# Flexural Testing of Structural Insulated Panels Before and After Creep Testing

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The effect of duration of load testing on flexural properties of structural insulated panels was investigated herein. Structural insulated panels were manufactured by a member of the Structural Insulated Panel Association (SIPA) in accordance with International Code Council-Evaluation Service Report 4689. Two panel depths 16.5 cm and 31.1 cm (6.5 in. and 12.25 in.) were tested in short duration 1/3-point bending per American Society for Testing and Materials standards. All structural insulated panels had joints or discontinuities in the foam layer in a location that was subject to shear stress during the bending tests. Failure mode for all panels was horizontal shear within the foam layer. Within each panel depth, no statistically significant differences were detected between the maximum load values before and after creep testing. This finding indicates that the creep test loading was not detrimental to the strength of the structural insulated panels. While the results were not deemed to be statistically different for the $\Delta y_{max}$ (midspan deflection at $P_{max}$) for the 31.1 cm depth class, they were statistically different from the 16.5 cm depth class. Overall, it appeared that there was minimal effect of the creep test loading on $\Delta y_{max}$ of the SIPs.

*DOI: 10.15376/biores.18.2.3319-3327*

*Keywords: Structural insulated panels (SIPs); Duration of load testing; Bending test; Foam; Building products; Construction materials*

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## INTRODUCTION

Structural insulated panels (SIPs) are sandwich-type products that are available commercially throughout North America. The SIPs contain an insulating foam core sandwiched between two structural facings, which typically are oriented strand board (OSB). They are widely used in both residential and nonresidential construction. They have highly reliable strength and stiffness properties that allow designers to use them in a wide range of structural applications. Moreover, they are lightweight, prefabricated for ease of installation, highly energy efficient, and meet the requirements of the 2021 International Energy Conservation Code (IECC). Additionally, they are compliant with International Residential Code (IRC) and the International Building Code (IBC), the latter through International Code Council Evaluation Service (ICC-ES) reports.

During typical manufacturing, OSB is applied as face layers over expanded polystyrene (EPS) foam panel cores using adhesives that must comply with ASTM D2559 and ICC AC05. Other facers or foam cores can be used. Discontinuities may occur in the foam where two pieces are butted together in the core layer. It has been previously shown (Shmulsky *et al*. 2022) that foam discontinuity influences overall mechanical properties of a SIP in bending when it is located within the shear zone (that is between the reaction support and the load head of the 1/3-point bending fixture). With this influence in mind, each specimen in this study had foam discontinuities located in the shear zone to ensure consistent, conservative property estimates.

For wood-based products, the duration of load and creep effects tests follow American Society for Testing and Materials (ASTM) D6815 (2015). Therein, the dead load values (and associated bending stress values) for the long-term "creep-rupture" or duration of load testing are based on laboratory short-term static bending tests: The specimens selected for these tests shall be tested at a constant stress level, $f_b$, as determined in accordance with Eq. 1 of D6815 where $f_b$= 0.55 × (5% PE), defined as $f_b$ = minimum applied bending stress, and 5% PE = the lower 5% point estimate, as determined from the short-term bending tests. For the 30-specimen samples herein, the respective 5% non-parametric point estimates were determined in accordance with ASTM D2915 (2017). As referenced in ASTM D6815 (2015), the short-term bending (hereafter static bending) tests were conducted per ASTM D4761 (2013), with testing following the joist form materials and Test Methods." This standard specifies full-scale flexural testing, that is testing in the structural size(s) in 1/3-point bending at a span: depth ratio ranging from 17:1 to 21:1. Per ASTM D4761 (2013), the rate of loading was maintained such that time to failure was approximately 1 min. Previous works (McDonald *et al.* 2014, 2018) investigated the creep behavior of SIPs with varying sample sizes. To date, no definitive information has become available regarding the full-scale flexural properties of SIPs after long term flexural stress at creep design bending loads. Therefore, the objective of this research is to compare the strength ($P_{max}$) and midspan deflection at $P_{max}$ ($\Delta y_{max}$) of SIP panels before and after load duration testing. Two depths, 31.1 and 16.5 cm (12.25 and 6.5 in.), were considered. Because the section properties of all specimens were the same, maximum load ($P_{max}$) trends are equivalent to both MOR and maximum moment ($M_{max}$) trends. Consistent with previous works, midspan deflection $\Delta y_{max}$ at $P_{max}$ are reported herein as an indication of panel stiffness.

## EXPERIMENTAL

### Specimens' Characteristics

The SIPs were manufactured at a Structural Insulated Panel Association (SIPA) member's commercial facility in accordance with ICC, Evaluation Service Report (ESR) 4689. Two depth classes, 16.5 and 31.1 cm (6.5 and12.25 in.) deep, were evaluated. All specimens were approximately 29.8 cm (11.8 in.) wide with 317 cm (125 in.) length for depth class 16.5 cm and 591.8 cm (233 in.) length for depth class 31.1 cm. Because they were manufactured at two different times, approximately half of the matched specimen pairs in each depth class had a foam density of approximately 0.016 g/cm$^3$ (1.0 lb/ft$^3$), while approximately half of the matched specimen pairs in each depth class had a foam density of approximately 0.02 g/cm$^3$ (1.2 lb/ft$^3$). Data from beams of differing foam densities were pooled because the SIPs were considered commodity products with non-differing design properties. Thus, potential differences related to foam densities are not considered herein.

The SIPs had EPS foam cores with 1.11 cm (7/16 in.) thick OSB facers. The OSB was APA-the Engineered Wood Association- Performance Rated Panels (PR-N610) that were produced by a North American-based commercial production facility. Test specimens had facers with a strong axis orientation with the OSB strength axis oriented parallel with the length of the SIP panel. The OSB was full length. That is, there were no visible end joints in either the top or bottom OSB facers.

## Testing

The research detailed herein occurred in three phases. Each phase used similarly specified SIPs. Prior to testing, specimens were segregated into matched pairs. Each pair was from the same parent (or master) panel. From each side matched pair, one specimen was used in a short-term bending test (phase 1), while the other specimen was used in the duration of load testing (phase 2) followed by a short-term bending test (phase 3). In this manner, variation was minimized within the matched pairs in the effort to compare flexure properties before and after duration of load testing.

### *Phase 1: Initial full-scale short-term bending tests*

Destructive static testing of two SIP's depths, 16.5 and 31.1 cm (6.5 and 12.25 in.), was conducted in short duration 1/3-point bending per ASTM-D6815 (2015). Figure 1 illustrates an exemplar full-scale 16.5 cm (6.5 in.) deep SIP test specimen in the 1/3-point bending test fixture awaiting the short-term bending test.


**Fig. 1.** Exemplar full-scale 16.5 cm (6.5 in) deep SIP test specimen in the 1/3-point test fixture

Specimens were tested in 1/3-point flexure at an approximate 18:1 span to depth ratio. Table 1 lists the various test combinations along with the number of specimens within each category. The failure mode in each case was horizontal shear within the foam core layer. Consistent with ASTM D6815, time to failure was targeted at 1 minute and the rate of loading was set accordingly.

**Table 1.** Sample Sizes of Short-Term Bending Tests Before and After Creep Tests

| Sample Size | 16.5 cm (6.5 in.) Depth | | | 31.1 cm (12.25 in.) Depth | |
|---|---|---|---|---|---|
| | **Before** | **After** | | **Before** | **After** |
| Target | 30 | 30 | | 30 | 30 |
| Actual | 31 | 29 | | 32 | 30 |

*Phase 2: 90-day full-scale duration of load tests with matched specimens, followed by 30 days with no load for creep recovery (creep test)*

This phase was conducted according to the ASTM-D6815 (2015). Figure 2 illustrates the battery of matched specimens undergoing the 90-day full-scale duration of load testing using sandbags for the dead loads. The results of Phase 2 duration of load testing are not reported herein and will be published in a subsequent report. Creep load levels were at the 5%-point estimate for bending stress as per ASTM-D6815.


**Fig. 2.** Battery of full-scale matched SIP specimens undergoing the 90-day duration of load testing

*Phase 3: Final full-scale short-term bending tests on the specimens subjected to the 90-day duration of load test followed by a 30-day recovery cycle*

Phase 3 testing followed the same protocol as Phase 1, wherein destructive static testing of two SIP's depths, 16.5 and 31.1 cm (6.5 and 12.25 in.), was conducted in short duration 1/3-point bending per ASTM-D6815 (2015). Specimens were tested in 1/3-point flexure at an approximate 18:1 span to depth ratio. However, the specimens in Phase 3 were those that had been subjected to the long-term duration of load testing (*i.e.*, Phase 2). Consistent with ASTM D6815, time to failure was targeted at 1 minute and the rate of loading was set accordingly.

The results of the initial (Phase 1) and final (Phase 3) full-scale bending tests are reported herein.

## STATISTICAL ANALYSIS

All data that belong to the maximum load and deflection were analyzed by both one-way analysis of variance (ANOVA) and paired t-tests using the procedure for linear mixed models (PROC GLIMMIX) and PROC TTEST of SAS 9.4© (SAS Institute, Cary, NC, USA). Differences were deemed significant at $P \leq 0.05$. The following model was used for analysis of the data that belong to one-way ANOVA (Eq. 1),

$$Y_i = \mu + L_i + E_i \quad (1)$$

where $\mu$ is the population mean; $L_i$ is the effect of duration of load (creep test) (L = 1 to 2); and $E_i$ is the residual error.

## RESULTS AND DISCUSSION

Summary statistics for $P_{max}$ and $\Delta y_{max}$ were computed within each depth class; 16.5 cm (6.5 in.) and 31.1 cm (12.25 in.), respectively. Summary statistic results of $P_{max}$ and $\Delta y_{max}$ before and after creep test for both depth classes are presented in Table 2.

The results indicate that there was little to no difference in the average $P_{max}$ before *versus* after creep testing for both depth classes and for the $\Delta y_{max}$ for the 31.1 cm (12.25 in) depth class with the differences being less than 2%. For the 16.5 cm (6.5 in.) depth class, the data show that the after creep testing average $\Delta y_{max}$ was approximately 7% greater than the before creep testing value. These results indicate there was minimal effect of the creep test loading on the strength ($P_{max}$) and $\Delta y_{max}$ for the test panels. To further analyze these results on a more rigorous statistical basis, an ANOVA and paired t-test analysis were completed as follows.

Both ANOVA and paired t-tests were used to test for differences in $P_{max}$, before and after duration of load testing. T-test pairing is based on the matched specimens that originate from the same parent panel. The results indicated that any difference in $P_{max}$ before *versus* after duration of load testing was not statistically significant. The statistical ANOVA show that there was no difference in $P_{max}$ of SIP specimens before *versus* after creep tests in both depth class (Table 2). The same result was observed in the paired T-test results for two depth classes, 16.5 cm (6.5 in.) and 31.1 cm (12.25 in.) (Table 3).

**Table 2.** Summary Statistics and ANOVA Results for Both Depth Classes; Before *Versus* After Creep Test

| Statistic | 16.5 cm (6.5 in.) | | | | | | | | 31.1 cm (12.25 in.) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P_{max}$ (N) | | $P_{max}$ (lbf) | | $\Delta y_{max}$ (cm) | | $\Delta y_{max}$ (in.) | | $P_{max}$ (N) | | $P_{max}$ (lbf) | | $\Delta y_{max}$ (cm) | | $\Delta y_{max}$ (in.) | |
| | **Before** | **After** | **Before** | **After** | **Before** | **After** | **Before** | **After** | **Before** | **After** | **Before** | **After** | **Before** | **After** | **Before** | **After** |
| Mean* | 4893[a] | 4933[a] | 1100[a] | 1109[a] | 3.23[b] | 3.45[a] | 1.27[b] | 1.36[a] | 5342[a] | 5213[a] | 1201[a] | 1172[a] | 4.19[a] | 4.29[a] | 1.65[a] | 1.69[a] |
| Std. Dev. | 583 | 796 | 131 | 179 | 0.28 | 0.23 | 0.11 | 0.09 | 503 | 721 | 113 | 162 | 0.28 | 0.56 | 0.11 | 0.22 |
| COV (%) | 12 | 16 | 12 | 16 | 9 | 7 | 9 | 7 | 9 | 14 | 9 | 14 | 7 | 13 | 7 | 13 |
| Maximum | 6076 | 6054 | 1366 | 1361 | 3.84 | 3.91 | 1.51 | 1.54 | 6268 | 6290 | 1409 | 1414 | 4.7 | 5.61 | 1.85 | 2.21 |
| Minimum | 3986 | 3852 | 896 | 866 | 2.64 | 2.95 | 1.04 | 1.16 | 4448 | 3532 | 1000 | 794 | 3.71 | 3 | 1.46 | 1.18 |
| Sample Size** | 31 | 29 | 31 | 29 | 31 | 29 | 31 | 29 | 32 | 30 | 32 | 30 | 32 | 30 | 32 | 30 |
| SEM | 179 | | 40 | | 0.069 | | 0.027 | | 157 | | 35 | | 0.111 | | 0.044 | |
| P-Value Before *vs* After | **0.8241** | | **0.8241** | | **0.0018** | | **0.0018** | | **0.4172** | | **0.4172** | | **0.4093** | | **0.4093** | |

*[a,b] Mean values with differing superscripts differ significantly at p = 0.05 level.
**Sample sizes vary from 29 to 32. In each case, additional specimens were included because matched specimens arrived in bundles of 32 (that is 4 specimens per master panel × 8 rows per bundle) and were thus available. The target minimum sample size for each depth class is 30 (*i.e.* 28 + 2), as 28 is the minimum number required to develop a non-parametric 5%-point estimate plus investigators included 2 additional specimens as extras for potential interruptions or problems during testing. During the preparation it was noted that one 12.25-inch deep specimen was damaged upon receipt and was thus removed. During testing, one 6.5-inch deep specimen's deflection did not record due to an electrical power surge. In each case, the minimum 28-specimen sample size was utilized and the statistical tests (ANOVA and paired t-test) account for differences in sample sizes.

**Table 3.** Paired T-test Results for Both Depth Classes; Before *versus* After Creep Test

| Statistic | 16.5 cm (6.5 in.) | | | | | | | | | 31.1 cm (12.25 in.) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **$P_{max}$ (N)** | | **$P_{max}$ (lbf)** | | **$\Delta y_{max}$ (cm)** | | **$\Delta y_{max}$ (in.)** | | | **$P_{max}$ (N)** | | **$P_{max}$ (lbf)** | | **$\Delta y_{max}$ (cm)** | | **$\Delta y_{max}$ (in.)** | |
| | **Before** | **After** | **Before** | **After** | **Before** | **After** | **Before** | **After** | | **Before** | **After** | **Before** | **After** | **Before** | **After** | **Before** | **After** |
| Mean* | 4903[a] | 4955[a] | 1102[a] | 1114[a] | 3.20[b] | 3.45[a] | 1.26[b] | 1.36[a] | | 5306[a] | 5191[a] | 1193[a] | 1167[a] | 4.16[a] | 4.26[a] | 1.64[a] | 1.68[a] |
| Std. Dev. | 608 | 803 | 137 | 181 | 0.27 | 0.25 | 0.11 | 0.10 | | 503 | 724 | 113 | 163 | 0.29 | 0.52 | 0.11 | 0.21 |
| COV (%) | 12 | 16 | 12 | 16 | 8 | 7 | 8 | 7 | | 9 | 14 | 9 | 14 | 7 | 12 | 7 | 12 |
| Maximum | 6075 | 6052 | 1366 | 1361 | 3.76 | 3.91 | 1.48 | 1.54 | | 6215 | 6294 | 1397 | 1415 | 4.70 | 5.03 | 1.85 | 1.98 |
| Minimum | 3984 | 3852 | 896 | 866 | 2.64 | 2.95 | 1.04 | 1.16 | | 4451 | 3533 | 1001 | 794 | 3.71 | 3.00 | 1.46 | 1.18 |
| Sample Size | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 |
| P-Value | **0.4571** | | **0.4571** | | **0.0008** | | **0.0008** | | | **0.2179** | | **0.2179** | | **0.2748** | | **0.2748** | |

*[a,b] Mean values with differing superscripts differ significantly at p = 0.05 level

Because the load configuration and section properties were the same, $P_{max}$ trends directly relate to MOR and maximum bending moment trends.

The results showed that $\Delta y_{max}$ was from 2% to 7% higher depending on depth in SIP specimens after creep test compared to before. Here again, both ANOVA and paired t-tests were used to test for differences in $\Delta y_{max}$, before and after duration of load testing. T-test pairing is based on the matched specimens that originate from the same parent panel. The results indicate that the difference in $\Delta y_{max}$ before *versus* after duration of load testing is statistically significant for the 16.5 cm (6.5 in.) but not for the 31.1 cm (12.25 in) depth class. This finding is consistent for both ANOVA and the paired t-test (Tables 2 and 3).

## CONCLUSIONS

1. Results of both the ANOVA and the paired T-tests indicated that no statistically significant difference was detected in the matched static bending specimen $P_{max}$ values before *versus* after creep testing in either SIP depth class. Because the specimens are of like section properties and span, the $P_{max}$ comparison is indicative of both MOR and maximum moment ($M_{max}$) capacity.
2. Results of both the ANOVA and the paired t-tests indicated that no statistically significant difference was detected in the matched static bending specimen $\Delta y_{max}$ values before *versus* after creep testing for the 31.1 cm depth class, but it was statistically different for the 16.5 cm depth class although the difference in average values was less than 7%.
3. The finding of no statistically significant differences between the $P_{max}$ before and after creep testing indicates that the creep test loading is not detrimental to the strength of the SIPs. While the results were not deemed to be statistically different for the $\Delta y_{max}$ for the 31.1 cm depth class, they were statistically different for the 16.5 cm depth class. Overall it appeared that there was minimal effect of the creep test loading on the midspan deflection ($\Delta y_{max}$) of the SIPs.
4. SIPs would be applicable for any roof applications. The National Design Specification for Wood Construction (NDS) provides load duration and creep factors (Kcr) for a wide range of wood products but no values are provided for SIPs.

## ACKNOWLEDGEMENTS

This publication is a contribution of the Forest and Wildlife Research Center, Mississippi State University. The authors acknowledge the support from USDA Forest Service Forest Products Laboratory (FPL) in Madison, Wisconsin, as a major contributor of technical assistance, advice, and guidance to this research. The authors also acknowledge USDA Forest Products Laboratory, Madison, WI and the Structural Insulated Panel Association (SIPA) for providing funding and materials, respectively.

Additionally, the authors would like to express appreciation to Dr. Jane Parish and the staff at Mississippi Agriculture and Forestry Experiment Station's North Mississippi Research and Extension Center, Mississippi State University, Verona, MS.

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Article submitted: January 25, 2023; Peer review completed: February 18, 2023; Revised version received and accepted: February 28, 2023; Published: March 21, 2023.
DOI: 10.15376/biores.18.2.3319-3327