

STUDY ON FLEXURAL BEHAVIOR OF COLD-FORMED STEEL-**ORIENTED STRAND BOARD COMPOSITE JOISTS**

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ABSTRACT: An environmentally friendly composite joist was proposed, which is comprised of top and bottom flanges made of cold-formed thin-walled hat-section steel connected with a web made of oriented strand board (OSB) by fasteners. The push-out tests were firstly carried out to compare the load-carrying capacity and stiffness of the cold-formed steel-OSB joints with different fasteners, i.e., cross slot countersunk head self-drilling self-tapping screws, hexagon flange head self-drilling self-tapping screws and hexagon bolts. It was found that the joints with the cross slot countersunk head selfdrilling self-tapping screws have the best mechanical performances. Then, the composite joists were tested under the fourpoint bending, and their flexural performance was compared with that of I-joists. The load-carrying capacity of composite joists with a screw spacing of 50 mm was 90% of that of I-joists, and their flexural stiffness was higher than that of Ijoists.

KEYWORDS: cold-formed steel, oriented strand board, self-tapping screws, composite joists, flexural behavior

1 - INTRODUCTION

I-joists (Figure 1) are widely used in light-frame wood constructions, which are one of the most common types of wooden residential buildings today. I-joist is an Ishaped flexural member, which is comprised of top and bottom flanges made of structural composite lumber or visually graded lumber, glued to a web made of woodbased structural board, typically oriented strand board (OSB). Compared to solid sawn timber, I-joists are more efficient for structural use [1, 2] and have the advantage of a lower variability of performance and a better dimensional stability [3].



Although I-joists have high stiffness, the utilization of adhesives will inevitably exert a detrimental influence on the environment, and the flanges and web are easily separated, which results in brittle failure.



Figure 2. Cold-formed thin-walled steels

The cold-formed thin-walled steel joists are alternative to I-joists in light-frame wood constructions [4]. However, the cold-formed thin-walled steels (Figure 2) are highly susceptible to local-distortional, flexural, and flexuraltorsional buckling, which can result in the significant reduction in load-carrying capacities [5].



Figure 3. Cold-formed thin-walled steel-OSB composite joist

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This study proposes an environmentally friendly composite joist, which is comprised of top and bottom flanges made of cold-formed thin-walled hat-section steel, connected with web made of OSB by fasteners, as shown in Figure 3, instead of I-joists and cold-formed thin-walled steel joists.

The push-out tests were firstly carried out to compare the load-carrying capacity and stiffness of the steel-OSB joints with different fasteners, i.e., cross slot countersunk head self-drilling self-tapping screws, hexagon flange head self-drilling self-tapping screws and hexagon bolts, to select the suitable fastener. The composite joists and Ijoists were then tested under the four-point bending, and their flexural performance was compared.

2 - MATERIALS AND METHODS

2.1 PUSH-OUT TESTS ON COLD-FORMED THIN-WALLED STEEL-OSB JOINTS

First, three series of cold-formed thin-walled steel-OSB joints were tested, which were assembled by three different fasteners, i.e., cross slot countersunk head self-drilling self-tapping screw (series STA), hexagon flange head self-drilling self-tapping screw (series STB) and hexagon bolt (series M), as shown in Figure 4. The nominal diameter of the screws is 4.8 mm, and the nominal diameter of the bolts is 5 mm. Four replicate specimens for each series were tested, and their dimensions are shown in Figure 5. The OSB boards with the thickness of 11.1 mm are 300 mm in length and 200 mm in width, and the cold-formed thin-walled hatsection steels with the thickness of 0.8 mm are 220 mm in length.

Due to the best joint performance, the cross slot countersunk head self-drilling self-tapping screws were adopted to explore the effect of fastener arrangements, where the heads of two screws were aligned in the same direction (series STA-S) and opposite direction (series STA-O) as shown in Figure 6.



(a) Cross slot countersunk head self-drilling self-tapping screw



(b) Hexagon flange head self-drilling self-tapping screw



(c) Hexagon bolt Figure 4. Type of fasteners



Series	Type of fasteners	Number of fasteners	
STA	Cross slot countersunk head	1	
STB M	Hexagon flange head self-	1	
	drilling self-tapping screw	1	
	Cross slot countersunk head	1	
81A-8	self-drilling self-tapping screw	2	
STA-O	Cross slot countersunk head self-drilling self-tapping screw	2	

The summary of the specimens is shown in Table 1 and the test setup is shown in Figure 7. The specimens were connected to the loading device through two bolts with a diameter of 16 mm.



The load was applied on the OSB board by following a loading procedure according to EN 26891 [7] at a constant loading rate of 2 mm/min. The slips between the OSB board and cold-formed thin-walled hat-section

steels were measured using two linear variable differential transformer (LVDT) displacement transducers.

The ultimate load (F_u) was determined using the maximum load, and the service stiffness (Ks) was determined according to EN 26891 [7].

An analysis of variance with p < 0.05 was conducted to evaluate statistical significance of the experimental results.

2.2 FOUR-POINT BENDING TESTS ON **COMPOSITE JOISTS**

I-joist (series I) and composite joists with screw spacing of 100 mm (series C-100) and 50 mm (series C-50) were tested. The flanges of the I-joist are made of laminated veneer lumber and the flanges of the composite joist are made of cold-formed thin-walled hat-section steel. Their webs are all made of OSB. The configurations and geometries of the specimens are shown in Figure 8. Two replicate specimens for series I and series C-100 and one specimen for series C-50 were tested.

The specimen was simply supported and loaded symmetrically in bending at two points at a constant loading rate of 2 mm/min, as shown in Figure 9. Two LVDTs are symmetrically arranged at the middle of the joist to measure the center deformations (ω_{center}) of the joist, and four LVDTs are antisymmetrically arranged on both sides of the joist to measure loading point deformations (ω_{load}) and support deformations ($\omega_{support}$) of the joist. To minimize the risk of possible local buckling, stiffeners were placed on the web close to supports and loading points.



Figure 9. Four-point bending test setup

Similarly, to minimize the risk of possible overall buckling, lateral supports were arranged at both ends of the supports, as shown in Figure 10. The reaction bearing plates were placed between the supports and the bottom surface of the specimens of composite joists and between the loading points and the top surface of the specimens of composite joists to minimize the risk of possible local indentations.



Figure 10. Diagram of lateral supports

The global stiffness $EI_{m,app}$ and local stiffness EI_m were calculated using Equation (1) and (2) according to GB/T 50329-2012 [8].

$$EI_{m,app} = \frac{\Delta Fa(3L^2 - 4a^2)}{48\Delta y}$$
(1)
$$\Delta F = 0.4F_{max} - 0.1F_{max}$$
$$\Delta y = \Delta \omega_{senfor} - \Delta \omega_{support}$$

where F_{max} is the maximum load, $\Delta \omega_{\text{center}}$ is the increment of deformation at the center of the joist corresponding to ΔF , $\Delta \omega_{\text{support}}$ is the increment of deformation at the support of the joist corresponding to ΔF , *L* is the span in bending and *L* = 2000 mm, and *a* is the distance between the loading point and the nearest support and *a* = 667 mm.

$$EI_{\rm m} = \frac{al_0^2 \Delta F}{16\Delta\omega}$$
(2)
$$\Delta\omega = \Delta\omega_{\rm center} - \Delta\omega_{\rm load}$$

where $\Delta \omega_{\text{load}}$ is the increment of deformation at the loading point of the joist corresponding to ΔF , and l_0 is the gauge length for the determination and $l_0 = 547$ mm.

3 - RESULTS AND DISCUSSION

3.1 BEHAVIOR OF COLD-FORMED STEEL-OSB JOINTS

As shown in Figure 11, bearing failures occurred on the OSB boards. Figure 12 shows the average load-slip curves, and Table 2 summarizes the experimental results.

Table 2: Load-carrying capacity and stiffness of joints

i.	F_{u}		K	Ks	
	Mean	COV	Mean	COV	
Series	(kN)	(%)	(kN/mm)	(%)	
STA	4.21	8.31	3.86	15.37	
STB	4.02	33.38	1.87	19.62	
М	4.24	18.83	1.73	20.12	
STA-S	7.81	17.94	5.07	6.90	
STA-O	8.00	18.93	4.65	35.16	





Figure 13 shows the experimental load-carrying capacities and stiffnesses of joints with three different fasteners. Their load-carrying capacities did not show statistically significant differences. The stiffness of steel-OSB joints with the cross slot countersunk head self-drilling self-tapping screw was significantly higher than that with the hexagon flange head self-drilling self-tapping screw and the hexagon bolt. Therefore, the performance of joints with cross slot countersunk head self-drilling self-tapping screw is the best.

Figure 14 shows the experimental load-carrying capacities and stiffnesses of individual cross slot countersunk head self-drilling self-tapping screw, which were obtained as the ratios of the load-carrying capacities and stiffnesses to the number of screws. The load-carrying capacities of individual screw did not show statistically significant differences, and the stiffnesses of individual screw in series STA-S was essentially the same as that of series STA-O. Therefore, the alignment direction of screw heads has no effect on the joint

performance. To facilitate faster assembly of the composite joists, the screw heads are aligned in the same direction.

3.2 BEHAVIOR OF COMPOSITE JOISTS

Figures 15-18 shows the experimental failure modes, and Figure 19 shows the load-deflection curves. After reaching the ultimate load, the specimens of I-joist immediately lost their load-carrying capacity and showed brittle failure. The separation occurred at the glued joint of the web of specimen I-1 and cracks appeared on the bottom flange, while a long crack formed in the web of specimen I-2 and the bottom flange was pulled off from the web.

The load-deflection curves of the series C-100 demonstrate good ductility. The load-carrying capacity of the series C-100 did not significantly decrease until the midspan deflection reached 30 mm. However, cracks appeared on their webs. The series C-50 failed due to the occurrence of overall buckling during the test.





(a) Separation of the glued joint





(b) The bottom flange pulled off from the web Figure 16. Failure mode of specimen I-2



Figure 17. Failure mode of specimen C-100-1





Figure 18. Failure mode of specimen $\overline{C-50-1}$



Figure 19. Load-midspan deflection curves of joist specimens

	Fu			<i>EI</i> _{m,app}			EIm		
	Value	Mean	V	alue	Mean	Value	e Mean		
Specimens	(kN)	(kN)	(kN	√m²)	$(kN \cdot m^2)$	(kN·m	2) (kN·m ²)		
I-1	34.94	41.66	60	600.8 584.4		394.8	371.5		
I-2	48.37	41.00	56	58.0	504.4	348.2	571.5		
C-100-1	30.48	30.07	70	705.9 638.3		677.2	615.6		
C-100-2	29.66	50.07	57	70.7	038.5	553.9	015.0		
C-50-1	37.52	-	7()6.8	-	624.9	-		
75 -00 -00 -00 -00 -00 -00 -00 -00 -00 -0		C-100	C-50	1000 800 600 400 200 200	Global st	0	Local stiffness		
	(a) Load-carrying capacity (b) Stiffness								
Figure 20. Performance analysis of wood I-joist and Cold-formed thin-walled steel-OSB composite joist									

Table 3: Summary of four point bending test results of joists

Table 3 summarizes the experimental results. Figure 20 shows the experimental load-carrying capacities and stiffnesses of three joists. The load-carrying capacity of composite joint with a screw spacing of 50 mm was 125% of that of composite joint with a screw spacing of 100 mm and the stiffness of composite joint with a screw spacing of 50 mm was 111% of that of composite joint with a screw spacing of 100 mm.

Meanwhile, the load-carrying capacity and the stiffness of composite joint with a screw spacing of 50 mm were 90% and 135% of those of I-joist.

4 - CONCLUSION

The cold-formed thin-walled steel-OSB joints with cross slot countersunk head self-drilling self-tapping screw showed favorable load-carrying capacity and stiffness. And there is no significant difference in the mechanical performances of joints with the screw heads aligned in the same direction and the opposite direction.

An environmentally friendly composite joist was proposed, which is comprised of top and bottom flanges made of cold-formed thin-walled hat-section steel connected with a web made of OSB by cross slot countersunk head self-drilling self-tapping screws. The composite joists show favorable flexural performance. After reducing the screw spacing from 100 mm to 50 mm, the load-carrying capacity of the composite joist increased by 25%, and the stiffness increased by 11%. The load-carrying capacity of the composite joist with a screw spacing of 50 mm was close to that of the I-joist, while the bending stiffness was higher than that of the I-joist. The failures of the composite joists were ductile, while the failures of the I-joists were brittle.

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