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SOME MECHANICAL PROPERTIES OF DENSIFIED AND LAMINATED LOMBARDY POPLAR (*POPULUS NIGRA* L.)

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ABSTRACT

In this study, it was studied the effects of densification and then lamination processes on some mechanical properties of Lombardy poplar (*Populus nigra* L.), which is one of the low density tree species. Densification temperatures were 80, 100, 120 and 140°C and ratios of densification were 15, 30 and 50 %. Furthermore, lamellas with a thickness of 4 mm cut from densified materials were laminated by bonding one on top of the other with urea formaldehyde (UF) and polyvinyl acetate (PVAc) adhesives. Bending, modulus of elasticity, compression and tensile tests were applied by preparing specimens from the pieces. According to test results, the most suitable temperature level was 120°C. As the ratio of densification was increased at this temperature level, increase were observed in the mechanical properties. Also, lamination provided significant increases in the mechanical values compared to laminated but undensified Lombardy poplar. Increases were observed in the mechanical properties reaching 444 % with application of densification and lamination processes.

KEYWORDS: Wood, densification, lamination, lombardy poplar, adhesive, strength.

INTRODUCTION

The density of wood is one of the most important factors that are effective on strength properties. Along with there being deviations stemming from structural properties, generally, as the density increases, an increase is also observed in the strength properties of wood. Consequently, a need is felt for woods with high density in the structural implementations where high resistance is sought. Intensive activities are undertaken for finding suitable methods that would increase the density of wood, since an increase in density provides important increases in the mechanical properties of wood. One of these implementations is the thermomechanical densification process. Since the resistance values obtained from high density woods can be reached with the densification process by increasing the densities of low density trees that have little importance commercially, these types of trees and rapidly growing trees with low density can acquire commercial importance. Furthermore, it is possible to reach even higher strength values than the strength values they have by densifying high density woods.

The studies related to the densification of wood have continued since 1900 when the first patent was obtained. The densification is a process, which takes as the basis the compression of wood under high pressure, the impregnation with a liquid material of the cell lumens or the combination of pressure and impregnation. Just as densification can be made by compressing in a radial direction that would form conditions that would not produce damage to the cell walls, it can also be made by filling under pressure the cavities in wood with polymers, melted natural resins, waxes, sulfur or melted metal (Kollmann et al. 1975; Kultiková 1999; Blomberg 2005).

Wood is defined as a viscoelastic material since its mechanical behavior remains between linear elastic solids and the behaviors of viscose liquids. As a requirement of its viscoelastic structure, the mechanical properties of wood are connected to time, temperature and moisture content. Wood displays a glassy behavior that can be equated with hardness and fragility at short time intervals, low temperatures and low moisture content values. Wood displays an elastic-like behavior that can be equated with softness and easy shape-ability at high temperatures for a long time and at high moisture content values. The transition phase between these two regions emerges and the temperature observed in the phase is called Tg, the glassy transition temperature (Wolcott et al. 1994). The glassy transition temperature is also known as the softening temperature, which depicts the softening behavior of the amorphous polymers. When the temperature of the polymers reaches the glassy transition temperature, the hardness of the material decreases in a rapid manner and a noteworthy increase in molecular activity is observed (Wolcott 1989). When the material passes this softening point, many properties of amorphous polymers, such as modulus of elasticity, change to a significant extent.

The viscoelastic structure of wood plays a significant role in the compression and densification processes. When the hemicelluloses and lignin are in the glassy transition stage, cracks and splits emerge in the wood. Temperatures higher than the glassy transition temperature provide for polymer activity and for the molecules to be reorganized. When the temperature of the wood is above the glassy transition temperature of the amorphous polymer, just as they will provide for not cracking or being able to give shape, large deformations as breaks can be observed in the wood (Wolcott et al. 1990).

The moisture content of wood is one of the important factors that affect softening temperature. An increase in the moisture content decreases the glassy transition temperature of the amorphous elements of wood. In a study by Hillis and Rozsa (1978) in which they examined the effect of the softening of the structural elements of wood by isolating hemicelluloses and lignins from wood above 160°C, they determined that moisture content lowered the softening point of hemicelluloses and lignins. First of all, the hemicellulose of the cell walls became softened at 54–56°C and the hardness of the wood decreased. The lignin in the center lamella and cell walls became softened at 72–128°C and were the cause of larger cross-sectional activity in width within fibers and between fibers. Hillis and Rozsa (1985) studied the softening temperature curves connected to width of annual rings in radiate pine. They determined that the softening temperature was 80 in hemicelluloses and 100°C in lignins. It was observed that there were differences in the softening temperatures of the hemicelluloses of heartwoods and sapwoods (Hillis 1984). According to Östberg et al. (1990), as the moisture content increases in spruce and birch, the softening temperature decreases. Water molecules provide for the plastification of wood polymers. Moisture forms secondary bonds with the polar groups in polymer molecules and provides for the spread of these. The secondary bonds between polymer chains are weakened connected to moisture content and provide more spaces for the environmental movement of polymer molecules. Thus, moisture increases the free volume of the system. This situation makes it possible for wood to take shape easily (Morsing 2000) and lowers the transition temperature (Sadoh 1981). Lenth (1999) studied the thermal softening behaviors of spring woods and summerwoods of pine and poplar at four moisturelevels between 0-20 % with the dielectric thermal analysis (DETA) method. According to this study, the softening of the amorphous structural elements at temperatures between 20-200°C is in conformity with the characteristic glassy transition temperatures.

In this study, it was aimed to determine the effect of temperature, ratio of compression and lamination of densified material on bending strength, modulus of elasticity in bending, tensile and compression strength in the solid and laminated Lombardy poplar (*Populus nigra* L.), which is one of the low density tree species.

MATERIAL AND METHODS

Materials

Lombardy poplar (Populus nigra L.)

The Lombardy poplar to be used in the study was obtained from Siteler in Ankara as logs with diameters between 32-38 cm. Care was taken that the logs were completely cylindrical and without defects.

Laboratory press

A 100 ton HURSAN T100 brand (Konya/Turkey) automatic laboratory press was used in the densification by compressing the specimens in a radial direction and in the lamination of densified materials. The platen dimensions of the press were 60 x 60 cm, the temperature intervals were 0-250°C and the pressure capacity was 25 MPa. Pressure and temperature of could be controlled and monitored automatically.

Adhesives

The urea formaldehyde (UF) adhesive used in lamination was obtained from Polisan Corporation. Its density was 1.24 $g\cdot cm^{-3}$ at 20°C, pH value 8.1, viscosity 170 centipoises and amount of solid substance was 55 %.

The polyvinyl acetate (PVAc) adhesive used in lamination was the Kleibit 302.2 and obtained from Polisan Corporation. Its density was 1.1 $g\cdot cm^{-3}$ at 20°C, pH value 3.0 and viscosity 120 centipoises.

Preparation of the specimens

Lumber was obtained from the logs in different widths connected to the diameter of the logs and in thicknesses of 60 mm with the radial cutting method (the annual rings are perpendicular to the surface). This lumber was stacked in accordance with the natural drying technique and kept in a heated environment. At the end of this period, the lumber was cut into densification pieces with a length of 550 mm (by taking into consideration the platen dimensions of the press), in different widths and in thicknesses of 60 mm. The pieces were conditioned in a conditioning chamber had a temperature of 20±2°C and a relative moisture content of 65±5 % to equalize the moisture to an air-dried moisture content of 12 % prior to densification until they reached an unchanging mass at measurements taken at 24-hour intervals. After conditioning, the pieces were wrapped with plastic sheets for preventing a change in moisture content and were kept until the densification stage.

Specimens in the number and dimensions specified in the standards were prepared by using the suitable processing techniques for determining the density, bending, modulus of elasticity, pressure and tensile strength of solid Lombardy poplar as the control group and densified Lombardy poplar. Furthermore, densified laminated poplar materials were obtained from the densified materials in the thickness of the control specimens by bonding in a laboratory press the lamellas one on top of the other cut at a thickness of 4 mm with UF and PVAc adhesives. Specimens were prepared from these materials in the suitable numbers and dimensions in accordance with the standards.

Method

Densification

The process given below was followed in the densification of Lombardy poplar with the open system thermo-mechanical method:

- Oven-dry and air-dry densities of Lombardy poplar were determined as 0.43 and 0.48 $g \cdot cm^{-3}$ in accordance with the TS 2472 (1976)
- The press was operated and it was provided that the platens reached the test temperatures (80, 100, 120 and 140°C) with a sensitivity of ±5°C by adjusting the thermostats.
- The stocks were placed on the lower platen of the press in a manner so that pressure would be applied in a radial direction. Furthermore, in order to check if the internal temperature of the stocks had reached the test temperatures, three temperature control stocks with thermometer were placed on both sides and the middle of the lower platen of the press. The thermometers were in the middle and side parts of the stocks.
- In order to ensure heat transfer from the platens to the surfaces of stocks, the upper platen was contacted on the stock surfaces without applying pressure.
- The stocks were kept in the press until their temperatures reached to 80, 100, 120, and 140°C. The internal temperatures of the stocks were monitored from the temperature control stocks with a thermometer.
- The pressure gauge of the press was adjusted to 6 and 8 MPa separately providing a densification ratio of 15, 30, and 50 % at different temperatures.
- Densification was made by compressing the stocks at a loading speed of 3 $m \cdot min^{-1}$ that would provide for densification at the ratios of 15, 30, and 50 %
- The press was kept closed for 10 min. by preserving pressure for preventing an increase in volume of the stocks with the spring-back effect. A residence time of 10 min after densification was the best time for achieving the lowest spring-back effect and was determined in preliminary tests.
- The stocks were removed from the press and kept in a closed environment for a period of 10 days.
- The average amount of humidity after cooling was determined to be 4 % according to the TS 2471 (1976) standards.

Physical and mechanical tests

The moisture content of the specimens were determined in accordance with the TS 2471 (1976) standards, densities in accordance with the TS 2472 (1976) standard, bending strength and modulus of elasticity in accordance with the TS 2474 (1976) and TS 2478 (1976) standards, compression strength in accordance with the TS 2595 (1977) standards and tensile strength were determined in accordance with the TS 2475 (1976) standards.

RESULTS AND DISCUSSION

The analysis of variance by using the SPSS-15 package program was made to determine whether or not the type of material, densification temperature, ratio of densification and the type of adhesive used in lamination were effective on bending strength, modulus of elasticity, compression and tensile strength according to the values obtained with tests for different variables. According to the results of the analysis of variance, since the level of error was smaller than 0.05 ($p<0.05$), all of the variables were found to be effective on bending strength, modulus of elasticity, compression and tensile strength with the single and multiple interactions. The homogeneity tests were made for determining whether or not the differences between the effective variables and the bending strength, modulus of elasticity, compression and tensile strength values were significant and the results have been given below.

Bending strength

Bending strength values and homogeneity groups of the variables according to type of wood, densification temperature, ratio of densification and type of adhesive used in lamination have been given in Tab. 1.

Tab. 1: Bending strength values and homogeneity groups of the variables.

Type of material	Densification temperature (°C)	Ratio of densification							
		Control		15 %		30 %		50 %	
		BS ($N \cdot mm^{-2}$)	HG	BS ($N \cdot mm^{-2}$)	HG	BS ($N \cdot mm^{-2}$)	HG	BS ($N \cdot mm^{-2}$)	HG
Solid Lombardy poplar	**Control**	**81.20**	**2**	****	**	****	**	****	**
Densified Lombardy poplar	80	****	**	88.12	4	101.52	10	79.76	1
	100	****	**	97.35	7	105.96	11	113.54	15
	120	****	**	101.79	9	106.39	11	115.88	16
	140	****	**	81.82	2	88.25	4	75.07	1
Laminated Lombardy poplar with PVAc	Control	89.46	4	****	**	****	**	****	**
Densified and laminated Lombardy poplar with PVAc	80	****	**	91.43	5	105.60	10	91.99	6
	100	****	**	99.62	8	101.44	10	116.72	16
	120	****	**	111.84	13	116.62	16	122.14	17
	140	****	**	81.66	2	84.47	4	84.05	3
Laminated Lombardy poplar with UF	Control	92.49	5	****	**	****	**	****	**
Densified and laminated Lombardy poplar with UF	80	****	**	100.06	8	109.62	13	99.88	8
	100	****	**	103.24	9	110.59	14	115.59	15
	120	****	**	106,97	12	112,17	15	130,80	18
	140	****	**	92.66	6	95.03	7	92.41	6

BS: Bending strength, HG: Homogeneity group, PVAc: Polyvinyl acetate adhesive, UF: Urea formaldehyde adhesive.

The densification process, connected to densification temperature and ratio provided an increase from 9 to 42 % in bending strength of Lombardy poplar. The most effective densification temperature was 120°C in densification from the aspect of bending strength and after this point; decreases were experienced in the bending strength at ratios reaching from 17 to 35 % connected to ratio of densification. An increase in the ratio of densification, excluding the lowest and highest temperature levels, also increased the bending strength.

The lamination process increased the bending strength 10 with PVAc adhesives and 14 % with UF adhesives when compared with solid Lombardy poplar. Whereas, the lamination of densified Lombardy poplar, connected to type of adhesive, densification temperature and ratio of densification provided increases reaching ratios of up to 25 in bending strength compared to densified Lombardy poplar. The increase in bending strength was 62 % when compared to solid Lombardy poplar.

Modulus of elasticity

Modulus of elasticity values and homogeneity groups of the variables according to type of wood, densification temperature, ratio of densification and type of adhesive used in lamination have been given in Tab. 2.

Tab. 2: Modulus of elasticity values and homogeneity groups of the variables.

Type of material	Densification temperature (°C)	Ratio of densification							
		Control		15 %		30 %		50 %	
		ME ($N \cdot mm^{-2}$)	HG	ME ($N \cdot mm^{-2}$)	HG	ME ($N \cdot mm^{-2}$)	HG	ME ($N \cdot mm^{-2}$)	HG
Solid Lombardy poplar	**Control**	**4963.74**	**3**	****	**	****	**	****	**
Densified Lombardy poplar	80	****	**	5390.80	6	5816.36	8	4540.57	1
	100	****	**	5952.20	9	6344.43	10	6568.63	12
	120	****	**	6260.53	10	6329.71	10	6866.11	14
	140	****	**	4894.36	2	5481.43	7	4146.14	1
Laminated Lombardy poplar with PVAc	Control	5382.84	6	****	**	****	**	****	**
Densified and laminated Lombardy poplar with PVAc	80	****	**	5779.55	8	6676.67	12	5892.68	8
	100	****	**	6278.91	9	6401.85	11	7498.60	16
	120	****	**	6744.14	13	7264.73	15	8058.45	17
	140	****	**	5602.87	7	5340.61	6	5034.73	5
Laminated Lombardy poplar with UF adhesive	Control	5555.37	7	****	**	****	**	****	**
Densified and laminated Lombardy poplar with UF	80	****	**	6035.64	9	6828.13	13	6351.44	11
	100	****	**	5820.49	7	6955.25	14	7031.67	15
	120	****	**	6724.17	13	6971.41	14	7903.96	16
	140	****	**	4905.31	2	6253.55	10	5853.40	8

ME: Modulus of elasticity, HG: Homogeneity group, PVAc: Polyvinyl acetate adhesive, UF: Urea formaldehyde adhesive.

The densification process, connected to densification temperature and ratio provided an increase from 9 up to 38 % in the modulus of elasticity of Lombardy poplar. The most effective densification temperature in densification was 120°C and after this point, decreases were experienced in the modulus of elasticity at ratios reaching from 13 to 40 % connected to the ratio of densification. An increase in the ratio of densification, excluding the lowest and highest levels of heat, also increased the modulus of elasticity.

The lamination process increased the modulus of elasticity 8 with PVAc adhesives and 12 % with UF adhesives when compared with solid Lombardy poplar. Whereas, lamination of densified Lombardy poplar provided increases connected to type of adhesive, densification temperature and ratio of densification at the ratios reaching up to 21 % in the modulus of elasticity compared to densified Lombardy poplar. The increase in the modulus of elasticity was 62 % when it was compared with solid Lombardy poplar.

Tensile strength parallel to the fibers

Values of tensile strength parallel to the fibers and homogeneity groups of the variables according to type of wood, densification temperature, ratio of densification and type of adhesive used in lamination have been given in Tab. 3.

Tab. 3: Tensile strength values parallel to the fibers and homogeneity groups of the variables according to type of material, densification temperature, ratio of densification and type of adhesive used in lamination.

Type of material	Densification temperature (°C)	Ratio of densification							
		Control		15 %		30 %		50 %	
		TSPF (N·mm^{-2})	HG	TSPF (N·mm^{-2})	HG	TSPF (N·mm^{-2})	HG	TSPF (N·mm^{-2})	HG
Solid Lombardy poplar	**Control**	**25.13**	**22**	****	**	****	**	****	**
Densified Lombardy poplar	80	****	**	43.17	21	61.76	20	73.48	13
	100	****	**	72.9	13	88.16	10	92.61	9
	120	****	**	96	8	100.95	6	131.39	2
	140	****	**	136.88	1	134.71	1	64.76	16
Laminated Lombardy poplar with PVAc	Control	41.33	21	****	**	****	**	****	**
Densified and laminated Lombardy poplar with PVAc	80	****	**	53.08	19	64.07	17	66.82	15
	100	****	**	72.82	13	80.69	12	96.38	7
	120	****	**	69.22	14	108.59	4	108.92	4
	140	****	**	103.77	5	93.57	9	57.25	18
Laminated Lombardy poplar with UF	Control	45.56	20	****	**	****	**	****	**
Densified and laminated Lombardy poplar with UF	80	****	**	55.89	18	67.26	15	72.72	13
	100	****	**	84.14	11	95.57	8	97.58	7
	120	****	**	103.23	6	108.42	4	114.59	3
	140	****	**	105.16	5	92.45	9	65.57	16

TSPF: Tensile strength parallel to the fibers, HG: Homogeneity group, PVAc: Polyvinyl acetate adhesive, UF: Urea formaldehyde adhesive.

Increases from 72 to 444 % could be provided in the tensile strength parallel to the fibers of Lombardy poplar connected to the densification temperature and ratio for the densification process. As the densification temperature and ratio of densification increased, excluding the ratio of densification of 50 % and level of temperature of 140°C, the tensile strength parallel to the fibers increased. Raising the temperature level from 80 to 140°C connected to the ratio of densification provides increased at ratios reaching from 80 to 216 % in the tensile strength parallel to the fibers. Increasing the ratio of densification at the temperature level of 140°C was not effective for an increase in tensile strength parallel to the fibers.

The lamination process increased the tensile strength parallel to the fibers 64 with PVAC adhesives and 80 % with UF adhesives when compared with solid Lombardy poplar. Whereas, the lamination of densified Lombardy poplar connected to the type of adhesive, densification temperature and ratio of densification provided an increase reaching the ratios of 165 % in the tensile strength parallel to the fibers when compared with densified Lombardy poplar. The increase in the tensile strength parallel to the fibers rose up to 356 % when it was compared to solid Lombardy poplar.

Compression strength parallel to the fibers

Values of compression strength parallel to the fibers and homogeneity groups of the variables according to type of wood, densification temperature, ratio of densification and type of adhesive used in lamination have been given in Tab. 4.

Tab. 4: Compression strength parallel to fibers and homogeneity groups of the variables.

Type of material	Densification temperature (°C)	Ratio of densification							
		Control		15 %		30 %		50 %	
		CSPF ($N\cdot mm^{-2}$)	HG	CSPF ($N\cdot mm^{-2}$)	HG	CSPF ($N\cdot mm^{-2}$)	HG	CSPF ($N\cdot mm^{-2}$)	HG
Solid Lombardy poplar	**Control**	**41.22**	**17**	****	**	****	**	****	**
Densified Lombardy poplar	80	****	**	45.87	16	59.35	10	58.36	11
	100	****	**	47.59	15	53.94	14	61.62	9
	120	****	**	61.56	9	67.6	6	67.58	6
	140	****	**	54.75	14	56.02	12	57.77	12
Laminated Lombardy poplar with PVAc adhesive	Control	46.09	16	****	**	****	**	****	**
Densified and laminated Lombardy poplar with PVAc	80	****	**	48.01	15	62.35	9	70.16	5
	100	****	**	67.22	6	71.46	3	72.07	3
	120	****	**	58.86	13	65.93	7	72.22	3
	140	****	**	67.1	6	52.86	14	43.73	16
Laminated Lombardy poplar with UF	Control	48.36	15	****	**	****	**	****	**
Densified and laminated Lombardy poplar with UF	80	****	**	58.36	11	62.48	8	70.59	4
	100	****	**	65.94	7	67.49	6	75.06	2
	120	****	**	70.58	4	78.86	1	79.7	1
	140	****	**	65.79	7	63.09	8	66.98	6

CSPF: Compression strength parallel to fibers, HG: Homogeneity group, PVAc: Polyvinyl acetate adhesive, UF: Urea formaldehyde adhesive.

When the data in the Tab. 4 were compared, the densification process provided increases from 11 to 64 % in the compression strength parallel to the fibers of Lombardy poplar connected to densification temperature and ratio. As the densification temperature and ratio of densification were increased, excluding the 50 % ratio of densification and 140°C temperature level, the compression strength parallel to the fibers increased. Increasing the temperature level from 80 to 120°C provided increases at ratios reaching from 14 to 36 % in the compression strength parallel to the fibers connected to ratio of densification. Raising the temperature level to 140°C and increasing the ratio of densification at the temperature level of 140°C were not effective on an increase in the compression strength parallel to the fibers.

The lamination process increased the compression strength parallel to the fibers 12 with PVAc adhesives and 17 % with UF adhesives when it was compared with solid Lombardy poplar. Whereas, the lamination of densified Lombardy poplar connected to type of adhesive, densification temperature and ratio of densification provided increases at ratios reaching 76 % in the compression strength parallel to the fibers compared to densified Lombard poplar. The increase in compression strength parallel to the fibers rose up to 93 % when it was compared with solid Lombardy poplar.

The densification process positively affected the mechanical properties of Lombardy poplar: Increases could be provided that reached ratios of 42 % in the bending strength connected to densification temperature and ratio, 38 % in the modulus of elasticity, 444 % in tensile strength parallel to the fibers and that reach ratios of 444 % in the compression strength parallel to the fibers. In general, while raising the temperature level from 80 to 120°C was the cause of an increase in the values for these mechanical properties, raising the temperature from 120 to 140°C was the cause of a decrease in values. Also, increasing the ratio of densification, excluding the 140°C temperature and 50 % ratio of densification interaction, was the cause of an increase in the values for mechanical properties.

The lamination process of Lombardy poplar increased the bending strength 10 with PVAc adhesives and 14 % with UF adhesives, the modulus of elasticity 8 with PVAc adhesives and 12 with UF adhesives, the tensile strength parallel to the fibers 65 with PVAc adhesives and 80 % with UF adhesives, and the compression strength parallel to the fibers 12 with PVAc adhesives and 17 % with UF adhesives when compared to solid wood. Making the lamination process with UF adhesive brought greater increases in the mechanical properties.

Whereas, the lamination of densified Lombardy poplar could provided increases at ratios reaching up to 25 % for bending strength, 21 % for modulus of elasticity, 165 % for tensile strength parallel to the fibers and up to 76 % for compression strength parallel to the fibers connected to type of adhesive, densification temperature and ratio of densification when compared to laminated Lombardy poplar. Also, the increases risen up to 62 % for bending strength and modulus of elasticity, 356 % for tensile strength parallel to the fibers and up to 93 % for compression strength parallel to the fibers when it is compared with solid Lombardy poplar.

Gašparik and Gaff (2015a) have reported that the bending strength of the densified beech wood by the cyclic loading was higher by 5.7 % than that of the non-densified wood. Ulker et al. (2012) stated that increases of 42 % in the bending strength, 20 % in the shear strength and 47 % in the compression strength after densification of the Scots pine were obtained in comparison with the non-densified Scots pine. The bending strength of the laminated beech wood consisting of densified and non-densified veneer and PVC film was 17.4 % higher compared to control sample (Gaff and Gašparik 2015b). Thermo-hydro-mechanically densification substantially augmented compression strength by approx. 20-fold in spruce and aprox. 3-fold in beech (Skyba and Schwarze 2009). The results of all these studies point out that the densification process increases mechanical properties of the wood. In this study, consistent with the literature results, ıt was found out that not only densification process but also lamination process after densification increased the aforementioned mechanical properties of the Lombardy poplar. It is contemplated that the differences among the results can take it's source from the methods and wood species.

CONCLUSIONS

The most suitable temperature level was 120°C among the temperatures of 80°C, 100, 120 and 140°C for the densification of Lombardy poplar and as the ratio of densification was increased at this temperature level, increases up to 444 % were observed in the selected mechanical properties. Also, the lamination of densified Lombardy poplar provided increases up to 165 % in the selected mechanical properties compared to densified Lombardy poplar. Consequently, the lamination process after densification of Lombardy poplar is recommended for higher mechanical strength.

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