LATERAL LOAD-CARRYING CONNECTION PROPERTIES AND WITHDRAWAL CAPACITY OF HYBRID POPLAR

*Arijit Sinha**†
Assistant Professor
119 Richardson Hall
Department of Wood Science and Engineering
Oregon State University
Corvallis, OR 97331
E-mail: Arijit.sinha@oregonstate.edu

Diana G. Avila
Undergraduate Research Assistant
School of Civil and Construction Engineering and Forest Engineering
Oregon State University
Corvallis, OR 97331
E-mail: Aviladia@onid.orst.edu

(Received August 2013)

Abstract. An experimental study is reported aimed at determining the yield load, withdrawal capacity, and validity of National Design Specification (NDS) yield models on connections between hybrid poplar and common sheathing materials using a dowel-type fastener. Plantation-grown hybrid poplar (Pacific Albus) was procured, and connections with two different thicknesses of oriented strandboard and plywood were constructed using a dowel-type fastener. The NDS does not list connection design values for low-density wood species. Therefore, it was important to validate the NDS yield model equations for applicability toward a low-density species such as hybrid poplar. The results quantify the lateral load-carrying and withdrawal capacities of hybrid poplar. Also, the prediction using NDS yield models consistently matched the observed yield loads and yield modes for all the sheathing types used in this study. The data suggest that the NDS yield model is an adequate tool for connection design even for low-density species, provided knowledge of dowel-bearing capacity of the hybrid poplar is known.

Keywords: Yield models, oriented strandboard, dowel bearing strength, laminated products, National Design Specification.

INTRODUCTION

Wood has historically been a material of choice for a myriad of applications such as construction, furniture, tools, and other products. Wood is a natural and renewable material and provides a green material option for all applications. However, faced with a dwindling supply of high-quality lumber from natural forests and stricter environmental regulations, poplar (*Populus* spp.) and its hybrids have been considered as alternative wood sources because of their rapid growth and ease of reproduction (Beaudoin et al 1992; Koubaa et al 1998). Poplar represents one of the most widespread hardwood species in North America (Balatinecz et al 2001). Nevertheless, it has long been characterized as a low-density (specific gravity 0.30-0.39), low-strength wood species (Mátyás and Peszlen 1997; Balatinecz et al 2001). Currently, poplar wood is primarily used as fiber for the pulp and paper industry and as engineered wood products such as oriented strandboard, laminated veneer lumber, and structural composite lumber (Balatinecz et al 2001).

In the Pacific Northwest (PNW) region of the US, 14,000 hectares of plantations of hybrid

---

* Corresponding author
† SWST member

Wood and Fiber Science, 46(1), 2014, pp. 97-108

poplar were established in the last quarter of the 1900s with the intention of providing raw material feedstock to the pulp and paper industry. These species have low specific gravity (0.30-0.35) and a short rotation period. Since the 1980s, however, the pulp and paper industry in the PNW region has shrunk by half because of competition from overseas (Law 2011). Consequently, the plantation fiber is used mainly as biomass, as pallets, and in the furniture industry. The hybrid poplar plantations are Forest Stewardship Council-certified as sustainable timber plantations and are marketed as Pacific Albus. A value-added and sustainable use for the wood is needed.

Cross-laminated timber (CLT) is an engineered wood composite made of at least three orthogonally bonded layers of solid-sawn lumber that are laminated by gluing longitudinal and transverse layers with structural adhesives to form a solid rectangular-shaped, straight, and planed timber intended for roof, floor, or wall applications. CLT is a potentially cost-competitive solution that complements the existing light frame and heavy timber options and is suitable for many applications that currently use concrete, masonry, and steel. This is not merely a new engineered composite panel product but an entirely new building technology that is revolutionizing the use of timber in construction in a way that has not been seen since the introduction of plywood as a structural-grade panel product. For hybrid poplar to be used successfully in CLT and other structural applications, a thorough knowledge of its mechanical and structural properties is required. The mechanical and structural properties of hybrid poplar have been well studied (Bendtsen et al 1981; Hall et al 1982; Kretschmann et al 1999; OWIC 2011). Initial research has shown that hybrid poplar can successfully be used in CLT applications (Kramer et al 2013). However, to be successfully integrated as a raw material feedstock for CLT and other structural applications, connection design values for connections using hybrid poplar and dowel-type fasteners (such as nails) are needed.

Dowel-type fasteners such as nails are permitted in two kinds of applications: 1) lateral loading, in which the force is applied perpendicular to the axis of the nail; and 2) withdrawal, in which force is applied axially. National Design Specifications (NDS) for timber construction provide design values for connections in lateral loading as well as in withdrawal (AFPA 2012). For lateral loading, NDS tables provide design values for wood with specific gravity of 0.35 or higher based on the European Yield Models (Johansen 1949). Because the average specific gravity of hybrid poplar is less than 0.35, the design for connections involving hybrid poplar is not dealt with in the NDS. A literature search only points to one study by the Oregon Wood Innovation Center (OWIC 2011) on withdrawal capacity of hybrid poplar. There is very limited information on lateral design values for a nailed connection using hybrid poplar. Insufficient information on the properties of connections with hybrid poplar is one of the major impediments for the species to be used in CLT or other structural applications.

The overarching goal of this study was to validate if NDS yield models on laterally loaded connections are applicable to a low-density species not currently covered by the NDS. Pacific Albus is used as an example of a low-density species because of its abundance in the PNW and its similarities with many Appalachian hardwoods. The objective of this study was to determine the strength and stiffness of laterally loaded hybrid poplar to common sheathing material. Furthermore, withdrawal, dowel bearing strength, and validity of NDS yield models on the laterally loaded connections were studied. More specifically, the objectives of the study were to

1. Determine the withdrawal values and dowel-bearing capacity for hybrid poplar;
2. Determine the yield loads of laterally loaded hybrid poplar to sheathing connections;
3. Determine if NDS yield models can be used to predict the nominal design capacity for hybrid poplar to sheathing connections; and
4. Study the failure modes of the connections.

MATERIAL AND METHODS

Connections

Hybrid poplar (Pacific Albus) was procured from plantations in Boardman, OR. Commercially available oriented strandboard (OSB) and plywood were obtained, each of two different thicknesses (Table 1). The panels were rated C-D exposure 1 with a span rating of 32/16. Average specific gravity of the panels is given in Table 2. Because this study was part of a larger study, only some parts of the boards were used for connection tests (this study). The remaining were reserved for a series of future testing aimed at characterizing mechanical and structural performance, which will be part of future publications.

The nailed connection samples were constructed using 38- × 140-mm hybrid poplar as the framing member and two thicknesses each of plywood and OSB, which represents the two most common sheathing materials used in construction today. As a result, four different sheathing materials were used. All relevant dimensions, thicknesses, and average density of all materials are presented in Table 1. Also presented in Table 1 is the test matrix for lateral nail connection tests and total number of samples. Standard stick-frame construction has two different sheathing-to-framing nail joint configurations. The connection geometries (Fig 1) are 1) panel edge connection (nail positioned 20.64 mm from the panel edge, loaded parallel to the fiber direction of the main member); and 2) plate connection (nail positioned 20.64 mm from the panel end, loaded perpendicular to fiber direction of the main member). These two geometries are referred to as edge geometry (EG) and plate geometry (PG).

A single-shear nail connection was constructed using smooth-shank nails (3.65 mm diameter, length = 75 mm, $f_{by} = 620$ MPa). The bending yield strength of the nail was evaluated by the manufacturer using ASTM (2007a). The nails were hammered in manually on the side of the hybrid poplar. The nails were centered in the thickness of the framing member. In both setups, the sides were flush, therefore the hybrid poplar and the sheathing material were smooth (meaning neither specimen extended more than the other). After the connections were constructed, the test samples were stored in an ASTM standard conditioning room that was maintained at 65% RH and 20°C. They were conditioned in the standard room until there was no further weight variation. After destructive testing of the connection samples, subsamples of each sample were cut from the sheathing and framing member. The subsamples were obtained as close as possible to the original position of the nail. Dowel bearing strength, moisture content (oven-dry basis), and specific gravity (based on oven-dry dimensions and weight) were measured as per ASTM (2007b).

Test Setup

Nail test. The edge test had the specimen structures clamped to a perpendicular metal

Table 1. Lateral nail test matrix.

Variable	Quantity	Description	Abbreviation
Connection geometry	2	Edge and plate	EG and PG
Framing member (FM)	1	Solid-sawn hybrid poplar 38 × 148 mm	
Sheathing member (SM)	4	SM1—OSB 11.9 mm, aspen	THNOSB
		SM2—OSB 28.9 mm, aspen	THKOSB
		SM3—plywood 11.75 mm, Douglas fir	THNPLY
		SM4—plywood 28.75 mm, Douglas fir	THKPLY
Fastener	1	SENCO (3.65 × 75 mm)[a]	
Replication	12		
Total	96	(2 × 1 × 4 × 1 × 12)	

[a] Fasteners were manufactured under brand name SENCO® by SENCO Brands Inc., Cincinnati, OH.

OSB, oriented strandboard; EG, edge geometry; PG, plate geometry.

Table 2. Dowel bearing strength and specific gravity (SG) of each material.

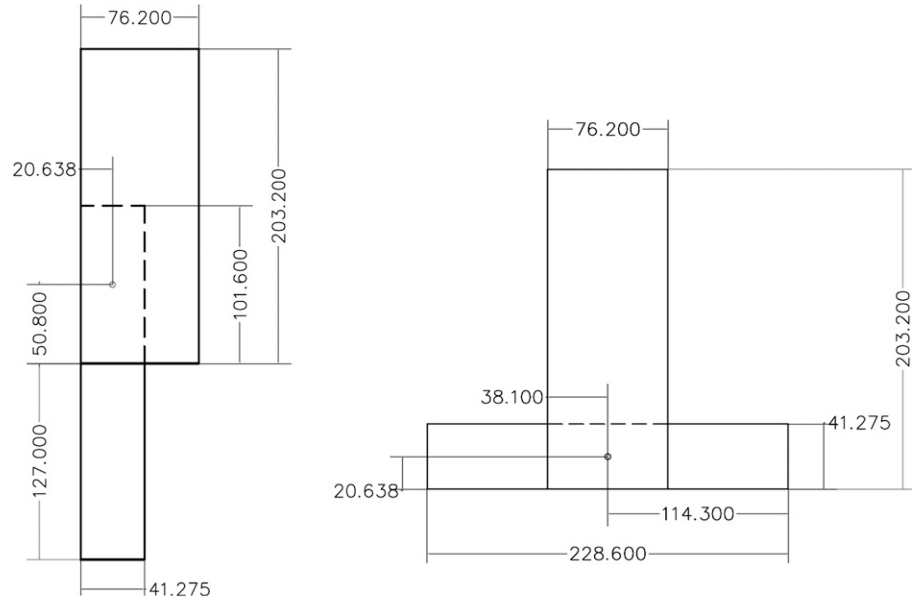
Material[a]	Length × base × height averages (mm)	Dowel bearing strength (MPa)	COV (%)	Average SG
Hybrid poplar (parallel)	50 × 33 × 36	23.43	16.6	0.34
Hybrid poplar (perpendicular)	50 × 74 × 15	15.69	25.8	0.33
THNOSB	12 × 76 × 36	26.07	32.7	0.58
THKOSB	29 × 76 × 37	29.45	17.8	0.58
THNPLY	12 × 75 × 38	23.52	18.8	0.47
THKPLY	29 × 76 × 37	40.20	22.3	0.54

[a] See Table 1 for definition of abbreviations.
COV, coefficient of variation.

bracket (Fig 2a), whereas the plate test had the specimen structures clamped to the floor of the machine (Fig 2b). Care was taken in setting up the apparatus to minimize all eccentricities in loading caused by nail withdrawal. The universal testing machine (UTM; Instron 5582, Norwood, MA) used had a steady displacement rate of 5 mm/min.

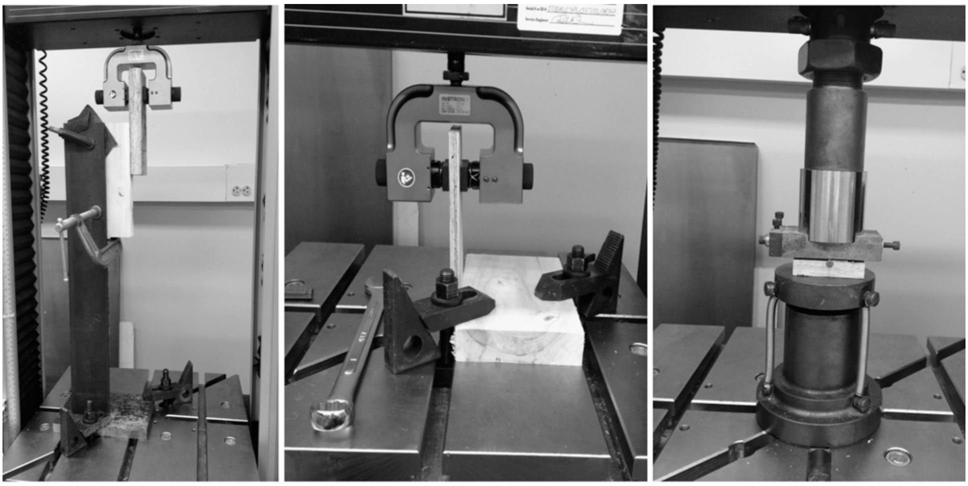
Load-deflection curves (P-Δ) were recorded for each test. The test was stopped after the P-Δ curve leveled off. Yield strength was calculated from the load and deflection curves using a 5% diameter offset. Yield strength is defined by the 5% offset method as the intersection of the load-deformation (P-Δ) curve and a line parallel to the initial linear portion of the P-Δ curve offset by 0.05 times the shank diameter of the nail in the positive direction. Here, the offset was rounded to 0.18 mm. Ultimate load from the load-deflection curve is the maximum load the connection can withstand without failure. However, the yield models suggest that for a connection, yield strength is considered to be the ultimate strength for the connection (Aune and Patton-Mallory 1986a; Peyer and Cramer 1999). Also, design of connections is based on this assumption. Hence, for this study, only yield strength was evaluated.

After testing each specimen, the nails were taken out of the wood by cutting around each nail and splitting the wood by hammering a



(a) Edge connection (b) Plate connection

Figure 1. Schematic of connections. All dimensions in millimeters.



(a) Edge connection (b) Plate connection (c) Dowel bearing

Figure 2. Test setup (a) edge connection tests; (b) plate connection tests; (c) dowel bearing test.

chisel on the wood. The mode of failure for a single-shear connection was then determined according to AFPA (1999).

Dowel test. Dowel bearing strength was calculated in accordance with ASTM (2007c) for each of the subsets obtained after the connection tests. The test setup is shown in Fig 2c. The subset samples were stored in the ASTM standard conditioning room. The samples were made by drilling a 3.65-mm hole in the specimen and cutting the hole in half with a band saw. The resulting dimensions are presented in Table 2. Also listed in Table 2 are the average specific gravity values of each material. Each specimen was centered under the load cell on top of a pedestal that had been leveled by slightly pressing it with a bearing block. The bearing block was set to barely touch the nail (3.65 mm diameter, 75 mm length) that was placed on top of the half hole. The UTM lowered the bearing block at a displacement rate of 2.0 mm/min, and the test was automatically stopped when the bearing block touched the wood. NDS defines the yield point using the 5% offset method as previously explained. The same definition is applied to determine the yield point in a dowel bearing strength test and is stipulated in NDS (AFPA 2012). Thus, the dowel bearing strength is also defined by the yield strength. The load and deflection curves produced were used to find the yield point at a 5% diameter offset, which is the dowel bearing strength of the wood and sheathing.

Withdrawal. The test samples were stored in the ASTM standard conditioning room. The samples were made by drilling 0.78-mm holes along a hybrid poplar board. The holes were 63.5 mm from the edge and 20.64 mm from the sides. The nails were hammered into the holes made. About 70% of the nail was inside the board, and a metal plate with a half hole was set below the nail head to ensure 30% of the nail extended outward. The specimens were tested to failure following ASTM (2007b) procedures for nail withdrawal tests. The nail was pulled up by the UTM at a displacement rate of 2.5 mm/min. The test was stopped when maximum load was reached. Maximum load was then recorded. A total of 30 nail withdrawal tests were conducted on randomly selected hybrid poplar boards.

Predictions Using National Design Specification Equations

Yield models. The predicted yield loads and mode of yielding were calculated using the

NDS yield models (AFPA 1999, 2012). The NDS defines six modes of yielding depending on which component of the connection yields. For example, different yield modes are assigned if yielding of the connection is caused by the crushing of materials in either member (framing and sheathing) or both members. Similarly, if the connection yield is caused by bending and subsequent yielding of the metal nail, a different yield mode is assigned. The inputs required to calculate the yield loads and yield modes are dowel bearing strength of framing and sheathing, bending yield strength of the nail, thicknesses of the sheathing and framing member, diameter and length of the nail, and any other geometrical parameter specific to the connection type being evaluated. With these parameters and the equations associated with the six yield modes (AFPA 1999), the yield loads were calculated. The predicted yield mode and predicted yield load that resulted in the smallest load value out of the calculated six modes were then chosen.

Withdrawals. Design values published in NDS are based on research using bright, common wire smooth-shank nails. The following expression provides a relationship among density of the wood, diameter of the nail, and withdrawal capacity for the design.

$$W = CG^{2.5}D \tag{1}$$

where W is allowable withdrawal strength (N/mm) per unit length of nail penetration, G is specific gravity, D is diameter of the nail in mm, and C is a constant (9.515 N/mm^2) for the design values. C is multiplied by a factor of 5 to represent the mean of experimental ultimate load values as recommended in FPL (2010; Chapter 8) and the NDS (AFPA 2012).

RESULTS AND DISCUSSION

Lateral Nail Connection Tests

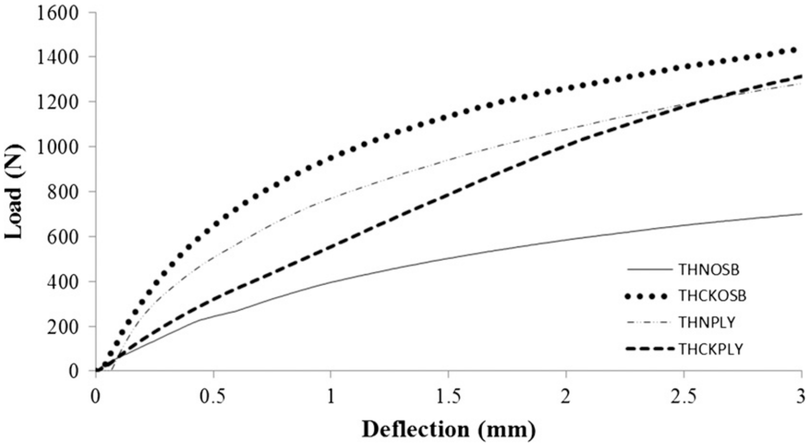
Average P-Δ curves for all sheathing material and both geometries, edge and plate, are presented in Fig 3. The yield was calculated using the 5% offset method for each individual P-Δ curve and was then averaged. A summary of all tests is presented in Table 3. For any given framing member and sheathing connection, plate connection yield load was lower than that of the corresponding edge connection yield loads. Previous studies dealing with lateral load-carrying capacity of connections also observed this trend (Kent et al 2004; Sinha et al 2011; Sinha and Miyamoto 2013). The difference in yield strength of EG and PG was expected because of the smaller edge distance for PG in the direction of loading of sheathing. Adding to the strength limiting factor for PG is the fact that the assembly is loaded perpendicular to the grain direction of the main member, and wood is weaker when subjected to tension perpendicular to the grain. There was an exception, however, in the thicker plywood, for which the plate connection had a higher yield load. The difference was statistically nonsignificant ($p = 0.21$) because of large variation in test results.

Dowel Bearing Strengths

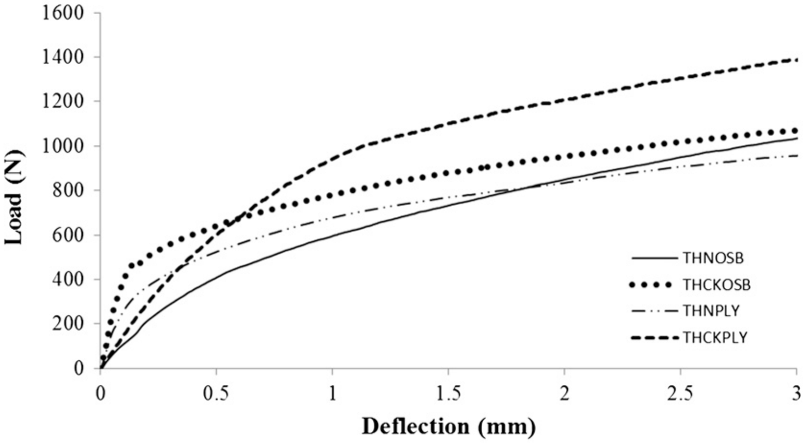
The dowel bearing yield strengths of framing and various sheathing materials are presented in Table 2. Dowel bearing strength calculations were based on the actual panel thicknesses for the framing and sheathing materials. The coefficient of variation (COV) associated with the dowel bearing strength and the average specific gravity of the material are also presented in Table 2. The COV associated with dowel bearing strength is comparable to previously published data on dowel bearing of similar materials (Sinha et al 2011). For hybrid poplar, the dowel bearing strength was lower in the perpendicular direction than the parallel to the grain direction, as expected. Also, the variability increased in the perpendicular direction. Kent et al (2004) and Sinha et al (2011) confirmed this observation.

Design Value Predictions Using National Design Specification Yield Models

Yield models use dowel bearing yield strength of the framing and sheathing material to predict yield strength for the connection. The yield



(a) **Edge Test Averages**



(b) **Plate Test Averages**

Figure 3. Average load-deflection diagram for lateral nail connection test for both edge (a) and plate (b) geometries (see Table 1 for definitions of abbreviations).

loads are calculated using NDS yield models (AFPA 2012).The dowel bearing yield strengths of the framing and sheathing members calculated after testing the subset of samples were used to predict the yield load and yield mode of the connection. Average values for each type of connection studied are presented in Table 4. The predicted yield load incorporated a reduction factor (Rd) stipulated in NDS (AFPA 2012). The reduction factor is based on the dowel diameter, and for this study, an Rd of 2.2 was used. Table 4 further compares predictions with the experimental yield strengths for the connections obtained from lateral nail tests. The predicted yield load values calculated using the NDS yield model are nominal design values. The nominal design values calculated from the dowel bearing tests are essentially lower tolerance values. To compare these values with experimental values, the predicted values need to be on the same level. These predicted values were then adjusted to a 10-min duration of load factor, C_d, of 1.6 as per NDS (AFPA 2012) and were called factored predicted yield loads (Table 4). This adjustment made sure that values being compared were on the same level.

Table 3. Summary of lateral nail test (n = 12 for each connection type).

Geometry	Sheathing[a]	Yield load (N)	COV (%)	Yield mode
Edge	THNOSB	504	21.6	IIIs
Plate	THNOSB	472	55.5	IIIs, II
Edge	THKOSB	698	30.9	IV
Plate	THKOSB	614	24.1	IV
Edge	THNPLY	602	20.4	IIIs
Plate	THNPLY	467	15.4	IIIs
Edge	THKPLY	627	32.7	IV, IIIm
Plate	THKPLY	750	35.5	IV

[a] See Table 1 for definition of abbreviations.
COV, coefficient of variation.

The NDS yield models predicted the yield strength of connections (Table 4) adequately for PG connections. The design index (Table 4), which is the ratio of the observed yield strength to the factored predicted yield strength, is a good indicator of the adequacy of NDS yield models to estimate the capacity of the connections. The design index was higher than 1.0 or within 3% of 1.0 for PG. Conversely, for EG, the design index was very close to 1.0, except for connections involving the thicker plywood (design index = 0.83; Table 4). Despite this exception, NDS yield models using the dowel bearing yield strength of materials tended to adequately predict the observed yield strength for both connection geometries.

Previous studies calculated the observed-to-predicted load ratios for wood–OSB connections. Aune and Patton-Mallory (1986b) validated the yield models using experimental data with various sheathing members and different nail types. Kent et al (2004) and Sinha et al (2011) previously validated that the NDS models reasonably predicted the yield strength values. Conversely, Theilen et al (1998) reported that the NDS yield model approach overestimated the observed yield strength of connections. The yield model does not dictate how connection yield strength is determined, and this uncertainty might have led to the discrepancy reported by Theilen et al (1998). Results of this study show that for both connection geometries, the NDS yield model approach is a reasonable indicator of the yield strength of connections between low-density hybrid poplar and a common sheathing material provided that the dowel bearing strength of the framing and sheathing member is known. Although, the average density of the hybrid poplar used in this study was below the range of NDS-tabulated values for lateral force resistance of nails, the NDS yield models and equations can adequately predict the connection

Table 4. Predictions using National Design Specification yield models for both edge and plate connection geometries.

	Predicted			Observed		
Connection[a]	Yield load (N)	Mode	Factored predicted yield load (N)	Yield load (N)	Mode	Design index
Edge						
THNOSB	320	IIIs	512	504	IIIs	0.98
THKOSB	445	IV	712	698	IV	0.98
THNPLY	308	IIIs	493	602	IIIs	1.22
THKPLY	475	IV	760	627	IV, IIIm	0.83
Plate						
THNOSB	290	IIIs	464	472	IIIs	1.02
THKOSB	397	IV	635	614	IV	0.97
THNPLY	279	IIIs	446	467	IIIs	1.05
THKPLY	414	IV	662	750	IV	1.13

[a] See Table 1 for definition of abbreviations.

capacity using hybrid poplar and common sheathing materials.

Yield Modes

The predominant yield mode observed for hybrid poplar connections with thinner framing members (the thinner plywood and thinner OSB) was IIIs (Table 3), which implies yielding by bending of the nail (Fig 4a-b) in the main member. For thicker members (OSB and plywood), the predominant observed yield mode was mode IV, in which bending of the fastener occurred inside both the framing and the sheathing member, followed by the development of plastic hinges at the bending points (Fig 4c-d). There was a high level of consistency in the predicted yield mode and the observed yield mode for all connection types and geometries. Regardless of the geometry, the predicted yield modes for thinner and thicker members were IIIs and IV, respectively. For PG, all samples yielded as per NDS yield model prediction except for two connections involving hybrid poplar and the thinner OSB, for which the yield mode observed was II, whereas predicted they were IIIs.

For EG involving OSB (both types) and the thinner plywood, all predicted and observed yield modes were consistent. For the thicker plywood, seven samples yielded in mode IV as predicted. Of the others, three samples yielded in mode IIIm (Fig 4e), whereas two samples yielded in mode II. In mode II, there is no significant bending of fastener observed, only crushing of wood in the main and side members. The nail salvaged after a mode II yielding is shown in Fig 4f. For connections to yield by mode IV, they must have adequate member thicknesses to allow bending of the metallic fastener and to facilitate formation of the plastic hinge in both members as illustrated by Blass et al (1999). The thicker plywood and OSB had average thicknesses of 28.75 and 28.875 mm, which facilitated formation of the plastic hinge within the main and side members to yield by mode IV. However, for the thicker plywood, not all samples showed mode IV yielding. This may have been caused by a multitude of factors, such as void spaces within the thickness of

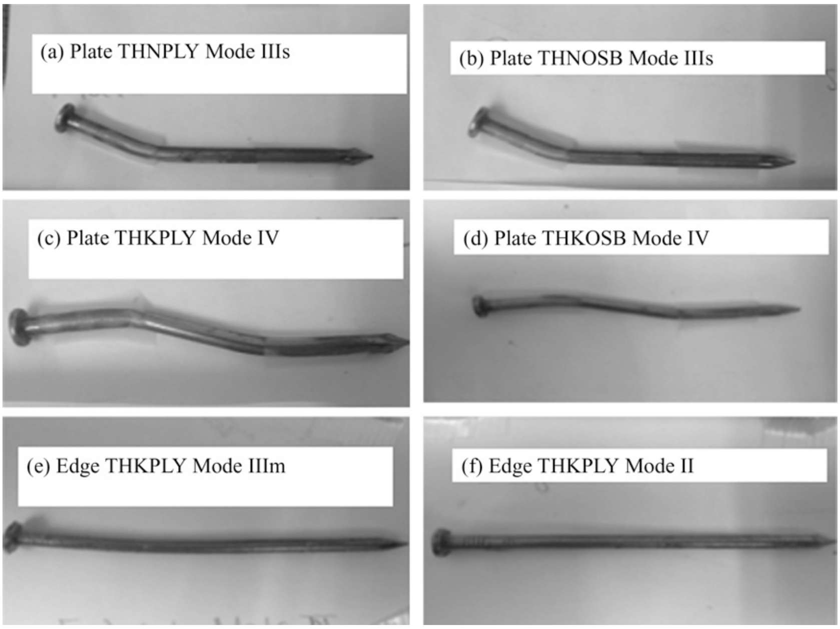


Figure 4. (a-f) Nail yielding modes (see Table 1 for definitions of abbreviations).

the plywood in the vicinity of nails, knots, and other manufacturing factors.

Nail Withdrawal

The results of 30 nail withdrawal tests along with specific gravity of the samples are presented in Table 5. Further calculated in Table 5 are the predicted ultimate withdrawal values using Eq 1. The average withdrawal value for hybrid poplar for the specific nail tested was 16.03 N/mm. These results are comparable with the experimental study conducted by OWIC (2011) in which average withdrawal values were calculated to be 14.2 N/mm. The withdrawal values are less than other comparable species such as cottonwood (black or eastern) or aspen as calculated by OWIC (2011). For example, black cottonwood's reported nail withdrawal capacity is 19 N/mm of nail penetration, which is 16% less than the calculated withdrawal value of hybrid poplar used in this study. Using specific gravity and shank diameter, the NDS equation predicted an average strength of 11.90 N/mm. Similar to the design index introduced in the lateral nail test section, a design index was calculated for withdrawal as well (Table 5). The average design index was 1.37 with a COV of 37%. Although the COV was high, most of the individual design indices were greater than unity, suggesting underestimation of the observed value, which is acceptable and desirable in engineering design. This further suggests that the tabulated values in the NDS based on Eq 1 can be adequately used for low-density species such as hybrid poplar.

Table 5. Withdrawal (W) test results and predictions using National Design Specification (NDS) equations.

Sample No	Density	W (N/mm)	NDS W (N/mm)	Design index
HP1	0.37	13.00	14.78	0.88
HP2	0.36	17.08	13.09	1.30
HP3	0.38	11.47	15.60	0.73
HP4	0.33	10.84	10.74	1.01
HP5	0.33	12.97	10.86	1.19
HP6	0.34	15.97	11.70	1.36
HP7	0.29	21.75	7.74	2.81
HP8	0.34	24.10	11.38	2.12
HP9	0.33	22.83	10.94	2.09
HP10	0.37	20.08	14.57	1.38
HP11	0.37	16.85	14.75	1.14
HP12	0.33	6.80	10.67	0.64
HP13	0.33	13.83	10.54	1.31
HP14	0.29	7.80	7.97	0.98
HP15	0.32	22.49	10.20	2.20
HP16	0.40	19.83	17.32	1.14
HP17	0.36	15.55	13.75	1.13
HP18	0.31	6.77	9.29	0.73
HP19	0.32	20.85	10.40	2.00
HP20	0.34	10.83	11.68	0.93
HP21	0.34	16.20	11.76	1.38
HP22	0.30	5.45	8.49	0.64
HP23	0.35	14.67	12.65	1.16
HP24	0.31	15.29	9.54	1.60
HP25	0.35	20.04	12.21	1.64
HP26	0.32	17.12	10.02	1.71
HP27	0.34	15.93	11.42	1.39
HP28	0.37	21.77	14.57	1.49
HP29	0.37	19.97	14.49	1.38
HP30	0.36	22.65	13.96	1.62
Average	0.34	16.03	11.90	1.37

CONCLUSIONS

Connection strength under lateral and withdrawal loads was studied for hybrid poplar and common sheathing connections. These values are comparable with low-density species. Although the tabulated values in the NDS do not include low-density species such as hybrid poplar, NDS yield models adequately and consistently predict the failure load and mode of the connections. Similarly, the NDS equation on withdrawal underpredicted the withdrawal capacity of the hybrid poplar samples studied. These results suggest that the NDS yield models and equations can adequately predict the lateral connection capacity of hybrid poplar and common sheathing materials. Results imply that low-density plantation-grown hybrid species such as Pacific Albus could come under the jurisdiction of NDS for connection design values.

ACKNOWLEDGMENTS

We extend our deepest gratitude to the Strengthening Education and Employment for Diverse Students (SEEDS) program of the College of Forestry, Oregon State University, for providing funds for the second author to work on the project. We also acknowledge the technical help of Milo Clauson and Byrne Miyamoto in the laboratory.

REFERENCES

AFPA (1999) General dowel equations for calculating lateral connection values. Technical Report 12. American Forest and Paper Association, Washington, DC.

AFPA (2012) National design specification® for wood construction. American Forest and Paper Association, Washington, DC.

ASTM (2007a) F 1575. Standard test method for determining bending yield moment of nails. American Society for Testing and Materials, West Conshohocken, PA.

ASTM (2007b) D 1761. Standard test method for mechanical fasteners in wood. American Society for Testing and Materials, West Conshohocken, PA.

ASTM (2007c) D 5764. Standard test method for evaluating dowel-bearing strength of wood and wood-base products, D 5764. American Society for Testing and Materials, West Conshohocken, PA.

Aune P, Patton-Mallory M (1986a) Lateral load bearing capacity of nailed joints based on the yield theory: Theoretical development. Res Pap FPL-469. USDA For Serv Forest Prod Lab, Madison, WI.

Aune P, Patton-Mallory M (1986b) Lateral load-bearing capacity of nailed joints based on the yield theory: Experimental verification. Res Pap FPL-470. USDA For Serv Forest Prod Lab, Madison, WI.

Balatinecz JJ, Kretschmann DE, Leclercq A (2001) Achievements in the utilization of poplar wood—Guideposts for the future. For Chron 77:265-269.

Beaudoin M, Hernández RE, Koubaa A, Poliquin J (1992) Interclonal, intraclonal and within-tree variation in wood density of poplar hybrid clones. Wood Fiber Sci 24:147-153.

Bendtsen BA, Maeglin RR, Deneke F (1981) Comparison of mechanical and anatomical properties of eastern cottonwood and populous hybrid NE-237. Wood Sci 14(1):1-15.

Blass HJ, Ehlbeck J, Rouger F (1999) Simplified design of joints with dowel-type fasteners. Pages 275-279 *in* Proc Pacific Timber Engineering Conference, March 14-18, 1999, Rotorua, New Zealand. Forest Research Institute Limited, Rotorua, New Zealand.

FPL (2010) Wood handbook: Wood as an engineering material. Gen Tech Rep FPL-GTR-190. USDA For Serv Forest Prod Lab, Madison, WI. 508 pp.

Hall RB, Hilton GD, Maynard CA (1982) Construction lumber from hybrid aspen plantations in the central states. J Forestry 80(5):291-294.

Johansen KW (1949) Theory of timber connectors. Publication No. 9, International Association of Bridges and Structural Engineering, Bern, Switzerland. Pages 249-262.

Kent SM, Leichti RJ, Rosowsky DV, Morrell JJ (2004) Effect of wood decay by Postia placenta on the lateral capacity of nailed oriented strandboard sheathing and douglas-fir framing members. Wood Fiber Sci 36(4): 560-572.

Koubaa A, Hernández RE, Beaudoin M, Poliquin J (1998) Interclonal, intraclonal, and within-tree variation in fiber length of poplar hybrid clones. Wood Fiber Sci 30:40-47.

Kramer A, Barbosa AR, Sinha A (2013) Viability of hybrid poplar in ANSI approved cross-laminated timber applications. J Mater Civ Eng (In press).

Kretschmann DE, Isebrands JG, Stanosz G, Dramm JR, Olstad A, Cole D, Samsel J (1999) Structural lumber properties of hybrid poplar. Res Pap FPL-RP-573 USDA For Serv Forest Prod Lab, Madison, WI. 8 pp.

Law S (2011) A crumpling paper industry. Once-mighty Oregon industry losing to mills overseas. The Portland Tribune (online issue). Portland, OR. http://www.chinasubsidies.com/portland-tribune-march2011.pdf (August 11, 2011).

Mátyás C, Peszlen I (1997) Effect of age on selected wood quality traits of poplar clones. Silvae Genet 46:64-72.

OWIC (2011) Properties of hybrid poplar. Oregon Wood Innovation Center report, Corvallis, OR. http://owic.oregonstate.edu/ (16 July 2013).

Peyer SM, Cramer SM (1999) Behavior of nailed connection at elevated temperature. Wood Fiber Sci 31 (3):264-276.

Sinha A, Gupta R, Nairn JA (2011) Thermal degradation of lateral yield strength of nailed wood connections. J Mater Civ Eng 23(6):812-822.

Sinha A, Miyamoto BT (2013) Lateral load carrying capacity of laminated bamboo lumber to oriented strand board connections. J Mater Civ Eng (in press).

Theilen RD, Bender DA, Pllock DG, Winistorfer SG (1998) Lateral resistance of ring-shank nail connections in Southern Pine lumber. Trans ASAE 41(2):465-472.