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Evaluation of Creep Performance of Structural Insulated Panels (SIPs)

Phase 3

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Abstract

In this study, the creep deflection behavior of structural insulated panels (SIPs) was evaluated for creep-rupture equivalence to solid wood per ASTM D6815. The SIP specimens used in the study had 0.44-in. oriented strandboard (OSB) facers with a core of expanded polystyrene (EPS) foam. The following four groups of 15 SIP specimens each were examined: 12.25 in. thick with 1.2-lb/ft^3 foam; 12.25 in. thick with 1.0-lb/ft^3 foam; 6.5 in. thick with 1.2-lb/ft^3 foam; and 6.5 in. thick with 1.0-lb/ft^3 foam. To determine creep performance, both 12.25-in.-thick specimen groups were combined into a single group of 30 and both 6.5-in.-thick specimen groups were combined into a single group of 30. Specimens were loaded using dead weight in a four-point bending configuration. Per ASTM D6815, the constant load was maintained for 90 days and deflection of each specimen was measured hourly using linear variable differential transformers (LVDTs). Based upon the findings from this study, it is concluded that SIPs have equivalent creep–rupture behavior to solid wood per ASTM D6815 and the duration of load factors for lumber from table 8 of ASTM D245 are applicable to SIPs.

Keywords: Creep, structural insulated sandwich panel, SIP, oriented strandboard, OSB, expanded polystyrene foam, EPS

Contents

Conversion table

English unit	Conversion factor	SI unit
inch (in.)	2.54×10^1	millimeter (mm)
pound, mass (lb)	4.535924×10^{-1}	kilogram (kg)
pound per cubic foot (lb ft^{-3})	1.601846×10^1	kilogram per cubic meter (kg m^{-3})

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Phase 3

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Introduction

In this study, equivalent creep–rupture behavior was established between structural insulated panels (SIPs) and solid wood per ASTM D6815 (ASTM 2015). For solid wood products, factors in table 8 of ASTM D245 (ASTM 2022) include adjustment to allowable design values for duration of load and factor of safety. For wood-based materials (WBM) that are not solid wood, the creep–rupture (duration of load) behaviors of the WBM must be equivalent to solid wood to apply ASTM D245 table 8 factors to the WBM. The criteria to establish equivalence is given in ASTM D6815. If a WBM passes the criteria established in ASTM D6815, it can be assumed that it has creep–rupture (duration of load) behavior equivalent to solid wood and the adjustments in table 8 of ASTM D245 may be applied to the WBM.

Structural insulated panels are engineered composite building materials designed as a sandwich structure that consists of an insulating layer of foam between two structural facers. The SIPs used in this study had facers of oriented strandboard (OSB) with expanded polystyrene (EPS) foam. Metal is another common facer material, and extruded polystyrene or polyurethane are also commonly used for insulating foam. SIPs share some structural similarities to an I beam. The rigid foam insulation core functions as a web, and the facers function as flanges. SIPs can replace several components of conventional wood framing such as studs, headers, purlins, rafters, and insulation. SIPs have several properties that make them desirable as building materials. They have highly reliable strength and stiffness properties, are lightweight, are prefabricated and easy to install, and are energy efficient, meeting the requirement of the 2021 International Energy Conservation Code (IECC).

The USDA Forest Service, Forest Products Laboratory (FPL); Mississippi State University (MSU) Department of Sustainable Bioproducts; Structural Insulated Panel Association (SIPA); and SIP producers are working together to investigate several performance characteristics of SIPs (Kochkin and others 2015; Yeh and others 2018, 2019; Rammer and Williamson 2020). In this study, the creep behavior of SIPs was examined.

This study is Phase 3 of a larger project to evaluate creep performance of SIPs. Phase 1 is described in McDonald and others (2014), which was a pilot study characterizing the loads and deflections expected for a full-scale test. Phase 2 is described in McDonald and others (2018), which was a full-scale test including 56 specimens. Unfortunately, technical issues hindered data collection in Phase 2, resulting in the extension of the project to Phase 3. In phase 3, we collected time and deflection data from SIPs under constant load during a period of 90 days per ASTM D6815. The data were used to establish creep–rupture equivalency to solid wood products and to develop creep models. The creep deflection models will be described in another publication.

Creep is the tendency of material to slowly deform while under sustained loading but at stress levels below the yield strength. Several factors are known to affect creep, including temperature, humidity and moisture levels, exposure time, and load. Creep behavior of SIPs was modeled extensively by Taylor and others (1997) and Rungthonkit and Yang (2009). In this report, SIP compliance with ASTM D6815 was examined using data collected during a 90-day duration of load test on SIP specimens. In section X1.2.4 of the appendix in ASTM D6815, it is stated that longer duration load tests are sometimes required when failure mechanisms are not understood or field experience with the material is limited. SIPs are an established building material with several decades of field use. Therefore, the 90-day duration of testing was used. Reviews of the strength as measured by peak load and stiffness as measured by maximum deflection at peak load before and after creep loading were presented by Shmulsky and others (2022) and Khademibami and others (2023). Modeling of the creep data will be addressed in a future publication.

The SIPs examined in this study were compliant with the International Residential Code (IRC), the 2021 IECC, and the International Building Code (IBC) through International Code Council Evaluation Service (ICC-ES) reports. SIPs are proprietary products manufactured by different companies in accordance with ICC-ES approved code reports. The specimens used in this study were from a single SIPA member operating in compliance with ICC-ESR 4689 (ICC 2024). However, the results are deemed to be applicable for all SIPs manufactured in compliance with ICC-ES code reports requiring the same OSB facers, adhesives, and EPS foam as evaluated in this study.

Methods and Materials

Specimens

In this study, SIPs of two thicknesses were examined: 6.5 and 12.25 in. The SIPs had OSB facers with EPS foam cores. The OSB facers were produced at a North American based commercial production facility. The OSB facers were 0.44-in. thick, which conformed with PR-N610 (APA 2024). The strong axis of the OSB was oriented parallel with the long axis of the SIP specimens. The OSB panels continued for the length of the specimens with no end joints. The 6.5-in. specimens had a 5.6-in.-thick core of EPS foam, and they were 11.75 in. wide and 125 in. long. The 12.25-in. specimens had an 11.4-in.-thick core of EPS foam, and they were 11.75 in. wide and 233 in. long. There were two manufacturing dates on the SIPs. Although the EPS foam density varied by manufacturing date, they met ASTM C578 (ASTM 2023) Type I, which requires a minimum density of 0.95 lb/ft^3. Approximately half of the 6.5- and 12.25-in. specimens had EPS foam with a density of 1.0 lb/ft^3, and the other half had EPS foam with a density of 1.2 lb/ft^3. For purposes of determining dead load stress, both 12.25-in.-thick specimen groups were combined into one group of 30 and both 6.5-in.-thick specimen groups were combined into another group of 30.

Dead Load

The dead load values for long-term duration of load testing were based on laboratory short-term static bending tests (Khademibami and others 2023). The specimens in this study are subjected to a constant stress, f_b, as prescribed in eq. 1 of ASTM D6815 and reproduced here as Equation (1). The 5% nonparameter point estimates were determined in accordance with ASTM D2915 (ASTM 2017). Short-term bending tests were conducted per ASTM 4761 (ASTM 2013).

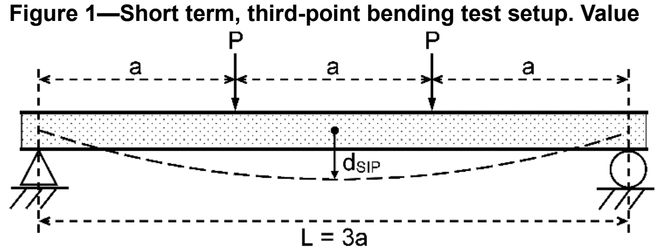
$$f_b = 0.55 \times (5\%\mathrm{PE}) \tag{1}$$

Where f_b is the minimum applied bending stress and 5%PE is the lower 5% point estimate of ultimate bending stress from short-term bending tests.

Testing

For the testing phase of this study, multiple commercially available SIP specimens were fabricated by a single SIPA member manufacturer. The specimens were ripped to 11.75-in. widths, producing matched pairs from a SIP base panel. One of the matched pairs was tested in a destructive, short-term, static, third-point bending test as shown in Figure 1. The other matched specimen was subjected to a nondestructive, 90-day dead load to measure creep deflection. The dead load was removed, and the SIP specimens underwent a 30-day recovery period. After the recovery period, those specimens were subjected to destructive, short-term, static third-point bending tests. A statistical analysis of the results of the bending tests was given in Khademibami and others (2023), which confirmed that there was minimal change in strength as measured by peak load and stiffness as measured by maximum deflection at peak load of SIPs as evaluated by the static load tests before and after the 90-day creep loading cycle followed by a 30-day unloaded recovery cycle.

Figure 1—Short term, third-point bending test setup. Value



P is one-half the total applied load. The span is L. Displacement, d_{SIP}, is measured at the neutral axis at the midpoint of the SIP.

Bending Test

Destructive, short-term, static third-point bending tests were conducted in accordance with ASTM D4761. The standard specifies a span to depth ratio between 17:1 and 21:1. The span to depth ratio of the test setup for this study was approximately 18:1. The rate of loading was set so that time to failure occurred at or about 1 minute. The failure mode in each case was shear within the EPS core layer caused by discontinuities in the foam (Shmulsky and others 2022). The short-term bending test setup is shown in Figure 1.

Duration of Load Test

The duration of load test was conducted in accordance with ASTM D6815. The load level was the 5% point estimate for bending stress (566 lb for 12.25-in. specimens; 494 lb for 6.5-in. specimens). The SIP specimens were loaded for 90 days. A loading platform was placed on the SIP during the duration of load testing, and sandbags were then placed on the loading platform. The platform had two cleats which were positioned at the third points of the SIP to match the loading conditions shown in Figure 2. Figure 3 shows the arrangement of the loaded SIP. For the duration of loading, the dead weight of the sandbags was applied at the third points of the SIP through the two platform supports. Deflection was measured at the midpoint of the SIP using linear variable differential transformers (LVDTs), which are accurate to 0.001 in. The deflections while under load during the 90-day study for the 6.5- and 12.25-in. thicknesses are shown in Figure 4a and 4b, respectively.

Results Showing ASTM D6815 Compliance

Acceptance criteria are given in section 5.4 of ASTM D6815. The three subsections include 5.4.1, adequate strength; 5.4.2, decreasing creep rate; and 5.4.3, fractional deflection. The criterion for adequate strength is given in section 5.4.1 and is defined as a number of failures less than the lower 5% nonparametric tolerance limit with 75% confidence. For a sample of 30, the critical order statistic is 1,

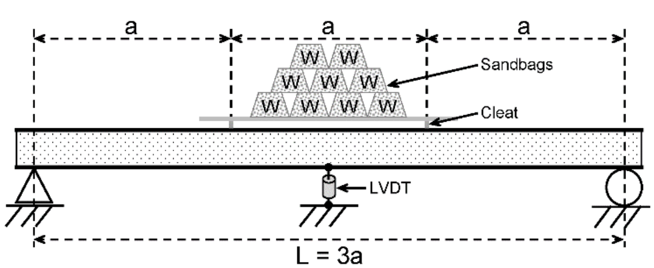


Figure 2—Third-point bending test setup. Approximately half the combined sandbag weight is loaded onto the SIP through each cleat. The span is L. Deflection is measured at the midpoint using an LVDT.

Figure 3—SIPs with loading platforms laden with sandbags for long duration loading (photos property of Mississippi State University).

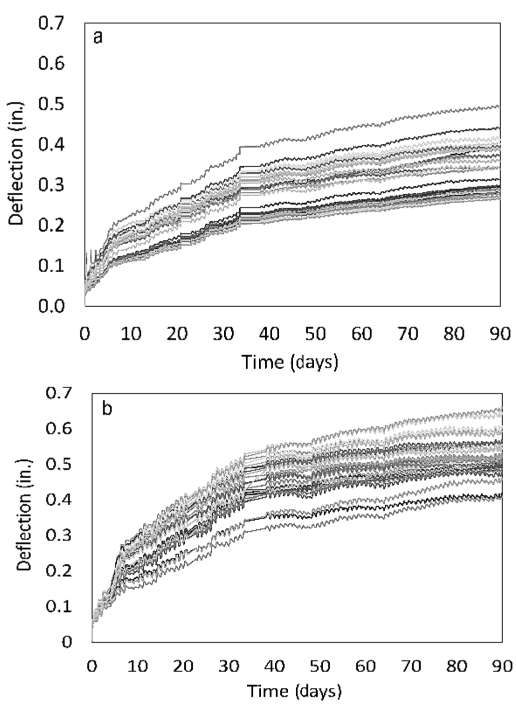


Figure 4—Creep deflection of (a) 6.5-in.-thick SIPs and (b) 12.25-in.-thick SIPs after time under load in days.

meaning that a single failure violates the criterion. Tables 1 and 2 list the creep deflection of each specimen. There were no failures during the 90-day constant load time for either thickness group. Both thickness groups passed the parameters given in section 5.4.1. Figure 4 shows the creep deflection of both thickness groups during the 90-day creep cycle. Only the creep data are shown; the initial elastic deflection is not shown but is given in Tables 1 and 2.

The decreasing creep rate criterion in section 5.4.2 states that all test specimens that do not fail during the 90-day constant load time shall show a decreasing creep rate. The example given separates the 90-day constant load time into three separate durations of 30 days each and specifies that the relationship between them should obey equation X2.1 of the standard. The equation is reprinted below as Equation (2). The deflections under load of all specimens obey Equation (2) as shown in Tables 1 and 2. Both thickness groups passed the parameters in section 5.4.2.

$$d_{30} - d_{\mathrm{i}} > d_{60} - d_{30} > d_{90} - d_{60} \qquad (2)$$

where d_{i} is the initial deflection measured after 1 minute of loading and d_{30}, d_{60}, and d_{90} are the deflections measured on day 30, 60, and 90, respectively.

The fractional deflection criterion in section 5.4.3 states that the ratio of the deflection measured at 90 days of loading, d_{90}, to the initial deflection, d_{i}, shall be less than or equal to 2.0. As shown in Tables 1 and 2, both thickness groups passed the parameters in section 5.4.3.

Based on meeting the ASTM D6815 criteria, the SIPs evaluated in this study can use the creep factor applicable to lumber.

Conclusions

This study was intended to demonstrate the conformance of SIPs with ASTM D6815, the standard specification for evaluation of duration of load and creep effects of wood and wood-based products. The magnitude of the 90-day load is specified in the same standard and calculated using a combination of ASTM D2915 and ASTM D4761. The 90-day deflection of the 6.5-in.-thick SIPs was between 0.27 and 0.50 in., and the same period deflection of the 12.25-in.-thick SIPs was between 0.41 and 0.66 in. All SIP specimens in this study passed the acceptance criteria of ASTM D6815 section 5.4. Based on these findings, it is concluded that SIPs manufactured in compliance with ICC-ESR 4689 are compliant with ASTM D6815. Also, any SIPs manufactured in compliance with ICC-ES code reports requiring the same OSB facers, adhesives, and EPS foam as evaluated in this study are concluded to be compliant with ASTM D6815.

Table 1—Results of creep deflection behavior tests of 6.5-in.-thick structural insulated panels (SIPs) according to ASTM D6815 acceptance criteria, sections 5.4.1, 5.4.2, and 5.4.3

	Acceptance criteria by section				
	5.4.1[a]		5.4.2[b]		5.4.3[c]
Specimen ID	d_i ($\times 10^{-3}$ in.)	$d_{90} - d_i$ ($\times 10^{-3}$ in.)	$d_{60} - d_{30}/d_{30} - d_i$	$d_{90} - d_{60}/d_{60} - d_{30}$	d_{90}/d_i
S02	888	281	0.33	0.62	1.32
S04	774	278	0.29	0.62	1.36
S06	655	286	0.34	0.50	1.44
S08	570	268	0.31	0.51	1.47
S10	526	290	0.31	0.52	1.55
S12	701	271	0.28	0.51	1.39
S14	803	295	0.31	0.58	1.37
S16	839	313	0.32	0.51	1.37
S18	803	297	0.30	0.56	1.37
S20	647	288	0.28	0.54	1.45
S22	579	280	0.30	0.53	1.48
S24	671	288	0.28	0.53	1.43
S26	781	281	0.29	0.55	1.36
S28	527	264	0.30	0.57	1.50
S30	503	286	0.31	0.61	1.57
S31	722	401	0.23	0.44	1.56
S32	780	385	0.29	0.44	1.49
S33	703	371	0.29	0.63	1.53
S34	780	390	0.27	0.82	1.50
S35	894	393	0.26	0.39	1.44
S36	704	371	0.31	0.51	1.53
S37	835	492	0.29	0.47	1.59
S38	890	439	0.30	0.49	1.49
S39	723	343	0.23	0.33	1.47
S40	688	340	0.24	0.48	1.49
S41	748	358	0.24	0.37	1.48
S42	832	340	0.31	0.42	1.41
S43	1,142	412	0.28	0.45	1.36
S44	683	390	0.31	0.47	1.57
S45	800	387	0.28	0.40	1.48

[a]5.4.1 must have no failures for samples containing 28 to 30 specimens. All specimens passed this criterion.

[b]5.4.2 $(d_{60} - d_{30})/(d_{30} - d_i) < 1$ and $(d_{90} - d_{60})/(d_{60} - d_{30}) < 1$. All specimens passed this criterion.

[c]5.4.3 $d_{90}/d_i < 2.0$. All specimens passed this criterion.

Table 2—Results of creep deflection behavior tests of 12.25-in.-thick structural insulated panels (SIPs) according to ASTM D6815 acceptance criteria, sections 5.4.1, 5.4.2, and 5.4.3

	Acceptance criteria by section				
	5.4.1[a]		5.4.2[b]		5.4.3[c]
Specimen ID	d_i ($\times 10^{-3}$ in.)	$d_{90} - d_i$ ($\times 10^{-3}$ in.)	$d_{60} - d_{30}/d_{30} - d_i$	$d_{90} - d_{60}/d_{60} - d_{30}$	d_{90}/d_i
B02[d]	—	—	—	—	—
B04	1,121	530	0.24	0.54	1.47
B06	958	527	0.26	0.63	1.55
B08	920	522	0.26	0.61	1.57
B10	1,037	517	0.27	0.56	1.50
B12	974	408	0.30	0.71	1.42
B14	1,052	504	0.22	0.52	1.48
B16	970	496	0.20	0.58	1.51
B18	1,038	501	0.19	0.56	1.48
B20	912	479	0.23	0.48	1.53
B22	1,029	416	0.21	0.66	1.40
B24	1,068	489	0.19	0.58	1.46
B26	977	487	0.21	0.51	1.50
B28	1,097	459	0.30	0.71	1.42
B30	1,123	510	0.21	0.60	1.45
B31	1,135	645	0.22	0.51	1.57
B32	1,036	600	0.18	0.47	1.58
B33	964	659	0.25	0.54	1.68
B34	984	565	0.16	0.52	1.57
B35	934	567	0.20	0.43	1.61
B36	883	508	0.17	0.34	1.58
B37	1,174	527	0.22	0.34	1.45
B38	1,176	518	0.19	0.34	1.44
B39	1,032	569	0.19	0.39	1.55
B40	996	522	0.18	0.32	1.52
B41	941	593	0.22	0.41	1.63
B42	926	545	0.31	0.25	1.59
B43	1,021	607	0.21	0.48	1.59
B44	1,148	555	0.19	0.45	1.48
B45[d]	—	—	—	—	—

[a]5.4.1 must have no failures for samples containing 28 to 30 specimens. All specimens passed this criterion.
[b]5.4.2 $(d_{60} - d_{30})/(d_{30} - d_i) < 1$ and $(d_{90} - d_{60})/(d_{60} - d_{30}) < 1$. All specimens passed this criterion.
[c]5.4.3 $d_{90}/d_i < 2.0$. All specimens passed this criterion.
[d]Electronic monitoring failures resulted in loss of data for B02 and B45. Neither failed 5.4.1.

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