The Influence of Foam Density on the Flexural Properties of Structural Insulated Panels

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Abstract

The effect of foam core density on the strength of structural insulated panels (SIPs) was investigated herein as part of a larger study to determine the creep performance of SIPs. Two depths (16.5 cm and 31.1 cm [6.5 in. and 12.25 in.]) of SIPs were tested in 1/3rd-point flexure according to the American Society of Testing and Materials standard ASTM D6815. Parent SIP panels, each approximately 122 cm (48 in.) wide, were manufactured by a SIPA member in accordance with ESR 4698 and sawn into beam, type elements, each approximately 29.8 cm (11.8 in.) wide, for mechanical testing. All specimens had discontinuities in the foam core in a location that was subject to high shear stress, i.e., between the reaction support and the load head, during the bending tests. The foam density in half of the specimens was approximately 0.016 g/cm^3 (1.0 lb/ft^3) and in the other half of the specimens, it was approximately 0.019 g/cm^3 (1.2 lb/ft^3). The flexural properties of these specimens based on the maximum load, P_{max} and deflection at failure Δy_{max} (two different depths and two different foam densities) were statistically compared by 2-tailed t test. The results showed that foam density affects the bending performance of SIPs. In both depths, beams with heavier foam cores were stronger for the specific test conditions used in this study. It is noted that results may not be applicable to other design situations such as SIPs subjected to uniform loading with randomly placed foam core joints.

Structural insulated panels (SIPs) have been used in the homebuilding industry for several decades. However, the long-term creep behavior of SIPs has not been well-studied. To fill this information gap, in 2021, a comprehensive investigation of the creep behavior of SIPs was initiated. The study reported herein is a component of that larger creep investigation.

Structural insulated panels contain a foam core that is typically expanded polystyrene (EPS) but may also be polyurethane or extruded polystyrene. In addition to increasing the panel depth and associated insulating value, the foam core of SIPs plays an important mechanical role. Not only does the foam core increase the section modulus and moment of inertia, but it also helps the panel act as a monolithic composite. The facers of the SIPS are typically oriented strand board (OSB) but may also be plywood. Facers need to be continuous for the length of the panel. The foam is adhered rigidly to the facers with exposure-rated adhesive complying with International Code Council (ICC) Acceptance Criteria 05 (AC 05).

Previous work has examined the performance of SIPs that were tested in bending and contained at least one discontinuity in the foam layer in the area of maximum shear (Shmulsky et al. 2022). In McDonald et al. (2018) a statistical sample with 28 specimens of each depth (16.5

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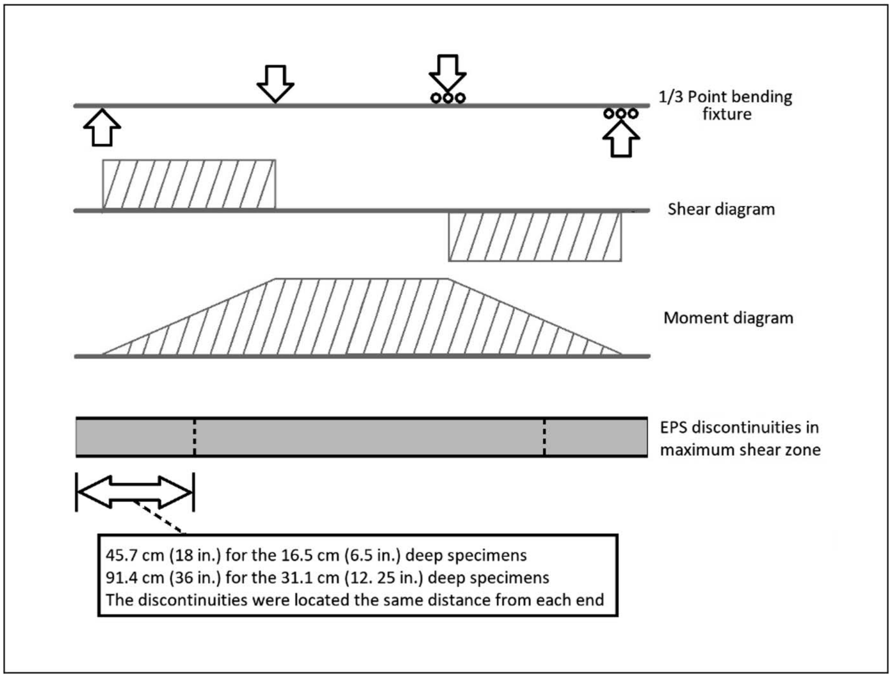

Figure 1.—Sketch of 1/3rd-point bending diagram, associated moment and shear diagrams, and location of shear discontinuities.

and 31.1 cm [6.5 in. and 12.25 in.] deep) were tested in bending. McDonald et al. (2018; p.11) noted that "the static bending tests typically failed in shear at the manufactured discontinuities in the EPS web. These discontinuities are points of dramatically decreased shear strength." Neither of these works describe potential differences in mechanical performance of SIPs that have differing foam densities.

It has been previously demonstrated (Shmulsky et al. 2022) that discontinuities (or the lack thereof), i.e., nonglued butt joints, in the foam when in the area of maximum shear stress are influential on SIP flexural performance. In the case of 1/3rd-point flexural loading, the zone of maximum shear stress is that between the reaction supports at the span ends and the load heads, which are located at the 1/3rd-point of the span. That research, Shmulsky et al. (2022), did not investigate potential differences in foam density among test specimens. Therefore, the objective of this research was to investigate the influence of foam density on the flexural performance of SIPs. It was hypothesized that higher density foam would yield stiffer and stronger SIPs. Herein, for this study all SIPs contained foam discontinuities in the areas of maximum shear stress (locations between reaction supports and load head in a 1/3rd-point bending test).

It is noted that the specimens tested herein are from one production facility. Each set of the four sets of specimens (that is two depths and two foam densities) was taken from a single shift. As such, the findings detailed herein are not intended to represent global design values for any of the mechanical properties.

Materials and Methods

The SIP's foam cores were EPS, with densities of approximately 0.016 g/cm^3 (1.0 lb/ft^3) and 0.019 g/cm^3 (1.2 lb/ft^3). All SIPs had 1.11-cm (7/16-in.) -thick OSB facers. All OSB materials were certified, and grade-stamped in accordance with APA (the Engineered Wood Association Product Report PR-N610). The OSB facers were full length, i.e., contained no end joints. All specimens were constructed with the OSB strength axis oriented parallel with the length of the SIP panel. All specimens were approximately 29.8 cm (11.8 in.) wide. Specimens were categorized into one of two depth classes, i.e., either 16.5 cm or 31.1 cm (6.5 in. or 12.25 in.) deep. All specimens were tested with a 140-kip capacity Instron universal testing machine outfitted with a 1/3rd-point flexure fixture. Testing followed that associated with ASTM D6815 (2015b) short beam tests with specific reference to ASTM D198 (2015a). Per ASTM D6815 (2015b), the target time to failure was 1 minute with none less than 10 seconds and none more than 10 minutes. The load rate was initially adjusted in an effort to achieve the desired 1-minute time to failure. Actual average times to failure were 0.975 and 1.43 minutes for the 16.5-cm and 31.1-cm (6.5-in. and 12.25-in.) depths, respectively. The load rate settled at approximately 1.9 in./min. The span to depth ratio was approximately 18:1. The bearing surfaces on which the specimens were supported were 3.81 $\times$ 30.5 cm (1.5 $\times$ 12 in.) long. Center point deflection was measured and recorded via a string encoder gauge affixed to each specimen at mid-span and mid-depth (neutral

Table 1.—Specimen and testing parameters. Values are in cm (in.).

Beam depth class	16.5 (6.5)	31.1 (12.25)
Span	297 (117)	549 (216)
Specimen length	305 (120)	579 (228)
Specimen width	29.8 (11.8)	29.8 (11.8)
Span/depth ratio	18	17.6
Location of shear discontinuities, distance from specimen ends	45.7 (18)	91.4 (36)

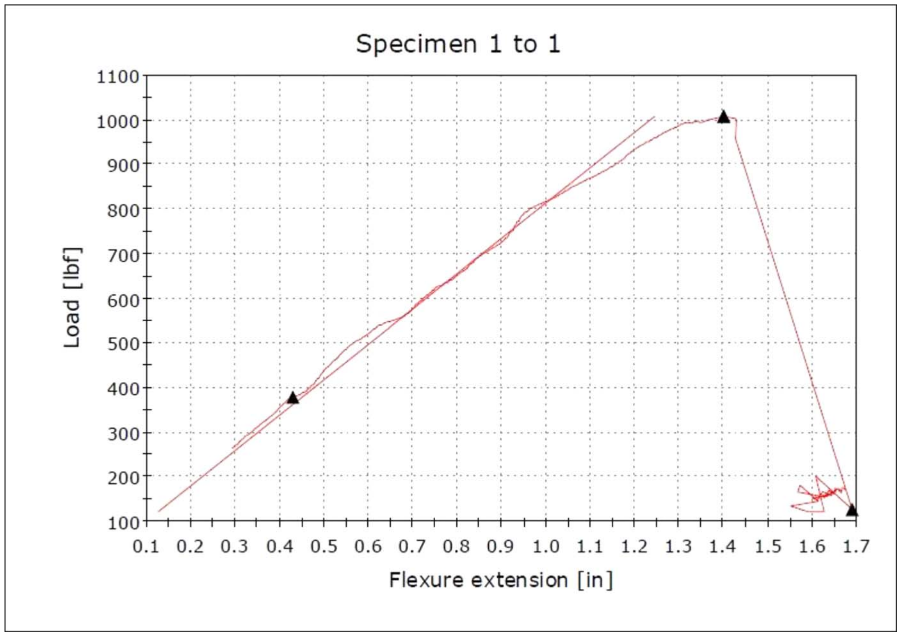

Figure 2.—Exemplar load versus center point deflection curve, for the 6.5-inch-deep specimen number 1, taken from the universal testing machine.

axis). All specimens had a foam discontinuity in each zone of maximum shear (Fig. 1). Table 1 lists the specimen and testing fixture parameters.

Statistical Analysis

The experimental design was a completely randomized design, and data for bending test in two types of the foam densities were analyzed using a 2-tailed *t* test. The alpha value of significance was 0.05.

Results and Discussions

It should be noted that the failure mode of all specimens was that of shear originating from the foam discontinuity. Figure 2 illustrates as exemplar the load versus center point displacement curve taken directly from the universal testing machine. Figure 3 illustrates a 16.5-cm (6.5-in.) -class beam at the time of failure in the testing machine. Figures 4 and 5 illustrate the shear failure mode in 16.5-cm (6.5-in.) and 31.1-cm (12.25-in.) -class beams, respectively. To evaluate the potential differences in flexural performance of SIPs with varying foam densities, the experiment was set up as two (one for each beam depth) 2-tailed *t* tests with the assumption of equal variance. Maximum load (P_{max}) summary statistics for the specimens as tested are shown in Table 2, along with *P* values of significance for the different foam densities within each panel depth.

Summary statistics for Δy_{max} are shown in Table 3, along with *P* values of significance for the different foam densities within each panel depth. Statistically, any differences in modulus of rupture (MOR) would follow the difference in P_{max}. The observed differences in P_{max} and Δy_{max} were statistically significant. All other factors (test regime, OSB materials, adhesives, foam type, etc.) were held

Figure 3.—Photograph of 16.5-cm (6.5-in.) -class beam in the testing machine at the time of failure.

Figure 4.—Shear failure mode in exemplar 16.5-cm (6.5-in.) -class beam. All beams in this depth class failed by this same mode.

Figure 5.—Shear failure mode in exemplar 31.1-cm (12.25-in.) -class beam. All beams in this depth class failed by this same mode.

constant, to the degree possible; therefore, it appears this finding is attributable to having two distinct foam densities for the core. This finding suggests that the foam core is influential with respect to SIP properties. As future research, the authors plan on developing a larger more comprehensive data set that will include core materials of several densities.

The results indicate that foam density influences the bending performance of SIPS. Foam densities of 0.016 g/cm^3 (1.0 lb/ft^3) and 0.019 g/cm^3 (1.2 lb/ft^3) developed statistically significant differences in bending strengths based on P_{max} in like-sized, large bending test specimens. With the 0.019-g/cm^3 (1.2-lb/ft^3) foam being 20 percent heavier than the 0.016-g/cm^3 (1.0-lb/ft^3), the 16.5-cm and 31.1-cm (6.5-in. and 12.25-in.) beams with heavier foam were 21.2 percent and 14 percent stronger, respectively. Essentially, the denser foam developed stronger and stiffer performance. This finding is logical because denser foam contains more polymer and less air in its bulk matrix. Previous related research evaluated SIP specimens of like size and architecture with the same test setup, load rates, environment, and overall methodology. In this work, as compared with that previous work, the only difference is the presence of the shear-zone discontinuities in the foam. Thus, the presence of foam discontinuities in the horizontal shear zone of test specimens reduced the capacity of the beams as compared with similar beams from previous research wherein such discontinuities were absent. It is reasonable perhaps to surmise that the stronger correlative relationship for the thinner specimens result from the well-established size effect, and its associated greater variability, related to the strength of wood structural members.

Conclusions

In the current research, the influence of foam density on the flexural properties of SIP bending members was evaluated. The results showed that that foam density has an impact on the bending performance of SIPs and in both two depths classes. SIPs with heavier foam were between 14 percent and 21 percent stronger depending on depth. Similarly, based on the statistical analysis, SIPs with denser foam were stiffer. It is noted that, as presented, these results may only be directly applicable to the testing parameters used in this study because design loads for SIPs in transverse bending are based on uniform loading in accordance with ICC Acceptance Criteria 04 (AC 04). The shear distribution in uniform loading is considerably different from that using a 1/3rd-point loading condition. These results, however, could be mathematically adjusted for uniform load situations. Also, the positioning of discontinuities (end joints) in the foam core are random in actual SIP production and may not necessarily be located in a high shear zone in service. Therefore, these results should be conservative because in-service foam discontinuities may be loaded in shear, similar to the test methodology herein, or may not be loaded in shear, in which case the SIP performance would be well above that noted herein.

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Table 2.—Summary statistics for P_{max} values from specimen testing. All specimen sections were equal within each depth class, so modulus of rupture (MOR) trends and differences would equal those for P_{max}.

	Depth: cm (in.)		Depth: cm (in.)	
	16.5 (6.5)		31.1 (12.25)	
Foam density (lb/ft^3)	1	1.2	1	1.2
Number	16	15	16	16
Mean: N (lbs)	4,417 (993)	5,400 (1,214)	4,995 (1,123)	5,693 (1,280)
Median: N (lbs)	4,452 (1,001)	5,422 (1,219)	4,924 (1,107)	5,569 (1,252)
SD: N (lbs)	250.9 (56.4)	357.6 (80.4)	346.5 (77.9)	384.3 (86.4)
Coefficient of Var. (%)	6	7	7	7
P value for significance with 2-tailed *t* test assuming equal variance	8.81×10^{-10}		7.99×10^{-6}	

Table 3.—Summary statistics for Δy_{max} values from specimen testing.

	Depth: cm (in.)		Depth: cm (in.)	
	16.5 (6.5)		31.1 (12.25)	
Foam density (lb/ft^3)	1	1.2	1	1.2
Number	16	15	16	16
Mean: cm (in.)	3.40 (1.34)	3.05 (1.20)	4.09 (1.61)	4.32 (1.70)
Median: cm (in.)	3.45 (1.36)	2.93 (1.18)	4.01 (1.58)	4.37 (1.72)
SD: cm (in.)	0.099	0.076	0.118	0.105
Coefficient of Var. (%)	7	6	7	6
P value for significance with 2-tailed *t* test assuming equal variance	8.78×10^{-5}		3.17×10^{-4}	

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