Bonding Performance of the Ten Species in the Spruce-Pine-Fir (South) Lumber Grouping for Cross-laminated Timber

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Maine Mass Timber Commercialization Center

University of Maine's Advanced Structures and Composites Center
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Note re. Report 21-121A-1594 revisions:

Editorial typos in Appendix C have been corrected. No conclusions have been affected.

1. Overview

1.1. Introduction

Cross-laminated timber (CLT) is an engineered wood product made of three or more orthogonally bonded layers of lumber that are glued together with structural adhesives to form a panel intended for roofs, floors, or walls.

Currently, there are no CLT manufacturers in the Northeastern U.S. despite the region having vast forestlands of commercial softwood timber. Sitting atop one of the planet's largest population centers, Maine is the region's primary wood basket, the most heavily forested state in the nation (as a percentage of land area) containing over 27 billion cubic feet of wood, i.e., live trees, on its forest land (USDA Forest Service, 2002). For CLT manufacturing in the Northeast, spruce-pine-fir-south (SPF-S) is the target grouping, with five major sawmills in the region producing 500 MMBF of dimensional lumber each year.

There are 10 species that make up the SPF-S grouping: red spruce (*Picea rubens*), black spruce (*Picea nigra*), white spruce (*Picea glauca*), Norway spruce (*Picea abies*), Engelmann spruce (*Picea engelmannii*), and Sitka spruce (*Picea sitchensis*), balsam fir (*Abies balsamia*), jack pine (*Pinus banksiana*), red pine (*Pinus resinosa*), and lodgepole pine (*Pinus contorta*).

1.2. Objective

Unlike other mass timber products, e.g., nail-laminated timber (NLT) and dowel laminated timber (DLT), CLT is a glued wood composite. The adhesives are responsible for transferring loads and must provide durable bonds during the structure's service life. The objective of this study was to evaluate the bond performance of all ten SPF-S species, as well as two other softwood species in the northeast: white pine (*Pinus strobus)* and eastern hemlock (*Tsuga canadensis)*, using the acceptance criteria in ANSI/APA PRG 320-2019, *Standard for Performance-Rated Cross-Laminated Timber*. Bond durability studies have been conducted on many of these species when adjacent pieces are glued parallel to one another (e.g. glulam). However, in CLT the cross-laminated nature of the composite means additional stresses on the bondline due to differential shrinkage. As such, this study is critical to derisk the siting of a CLT manufacturing facility in the region by ensuring that the bondline durability of all species is known.

2. Materials & CLT Fabrication

The materials used for this study were nominal 2x4 or 2x6 SPF-S, based on availability. Since all test specimens were prepared in such a way that all laminations in the major and minor strength directions were continuous (i.e., did not include an edge joint between laminations) the difference in lamination width, as part of manufacturing, had no effect on the test results. Loctite® Purbond HB X202 adhesive and Loctite® 3105 Purbond Primer, from Henkel Adhesives, were used as the adhesive system. Manufacturing and testing was conducted at the Advanced Structures and Composites Center (ASCC), located at the University of Maine, an ISO 17025 accredited lab whose scope of accreditation includes ANSI/APA PRG-320.

Two 24”x24” five-layer CLT panels were fabricated for each of the 12 species investigated as part of this study, for a total of 24 billets.

2.1. Lumber

Lumber was sourced from various mills throughout the U.S. (nine of the species grow in the Northeast, three in the Northwest) and sent to the ASCC for conditioning, manufacturing, and testing. The lumber was conditioned to 12 ± 3% moisture content (MC) in a 5,000 board foot Nyle dehumidification dry kiln. After conditioning, boards were edged using a jointer to eliminate the rounded edge easing of the lumber. Immediately prior to adhesive application and pressing, boards were planed to a thickness of 1 3/8”, with approximately 1/16” removed from each wide face to provide a fresh surface when applying primer and adhesive.

2.2. Primer

Loctite® 3105 Purbond Primer (5% weight concentration, i.e., 5 grams of primer mixed with 95 grams of water) was applied to each lumber face at a target spread rate of 0.004 lb/ft^2 (20 g/m^2) using a hand pump sprayer. One board from each layer was selected and weighed before and after application to calibrate and confirm the spray loading. Stickers were placed in between primed layers to allow air flow between layers to facilitate drying. Ten minutes passed after applying primer before spreading adhesive to allow the primer to dry and activate. Product specifications, as supplied by the manufacturer, are included as Appendix A.

2.3. Adhesive

The adhesive used was a single part polyurethane Loctite® HBX 202 PURBOND applied at a spread rate of 0.0369 lb/ft^2 (180 g/m^2). Product specifications, as supplied by the manufacturer, are included as Appendix B. Adhesive was applied to one of the two board faces comprising a bondline and hand spread using a putty knife.

2.4. Lay-up

Prior to applying adhesive, a clean rag was used to remove any potential debris that may have settled on the boards. Boards of a given layer were laid side by side and a pre-measured amount of adhesive was poured on top and spread. Once the glue was applied to the first layer, the transverse layer boards were laid atop and resin was applied and spread. This process was repeated for the remaining layers. Once the layup was complete, ratchet straps were placed around the perimeter and tightened to minimize movement and edge gaps during pressing.

One board in each layer was weighed prior to and after adhesive application to verify the spread rate. Per the Technical Datasheet, an open assembly time (from starting the adhesive application to pressing) of 20 minutes or less was targeted and achieved.

Each panel was then cold-pressed at 120 psi for 100 minutes in a 34” x 34” 450 ton Dieffenbacher hydraulic press. Once pressed, the billets were labeled and stored at laboratory conditions for at least 24 hours prior to being cut into test specimens.

Figure 1. Norway spruce CLT billet after being removed from oven.

Figure 2. CLT billets after being trimmed and prior to specimen preparation.

3. Testing

3.1. Specimen Preparation

Specimen preparation was done in accordance with ANSI/APA PRG 320-2019. Three block shear ("B" specimens) and three delamination ("D" specimens) specimens were cut from each panel at the locations shown in Figure 3 and labeled to indicate the panel number and specimen position within the panel. The specimens were prepared in such a way that all laminations in

the major and minor strength directions were continuous (i.e., did not include an edge joint between laminations). The "B" and "D" specimens were prepared in accordance with Figures 4 and 5, respectively.

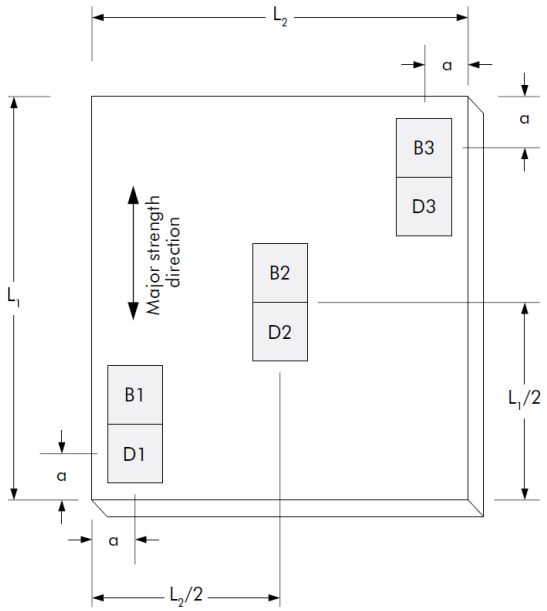


Figure 3. Block shear ("B") and delamination ("D") specimen locations. A = 4 ± 1 inches, L_1 = 24 to 36 inches, and L_2 = 24 to 36 inches

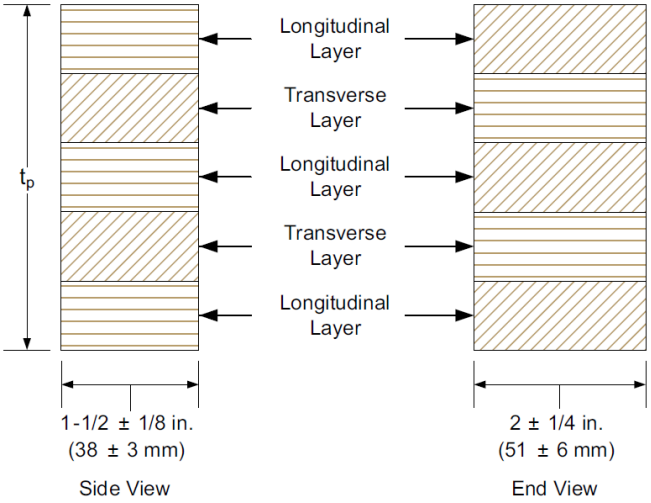


Figure 4. Straight-block shear specimen configuration.

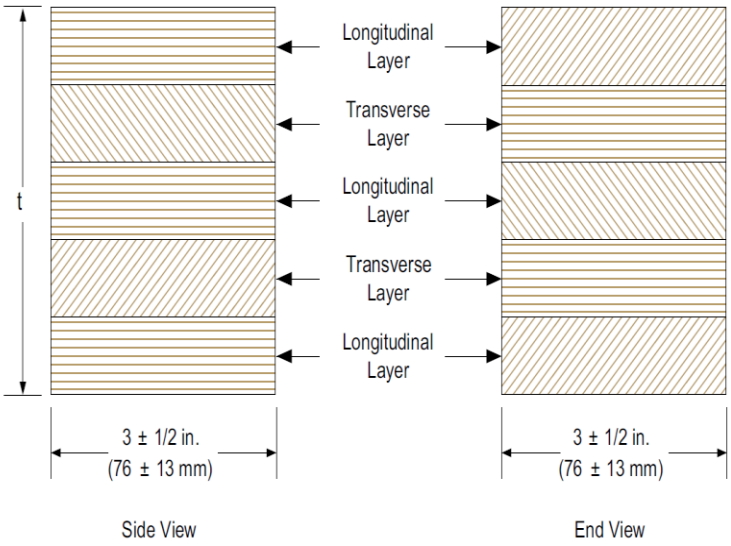


Figure 5. Delamination specimen configuration

3.2. Shear Testing

Block shear testing followed ANSI/APA PRG 320-2019, Section 8.2.5. Specimens were placed in a standard shearing tool, and tested for shear by compression loading at a uniform rate of 0.50 inches/minute. Specimens were positioned in the fixture with the bond line directly in the shear plane. Force was applied within a 22-kip Instron hydraulic testing frame using a 5-kip calibrated load cell (Figure 6).

Figure 6. Block shear testing.

3.3. Cyclic Delamination Testing

Delamination testing followed ANSI/APA PRG 320-2019, Section 8.2.6. Initial weights of the specimens were measured to the nearest gram prior to placing the specimens in a pressure vessel. Specimens were weighed down and submerged in water at a temperature of 65 to 85 ºF. A vacuum of 20-25 in-Hg was applied and held for 30 minutes. The vacuum was released, and a pressure of 70-80 psi was applied for 2 hours. Specimens were then removed from the pressure vessel and dried at 160ºF until their weights were between 110% and 115% of their original weight. Once dried, specimens were removed from the oven, and delamination was measured immediately.

Figure 7. Cyclic delamination specimens being prepared for vacuum-pressure soak.

Figure 8. Cyclic delamination specimens within the ASCC pressure cylinder.

4. Results

4.1. Criteria

The acceptance criteria for block shear and delamination specimens is published in Section 6.3.3 of ANSI/APA PRG 320-2019:

- Block Shear
  - The average wood failure of all specimens combined shall be equal to or greater than 80%.
  - At least 95% of all specimens shall have a wood failure of 60% minimum, and
  - For specimens with wood failure below 50%, a second block shear specimen shall be permitted to be prepared from the same bond line and tested. Wood failure of the second specimen shall be 80% minimum.
- Delamination
  - The average delamination of all bond lines in each specimen shall not exceed 5%, and,
  - If the average delamination of all bond lines in a specimen exceeds 5%, but is not more than 10%, a second delamination specimens shall be permitted to be prepared from the same CLT panel and tested. The average delamination of all bond lines in the second specimens shall be no more than 5%.

4.2. Block Shear Results

A summary of the test results is presented in Table 1. All species met the minimum requirements of acceptance criteria of ANSI/APA PRG 320-2019. Complete data sets are provided in Appendix C.

Wood failure was estimated at the time of testing and then again by another staff member to corroborate the results of the first estimate. The HBX 202 PURBOND adhesive used contains a UV indicator that glows white under a black light, assisting in identification of adhesive failure. Shear strength values are reported in Appendix C, as information only, since this is not a criterion of ANSI/APA PRG 320-2019.

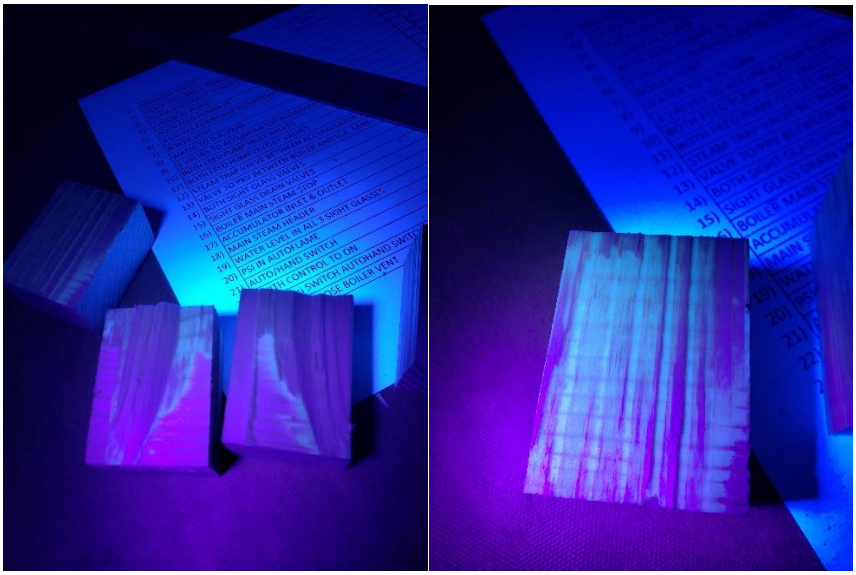


Figure 9. Examples of high (left) and low (right) amounts of wood failure

Table 1. Shear Test Results

Species		Average Wood Failure (%)	% of specimens with WF < 60%	Pass/Fail?
balsam Fir	*Abies balsamia*	98	0	Pass
black spruce	*Picea nigra*	99	0	
Engelmann spruce	*Tsuga canadensis*	95	0	
jack pine	*Picea engelmannii*	100	0	
lodgepole pine	*Pinus banksiana*	97	4	
Norway spruce	*Pinus contorta*	96	4	
red pine	*Picea abies*	97	0	
red spruce	*Pinus resinosa*	97	0	
Sitka spruce	*Picea rubens*	98	0	
white spruce	*Picea sitchensis*	95	4	
eastern hemlock	*Pinus strobus*	94	4	Pass
white pine	*Picea glauca*	98	0	

4.3. Delamination Results

A summary of the test results is shown in Table 2. All species met the minimum acceptance criteria of ANSI/APA PRG 320-2019. Complete data sets are provided in Appendix D.

Measurements were taken using a calibrated steel ruler graduated in 0.01” and 0.10” divisions in accordance with ASTM D2559. Once measurements were completed, photos of every surface were taken for later reference. If any delamination was present then close-up photos of that specific location were taken.

Figure 10. Example of Post Drying Delamination Sample

Table 2. Delamination Results

Species		Maximum Specimen Delamination (%)	Pass/Fail?
balsam Fir	*Abies balsamia*	4.7	Pass
black spruce	*Picea nigra*	2.5	
Engelmann spruce	*Tsuga canadensis*	3.8	
jack pine	*Picea engelmannii*	3.6	
lodgepole pine	*Pinus banksiana*	4.6	
Norway spruce	*Pinus contorta*	3.5	
red pine	*Picea abies*	1.7	
red spruce	*Pinus resinosa*	4.4	
Sitka spruce	*Picea rubens*	0.0	
white spruce	*Picea sitchensis*	5	
eastern hemlock	*Pinus strobus*	0.0	Pass
white pine	*Picea glauca*	1.7	

5. Conclusions

A major objective of this study was to provide data in order to de-risk the investment of siting a mill in the region for potential CLT manufacturers. Clearly, the availability, grade, and "glue-ability" of local species are of major importance to future CLT producers in the area. The work presented herein addresses the lattermost variable. All species in the SPF-S grouping, as well as two other Northeastern species (white pine and eastern hemlock), have demonstrated compliance with the face-bond acceptance criteria of ANSI/APA PRG 320-2019. It is therefore concluded that all species in the SPF-S grouping are acceptable lamstock for CLT production from an adhesive bonding perspective.

6. References

ANSI/APA. 2019. *PRG 320 Standard for Performance-Rated Cross-Laminated Timber*. APA – The Engineered Wood Association. Tacoma, WA.

ASTM D2559. 2018. *D2559-12a (2018) Standard Specification for Adhesives for Bonded Structural Wood Products for Use Under Exterior Exposure Conditions*. American Society of Testing and Materials (ASTM). West Conshohocken, PA.

USDA Forest Service. 2020. *Forests of Maine, 2019*. Resource Update FS-236. Madison, WI: U.S. Department of Agriculture, Forest Service. 2p. https://doi.org/10.2737/FS-RU-236

7. Appendices

Appendix A:
Loctite PR 3105 Primer Information
(1 page)

Purbond
Adhesive systems for engineered wood

Application instructions:

Bonding of SPRUCE/PINE/FIR wood with primer LOCTITE PR 3105 and PURBOND HB X adhesives

When bonding spruce/pine/fir (SPF) wood with PURBOND HB X adhesives, it is recommended to condition the planed surfaces of both mating components with primer LOCTITE PR 3105.

The following points must be observed when applying the patented primer solution.

Surface quality of the wood

In accordance with the TDS of the PURBOND HB X adhesive used

Preparation of the primer solution

Generally mix only as much primer solution as needed.
Mixing of primer concentrate LOCTITE PR 3105 with tap water from the local water main (a water softener may be required if the tap water is hard)

- Concentration (weight percent): 5%
  → Mix (by weight) 1 part LOCTITE PR 3105 with 19 parts (by weight) tap water.
- Prior to application, the primer solution should be gently stirred resp. swung.

Primer application

- Application quantity 20 g/m² (2 g/ft²)
- No later than 6 hours after planning and prior to adhesive application under consideration of activation time.
- Sprayed – uniformly over each mating part surface

Activation time

- Min. 10 minutes
- The surfaces of the lamellas should not be covered/stacked during the activation time; they must be exposed to the ambient air.

Adhesive application

According to the TDS of the adhesive used

Clamping Pressure

0.8 - 1.2 N/mm² (120 – 175 psi): Edge and Face Gluing
0.6 - 0.8 N/mm² (80 – 120 psi): Cross Laminated Timber

Waiting and press time

- After assembly of the last lamella and prior to pressing, a 5 to 10 minutes waiting time must be adhered, without exceeding the open time of the adhesive.
- Twice the nominal press time of the PURBOND HB X adhesive used (see TDS).

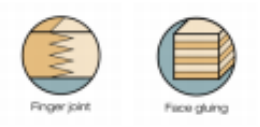
Adhesive systems for engineered wood

PURBOND CENTER OF COMPETENCE, 8/8/2017

Purbond AG • CH-6203 Sempach Station • Switzerland • Tel: +41 (0)41 469 6860 • Fax: +41 (0)41 469 6870 • www.purbond.com

Appendix B:
Loctite HB X202 Adhesive Information
(4 pages)

LOCTITE



LOCTITE HB X202 PURBOND

Single-component polyurethane adhesive for the manufacture of engineered wood products

LOCTITE HB X202 PURBOND
Henkel Technik / 07-2015

Adhesive systems for engineered wood

Properties

LOCTITE HB X202 PURBOND is a liquid single-component polyurethane adhesive. The adhesive cures under the action of air humidity and moisture in the wood to yield a strong non-brittle film. Slight foaming of the adhesive during hardening is caused by the chemical reaction and is normal. PURBOND HB X202 is manufactured without the addition of solvents or formaldehyde.

LOCTITE HB X202 PURBOND is successfully tested by third-party testing agencies and approved for the production of engineered wood products as specified on Page 4 of this data sheet (Section headed Certifications and Registrations).

Product data

Basis	Isocyanate pre-polymer
Consistency	Good flow properties
Assembly time[1]	**20 minutes**
Press time/Curing time[1]	**50 minutes**
Viscosity Brookfield	Approx. 14'000 mPa.s (Sp. 5 / 20 UpM / 68 °F (20 °C), measurement between 16 to 36 hours after production)
Color shade	Liquid adhesive: amber Cured adhesive film: wood tone
Density	Approx. 72 lb/ft^3 (1'150 kg/m^3)
Solids content	100 % and free from fibres and abrasive fillers
Fire hazard	Flame resistant
Resistance	To weak alkalis, acids and solvents
Safety	See Safety Data Sheet (SDS) of LOCTITE HB X202 PURBOND. Available from Henkel or at www.henkel.com.

[1] More information regarding the assembly time and press time/curing time can be found on pages 2 and 3.

LOCTITE®

Adhesive systems for engineered wood

Application	**Directions of use for end-joints (finger joints).**
Preparation	LOCTITE HB X202 PURBOND is a single-component adhesive and is processed in a closed system directly from the container in which it is supplied. Automatic finger joint machines must be specially equipped with an appropriate application system to process LOCTITE HB X202 PURBOND. All machine parts that come into contact with the adhesive must be treated with LOCTITE TRENNMITTEL/RELEASE AGENT PURBOND resp. LOCTITE TRENNPASTE/RELEASE PASTE PURBOND before processing.
Wood moisture content	The wood moisture content at the joint surfaces that are to be glued together must be not less than 8 %. The permissible upper limit of the wood moisture content is governed by the respective national product standards (i.e. ANSI/AITC A190.1). 12% moisture content is the optimal condition for this product. Acc. ANSI/AITC A190.1:2007 the maximum permissible difference in wood moisture content between the ends of the pieces that are to be joined shall not be more than 5 %.
Adhesive application	Application of the adhesive takes place via a suitable application system (comb application or contactless application in conjunction with the relevant approvals where necessary). Depending on the application system, the adhesive is applied to one or both sides at the rate of 25 lbs/1,000 ft. sq. to 40 lbs/1,000 ft. sq. (125 g/m² to 200 g/m²). The exact amount within this range is dependent upon the quality of wood and process equipment. Uniform wetting of the finger profile must be guaranteed. The components are pressed together immediately afterwards. Proper application rate is evidenced by very slight and even squeeze-out along the entire glue line.
Assembly time	The components to be glued must be assembled together and the press force applied immediately, but at the latest 20 minutes after the start of adhesive application (maximum assembly time). The maximum assembly time of the moisture-reactive LOCTITE HB X202 PURBOND is influenced by the climate conditions prevailing in the room during processing. Higher temperature and higher air humidity shorten the assembly time. It is absolutely essential that the adhesive is still capable of adhering when the press force is applied.
Curing time	The curing time of the adhesive is 50 minutes at 68 °F (20 °C) and 65 % air humidity.
Press force	The press force applied (depending on the finger length and profile) must guarantee a precisely fitting joint. The specifications in accordance with national guidelines must be observed in this respect.
Further processing	The components can undergo further processing after the curing time of the adhesive has elapsed.
Storage time after bonding	The bonded components must be stored at a temperature of approx. 68 °F (20 °C) for at least 2 hours after the press time has elapsed.
Other recommendations	The following supplementary instructions must be observed when manufacturing finger joints for load-bearing structural components: 1. The approvals (see the Section headed Certifications and Registrations). 2. The temperature in the production room should be 68 °F (20 °C). This applies equally for the wood and the adhesive. 3. Suitable quality control scheme in accordance with national guidelines is recommended to guarantee a high quality of glued joints.

LOCTITE®

Adhesive systems for engineered wood

Application	**Direction of use for face-joints (lamination)**
Preparation	LOCTITE HB X202 PURBOND is a single-component adhesive and is processed in a closed system directly from the container in which it is supplied. The surfaces to be glued together must be clean and free from adhesive-repellent substances such as oils, greases or release agents. All machine parts that come into contact with the adhesive must be treated with LOCTITE TRENNMITTEL/RELEASE AGENT PURBOND resp. LOCTITE TRENNPASTE/RELEASE PASTE PURBOND before processing.
Wood moisture conent	The wood moisture content at the joint surfaces that are to be glued together must be not less than 8 %. The permissible upper limit of the wood moisture content is governed by the respective national product standards (i.e. ANSI/AITC A190.1). 12% moisture content is the optimal condition for this product. Acc. ANSI/AITC A190.1:2007 the maximum permissible difference in wood moisture content between the ends of the pieces that are to be joined shall not be more than 5 %.
Adhesive application	LOCTITE HB X202 PURBOND is applied automatically using a special application system in a through-feed process. The adhesive is applied one-sided at the rate of 20 lbs/1,000 ft. sq. to 35 lbs/1,000 ft. sq. (100 g/m² to 180 g/m²). The exact amount within this range is dependent upon the quality of wood and process equipment. The amount of adhesive applied must guarantee uniform wetting of the joint component surface. Proper application rate is evidenced by very slight and even squeeze-out along the entire glue line.
Assembly time	The components to be glued must be assembled together and the press force applied immediately, but at the latest 20 minutes after the start of adhesive application (maximum assembly time). The maximum assembly time of the moisture-reactive LOCTITE HB X202 PURBOND is influenced by the climate conditions prevailing in the room during processing. Higher temperature and higher air humidity shorten the assembly time. It is absolutely essential that the press force is applied before any skinning on the adhesive surface and while the adhesive is still capable of adhering.
Press time	Press time depends on the existing climatic conditions of the surrounding and on the present temperature of the material. Minimum press time under conditions of 68 °F (20 °C), 65 % relative humidity and 12 % wood moisture content is 50 minutes.
Pressure	The applied press force must guarantee optimum fitting of the joint components. Normally, a press force of 120 psi to 200 psi (0.8 N/mm² to 1.4 N/mm²), which is generally customary in glued timber construction, is applied. For cross laminated timber constructions, a press force of 80 psi to 120 psi (0.6 N/mm² to 0.8 N/mm²) is applied.
Further processing	The components can undergo further processing immediately after the press time has elapsed.
Storage time after bonding	The bonded components must be stored at a temperature of approx. 68 °F (20 °C) for at least 4 hours after the press time has elapsed.
Other recommendations	The following supplementary instructions must be observed when manufacturing finger joints for load-bearing structural components: 1. The approvals (see the Section headed Certifications and Registrations). 2. The temperature in the production room should be 68 °F (20 °C). This applies equally for the wood and the adhesive. 3. Suitable quality control scheme in accordance with national guidelines is recommended to guarantee a high quality of glued joints.

LOCTITE®

Adhesive systems for engineered wood

Protection/safety and cleaning

Safety precautions and cleaning measures

Occupational safety/protection

It is urgently recommended to wear protective gloves – Henkel Arbeitshandschuhe/Handling Gloves – and protective goggles when handling liquid adhesive and release agent.

Plant protection and cleaning

LOCTITE TRENNMITTEL/RELEASE AGENT PURBOND resp. LOCTITE TRENNPASTE/RELEASE PASTE PURBOND prevent adhesive adhering to plant and tools. Before bringing a plant into operation, all the parts that come into contact with adhesive must be treated (see the corresponding TDS).

Henkel Reinigungsmittel/Cleaning Agent is suitable for cured adhesive on tools or machine parts. Compatibility must be checked before using the cleaning agent.

Protective goggles and chemically resistant Henkel Reinigungs-handschuhe/Cleaning Gloves (special black gloves) must be worn when working with Henkel Reinigungsmittel/Cleaning Agent.

Certification and Registration

Certifications and Registrations

North America

LOCTITE HB X202 PURBOND fulfils the requirements of E119.

LOCTITE HB X202 PURBOND fulfils all requirements of AITC 405-2008 (Standard for Adhesives for Use in Structural Glued Laminated Timber). To this effect, the following tests were passed:

ASTM D2559 (Strength, Delamination and Creep Resistance)
ASTM D7247 (High Temp. Exposure)
CSA 0177 A2 (High Temp. Exposure)
CSA O112.9 (Section 4.10.2, B2: High Temp. Creep Test)
ASTM D1151 (Exposure No. 3: Vacuum-Soak-Freeze Test)
ASTM D1183 (Cond. D Exterior Marine: Ocean Water Test)

JAIA F☆☆☆☆

Formaldehyde Standard:
JAIA (Japan Adhesive Industry Association) Independent Control Standard against Indoor Air Pollution.

Register Number: **JAIA-011852**

Guarantee

This information is based on internal test results, our Henkel application laboratory and our customers' experience.

Henkel guarantee a consistent quality of this product which is manufactured in accordance with ISO 9001 / ISO 14001 guidelines.

The product was found suitable for all applications and uses listed above; for other uses or applications Henkel strongly suggest you to contact our technical support staff.

In general the sales and delivery conditions of Henkel apply.

Appendix C:
Block Shear Test Results
(6 pages)

Table C.1. Balsam fir

Panel-Specimen-BL	Length (in)	Width (in)	Ult. Load (lbf)	F_v (psi)	Wood Failure (%)	Avg WF (%)	% w/ WF > 60%
1-1-1	1.525	1.994	1,364	449	100	98	0.0
1-1-2	1.522	1.995	1,795	591	100		
1-1-3	1.525	1.989	1,253	413	100		
1-1-4	1.525	1.977	1,046	347	100		
1-2-1	1.503	1.981	920	309	100		
1-2-2	1.507	1.995	828	276	100		
1-2-3	1.503	2.005	1,155	383	100		
1-2-4	1.504	2.018	1,012	334	100		
1-3-1	1.540	2.004	1,314	426	100		
1-3-2	1.534	2.016	734	238	100		
1-3-3	1.530	2.021	1,331	430	100		
1-3-4	1.527	2.021	454	147	100		
2-1-1	1.476	2.024	1,930	646	95		
2-1-2	1.481	2.018	1,216	407	95		
2-1-3	1.485	2.018	1,271	424	80		
2-1-4	1.485	2.017	1,408	470	100		
2-2-1	1.492	2.043	1,372	450	100		
2-2-2	1.502	2.013	1,660	549	90		
2-2-3	1.513	1.995	1,335	442	100		
2-2-4	1.525	1.978	702	233	100		
2-3-1	1.502	2.027	1,212	398	100		
2-3-2	1.502	2.026	671	220	95		
2-3-3	1.500	2.026	1,292	425	95		
2-3-4	1.490	2.019	1,156	384	100		

Table C.2. Black spruce

Panel-Specimen-BL	Length (in)	Width (in)	Ult. Load (lbf)	F_v (psi)	Wood Failure (%)	Avg WF (%)	% w/ WF > 60%
1-1-1	1.493	2.039	2,065	679	100	99	0.0
1-1-2	1.486	2.048	1,304	428	100		
1-1-3	1.489	2.059	2,068	675	100		
1-1-4	1.495	2.075	1,819	586	100		
1-2-1	1.506	1.967	1,157	391	100		
1-2-2	1.503	1.977	1,156	389	100		
1-2-3	1.502	1.979	2,466	830	100		
1-2-4	1.506	1.982	1,878	630	100		
1-3-1	1.505	2.019	1,123	369	100		
1-3-2	1.509	2.030	1,363	445	100		
1-3-3	1.504	2.025	2,377	780	100		
1-3-4	1.508	2.022	1,639	538	100		
2-1-1	1.506	2.019	1,495	492	100		
2-1-2	1.507	2.011	1,165	384	100		
2-1-3	1.505	2.001	1,594	529	100		
2-1-4	1.505	1.988	1,312	438	70		
2-2-1	1.501	2.009	1,690	561	100		
2-2-2	1.500	2.013	1,022	339	100		
2-2-3	1.499	2.018	2,084	689	100		
2-2-4	1.497	2.021	1,060	350	100		
2-3-1	1.507	2.028	1,411	462	100		
2-3-2	1.503	2.014	833	275	100		
2-3-3	1.502	2.003	2,665	886	100		
2-3-4	1.499	2.007	2,041	679	100		

Table C.3. Eastern hemlock

Panel-Specimen-BL	Length (in)	Width (in)	Ult. Load (lbf)	F_v (psi)	Wood Failure (%)	Avg WF (%)	% w/ WF > 60%
1-1-1	1.531	2.030	779	251	0	94	4.2
1-1-2	1.531	2.016	916	297	100		
1-1-3	1.529	2.011	1,379	449	100		
1-1-4	1.531	1.995	944	309	100		
1-2-1	1.493	2.004	1,190	398	100		
1-2-2	1.492	1.997	742	249	80		
1-2-3	1.490	1.988	1,527	516	100		
1-2-4	1.495	1.982	676	228	100		
1-3-1	1.489	2.016	1,663	554	100		
1-3-2	1.489	2.019	1,148	382	85		
1-3-3	1.487	2.029	1,058	351	100		
1-3-4	1.489	2.037	639	211	100		
2-1-1	1.520	1.992	1,746	577	100		
2-1-2	1.521	1.999	831	273	100		
2-1-3	1.530	2.002	2,440	796	100		
2-1-4	1.526	2.006	933	305	100		
2-2-1	1.500	2.010	884	293	100		
2-2-2	1.498	2.013	972	322	100		
2-2-3	1.499	2.011	1,245	413	100		
2-2-4	1.498	2.010	1,168	388	100		
2-3-1	1.467	2.010	1,543	524	100		
2-3-2	1.465	2.002	903	308	95		
2-3-3	1.463	1.995	2,254	772	100		
2-3-4	1.453	1.986	1,171	406	100		

Table C.4. Engelmann spruce

Panel-Specimen-BL	Length (in)	Width (in)	Ult. Load (lbf)	F_v (psi)	Wood Failure (%)	Avg WF (%)	% w/ WF > 60%
1-1-1	1.500	1.995	1,489	498	100	95	0.0
1-1-2	1.503	1.994	1,125	376	80		
1-1-3	1.497	1.995	1,073	359	85		
1-1-4	1.492	1.995	771	259	100		
1-2-1	1.497	2.030	1,710	563	70		
1-2-2	1.506	2.030	1,309	428	90		
1-2-3	1.513	2.030	1,853	603	100		
1-2-4	1.530	2.027	1,302	420	100		
1-3-1	1.517	1.976	853	284	95		
1-3-2	1.525	1.977	622	206	100		
1-3-3	1.535	1.980	1,290	425	100		
1-3-4	1.544	1.973	1,026	337	100		
2-1-1	1.492	1.980	2,094	709	100		
2-1-2	1.493	1.977	1,348	457	100		
2-1-3	1.486	1.972	1,335	456	100		
2-1-4	1.484	1.962	1,078	370	80		
2-2-1	1.510	2.031	1,896	618	100		
2-2-2	1.507	2.022	167	55	100		
2-2-3	1.503	2.009	1,338	443	100		
2-2-4	1.507	1.987	794	265	85		
2-3-1	1.510	2.035	978	318	100		
2-3-2	1.505	2.038	712	232	100		
2-3-3	1.500	2.039	899	294	100		
2-3-4	1.500	2.039	711	233	100		

Table C.5: Jack pine

Panel-Specimen-BL	Length (in)	Width (in)	Ult. Load (lbf)	F_v (psi)	Wood Failure (%)	Avg WF (%)	% w/ WF > 60%
1-1-1	1.505	2.033	3,338	1,091	100		
1-1-2	1.504	2.032	1,557	510	100		
1-1-3	1.498	2.028	2,169	714	100		
1-1-4	1.500	2.027	1,774	584	100		
1-2-1	1.489	1.978	1,881	639	100		
1-2-2	1.489	1.991	1,593	538	100		
1-2-3	1.487	2.005	2,255	757	100		
1-2-4	1.486	2.008	1,741	584	100		
1-3-1	1.511	2.021	1,932	633	100		
1-3-2	1.508	2.028	1,868	611	100		
1-3-3	1.503	2.028	2,350	771	100		
1-3-4	1.507	2.031	3,073	1,004	100	100	0.0
2-1-1	1.510	2.032	2,436	794	100		
2-1-2	1.510	2.047	1,960	634	100		
2-1-3	1.508	2.066	2,046	657	100		
2-1-4	1.499	2.083	1,729	554	95		
2-2-1	1.507	2.049	1,954	633	100		
2-2-2	1.509	2.043	1,466	475	100		
2-2-3	1.504	2.037	1,956	639	100		
2-2-4	1.506	2.029	1,967	644	100		
2-3-1	1.488	2.009	1,618	541	100		
2-3-2	1.494	2.012	1,236	411	100		
2-3-3	1.487	2.006	1,754	588	100		
2-3-4	1.489	1.997	1,392	468	100		

Table C.6. Lodgepole pine

Panel-Specimen-BL	Length (in)	Width (in)	Ult. Load (lbf)	F_v (psi)	Wood Failure (%)	Avg WF (%)	% w/ WF > 60%
1-1-1	1.510	2.016	1,760	578	100		
1-1-2	1.512	2.003	1,547	511	100		
1-1-3	1.517	1.990	1,213	402	100		
1-1-4	1.520	1.970	1,285	429	100		
1-2-1	1.508	1.991	2,003	667	100		
1-2-2	1.508	1.997	1,447	481	100		
1-2-3	1.509	2.003	836	276	100		
1-2-4	1.509	2.007	718	237	100		
1-3-1	1.520	2.015	2,001	653	100		
1-3-2	1.529	2.012	1,551	504	100		
1-3-3	1.539	2.006	1,072	347	100		
1-3-4	1.546	1.996	1,144	371	100	97	4.2
2-1-1	1.533	2.000	1,631	532	100		
2-1-2	1.531	1.999	1,081	353	100		
2-1-3	1.529	2.003	1,668	545	100		
2-1-4	1.532	2.005	1,960	638	95		
2-2-1	1.514	2.022	1,410	460	50		
2-2-2	1.513	2.017	2,066	677	100		
2-2-3	1.511	2.017	1,289	423	100		
2-2-4	1.508	2.008	1,048	346	100		
2-3-1	1.508	2.028	1,730	566	95		
2-3-2	1.511	2.023	2,417	791	100		
2-3-3	1.512	2.020	2,151	705	85		
2-3-4	1.514	2.017	1,856	608	100		

Table C.7: Norway spruce

Panel-Specimen-BL	Length (in)	Width (in)	Ult. Load (lbf)	F_v (psi)	Wood Failure (%)	Avg WF (%)	% w/ WF > 60%
1-1-1	1.512	2.032	1,416	461	35	96	4.2
1-1-2	1.514	2.029	1,026	334	95		
1-1-3	1.512	2.029	731	238	100		
1-1-4	1.512	2.026	744	243	100		
1-2-1	1.493	2.013	1,482	493	95		
1-2-2	1.492	2.012	1,083	361	100		
1-2-3	1.490	2.010	1,127	376	100		
1-2-4	1.487	2.005	1,028	345	100		
1-3-1	1.491	2.023	1,271	422	100		
1-3-2	1.491	2.027	959	318	100		
1-3-3	1.486	2.032	977	324	100		
1-3-4	1.482	2.038	957	317	85		
2-1-1	1.494	2.011	1,019	339	100		
2-1-2	1.492	2.022	557	185	100		
2-1-3	1.492	2.026	1,077	356	85		
2-1-4	1.490	2.030	660	218	100		
2-2-1	1.502	2.039	868	284	100		
2-2-2	1.499	2.018	617	204	100		
2-2-3	1.496	2.004	1,375	459	100		
2-2-4	1.497	1.985	685	231	100		
2-3-1	1.515	2.008	672	221	100		
2-3-2	1.519	2.008	719	236	100		
2-3-3	1.518	2.011	964	316	100		
2-3-4	1.519	2.009	1,071	351	100		

Table C.8: Red pine

Panel-Specimen-BL	Length (in)	Width (in)	Ult. Load (lbf)	F_v (psi)	Wood Failure (%)	Avg WF (%)	% w/ WF > 60%
1-1-1	1.506	1.998	1,596	531	90	97	0.0
1-1-2	1.509	2.006	1,515	501	100		
1-1-3	1.510	2.013	1,630	536	100		
1-1-4	1.511	1.997	1,492	495	100		
1-2-1	1.511	1.977	1,508	505	95		
1-2-2	1.511	1.980	1,246	416	100		
1-2-3	1.510	1.978	1,429	478	100		
1-2-4	1.513	1.977	1,320	441	100		
1-3-1	1.513	2.042	1,758	569	85		
1-3-2	1.512	2.037	1,870	607	100		
1-3-3	1.513	2.031	1,666	542	100		
1-3-4	1.507	2.020	1,217	400	100		
2-1-1	1.516	2.002	1,766	582	100		
2-1-2	1.518	2.003	1,842	606	95		
2-1-3	1.514	2.005	1,378	454	100		
2-1-4	1.513	1.996	1,340	444	100		
2-2-1	1.490	2.011	1,224	409	95		
2-2-2	1.493	2.025	1,357	449	100		
2-2-3	1.497	2.031	1,458	480	100		
2-2-4	1.496	2.042	1,220	399	100		
2-3-1	1.525	1.995	1,110	365	100		
2-3-2	1.523	1.997	812	267	60		
2-3-3	1.520	2.003	1,645	540	100		
2-3-4	1.521	2.001	1,415	465	100		

Table C.9: Red spruce

Panel-Specimen-BL	Length (in)	Width (in)	Ult. Load (lbf)	F_v (psi)	Wood Failure (%)	Avg WF (%)	% w/ WF > 60%
1-1-1	1.524	2.017	1,863	606	95	96	0.0
1-1-2	1.523	2.010	1,598	522	95		
1-1-3	1.521	1.999	2,326	765	100		
1-1-4	1.521	1.988	2,125	703	100		
1-2-1	1.511	1.973	1,745	586	90		
1-2-2	1.512	1.971	1,062	357	75		
1-2-3	1.509	1.958	1,216	412	100		
1-2-4	1.509	1.942	1,709	583	100		
1-3-1	1.517	1.984	1,302	433	100		
1-3-2	1.518	1.985	1,230	408	90		
1-3-3	1.515	1.975	1,403	469	100		
1-3-4	1.517	1.965	885	297	100		
2-1-1	1.512	2.058	1,469	472	90		
2-1-2	1.513	2.055	1,303	419	100		
2-1-3	1.515	2.056	1,272	409	100		
2-1-4	1.514	2.047	903	291	100		
2-2-1	1.498	1.986	1,301	437	100		
2-2-2	1.498	1.999	997	333	95		
2-2-3	1.496	2.009	2,074	690	95		
2-2-4	1.497	2.011	2,038	677	100		
2-3-1	1.507	2.035	1,205	393	100		
2-3-2	1.507	2.038	1,161	378	100		
2-3-3	1.508	2.044	1,521	494	75		
2-3-4	1.507	2.045	1,079	350	95		

Table C.10: Sitka spruce

Panel-Specimen-BL	Length (in)	Width (in)	Ult. Load (lbf)	F_v (psi)	Wood Failure (%)	Avg WF (%)	% w/ WF > 60%
1-1-1	1.488	2.031	1,271	420	100	98	0.0
1-1-2	1.487	2.028	1,430	474	100		
1-1-3	1.486	2.017	2,594	866	100		
1-1-4	1.484	2.007	1,786	600	100		
1-2-1	1.505	2.027	1,464	480	90		
1-2-2	1.508	2.023	837	274	100		
1-2-3	1.508	2.014	1,115	367	100		
1-2-4	1.511	2.001	1,022	338	95		
1-3-1	1.513	1.989	1,282	426	100		
1-3-2	1.511	1.998	722	239	100		
1-3-3	1.507	1.998	1,424	473	100		
1-3-4	1.509	1.998	1,006	334	80		
2-1-1	1.485	1.997	1,274	430	100		
2-1-2	1.480	1.993	890	302	100		
2-1-3	1.472	1.986	1,752	599	100		
2-1-4	1.463	1.979	1,422	491	100		
2-2-1	1.529	2.009	1,453	473	100		
2-2-2	1.537	2.000	1,137	370	90		
2-2-3	1.549	1.991	2,552	828	100		
2-2-4	1.554	1.985	1,907	618	100		
2-3-1	1.552	2.008	2,512	806	100		
2-3-2	1.542	2.020	1,876	602	100		
2-3-3	1.529	2.028	1,860	600	100		
2-3-4	1.520	2.041	878	283	95		

Table C.11: White pine

Panel-Specimen-BL	Length (in)	Width (in)	Ult. Load (lbf)	F_v (psi)	Wood Failure (%)	Avg WF (%)	% w/ WF > 60%
1-1-1	1.508	1.984	1,423	476	100		
1-1-2	1.508	1.982	1,145	383	100		
1-1-3	1.510	1.981	1,371	458	100		
1-1-4	1.511	1.977	1,260	422	95		
1-2-1	1.477	1.981	1,470	502	100		
1-2-2	1.479	1.988	1,222	415	90		
1-2-3	1.479	1.992	1,545	524	90		
1-2-4	1.476	1.993	1,247	424	100		
1-3-1	1.487	2.011	1,591	532	100		
1-3-2	1.488	2.000	964	324	100		
1-3-3	1.485	1.980	1,484	505	100		
1-3-4	1.487	1.965	975	334	100		
2-1-1	1.505	1.968	1,837	620	95	98	0.0
2-1-2	1.506	1.970	1,801	607	100		
2-1-3	1.504	1.976	1,992	670	100		
2-1-4	1.503	1.953	1,387	473	85		
2-2-1	1.500	2.016	1,500	496	100		
2-2-2	1.500	2.022	1,388	458	100		
2-2-3	1.500	2.026	1,163	383	90		
2-2-4	1.499	2.038	1,107	363	100		
2-3-1	1.513	1.955	1,252	423	95		
2-3-2	1.512	1.961	1,426	481	100		
2-3-3	1.516	1.966	1,758	590	100		
2-3-4	1.513	1.957	1,532	517	100		

Table C.12: White spruce

Panel-Specimen-BL	Length (in)	Width (in)	Ult. Load (lbf)	F_v (psi)	Wood Failure (%)	Avg WF (%)	% w/ WF > 60%
1-1-1	1.505	1.977	1,081	364	85		
1-1-2	1.500	1.979	992	334	100		
1-1-3	1.503	1.979	1,743	586	100		
1-1-4	1.504	1.973	1,489	502	100		
1-2-1	1.507	1.997	1,589	528	100		
1-2-2	1.510	1.997	791	262	100		
1-2-3	1.512	1.997	1,346	446	100		
1-2-4	1.515	1.995	928	307	100		
1-3-1	1.506	2.019	1,177	387	100		
1-3-2	1.508	2.012	780	257	100		
1-3-3	1.508	1.998	1,520	505	100		
1-3-4	1.510	1.979	1,310	438	100		
2-1-1	1.535	1.994	1,275	417	90	95	4.2
2-1-2	1.538	1.994	1,119	365	95		
2-1-3	1.541	1.990	1,060	346	100		
2-1-4	1.542	1.977	605	198	0		
2-2-1	1.508	2.023	1,087	356	100		
2-2-2	1.506	2.034	1,369	447	100		
2-2-3	1.509	2.026	2,018	660	100		
2-2-4	1.511	2.037	1,368	445	100		
2-3-1	1.509	2.022	1,367	448	100		
2-3-2	1.514	2.018	1,179	386	100		
2-3-3	1.512	2.009	1,825	601	100		
2-3-4	1.509	1.993	2,208	734	100		

Appendix D:
Delamination Test Results
(6 pages)

Table D.1. Balsam fir

Panel-Specimen-BL	Total Bond Length (in)	Total Delam (in)	% Delam
1-1-1	11.935	0.0	0.0%
1-1-2	11.929	0.0	0.0%
1-1-3	11.919	0.0	0.0%
1-1-4	11.919	0.0	0.0%
1-2-1	11.992	0.0	0.0%
1-2-2	11.984	0.0	0.0%
1-2-3	11.970	0.0	0.0%
1-2-4	11.963	0.0	0.0%
1-3-1	11.954	0.0	0.0%
1-3-2	11.940	0.0	0.0%
1-3-3	11.937	0.0	0.0%
1-3-4	11.938	0.0	0.0%
2-1-1	11.948	0.0	0.0%
2-1-2	11.950	0.0	0.0%
2-1-3	11.943	0.0	0.0%
2-1-4	11.918	0.0	0.0%
2-2-1	12.024	0.0	0.0%
2-2-2	12.037	0.0	0.0%
2-2-3	12.046	0.0	0.0%
2-2-4	11.977	2.3	4.7%
2-3-1	12.193	0.0	0.0%
2-3-2	12.274	0.0	0.0%
2-3-3	12.371	0.0	0.0%
2-3-4	12.470	0.0	0.0%

Table D.2. Black spruce

Panel-Specimen-BL	Total Bond Length (in)	Total Delam (in)	% Delam
1-1-1	12.022	0.0	0.0%
1-1-2	12.015	1.2	2.5%
1-1-3	12.008	0.0	0.0%
1-1-4	11.999	0.0	0.0%
1-2-1	12.046	0.0	0.0%
1-2-2	12.082	0.0	0.0%
1-2-3	12.088	0.0	0.0%
1-2-4	12.070	0.0	0.0%
1-3-1	11.957	0.0	0.0%
1-3-2	11.959	0.0	0.0%
1-3-3	11.943	0.0	0.0%
1-3-4	11.907	0.0	0.0%
2-1-1	12.140	0.0	0.0%
2-1-2	12.143	0.0	0.0%
2-1-3	12.145	0.0	0.0%
2-1-4	12.056	0.0	0.0%
2-2-1	11.838	0.0	0.0%
2-2-2	11.868	0.0	0.0%
2-2-3	11.931	0.0	0.0%
2-2-4	11.957	0.0	0.0%
2-3-1	11.769	0.0	0.0%
2-3-2	11.763	0.0	0.0%
2-3-3	11.751	0.0	0.0%
2-3-4	11.676	0.0	0.0%

Table D.3. Eastern hemlock

Panel-Specimen-BL	Total Bond Length (in)	Total Delam (in)	% Delam
1-1-1	12.006	0.0	0.0%
1-1-2	12.005	0.0	0.0%
1-1-3	11.994	0.0	0.0%
1-1-4	11.974	0.0	0.0%
1-2-1	12.056	0.0	0.0%
1-2-2	12.074	0.0	0.0%
1-2-3	12.091	0.0	0.0%
1-2-4	12.069	0.0	0.0%
1-3-1	12.100	0.0	0.0%
1-3-2	12.110	0.0	0.0%
1-3-3	12.120	0.0	0.0%
1-3-4	12.108	0.0	0.0%
2-1-1	12.060	0.0	0.0%
2-1-2	12.072	0.0	0.0%
2-1-3	12.083	0.0	0.0%
2-1-4	12.069	0.0	0.0%
2-2-1	12.110	0.0	0.0%
2-2-2	12.118	0.0	0.0%
2-2-3	12.099	0.0	0.0%
2-2-4	12.073	0.0	0.0%
2-3-1	12.289	0.0	0.0%
2-3-2	12.240	0.0	0.0%
2-3-3	12.192	0.0	0.0%
2-3-4	12.119	0.0	0.0%

Table D.4. Engelmann spruce

Panel-Specimen-BL	Total Bond Length (in)	Total Delam (in)	% Delam
1-1-1	12.001	0.0	0.0%
1-1-2	11.994	0.0	0.0%
1-1-3	11.992	0.0	0.0%
1-1-4	11.909	1.8	3.7%
1-2-1	11.995	0.0	0.0%
1-2-2	11.995	0.0	0.0%
1-2-3	11.994	0.0	0.0%
1-2-4	11.991	0.0	0.0%
1-3-1	12.090	0.0	0.0%
1-3-2	12.114	0.0	0.0%
1-3-3	12.125	0.0	0.0%
1-3-4	12.115	0.0	0.0%
2-1-1	11.951	0.0	0.0%
2-1-2	11.956	1.8	3.8%
2-1-3	11.950	0.0	0.0%
2-1-4	11.922	0.0	0.0%
2-2-1	12.044	0.0	0.0%
2-2-2	12.043	0.0	0.0%
2-2-3	12.044	0.0	0.0%
2-2-4	12.036	0.0	0.0%
2-3-1	12.082	0.0	0.0%
2-3-2	12.082	0.0	0.0%
2-3-3	12.098	0.0	0.0%
2-3-4	12.120	0.0	0.0%

Table D.5. Jack pine

Panel-Specimen-BL	Total Bond Length (in)	Total Delam (in)	% Delam
1-1-1	12.048	0.0	0.0%
1-1-2	12.044	0.0	0.0%
1-1-3	12.041	0.0	0.0%
1-1-4	12.037	0.0	0.0%
1-2-1	12.052	1.8	3.6%
1-2-2	12.063	0.0	0.0%
1-2-3	12.075	0.0	0.0%
1-2-4	12.072	0.0	0.0%
1-3-1	12.019	0.0	0.0%
1-3-2	12.005	0.0	0.0%
1-3-3	12.008	0.0	0.0%
1-3-4	12.001	0	0.0%
2-1-1	11.986	0.0	0.0%
2-1-2	12.001	0.0	0.0%
2-1-3	11.968	0.0	0.0%
2-1-4	12.011	0.0	0.0%
2-2-1	12.087	0.0	0.0%
2-2-2	12.098	0.0	0.0%
2-2-3	12.096	0.0	0.0%
2-2-4	12.102	0.0	0.0%
2-3-1	12.075	0.0	0.0%
2-3-2	12.081	0.0	0.0%
2-3-3	12.092	0.0	0.0%
2-3-4	12.081	0.0	0.0%

Table D.6. Lodgepole pine

Panel-Specimen-BL	Total Bond Length (in)	Total Delam (in)	% Delam
1-1-1	12.035	0.0	0.0%
1-1-2	12.036	0.0	0.0%
1-1-3	12.038	0.0	0.0%
1-1-4	11.987	0.0	0.0%
1-2-1	12.024	0.0	0.0%
1-2-2	12.013	0.0	0.0%
1-2-3	12.005	0.0	0.0%
1-2-4	11.997	2.2	4.6%
1-3-1	12.005	0.0	0.0%
1-3-2	12.038	0.0	0.0%
1-3-3	12.069	0.0	0.0%
1-3-4	12.092	0.0	0.0%
2-1-1	12.058	0.0	0.0%
2-1-2	12.066	0.0	0.0%
2-1-3	12.067	0.0	0.0%
2-1-4	12.075	0.0	0.0%
2-2-1	12.019	0.0	0.0%
2-2-2	12.038	0.0	0.0%
2-2-3	12.046	0.0	0.0%
2-2-4	12.038	0.0	0.0%
2-3-1	11.930	0.0	0.0%
2-3-2	11.927	0.0	0.0%
2-3-3	11.915	0.0	0.0%
2-3-4	11.900	0.0	0.0%

Table D.7. Norway spruce

Panel-Specimen-BL	Total Bond Length (in)	Total Delam (in)	% Delam
1-1-1	12.026	0.0	0.0%
1-1-2	12.022	1.5	3.1%
1-1-3	12.019	0.0	0.0%
1-1-4	12.016	0.0	0.0%
1-2-1	12.151	0.0	0.0%
1-2-2	12.151	0.0	0.0%
1-2-3	12.148	0.0	0.0%
1-2-4	12.141	0.0	0.0%
1-3-1	12.046	0.0	0.0%
1-3-2	12.053	0.0	0.0%
1-3-3	12.054	0.0	0.0%
1-3-4	12.055	0	0.0%
2-1-1	12.087	0.0	0.0%
2-1-2	12.097	0.0	0.0%
2-1-3	12.083	0.0	0.0%
2-1-4	12.089	0.0	0.0%
2-2-1	12.009	0.0	0.0%
2-2-2	12.026	1.7	3.5%
2-2-3	12.036	0.0	0.0%
2-2-4	12.040	0.0	0.0%
2-3-1	12.094	0.0	0.0%
2-3-2	12.096	0.0	0.0%
2-3-3	12.095	0.0	0.0%
2-3-4	12.098	0.0	0.0%

Table D.8. Red pine

Panel-Specimen-BL	Total Bond Length (in)	Total Delam (in)	% Delam
1-1-1	12.053	0.4	0.8%
1-1-2	12.051	0.0	0.0%
1-1-3	12.062	0.0	0.0%
1-1-4	12.036	0.0	0.0%
1-2-1	11.918	0.0	0.0%
1-2-2	11.914	0.0	0.0%
1-2-3	11.917	0.0	0.0%
1-2-4	11.809	0.0	0.0%
1-3-1	12.022	0.0	0.0%
1-3-2	12.020	0.0	0.0%
1-3-3	12.019	0.0	0.0%
1-3-4	11.968	0	0.0%
2-1-1	11.779	0.0	0.0%
2-1-2	11.790	0.0	0.0%
2-1-3	11.802	0.0	0.0%
2-1-4	11.785	0.0	0.0%
2-2-1	11.974	0.0	0.0%
2-2-2	11.971	0.0	0.0%
2-2-3	11.969	0.0	0.0%
2-2-4	11.971	0.8	1.7%
2-3-1	11.956	0.0	0.0%
2-3-2	11.960	0.0	0.0%
2-3-3	11.950	0.0	0.0%
2-3-4	11.949	0.0	0.0%

Table D.9. Red spruce

Panel-Specimen-BL	Total Bond Length (in)	Total Delam (in)	% Delam
1-1-1	11.959	0.0	0.0%
1-1-2	11.975	0.0	0.0%
1-1-3	11.996	0.0	0.0%
1-1-4	12.002	0.0	0.0%
1-2-1	11.903	0.0	0.0%
1-2-2	11.898	0.0	0.0%
1-2-3	11.887	0.0	0.0%
1-2-4	11.817	0.0	0.0%
1-3-1	11.970	0.0	0.0%
1-3-2	11.986	0.0	0.0%
1-3-3	12.001	0.0	0.0%
1-3-4	12.002	0.0	0.0%
2-1-1	12.049	2.1	4.4%
2-1-2	12.055	0.0	0.0%
2-1-3	12.064	0.0	0.0%
2-1-4	12.011	0.0	0.0%
2-2-1	12.345	0.0	0.0%
2-2-2	12.347	0.0	0.0%
2-2-3	12.348	0.0	0.0%
2-2-4	12.345	0.0	0.0%
2-3-1	12.047	0.0	0.0%
2-3-2	12.064	0.0	0.0%
2-3-3	12.075	0.0	0.0%
2-3-4	11.998	0.0	0.0%

Table D.10. Sitka spruce

Panel-Specimen-BL	Total Bond Length (in)	Total Delam (in)	% Delam
1-1-1	12.035	0.0	0.0%
1-1-2	12.041	0.0	0.0%
1-1-3	12.056	0.0	0.0%
1-1-4	12.050	0.0	0.0%
1-2-1	12.048	0.0	0.0%
1-2-2	12.073	0.0	0.0%
1-2-3	12.095	0.0	0.0%
1-2-4	12.106	0.0	0.0%
1-3-1	12.103	0	0.0%
1-3-2	12.107	0	0.0%
1-3-3	12.103	0	0.0%
1-3-4	12.001	0	0.0%
2-1-1	12.101	0.0	0.0%
2-1-2	12.102	0.0	0.0%
2-1-3	12.117	0.0	0.0%
2-1-4	12.109	0.0	0.0%
2-2-1	11.944	0.0	0.0%
2-2-2	11.937	0.0	0.0%
2-2-3	11.936	0.0	0.0%
2-2-4	11.932	0.0	0.0%
2-3-1	11.971	0.0	0.0%
2-3-2	12.005	0.0	0.0%
2-3-3	12.028	0.0	0.0%
2-3-4	12.004	0	0.0%

Table D.11. White pine

Panel-Specimen-BL	Total Bond Length (in)	Total Delam (in)	% Delam
1-1-1	12.020	0.0	0.0%
1-1-2	12.021	0.0	0.0%
1-1-3	12.030	0.0	0.0%
1-1-4	12.045	0.0	0.0%
1-2-1	11.987	0.0	0.0%
1-2-2	12.000	0.0	0.0%
1-2-3	11.993	0.0	0.0%
1-2-4	11.979	0.0	0.0%
1-3-1	12.005	0.0	0.0%
1-3-2	12.005	0.0	0.0%
1-3-3	12.001	0.0	0.0%
1-3-4	11.946	0.0	0.0%
2-1-1	12.158	0.0	0.0%
2-1-2	12.172	0.0	0.0%
2-1-3	12.186	0.0	0.0%
2-1-4	12.130	0.0	0.0%
2-2-1	11.996	0.0	0.0%
2-2-2	11.990	0.0	0.0%
2-2-3	12.007	0.0	0.0%
2-2-4	11.966	0.0	0.0%
2-3-1	11.979	0.0	0.0%
2-3-2	11.989	0.0	0.0%
2-3-3	11.990	0.0	0.0%
2-3-4	11.976	0.8	1.7%

Table D.12. White spruce

Panel-Specimen-BL	Total Bond Length (in)	Total Delam (in)	% Delam
1-1-1	12.056	0.0	0.0%
1-1-2	12.064	0.0	0.0%
1-1-3	12.077	0.0	0.0%
1-1-4	12.038	0.0	0.0%
1-2-1	12.078	0.0	0.0%
1-2-2	12.089	0.0	0.0%
1-2-3	12.106	0.0	0.0%
1-2-4	12.072	0.0	0.0%
1-3-1	12.004	0.0	0.0%
1-3-2	12.005	0.0	0.0%
1-3-3	12.006	0.0	0.0%
1-3-4	12.022	0.0	0.0%
2-1-1	12.011	0.0	0.0%
2-1-2	12.021	0.7	1.5%
2-1-3	12.023	1.7	3.5%
2-1-4	11.954	0.0	0.0%
2-2-1	11.944	0.0	0.0%
2-2-2	11.946	0.0	0.0%
2-2-3	11.942	1.1	2.4%
2-2-4	11.932	0.0	0.0%
2-3-1	11.995	0.0	0.0%
2-3-2	12.009	0.0	0.0%
2-3-3	12.008	0.0	0.0%
2-3-4	11.915	0.0	0.0%