Analysis of Usability in Furniture Production of Wood Plastic Laminated Board

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The objective of this study was to manufacture a lightweight and easily producible wood plastic laminate (WPL) board that could be used in the furniture sector. Eastern beech (*Fagus orientalis* L.) veneer papels (A) and hollow polycarbonate boards (B), both with a thickness of 4 mm, were laminated in different combinations using polyurethane (PUR) and polychloroprene (PCR) adhesives. The physical and mechanical properties of the WPL boards obtained were determined according to the principles specified in the EN 326-1, EN 317, EN 310, ASTM D1037, and ASTM D1761 standards. Subsequently, the specimens were compared with particle boards (PB), medium density fiberboards (MDF), and okoume plywoods (PW). According to the results, the AABAA, ABABA, and ABBBA combinations of the WPL materials had better physical properties, such as weight, water absorption, and swelling thickness, compared to the other composites. Furthermore, because the WPL materials had a high bending resistance, modulus of elasticity, and nail and screw withdrawal strength, they could be used instead of PB and MDF. The WPL material obtained within the scope of this study are suitable for furniture making.

Keywords: Wood plastic; Composite material; Furniture production; Physical mechanical properties

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INTRODUCTION

Wood has been used for centuries to make furniture and construction materials. However, because wood is a natural material, it requires continuous upkeep and can degrade quicker than other materials, especially as wood continuously gains and loses moisture because of its hygroscopic properties. Because of wood's hygroscopic nature, it is continuously changing its dimensional stabilization and aesthetic appearance. Furthermore, the flexible and changeable decorations that have come into common use have contributed to the inability to transport the wood products easily because of the weight of the furniture.

The improvements in the properties of wood materials have triggered technological advances in the wood industry. Scientific studies have made substantial contributions by determining the properties that shorten the lifespan of wood products and by eliminating those properties (Burdurlu *et al*. 2007). Currently, the application of the lamination technique and the integration of plastics into wood materials yield a decrease in moisture gain/loss and provide dimensional stabilization of the wood materials.

Laminated lumber is produced by adhering wood veneers with equal or varied thicknesses or tree species together, ensuring that the grains are parallel (Burdurlu *et al*. 2007; Melo and Menezzi 2014; Rahayu *et al*. 2014; Gaff and Gasparik 2015). Zhang *et al*. (2014) stated that the mechanical resistance of different joining mechanisms in laminated veneer lumber (LVL) production could be improved. Results from the cited study showed that manufactured bamboo products containing lap-joint combinations had the best mechanical resistance, followed by the toe-joint, tape-joint, and butt-joint combinations.

One of the most significant technical advantages of LVL is the specific performance characteristics in its design. By strategically placing selected veneer sheets within the composite, it is possible to manufacture a wood-based product that has well-controlled physical and mechanical properties (Wang *et al*. 2003; Rahayu *et al*. 2014). Moreover, different composite materials with varying structural properties can be combined during the manufacturing process to overall enhance the properties of the final product (Burdurlu *et al*. 2007; Bal 2014; Yang *et al*. 2014; Ozkaya *et al*. 2015).

According to the literature studies, it is observed that LVL intercalation material is mostly produced by different wood specimen (Burdurlu *et al*. 2007; Melo and Menezzi 2014; Rahayu *et al*. 2014; Gaff and Gasparik 2015). This is in relation to the fact that the material is produced as layers, which can be integrated easily. Likewise, plastic materials can be fabricated between the layers nowadays. Besides, that the polycarbonates have widely been used in the construction sectors is well known. Polycarbonate materials (as an intercalation structure) occupy a crucial place on LVL material technology due to their intrinsic mechanical characteristics such as being lightweight, penetrable, nonflammable, elastic, easy to process, and cuttable by simple hand tools. To the best of our knowledge, the scientific studies including polycarbonate have focused on either only the production technology or the effects on human health of the materials until now.

In light of this knowledge, this study attempted to reduce the hygroscopic properties of natural wood material by producing an alternative, WPL material, with the favorable characteristics of being lightweight, water-resistant, and easily producible, for use in the furniture sector. With this purpose, the physical and mechanical properties of WPL materials containing a combination of eastern beech (*Fagus orientalis* L.) and hollow polycarbonate boards were evaluated.

EXPERIMENTAL

Wood Material

Eastern beech (*Fagus orientalis* L.) was chosen because it is commonly used in Turkey's furniture sector; it is also easily obtainable, economical in price, and the methods for processing are familiar. Eastern beech logs, from Kapsan Veneer and Wood Industry Company in Düzce, Turkey, were cut into veneer papels with dimensions of 4 ± 0.5 x 250 x 2100 mm (T x W x L) using the cutting veneer method (TS 1250 2005) by taking into account the drying share and the test specimen measurements. The principles specified in the TS 2470 standard (2005) were followed for the preparation of the specimens, and specimens were selected to be free of decay, knots, splits, and color and/or density differences. Prior to the lamination process, specimens were kept in a climatization chamber at a temperature of 20 ± 2 ºC and a relative humidity of 65 ± 3% until they reached a constant weight, according to TS 2471 (2005).

Plastic Material

Polycarbonate boards were used as a plastic material. Because it is a material that can be recycled, the lack of a detrimental effect on human health, it is easily obtained, being suitable for LVL production process. The lightweight can be attributed to a hollow structure. They were purchased from the Zet Construction Company in Istanbul, Turkey. Polycarbonates are a special group of thermoplastics that have an amorphous structure. They have functional groups connected by carbonate groups (-O-CO-O-) within long molecular chains (Aslan 2005). This plastic type, which is easy to process, mold, and shape thermally, is commonly used in the modern manufacturing sector. Hollow polycarbonate boards with dimensions of 4 x 2100 x 6000 mm were cut into sizes determined according to the lamination combinations.

Adhesives

Polyvinyl acetate (PVAc), urea formaldehyde (UF), polyurethane (PUR), and polychloroprene (PCR) adhesives from the Durante Vivan company in Italy were used in joining the wood and plastic materials. The manufacturer instructions from the supply companies were followed when applying the adhesives. After the pre-tests were conducted, it was found that the PVAc and UF adhesives were not appropriate for gluing the polycarbonate boards together. Consequently, these adhesive types were removed from the experimental design.

Application of the Laminating Process

The determination of the physical and mechanical properties of the WPL boards produced and the board combinations occurred in three stages (Fig. 1). The WPL board production conditions are shown in Table 1.

Table 1. WPL Production Conditions

Veneer moisture content	12 ± 2%
Room temperature during gluing process	20 ± 2 °C
Relative humidity	65 ± 3%
Type of adhesive	PUR and PCR
Average adhesive weight application	180 ± 10 g/m^2
Pressing application	Cold press (20 ± 2 °C)
Pressure	9 (N/mm^2)
Pressure time	3 h

PUR: polyurethane; PCR: polychloroprene

In the first stage, the preparatory procedures (rough cutting, sanding, gluing, pressing, and WPL material manufacture) were completed. First, the eastern beech veneer papels, at an air-dried humidity, were sanded to a thickness of 4 mm using 100 grit sandpaper in a calibrated sanding machine (Version 1100 Melkuç Machine Company, Ankara, Turkey). Subsequently, the samples were kept at a temperature of 20 ± 2 °C and a relative humidity of 65 ± 3% before the lamination process (TS 2471 2005). The WPL composites were produced by the eastern beech veneer papels (A) and the polycarbonate boards in different combination of AAAAA, BBBBB, ABBBA, ABABA, AABBA, ABBAA, and AABAA, which were glued together by PUR and PCR adhesives. However, because a deformation was determined for the AABBA and ABBAA board combinations, these combinations were removed from the experimental design. As a replacement for the combinations removed, ABTBA and ATBTA (T = polycarbonate board placed perpendicular to the fibers) combination types were added to the experimental design in a manner suitable for plywood production (Fig. 2).

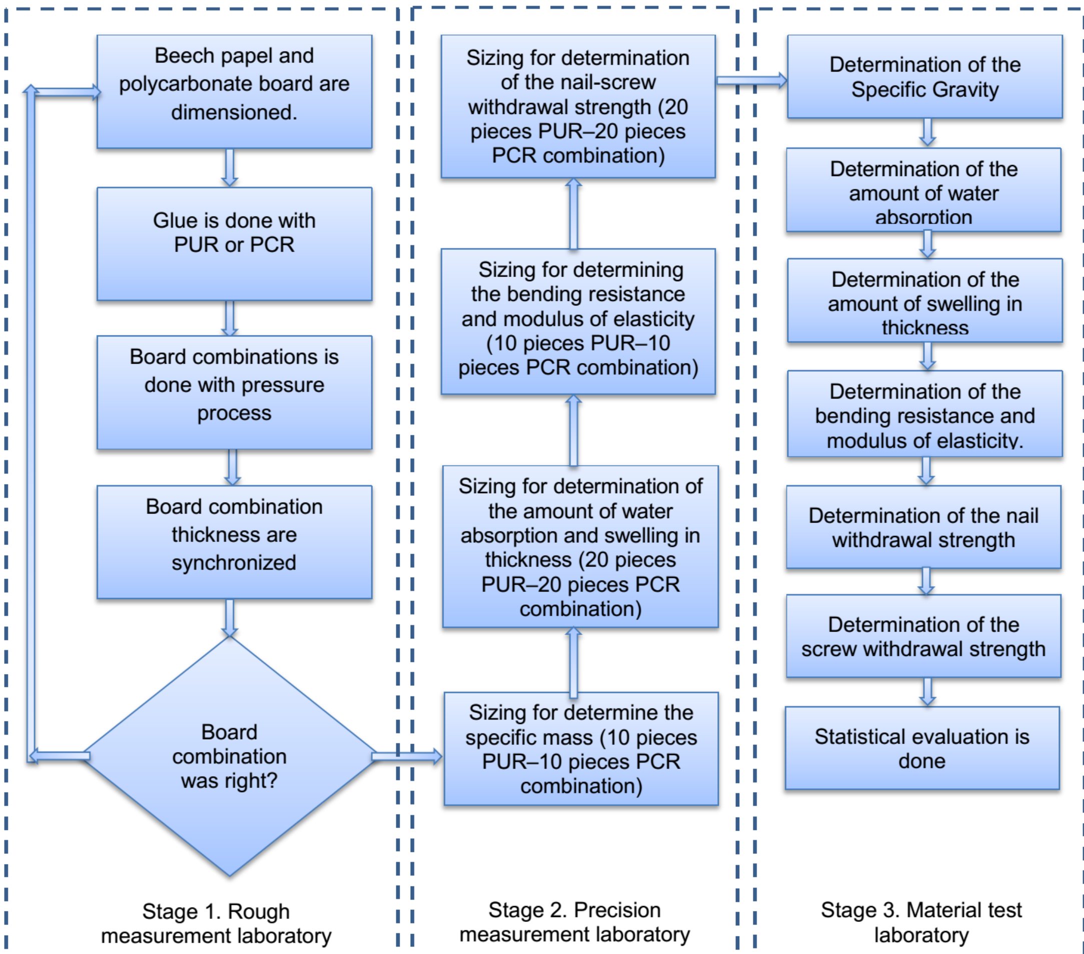

Fig. 1. Schematic diagram of experimental design

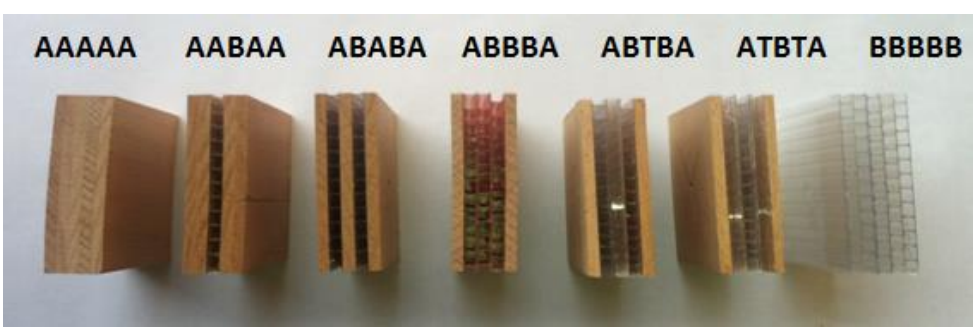

Fig. 2. WPL board combination types

At the second stage, the test specimens were obtained from the WPL boards manufactured by making the measurements according to the following standards: EN 310 (1993); EN 317 (1993); EN 326-1 (1993); ASTM D1037 (1987); and ASTM D1761 (1995).

Previously, the test specimens were kept in a climatization chamber at a temperature of 20 ± 2 ºC and a relative humidity of 65 ± 3%, until the weights of the specimens were constant (until reaching a moisture content of 12%), for the purpose of homogenization of moisture by volume before the experiments. Subsequently, the specimens were put into plastic bags to prevent loss of moisture until further testing.

At the third stage, the tests were performed and the data were statistically evaluated. The results of the WPL board combinations were compared and it was determined whether or not they could be used in furniture production. Control specimens of medium density fiberboard (MDF), particle board (PB), and beech plywood (PW) were additionally used for comparison; as these materials were already prepared, they only underwent the 2nd and 3rd stage procedures.

Methods

Determination of the specific gravity

Square specimens were prepared in the dimensions of 50 ± 1 mm according to the principles specified in the EN 326-1 standard (1993). The climatized specimens were weighed on an analytical scale (Precisa XB 320 C, Switzerland) with a sensitivity of ± 0.01 g, and the dimensions were measured with calipers (Mitutoyo 500-181-30, Japan) with a sensitivity of ± 0.01 mm. According to the EN 323 standard (1993), the specific gravity (δ_a) for each specimen was determined using Eq. 1,

$$\delta_a(g/cm^3) = \frac{m}{a \times b \times t} \tag{1}$$

where *m* is the weight of the test specimen (g), *t* is the thickness of the test specimen (cm), *a* is the width of the test specimen (cm), and *b* is the length of the test specimen (cm).

Water absorption and swelling thickness

To determine the amount of water absorption and swelling thickness, square test specimens with dimensions of 50 ± 1 mm were prepared according to the EN 317 standard (1993). The specimens were climatized until they reached a constant weight, after which their thicknesses were measured. Then, the specimens were submerged in a water container, 25 ± 5 mm below the water surface, for periods of 2 and 24 h. After removing the excess water with a cloth, the masses and thicknesses were measured. The amount of water absorbed (S_a) was calculated using Eq. 2, and the swelling thickness (G_t) was calculated using Eq. 3:

$$S_a(\%) = \frac{m_2 - m_1}{m_1} \times 100 \tag{2}$$

$$G_t(\%) = \frac{t_2 - t_1}{t_1} \times 100 \tag{3}$$

where m_1 is the mass of the test specimen before being submerged in water (g), m_2 is the mass of the test specimen after being submerged in water (g), t_1 is the thickness of the test specimen before being submerged in water (mm), and t_2 is the thickness of the test specimen after being submerged in water (mm).

Bending resistance and modulus of elasticity

The EN 310 standard (1993) was followed for determining the bending resistance and modulus of elasticity. Test specimens were prepared with dimensions of 50 mm x 430 mm. The loading mechanism on a universal test machine (Version 7012-50kN, UTEST Company, Turkey) was operated at a speed of 6 mm/min, in a manner that would provide for the realization of breaking within 1 to 2 min after loading (Fig. 3). The bending resistance (σ_{ϵ}) was calculated using Eq. 4, and the modulus of elasticity (E) was calculated using Eq. 5,

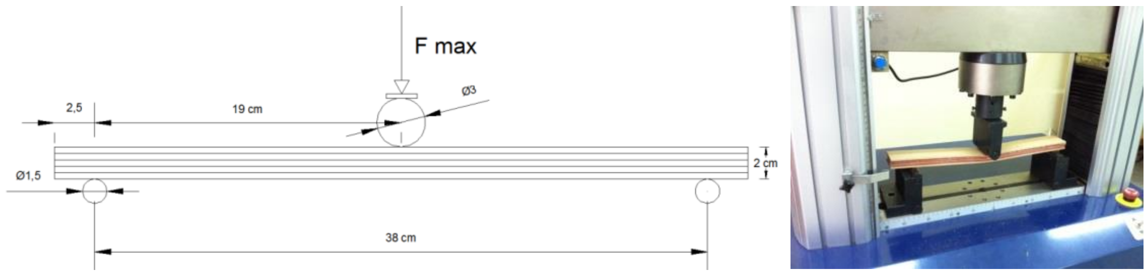

Fig. 3. The bending resistance test apparatus

$$\sigma_e(N/mm^2) = \frac{3 \times F \times L}{2 \times b \times t^2} \tag{4}$$

$$E(N/mm^2) = \frac{F \times L^3}{4 \times \Delta e \times b \times t^3} \tag{5}$$

where F is the maximum force at the moment of breaking (N), L is the aperture between support points (mm), t is the specimen thickness (mm), b is the specimen width (mm), and Δe is the deflection due to the load (mm).

Nail and screw withdrawal strengths

The nail and screw withdraw strengths were determined according to the principles of the ASTM D1037 (1987) and ASTM D1761 (1995) standards. The specimens were prepared separately with dimensions of 75 mm x 75 mm. The specimens prepared were marked exactly in the middle for nailing the nails and screwing the screws, and a 2-mm-diameter guide hole was opened for the screw withdrawal specimens. Nails and screws, with dimensions of 2.5 mm x 50 mm and 3.5 mm × 3.5 mm, respectively, were used in the experiment. The nails were nailed perpendicularly to a depth of 16 mm into the specimen's surface with the help of a mold, whereas the screws were screwed in a manner to enter 17 mm with the help of a mold.

The withdrawing load in the experiment was applied (Version 7012-50kN, UTEST Company, Turkey) at a speed of 2 mm/min, according to the principles specified in the ASTM D 1037 standard (1987; Fig. 4). At the conclusion of the experiment, the nail and screw withdrawing strengths (σ) from the WPL materials were calculated using Eq. 6,

$$\sigma(N/mm^2) = \frac{F}{A} \tag{6}$$

where F is the maximum withdrawing force (N) and A is the surface area of the portion of the screw or nail that entered the board (mm^2).

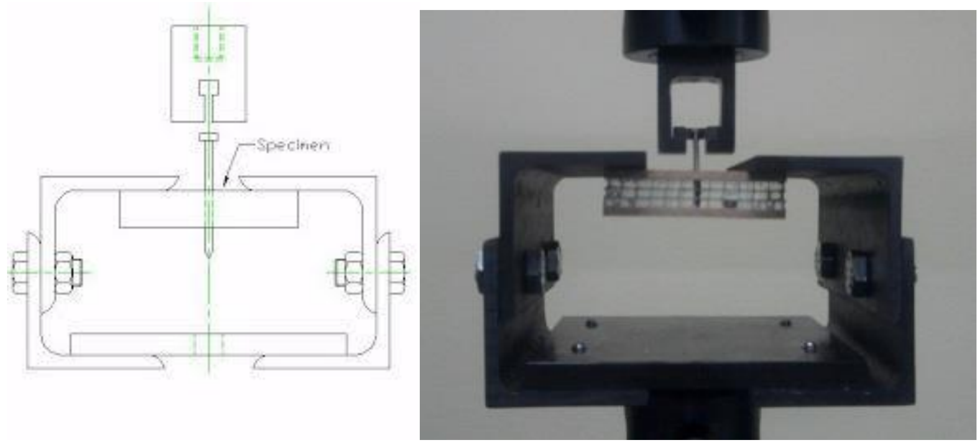

Fig. 4. Screw and nail tensile test apparatus

Evaluation of Data

The data were analyzed using the SPSS statistical software (Version 21.0, SPSS Inc., Chicago, IL, USA). Analysis of variance (ANOVA) was used to determine whether there were any significant differences among the WPL board production types. ANOVA followed by Duncan's test was performed to show significant differences ($P < 0.05$).

RESULTS AND DISCUSSION

Specific Gravity

As the ratio of polycarbonate within the WPL board combinations increased, the specific gravity decreased (Fig. 5). This result can be ascribed to the empty spaces in the polycarbonate structure, which contributed to the low specific gravity. It was determined from the literature that in laminated boards containing beech and cardboard, as the ratio of cardboard increased, the specific gravity decreased. In addition, similar results were obtained when a filling substance with a density lower than wood was used (Celebi *et al.* 2006).

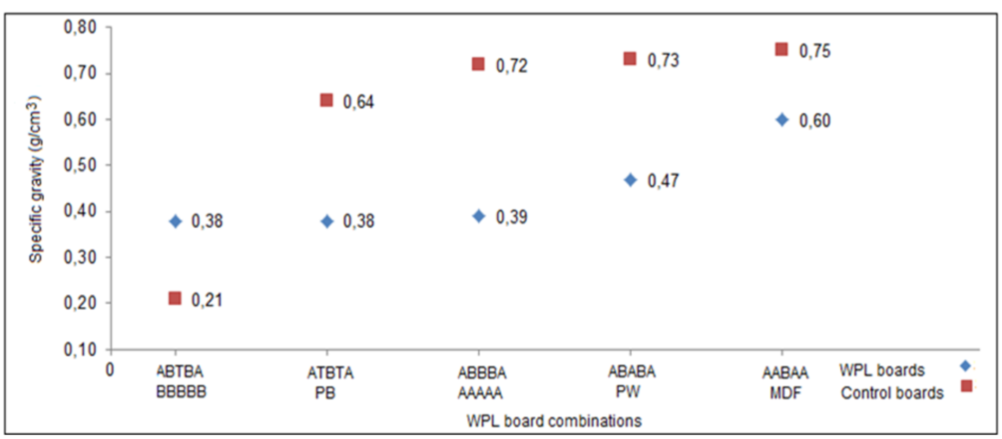

Fig. 5. Determination of the specific gravity

In a different study, it was reported that in laminated boards containing beech and poplar materials, as the ratio of poplar increased, the specific gravity decreased (Burdurlu *et al.* 2007). At the same time, results from Colakoglu *et al*. (2003), Bal and Bektaş (2012), and Gaff and Gasparik (2015) showed that the density of beech LVL was 0.720 g/cm^3, 0.653 to 0.677 g/cm^3, and 0.750 to 0.820 g/cm^3, respectively. The results of the present study are thus in accordance with the results from the literature.

Water Absorption and Ratio of Swelling Thickness

As the submersion time in water increased, the amount of water absorbed into the WPL boards and their subsequent swelling thicknesses increased. However, the amount of water absorbed and the increase in thickness was greater in the control specimens. Furthermore, as the polycarbonate layers in the WPL materials increased, the water absorption and ratios of swelling thickness after 2 and 24 h decreased (Figs. 6 and 7). This occurred because as the beech material drew water into its structure, the polycarbonate, because of its hydrophobic structure, did not absorb water as well.

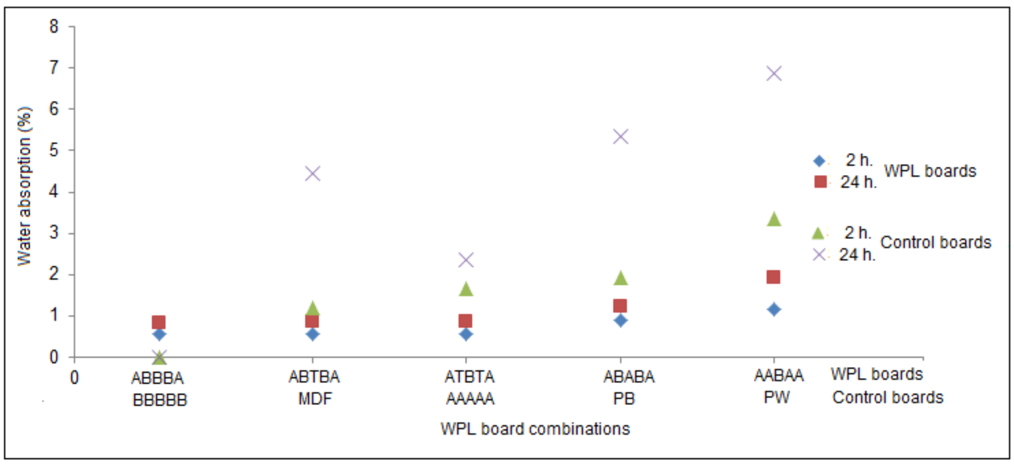

Fig. 6. Water absorption behavior of the WPL board combinations

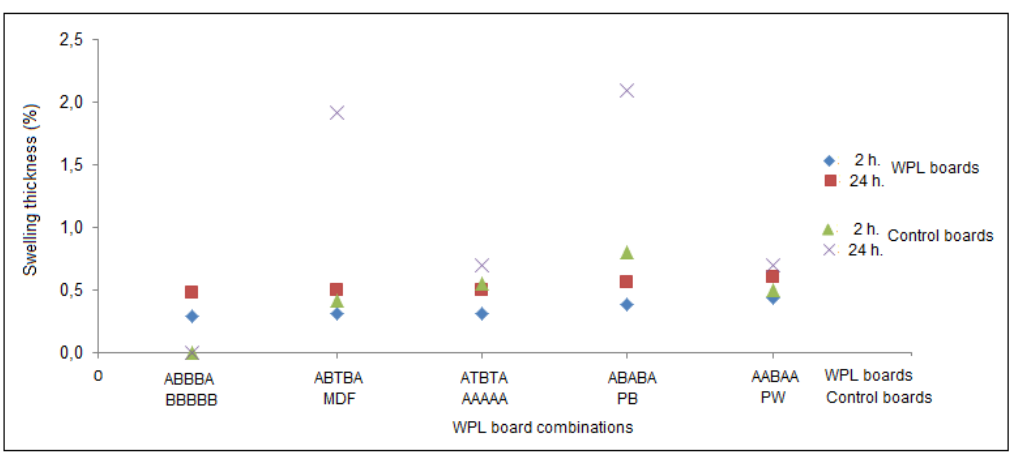

Fig. 7. Swelling thickness behavior of the WPL board combinations

Results in the literature suggest that wood or wood fiber materials used as a filler in wood plastic composite (WPC) materials increase the water absorption values and dimensions of the composite materials (Vladkova *et al*. 2006; Zhang *et al*. 2006). In a different study, it was stated that the ratio of water absorption of the plastic material was almost zero and after WPC was submerged in water for 24 h, the moisture content ratio was 0.7% to 3% of its initial weight, or approximately 24% of an impregnated piece of wood (Klyosov 2007). Wechsler and Hızıroğlu (2007), Tisserat *et al*. (2013), and Li *et al*. (2014) reported that as the submersion time in water increases, the water drawn into the structure of the WPC also increases. Ulay and Güler (2010) determined that the change in thickness was 1% in foam composite sandwich panels within 24 h, 19% in particle boards, and 3% to 5% in okoume and poplar plywoods.

Bending Resistance

The bending resistances of the WPL board combinations were calculated using Eq. 4. Results from a One-Way ANOVA showed that the adhesive types had no significant effect (F = 0.856, $P > 0.05$) on bending strength (Table 2).

Table 2. ANOVA Test Results for Glue Type - Bending Resistance

Glue type– Bending resistance	Sum of Squares	Degrees of Freedom	Mean Square	F - Number	Level of Significance (P)
Intergroup	1133,679	2	566,839	0,856	0,426
Groupware	133043,429	201	661,908		
Total	134177,107	203			

Statistically significant differences were determined among the WPL board combinations and the bending resistance values (F = 76.627, $P < 0.05$) (Table 3). The Duncan test was used to compare the treatment means, and the results are shown in Table 4. Accordingly, the intra-group differences among the BBBBB–PB, ATBTA–ABTBA–ABBBA, and ABTBA–ABBBA–MDF production types were not significant, suggesting that they could be used interchangeably.

As the number of plastic layers in the WPL board combinations decreased, the bending resistance increased. This may have resulted from the lower density of polycarbonate (Burdurlu *et al*. 2006; Celebi *et al*. 2006; Kılıç 2011; Gaff and Gasparik 2015). Furthermore, the bending resistance also appeared to be dependent on the number of plastic layers in the WPL board combinations (Kılıç 2011; Gaff and Gasparik 2015).

Table 3. ANOVA Test Results for WPL Board Combinations - Bending Resistance

WPL board combinations – Bending resistance	Sum of Squares	Degrees of Freedom	Mean Square	F - Number	Level of Significance (P)
Intergroup	104719,048	9	11635,450	76,627	0,000
Groupware	29458,059	194	151,846		
Total	134177,107	203			

Table 4. Duncan Test Results for WPL Board Combinations -Bending Resistance

Homogeneity Groups; subset for α = 0.05						
1	2	3	4	5	6	7
BBBBB[a*] PB[b]	ATBTA[c] ABTBA[d] ABBBA[e]	ABTBA[d] ABBBA[e] MDF[f]	ABABA[g]	AABAA[h]	PW[i]	AAAAA[j**]
Arithmetic Mean (N/mm^2)						
9.68[a*] 11.76[b]	21.25[c] 25.18[d] 29.09[e]	25.18[d] 29.09[e] 32.95[f]	41.90[g]	52.11[h]	68.05[i]	82.90[j**]

a-j: Groups with the same letters in each column indicate that there is no statistical difference ($p<0.05$) between the samples according to the Duncan's multiple range test.*: The lowest bending resistance value; **: The highest bending resistance value

The modulus of elasticity values of the WPL board combinations were calculated using Eq. 5. Just as with the bending resistance, there were no significant differences among the type of adhesive and the modulus of elasticity values (F = 3.771, $P > 0.05$) (Table 5). On the other hand, there were significant differences among the board combinations and the modulus of elasticity values (F = 65.304, $P < 0.05$) (Table 6). The Duncan test results are shown in Table 7. Accordingly, the intra-group differences among the BBBBB–ATBTA–ABTBA, ATBTA–ABTBA–PB, and PB–MDF combinations were not significant, suggesting that they could be used interchangeably.

Table 5. ANOVA Test Results for WPL Glue Type - Modulus of Elasticity

Glue type– The modulus of elasticity	Sum of Squares	Degrees of Freedom	Mean Square	F - Number	Level of Significance (P)
Intergroup	5,39E+07	1	5,39E+07	3,771	0,054
Groupware	2,37E+09	166	1,43E+07		
Total	2,43E+09	167			

Table 6. ANOVA Test Results for WPL Board Combinations - Modulus of Elasticity

WPL board combinations – Bending resistance	Sum of Squares	Degrees of Freedom	Mean Square	F - Number	Level of Significance (P)
Intergroup	2,35E+09	9	2,61E+08	65,304	0,000
Groupware	7,74E+08	194	3989386,79		
Total	3,12E+09	203			

As the number of layers of polycarbonate within the WPL board combinations increased, the modulus of elasticity decreased. A similar situation was also found in the literature (Burdurlu *et al*. 2006; Celebi *et al*. 2006; Kılıç 2011). Furthermore, Tisserat (2013) reported that when WPCs were submerged in water, their modulus of elasticity increased slightly. Wechsler and Hızıroğlu (2007) determined that the modulus of elasticity values in WPL boards containing TR06 (a blend of fatty acid metal soap and an amide) was higher than those without TR06.

Table 7. Duncan Test Results for WPL Board Combinations - Modulus of Elasticity

Homogeneity Groups; subset for α = 0.05						
1	2	3	4	5	6	7
BBBBB^{a*} ATBTA^{b} ABTBA^{c}	ATBTA^{b} ABTBA^{c} PB^{d}	PB^{d} MDF^{e}	ABBBA^{f}	ABABA^{g} AABAA^{h}	PW^{i}	AAAAA^{j**}
Arithmetic Mean (N/mm^2)						
415.54^{a*} 1026.54^{b} 1487.04^{c}	1026.54^{b} 1487.04^{c} 2239.67^{d}	2239.67^{d} 3049.33^{e}	4667.63^{f}	6372.42^{g} 7434.13^{h}	9014.12^{i}	10329.21^{j**}

a-j: Groups with the same letters in each column indicate that there is no statistical difference (p<0.05) between the samples according to the Duncan's multiple range test.*: The lowest modulus of elasticity value; **: The highest modulus of elasticity value

Screw and Nail Withdrawing Strengths

According to the results from the One-Way ANOVA, significant differences were determined among the WPL board combinations and the screw (F = 234.647, P < 0.05) and nail (F = 169.621, P < 0.05) withdrawing strengths. The Duncan test results for determining the mean combination differences are shown in Tables 8 and 9.

Table 8. Duncan Test Results for Screw Withdrawing Strength

Homogeneity Groups; subset for α = 0.05					
1	2	3	4	5	6
ABBBA^{a*} BBBBB^{b}	BBBBB^{b} ABTBA^{c}	PB^{d} ATBTA^{e}	ABABA^{f} AABAA^{g}	MDF^{h} AAAAA^{i}	PW^{j**}
Arithmetic Mean (N/mm^2)					
3.95^{a*} 4.37^{b}	4.37^{b} 5.13^{c}	6.72^{d} 7.02^{e}	9.90^{f} 9.96^{g}	11.63^{h} 11.84^{i}	19.60^{j**}

a-j: Groups with the same letters in each column indicate that there is no statistical difference (p<0.05) between the samples according to the Duncan's multiple range test.*: The lowest screw withdrawing strength value; **: The highest screw withdrawing strength value

Table 9. Duncan Test Results for Nail Withdrawing Strength

Homogeneity Groups; subset for α = 0.05					
1	2	3	4	5	6
ABTBA^{a*} BBBBB^{b} ABBBA^{c} ATBTA^{d}	ATBTA^{d} PB^{e}	ABABA^{f}	AABAA^{g}	MDF^{h}	PW^{i} AAAAA^{j**}
Arithmetic Mean (N/mm^2)					
0.58^{a*} 0.70^{b} 0.79^{c} 0.88^{d}	0.88^{d} 1.20^{e}	1.79^{f}	2.47^{g}	4.33^{h}	4.84^{i} 4.86^{j**}

a-j: Groups with the same letters in each column indicate that there is no statistical difference (p<0.05) between the samples according to the Duncan's multiple range test.*: The lowest nail withdrawing strength value; **: The highest nail withdrawing strength value

Accordingly, the intra-group difference among the ABTBA –BBBBB – ABBBA–ATBTA, ATBTA–PB, and PW–AAAAA combinations for screw withdrawing strengths and among the ABBBA–BBBBB, BBBBB–ABTBA, YL–ATBTA, ABABA–AABAA, and MDF–AAAAA combinations for nail withdrawing strengths were not significant, suggesting that they could be used interchangeably.

As the number of layers in the WPL board combinations increased, the screw and nail withdrawing strengths decreased. The reason for this could be that the solid structure of the wood material provided a stronger hold for the steps of the screw. Furthermore, the fact that the nails and screws used were not produced for plastic materials, and that the empty spaces in the hollow structure were polycarbonate, could have decreased the nail and screw withdrawal strengths. Ghanbari *et al*. (2014) reported that as the poplar ratio of the WPC material increased, the screw and nail withdrawing strengths increased. Chavooshi *et al*. (2014) reported that as the MDF powder content in the WPC mixture decreased, the screw and nail withdrawing strengths decreased. Other studies obtained similar results (Chavooshi and Madhoushi 2013; Madhoushi *et al*. 2014). Furthermore, Chavooshi *et al.* (2014) stated that as the relative humidity of the composite material increased, the nail and screw withdrawing strengths decreased. According to Celebi and Kılıç (2007), the screw withdrawing strength in LVL was found to be higher than that for nails. Özçifçi (2009) reported that opening a suitable pilot hole before screwing into the LVL surface increased the screw withdrawing strength.

CONCLUSIONS

1. In this study, physical and mechanical properties of WPL composite materials produced with eastern beech veneer and polycarbonate layered combinations were evaluated. By comparing the properties of the new WPL materials with MDF, PB, and PW control specimens these are commonly used in furniture production was determined, that the WPL boards may be suitable to use in furniture industry. The used adhesive types had no significant effect on specific gravity, water absorption, or bending strength.
2. Results showed that as the amount of polycarbonate in the WPL material increased, there was a decrease in the specific gravity, swelling thickness, and water absorption capabilities. A low specific gravity would produce lighter weight furniture. Furthermore, a decrease in the ratio of swelling thickness and water absorption would provide an advantage when furniture is used in damp places. For these reasons, the WPL materials containing polycarbonate layer would be recommended in place of MDF, PB, and PW for furniture produced for damp conditions.
3. According to the bending resistance and modulus of elasticity test results, all of the WPL board combinations might be used instead of PB, and all of the board combinations excluding the BBBBB, ABTBA, and ATBTA composites might be used instead of MDF. However, none of the board combinations produced could be used instead of PW.
4. According to the nail and screw withdrawing strength test results, the ABABA and AABAA board combinations might be used instead of PB. However, none of the board combinations produced could be used instead of MDF or PW.

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