	75.9	892.02	1.906	2,109
31A	149.8	40.9	837.34	1.421	1,136
38A	149.5	44.3	836.00	1.556	1,232
43A	147.6	44.4	825.52	1.533	1,233
Average	151.3	53.9	845.89	1.811	1,497
COV[b]	0.04	0.28	0.04	0.28	0.28

[a]Specimens were 12 in. wide by 12.25 in. deep. Test span and shear leg length were 18 ft and 72 in., respectively. Two failure modes were observed, each with a consistent strength value: Specimen that had adhesion failure failed near 1,200 lbf. Specimen that had flange compression failed near 2,000 lbf.
[b]COV, coefficient of variation.

Table 3. FPL short-term bending, 2× end block[a]

Sample ID	*EI* (×10^6 lbf-in^2)	Max *M* (×10^3 lbf-in.)	Slope (lbf/in.)	Ext P_{Max} (in.)	P_{Max} (lbf)
27A	144.7	39.9	809.15	1.407	1,109
28A	149.5	41.2	835.85	1.434	1,145
30A	146.9	46.5	821.33	1.627	1,291
34A	149.2	43.6	834.26	1.492	1,210
36A	154.6	47.4	864.59	1.625	1,317
40A	155.5	70.8	869.26	2.396	1,966
41A	148.5	71.8	830.05	2.640	1,996
45A	145.0	46.9	810.91	1.673	1,304
46A	145.9	45.9	815.55	1.631	1,276
Average	148.9	50.5	832.33	1.769	1,402
COV	0.03	0.24	0.03	0.25	0.24

[a]Specimens were 12 in. wide by 12.25 in. deep. Test span and shear leg length were 18 ft and 72 in., respectively. Two failure modes were observed, each with a consistent strength value: Specimen that had adhesion failure failed near 1,200 lbf. Specimen that had flange compression failed near 2,000 lbf.
[b]COV, coefficient of variation.

Table 4. FPL bending after creep, foam flush ends[a]

Sample ID	*EI* ($\times 10^6$ lbf-in^2)	Max *M* ($\times 10^3$ lbf-in.)	Slope (lbf/in.)	Ext P_{Max} (in.)	P_{Max} (lbf)
3A	153.5	42.0	858.51	1.437	1,167
15A	153.7	44.1	859.37	1.558	1,225
20A	152.0	46.1	849.66	1.609	1,280
4A	152.6	43.5	853.49	1.473	1,209
9A	154.0	74.4	860.79	2.664	2,067
19A	146.2	44.9	817.24	1.609	1,248
2A	148.9	41.9	832.38	1.444	1,165
8A	151.9	79.4	849.17	2.936	2,205
18A	145.9	46.5	815.90	1.658	1,292
Average	151	51.4	844.06	1.821	1,429
COV[b]	0.02	0.28	0.02	0.31	0.28

[a]Specimens were 12 in. wide by 12.25 in. deep. Test span and shear leg length were 18 ft and 72 in., respectively.
[b]COV, coefficient of variation.

Table 5. FPL bending after creep, 2× end block[a]

Sample ID	*EI* ($\times 10^6$ lbf-in^2)	Max *M* ($\times 10^3$ lbf-in.)	Slope (lbf/in.)	Ext P_{Max} (in.)	P_{Max} (lbf)
37A	159.0	46.6	888.85	1.577	1,293
39A	152.4	47.6	852.27	1.620	1,323
48A	151.1	87.5	844.80	3.422	2,431
42A	145.2	38.4	812.02	1.348	1,065
47A	145.3	44.1	812.28	1.565	1,224
29A	145.9	47.0	815.80	1.668	1,306
26A	149.3	45.7	834.61	1.594	1,269
32A	190.7	81.2	1066.36	3.169	2,256
35A	202.5	36.4	1132.11	0.962	1,012
Average	160.2	52.7	895.46	1.881	1,464
COV[b]	0.13	0.35	0.13	0.44	0.35

[a]Specimens were 12 in. wide by 12.25 in. deep. Test span and shear leg length were 18 ft and 72 in., respectively.
[b]COV, coefficient of variation.

Table 6. APA short-term bending, foam flush end detail[a]

Sample ID	P_{Max} (lbf)	Midspan deflection (in.) at four loads			
		P_{Max}	695 lbf	463 lbf	232 lbf
17B	1,826	1.102	0.154	0.096	0.043
11B	2,045	1.375	0.114	0.070	0.029
14B	1,892	1.175	0.140	0.089	0.042
7B	2,164	1.245	0.096	0.049	0.009
24B	2,194	1.510	0.147	0.094	0.044
12B	2,051	1.312	0.129	0.080	0.036
23B	2,097	1.483	0.135	0.087	0.038
10B	2,160	1.505	0.120	0.075	0.033
6B	2,331	1.505	0.110	0.067	0.032
Average	2,084	1.357	0.127	0.079	0.034
COV[b]	0.07	0.12	0.15	0.19	0.32

[a]Specimens were 12 in. wide by 12.25 in. deep. Test span was 4 ft.
[b]COV, coefficient of variation.

Table 7. APA short-term bending, 2× end block detail[a]

Sample ID	P_{Max} (lbf)	Midspan deflection (in.) at four loads			
		P_{Max}	469 lbf	313 lbf	156 lbf
45B	1,487	0.339	0.102	0.064	0.023
40B	1,578	0.233	0.055	0.033	0.009
27B	1,399	0.226	0.065	0.041	0.020
28B	1,493	0.245	0.054	0.027	0.005
36B	1,596	0.259	0.061	0.037	0.014
30B	1,129	0.184	0.064	0.041	0.019
46B	1,419	0.279	0.085	0.057	0.030
41B	1,387	0.341	0.137	0.104	0.063
34B	1,173	0.158	0.055	0.033	0.013
Average	1,407	0.252	0.075	0.049	0.022
COV[b]	0.12	0.25	0.37	0.49	0.79

[a]Specimens were 12 in. wide by 12.25 in. deep. Test span was 4 ft.
[b]COV, coefficient of variation.

Table 8. APA bending after creep, foam flush end detail[a]

Sample ID	P_{Max} (lbf)	Midspan deflection (in.) at four loads			
		P_{Max}	695 lbf	463 lbf	232 lbf
2B	2,029	1.172	0.159	0.103	0.043
8B	2,002	0.921	0.136	0.085	0.025
18B	2,133	1.489	0.162	0.104	0.049
4B	2,210	1.598	0.146	0.094	0.041
9B	1,986	1.132	0.160	0.104	0.032
19B	2,007	1.412	0.229	0.136	0.052
3B	1,972	1.365	0.136	0.078	0.030
15B	2,063	1.366	0.145	0.065	0.026
20B	1,887	1.151	0.146	0.087	0.033
Average	2,032	1.290	0.158	0.095	0.037
COV[b]	0.05	0.16	0.18	0.21	0.27

[a]Specimens were 12 in. wide by 12.25 in. deep. Test span was 4 ft.
[b]COV, coefficient of variation.

Table 9. APA bending after creep, 2× end block detail[a]

Sample ID	P_{Max} (lbf)	Midspan deflection (in.) at four loads			
		P_{Max}	469 lbf	313 lbf	156 lbf
26B	1,525	0.305	0.094	0.063	0.029
32B	1,525	0.279	0.072	0.045	0.019
35B	1,620	0.498	0.061	0.038	0.013
29B	1,644	0.330	0.080	0.050	0.021
42B	1,242	0.242	0.079	0.051	0.023
47B	1,382	0.266	0.078	0.051	0.021
37B	1,471	0.232	0.058	0.037	0.014
39B	1,575	0.253	0.060	0.025	0.007
48B	1,592	0.325	0.084	0.052	0.024
Average	1,508	0.303	0.074	0.046	0.019
COV[b]	0.08	0.27	0.17	0.24	0.35

[a]Specimens were 12 in. wide by 12 ¼ in. deep. Test span was 4 ft.
[b]COV, coefficient of variation.

Table 10. FPL creep and recovery summary

Sample ID	Load	Ends	Initial deflection under load (in.)	Group average (in.)	Final creep deflection (in.)	Group average (in.)	Fractional creep (%)	Group average (%)	Residual deflection after recovery (in.)	Group average (in.)
35A	High	Block	0.587	0.607	0.369	0.304	63	50	0.085	0.068
26A	High	Block	0.644		0.316		49		0.082	
32A	High	Block	0.588		0.226		38		0.037	
18A	High	Foam	0.697	0.714	0.349	0.195	50	27	0.124	0.086
2A	High	Foam	0.725		0.218		30		0.111	
8A	High	Foam	0.720		0.017		2		0.023	
47A	Medium	Block	0.684	0.615	0.103	0.051	15	8	0.045	0.033
29A	Medium	Block	0.575		0.006		1		0.025	
42A	Medium	Block	0.585		0.056		10		0.028	
19A	Medium	Foam	0.595	0.555	0.181	0.137	30	24	0.047	0.037
4A	Medium	Foam	0.549		0.136		25		0.040	
9A	Medium	Foam	0.521		0.094		18		0.022	
39A	Low	Block	0.293	0.266	0.104	0.074	36	27	0.011	0.014
48A	Low	Block	0.265		0.058		22		0.023	
37A	Low	Block	0.241		0.059		25		0.010	
20A	Low	Foam	0.232	0.230	0.091	0.110	39	48	0.020	0.021
3A	Low	Foam	0.249		0.127		51		0.009	
15A	Low	Foam	0.210		0.113		54		0.036	

Table 11. APA creep and recovery summary

Sample ID	Load	Ends	Initial deflection under load (in.)	Group average (in.)	Final creep deflection (in.)	Group average (in.)	Residual deflection after recovery (in.)	Group average (in.)
26B	High	Block	0.080	0.066	0.143	0.123	0.053	0.041
32B	High	Block	0.068		0.122		0.049	
35B	High	Block	0.049		0.104		0.021	
2B	High	Foam	0.100	0.113	0.246	0.288	0.066	0.077
8B	High	Foam	0.114		0.283		0.065	
18B	High	Foam	0.125		0.334		0.099	
29B	Medium	Block	0.039	0.044	0.091	0.086	0.029	0.040
42B	Medium	Block	0.047		0.096		0.045	
47B	Medium	Block	0.045		0.072		0.047	
4B	Medium	Foam	0.059	0.060	0.102	0.113	0.006	0.012
9B	Medium	Foam	0.067		0.118		0.004	
19B	Medium	Foam	0.055		0.118		0.027	
37B	Low	Block	0.004	0.011	0.016	0.029	0.005	0.016
39B	Low	Block	0.010		0.028		0.020	
48B	Low	Block	0.018		0.042		0.022	
3B	Low	Foam	0.020	0.016	0.035	0.031	0.010	0.012
15B	Low	Foam	0.019		0.032		0.002	
20B	Low	Foam	0.009		0.026		0.024	

Figure 1. End conditions for blocked (top) and foam flush (bottom).

Figure 2. FPL static loading diagram.

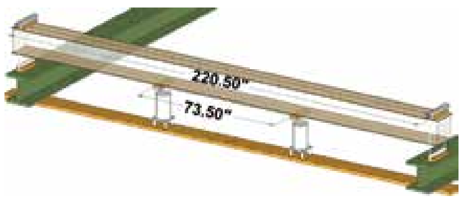

Figure 3. Creep loading diagram (FPL).

Figure 4. Static bending test setup (FPL).

Figure 5. Creep test setup (FPL).

Figure 6. Static bending test setup (APA–The Engineered Wood Association).

Figure 7. Creep test setup (APA–The Engineered Wood Association).

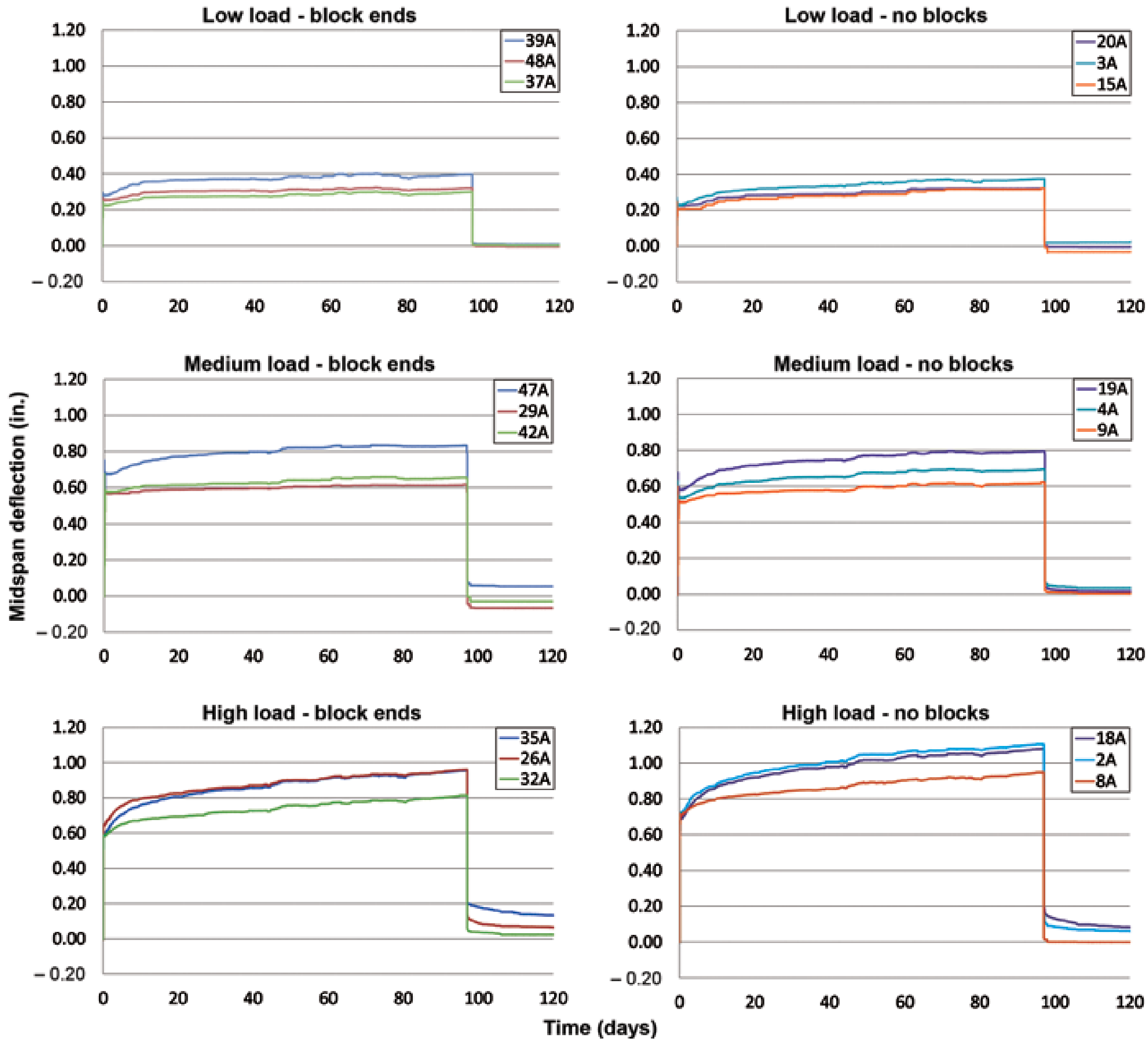

Figure 8. Graphs of creep samples after 120 days (FPL).

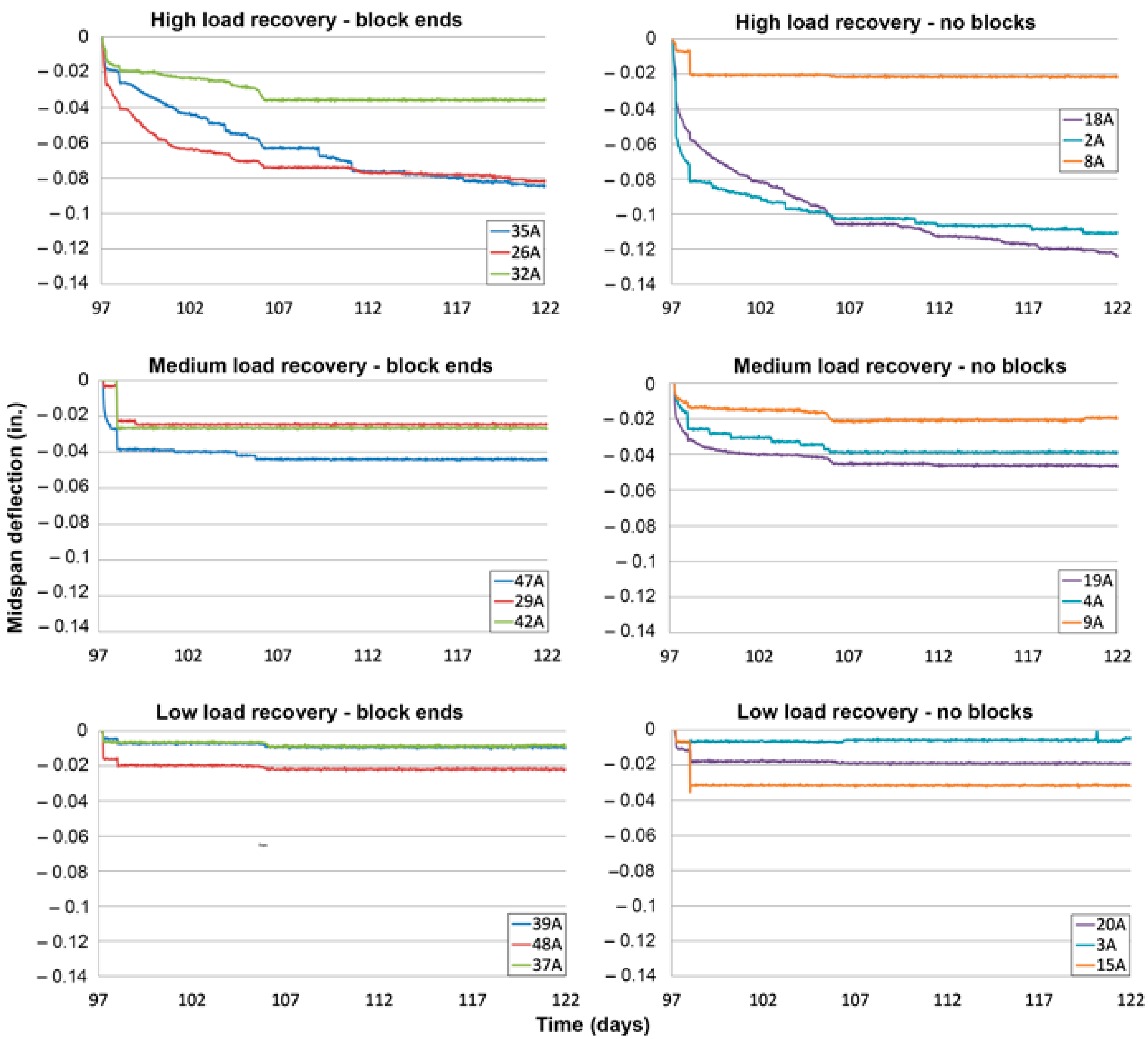

Figure 9. Graphs of creep recovery (FPL).

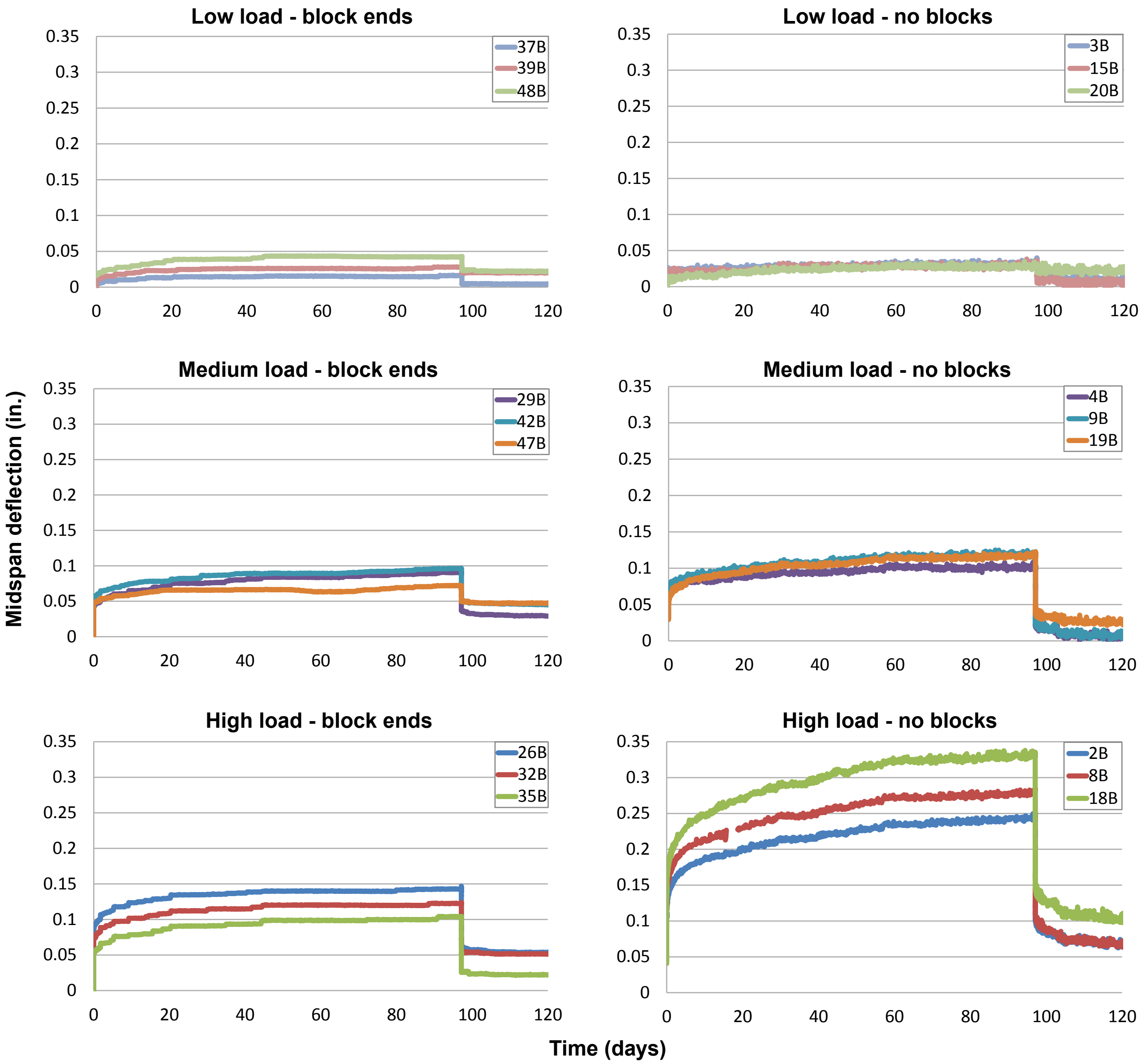

Figure 10. Graphs of creep samples after 120 days (APA–The Engineered Wood Association).

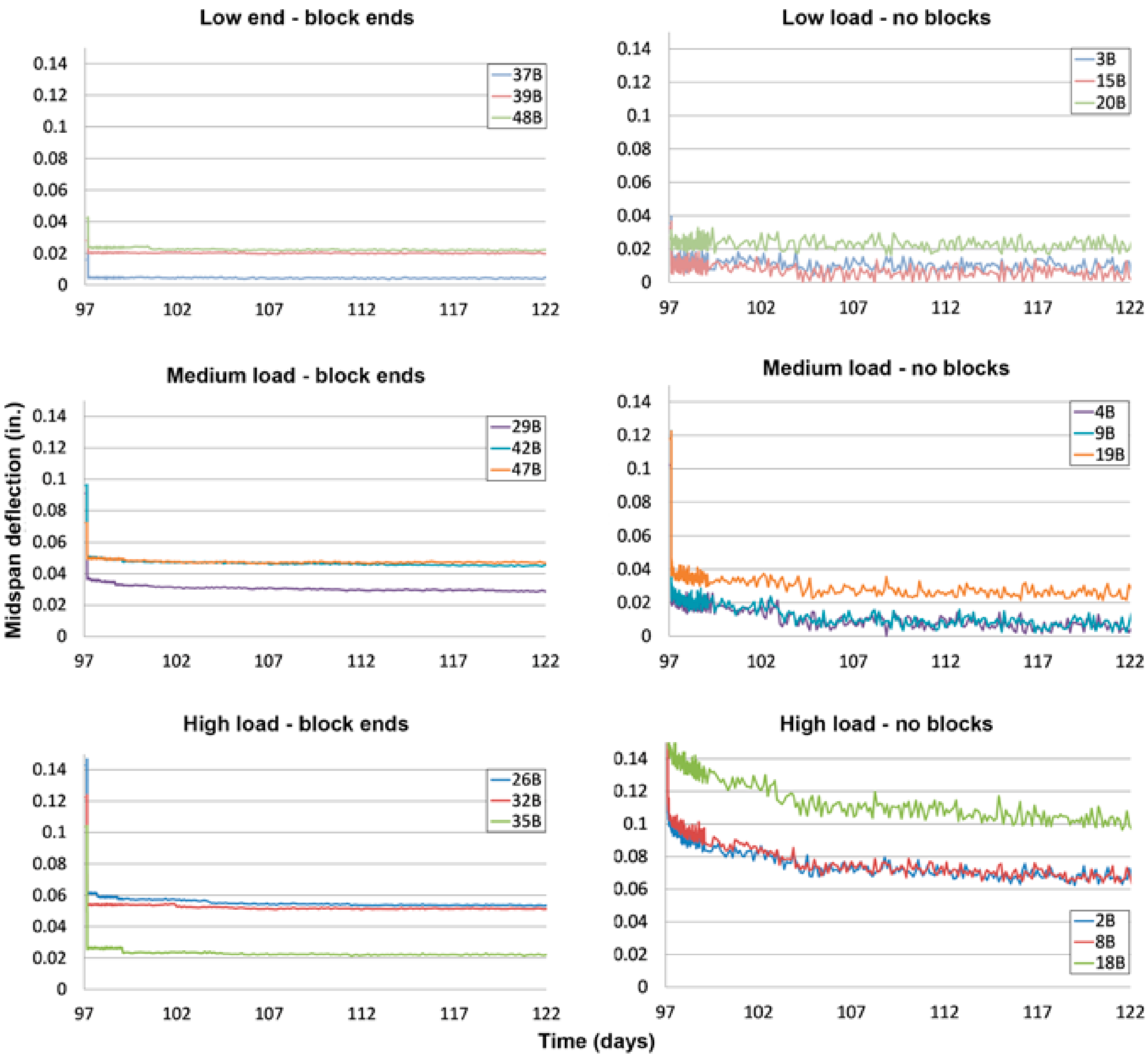

Figure 11. Graphs of creep recovery (APA–The Engineered Wood Association).

Figure 12. Adhesion failure (FPL).

Figure 13. Compression failure (FPL).

Figure 14. Short-term bending, typical failure mode (OSB bending) of foam flush detail (top) and typical failure mode (tearing of EPS foam) of 2× end block detail (bottom) (APA–The Engineered Wood Association).