

Bonding Wood Veneer with Biobased Poly(Lactic Acid) Thermoplastic Polyesters: Potential Applications for Consolidated Wood Veneer and Overlay Products

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Abstract: This study reports on the use of poly(lactic acid) (PLA) as a renewable thermoplastic adhesive for laminated panels using birch, spruce, and pine veneers. Consolidated panels were prepared from veneer and PLA foils by hot-pressing from 140 to 180 °C to achieve minimum bondline temperatures. Evaluation of panel properties revealed that the PLA-bonded panels met minimum tensile strength and internal bond strength performance criteria. However, the adhesion interface which developed within individual bondlines varied with distinctions between hardwood and softwood species and PLA grades. Birch samples developed greater bondline strength with a higher pressing temperature using semi-crystalline PLA, whereas higher temperatures produced a poorer performance with the use of amorphous PLA. Panels formed with spruce or pine veneers had lower bondline performance and were also similarly distinguished by their pressing temperature and PLA grade. Furthermore, the potential for PLA-bonded laminated panels was demonstrated by cold water soak testing. Samples exhibiting relatively greater bondline adhesion had wet tensile strength values comparable to those tested in dry state. Our study outcomes suggest the potential for PLA bonding of veneers and panel overlays with the added benefits of being renewable and a no added formaldehyde system.

Keywords: poly(lactic acid); PLA; PLA bondlines; wood adhesives; plywood; wood veneer laminates; wood plastic composites

Supplementary Materials

Table S1. Sample acronyms used.

Species	PLA Grade	Pressing Temperature (°C)	Sample
Birch	Amorphous	140	140BA
		160	160BA
		180	180BA
	Semi-Crystalline	140	140BC
		160	160BC
		180	180BC
Spruce	Amorphous	140	140PA
		160	160PA
		180	180PA
	Semi-Crystalline	140	140PC
		160	160PC
		180	180PC
Radiata pine	Amorphous	140	140RPA
		160	160RPA

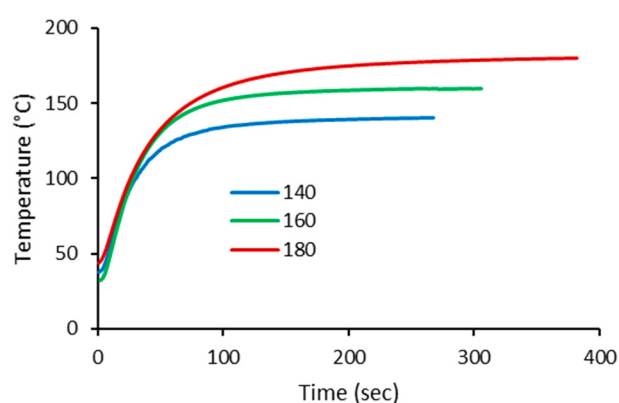


Figure S1. Examples of middle bondline temperature profiles of consolidated 7-ply panels formed spruce veneer at differing pressing temperatures.

Tensile specimen cutting and testing was according to:

ASTM D906-98(2017) Standard Test Method for Strength Properties of Adhesives in Plywood Type Construction in Shear by Tension Loading;
EN314-1 European standard for plywood bonding and quality.

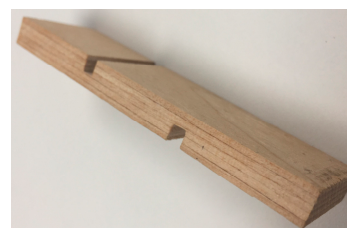
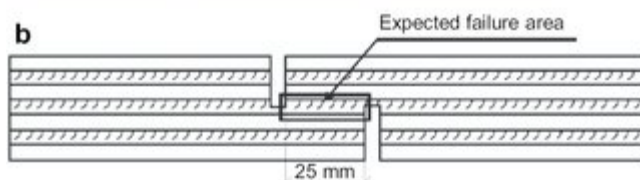


Table S2. Inner Bondline Statistics: Student T-test Least-Significant-Difference (LSD) Threshold Matrix.

	140BA	180BA	160BC	180BC	140PA	160RPA	140BC	160BA	160PA	180PC	180PA	140PC	140RPA	160PC
140BA		-1.39	-0.79	-0.75	-0.25	-0.15	-0.20	-0.12	0.45	0.51	0.81	1.43	1.33	1.82
180BA	-1.39		-0.74	-0.70	-0.19	-0.10	-0.15	-0.07	0.50	0.55	0.87	1.49	1.36	1.88
160BC	-0.79	-0.74		-1.30	-0.80	-0.70	-0.76	-0.68	-0.10	-0.05	0.26	0.88	0.75	1.27
180BC	-0.75	-0.70	-1.30		-0.84	-0.74	-0.80	-0.72	-0.15	-0.09	0.22	0.84	0.71	1.23
140PA	-0.25	-0.19	-0.80	-0.84		-1.24	-1.30	-1.22	-0.65	-0.59	-0.28	0.34	0.21	0.73
160RPA	-0.15	-0.10	-0.70	-0.74	-1.24		-1.28	-1.20	-0.63	-0.58	-0.26	0.36	0.22	0.75
140BC	-0.20	-0.15	-0.76	-0.80	-1.30	-1.28		-1.26	-0.69	-0.64	-0.32	0.30	0.17	0.69
160BA	-0.12	-0.07	-0.68	-0.72	-1.22	-1.20	-1.26		-0.77	-0.72	-0.41	0.22	0.09	0.61
160PA	0.45	0.50	-0.10	-0.15	-0.65	-0.63	-0.69	-0.77		-1.29	-0.98	-0.36	-0.48	0.03
180PC	0.51	0.55	-0.05	-0.09	-0.59	-0.58	-0.64	-0.72	-1.29		-1.19	-0.57	-0.68	-0.18
180PA	0.81	0.87	0.26	0.22	-0.28	-0.26	-0.32	-0.41	-0.98	-1.19		-0.72	-0.85	-0.33
140PC	1.43	1.49	0.88	0.84	0.34	0.36	0.30	0.22	-0.36	-0.57	-0.72		-1.47	-0.95
140RPA	1.33	1.36	0.75	0.71	0.21	0.22	0.17	0.09	-0.48	-0.68	-0.85	-1.47		-1.69
160PC	1.82	1.88	1.27	1.23	0.73	0.75	0.69	0.61	0.03	-0.18	-0.33	-0.95	-1.69	

Matrix showing if a difference exceeds the least significant difference for all comparisons. Positive values show pairs of means that are significantly different.

Table S3. Outer Bondline Statistics: Student T-test Least-Significant-Difference (LSD) Threshold Matrix.

	140BA	180BC	160BA	140BC	160 PA	160BC	140PC	140PA	160PC	180PC	180BA	180PA
140BA		-0.37	0.52	0.76	1.20	1.53	2.10	2.19	2.22	2.70	3.04	3.40
180BC	-0.37		-0.24	0.00	0.44	0.77	1.34	1.43	1.46	1.94	2.29	2.64
160BA	0.52	-0.24		-0.77	-0.33	0.01	0.58	0.66	0.70	1.17	1.51	1.87
140BC	0.76	0.00	-0.77		-0.57	-0.23	0.34	0.42	0.46	0.93	1.27	1.63
160PA	1.20	0.44	-0.33	-0.57		-0.68	-0.11	-0.02	0.01	0.49	0.83	1.19
160BC	1.53	0.77	0.01	-0.23	-0.68		-0.44	-0.36	-0.32	0.16	0.50	0.85
140PC	2.10	1.34	0.58	0.34	-0.11	-0.44		-0.93	-0.89	-0.41	-0.07	0.28
140PA	2.19	1.43	0.66	0.42	-0.02	-0.36	-0.93		-0.97	-0.49	-0.16	0.20
160PC	2.22	1.46	0.70	0.46	0.01	-0.32	-0.89	-0.97		-0.53	-0.19	0.16
180PC	2.70	1.94	1.17	0.93	0.49	0.16	-0.41	-0.49	-0.53		-0.67	-0.31
180BA	3.04	2.29	1.51	1.27	0.83	0.50	-0.07	-0.16	-0.19	-0.67		-0.96
180PA	3.40	2.64	1.87	1.63	1.19	0.85	0.28	0.20	0.16	-0.31	-0.96	

Matrix showing if a difference exceeds the least significant difference for all comparisons (Abs(Dif)-LSD); Positive values show pairs of means that are significantly different.

Table S4. Comparison of inner and outer bondline strength.

Sample	p-value
140 BA	0.0425
160 BA	0.0019
180 BA	0.004
140 BC	0.0083
160 BC	0.6077
180 BC	0.054
140 PA	0.8784
160 PA	0.0339
180 PA	0.9922
140 PC	0.0308
160 PC	0.0015
180 PC	0.4525

Table S5. Bondline Wet Strength Statistics: Student T-test Least-Significant-Difference (LSD) Threshold Matrix.

	140BA	160BA	180BC	160BC	180BA	160PA	140BC	140PA	180PA	140PC	160PC	180PC
140BA		-0.73	-0.04	0.05	1.25	1.52	1.75	1.81	2.73	2.87	3.13	3.18
160BA	-0.73		-0.43	-0.35	0.85	1.12	1.36	1.41	2.34	2.47	2.74	2.79
180BC	-0.04	-0.43		-1.17	0.03	0.30	0.53	0.59	1.51	1.65	1.91	1.96
160BC	0.05	-0.35	-1.17		0.08	0.35	0.58	0.64	1.56	1.70	1.96	2.01
180BA	1.25	0.85	0.03	0.08		-0.99	-0.76	-0.70	0.23	0.36	0.63	0.68
160PA	1.52	1.12	0.30	0.35	-0.99		-1.03	-0.97	-0.04	0.09	0.36	0.41
140BC	1.75	1.36	0.53	0.58	-0.76	-1.03		-1.06	-0.14	0.00	0.26	0.31
140PA	1.81	1.41	0.59	0.64	-0.70	-0.97	-1.06		-0.20	-0.06	0.20	0.25
180PA	2.73	2.34	1.51	1.56	0.23	-0.04	-0.14	-0.20		-1.12	-0.86	-0.81
140PC	2.87	2.47	1.65	1.70	0.36	0.09	0.00	-0.06	-1.12		-0.86	-0.81
160PC	3.13	2.74	1.91	1.96	0.63	0.36	0.26	0.20	-0.86	-0.86		-1.21
180PC	3.18	2.79	1.96	2.01	0.68	0.41	0.31	0.25	-0.81	-0.81	-1.21	

Matrix showing if a difference exceeds the least significant difference for all comparisons (Abs(Dif)-LSD); Positive values show pairs of means that are significantly different.

Table S6. Comparison of bondline dry and wet strength.

Sample	p-value
140 BA	0.0240
140 BC	0.0002
140 PA	0.0013
140 PC	0.0016
160 BA	0.7328
160 BC	0.0563
160 PA	0.0057
160 PC	0.0010
180 BA	0.0052
180 BC	0.1742
180 PA	0.0004
180 PC	<0.0001

Table S7. Internal Bond Strength Statistics: Student T-test Least-Significant-Difference (LSD) Threshold Matrix.

	160BA	160BC	140BA	140PA	160PA	180BA	180BC	180PA	160PC	140BC	140PC	180PC
160BA		-0.22	-0.16	-0.15	-0.17	-0.08	0.02	0.16	0.33	0.42	0.48	0.56
160BC	-0.22		-0.23	-0.22	-0.24	-0.15	-0.05	0.09	0.26	0.35	0.42	0.49
140BA	-0.16	-0.23		-0.26	-0.28	-0.18	-0.08	0.06	0.23	0.32	0.38	0.46
140PA	-0.15	-0.22	-0.26		-0.28	-0.19	-0.09	0.05	0.22	0.31	0.38	0.45
160PA	-0.17	-0.24	-0.28	-0.28		-0.23	-0.13	0.01	0.19	0.27	0.34	0.41
180BA	-0.08	-0.15	-0.18	-0.19	-0.23		-0.19	-0.05	0.13	0.21	0.28	0.35
180BC	0.02	-0.05	-0.08	-0.09	-0.13	-0.19		-0.15	0.03	0.11	0.18	0.25
180PA	0.16	0.09	0.06	0.05	0.01	-0.05	-0.15		-0.09	0.00	0.06	0.14
160PC	0.33	0.26	0.23	0.22	0.19	0.13	0.03	-0.09		-0.23	-0.17	-0.09
140BC	0.42	0.35	0.32	0.31	0.27	0.21	0.11	0.00	-0.23		-0.22	-0.15
140PC	0.48	0.42	0.38	0.38	0.34	0.28	0.18	0.06	-0.17	-0.22		-0.24
180PC	0.56	0.49	0.46	0.45	0.41	0.35	0.25	0.14	-0.09	-0.15	-0.24	

Matrix showing if a difference exceeds the least significant difference for all comparisons (Abs(Dif)-LSD); Positive values show pairs of means that are significantly different.



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