Environmental Engineering and Management Journal December 2018, Vol. 17, No. 12, 2857-2864
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

"Gheorghe Asachi" Technical University of Iasi, Romania

EFFECT OF CORE LAYER COMPOSITION ON WATER RESISTANCE AND MECHANICAL PROPERTIES OF HYBRID PARTICLEBOARD

Jin Heon Kwon[1], Nadir Ayrilmis[2]*, Tae Hyung Han[1]

[1]*Department of Forest Biomaterials Engineering, College of Forest and Environmental Sciences, Kangwon National University, 200-701, Chuncheon, Republic of Korea*
[2]*Department of Wood Mechanics and Technology, Faculty of Forestry, Istanbul University-Cerrahpasa, Bahcekoy, 34473, Sariyer, Istanbul, Turkey*

Abstract

In this study, the effect of raw material formulation used in the core layer on the water resistance and mechanical properties of particleboard made from a mixture of rice husk and wood particles was investigated. For this aim, four series of particleboard core layer were produced from different proportions of rice husk/wood particles, different amounts of urea-formaldehyde (UF) adhesive, low density polyethylene (LDPE), and maleic anhydride grafted polyethylene (MAPE), respectively. The amounts of the LDPE and MAPE in the core layer were gradually increased up to 30 wt% and 6 wt%, respectively, while the amount of the UF adhesive was gradually decreased from 8 to 0 wt%. The water absorption, thickness swelling, and internal bond strength of particleboard were greatly improved by the incorporation of LDPE and MAPE into the core layer. The bending properties of the particleboard improved with increasing the LDPE content up to 20 wt%. The MOR and MOE of the particleboard increased with the incorporation MAPE into the core layer.

Key words: compatibilizer, dimensional stability, particleboard, rice husk, wood

Received: December, 2014; Revised final: March, 2015; Accepted: March, 2015; Published in final edited form: December 2018

1. Introduction

Due to growing demand for panel-type furniture as function of increasing human population, the interest in using of agricultural residues for the production of wood-based panels such as particleboard and fiberboard has been recently increased. Rice husk is the major by-product of rice-processing industries which must be appropriately managed. On average 20 wt% of the rice paddy is husk (Madrid et al., 2012). The holocellulose (cellulose combined with hemicellulose) content in rice husk is about 54 wt%, but the composition of ash (11 to 20 wt%) and lignin (25 to 30 wt%) differ depending on the species (Hwang and Chandra, 1997). In view of Korea's agricultural rise and the increase in agricultural residues, the use of rice husk in the production of particleboard can be alternative to decreasing wood resources.

The physical and mechanical properties of wood-based panels depend on the adhesive characteristics. Urea-formaldehyde (UF) adhesive is commonly used in the manufacture of wood-based panels such as plywood, particleboard, and fiberboard. The advantages of UF adhesive are low cost, water solubility, easy use (under a wide variety of curing conditions), relatively low cure temperature, microorganisms resistance, excellent thermal properties, and colorless (especially of the cured adhesive) (Nikvash et al., 2013). But, the UF adhesive has drawbacks of low water resistance and high formaldehyde emission (No and Kim, 2005).

Thermoplastics such as polypropylene and polyethylene are widely used in wood composite

* Author to whom all correspondence should be addressed: e-mail: nadiray@istanbul.edu.tr; Phone: 90-212-338 2400; Fax: 90-212-338 2424

industry as binder today. As compared to the wood material, thermoplastics have higher dimensional stability (hydrophobicity) and better weathering and fungus resistance. Low density polyethylene (LDPE) remains a popular plastic in use today because of its versatility (large range of density, molecular weight (MW) and MW distribution, and chemical inertness) and low melting temperature (Anonymous, 2008; Dascălu and Negrea, 2016; Ropoto et al., 2011). As compared to polypropylene or high density polyethylene, LDPE is a suitable thermoplastic for improving of core layer of the particleboard due to its low melting temperature which is around 100°C. Because the maximum temperature in a particleboard core only reaches a maximum of 100 to 110 °C during the hot pressing (Pizzi, 1994).

Three layer particleboard is one of the most commonly used panel products in furniture industry. The core layer of the particleboard significantly affects the water resistance of the board due to its high shell ratio. The improvement in the bonding between the core layer particles can improve the water resistance and mechanical properties of the particleboard. The high amount of silica content could be a problem in the manufacture rice husk particleboard made using UF adhesive. In previous studies, it was reported that the bonding performance between the UF adhesive and rice husk was low because the UF adhesive was chemically incompatible with the rice husk surface (Ciannamea et al., 2010; Lee et al., 2003; Yasin et al., 2010). The incorporation of the LDPE and MAPE into the core layer can improve the bonding between rice husk particles, which results in higher water resistance and internal bond strength. In this study, we focused on the effect of raw material formulation used in the core on the properties of hybrid particleboard. For this aim, different proportions of rice husk/wood particles, and different amounts of UF adhesive, LDPE, and maleic anhydride-grafted polyethylene (MAPE) used in the core layer were investigated.

2. Experimental

2.1. Materials

2.1.1. Wood particles and rice husk particles

The face and core layer particles having a moisture content between 4-6% based on the oven-dry weight of the wood particle were supplied from a commercial particleboard plant in South Korea. The rice husk particles were supplied from a commercial rice mill in South Korea. The wood and rice husk particles were dried in a laboratory oven at 90 °C for 24 h to reach 1-2% moisture content.

2.1.2. Adhesive

A commercial E1 (urea/formaldehyde ratio = 1/0.8) grade liquid UF adhesive with a solid content of 55% (specific gravity: 1.2 and pH: 7.9) was used in the manufacture of the particleboard. As a catalyst, 1 wt% of ammonium chloride solution with 20% solids content based on the adhesive solids content was mixed with the liquid UF adhesive. No wax or other hydrophobic substance was used in the particleboard manufacture.

2.1.2. Polymer matrix and compatibilizing agent

The LDPE powder (average particle size: 50 mesh) was obtained from M.J Powder company in South Korea. The melt flow index and density of the LDPE were 24 g/10 min and 0.926 g/cm^3, and, respectively. The compatibilizing agent (MAPE) (MFI/190°C, 2.16 kg = 1.5 g/10min and density: 0.93 g/cm^3) powder was obtained from Lotte Chemical Company in South Korea.

2.1.3. Preparation of hybrid particleboard

The experimental particleboards were produced under laboratory conditions (Fig. 1). The layer composition of the particleboard was 15:70:15 (face/core/face) by weight. Top and bottom surfaces were made from the fine wood particles while the core layer was made from a mixture of wood and rice husk particles. Four series of particleboard core layer were produced according to the experimental design given in Table 1. The proportion of rice husk and wood particles in the core layer was fixed as 35/35 (by weight) in the phases 1-3. First the surface layer particles were blended with the UF adhesive using an air-atomizing nozzle *within a* blending *time* of approximately 5 min in a drum type blender. Then the core layers, except for phase 4, were blended with the UF adhesive.

Following the blending process, the wood particles were hand-formed into a mat using wood mold. The adhesive mixed wood particles were placed in a forming box by hand to form three layer particleboard mat. The cold press was applied to the particleboard mats to decrease mat thickness before hot pressing. The particleboard mats were then hot-pressed in a hot press. The hot press temperature, pressing time and pressure were 180 °C, 2.8 N/mm^2, and 7 min, respectively. The resulting particleboards were cut into 280 mm x 280 mm x 10 mm in size. Two particleboard for each particleboard code were produced (Table 1).

2.2. Methods

2.2.1. Determination of physical and mechanical properties of particleboard

One day thickness swelling (TS) and water absorption (WA) tests were performed according to test method specified in EN 317 (1993). Ten specimens with dimensions of 50 mm x 50 mm x 10 mm were used for each particleboard code. The densities of specimens were determined according to EN 323 (1993). Bending strength (MOR) and modulus of elasticity in bending (MOE) of the specimens were conducted according to EN 310 (1993). A total of 12 specimens (250 mm x 50 mm x 10 mm) (6 // and 6 ⊥ to the particleboard surface) were tested for each particleboard code to determine the MOR and MOE.

Table 1. Experimental design

Phase	*Particle board code*	*Particle content, % weight*			*UF adhesive content, % weight*		*LDPE content, % weight*	*MAPE content, % weight*
		Surface layer	*Core layer*		*Surface layer*	*Core layer*	*Core layer*	*Core layer*
		Wood	*Rice husk*	*Wood*				
Phase I	1	30	70	0	12	8	-	-
	2	30	45	25	12	8	-	-
	3	30	35	35	12	8	-	-
	4	30	25	45	12	8	-	-
	5	30	0	70	12	8	-	-
Phase II	6	30	35	35	12	8	5	-
	7	30	35	35	12	8	10	-
	8	30	35	35	12	8	15	-
	9	30	35	35	12	8	20	-
	10	30	35	35	12	8	25	-
	11	30	35	35	12	8	30	-
Phase III	12	30	35	35	12	7	15	-
	13	30	35	35	12	5	15	-
	14	30	35	35	12	3	15	-
	15	30	35	35	12	1	15	-
	16	30	35	35	12	-	15	-
Phase IV	17	30	35	35	12	-	30	0
	18	30	35	35	12	-	30	1.5
	19	30	35	35	12	-	30	3
	20	30	35	35	12	-	30	4.5
	21	30	35	35	12	-	30	6

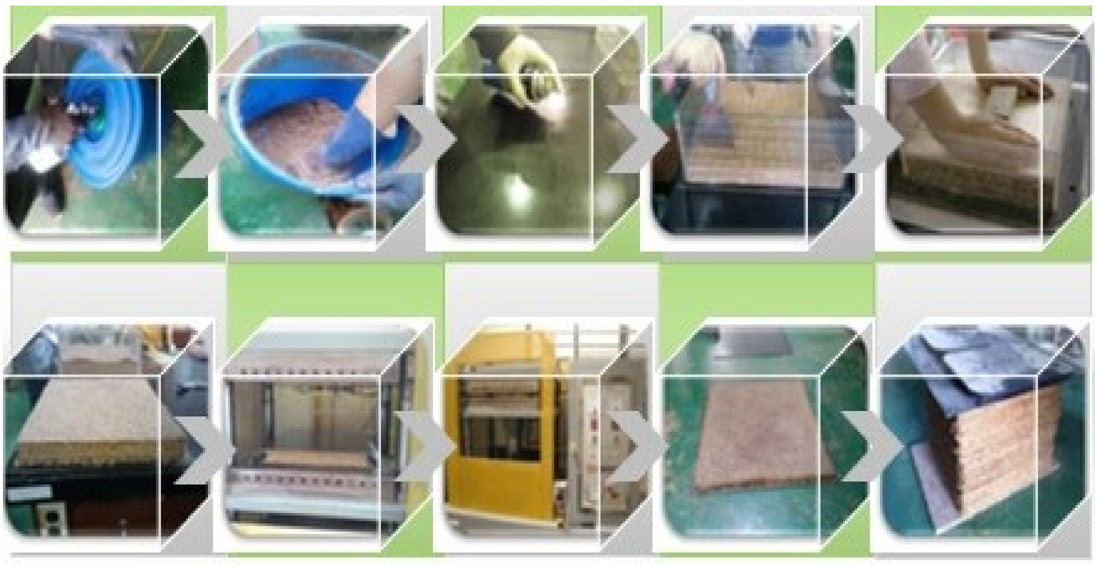

Fig. 1. Production of three layer hybrid particleboard under laboratory conditions

Internal bond (IB) tests were performed on the specimens cut from the particleboard according to EN 319 (1993). Ten specimens (50 mm x 50 mm x 10 mm) were used for each particleboard code.

3. Results and discussions

3.1. Water resistance of particleboard

The TS and WA properties of all the particleboard codes are given in Table 2. In the phase I of the present study, the TS and WA of the particleboard decreased with increasing the wood particle content in the core layer. As the rice husk content decreased from 70 to 0 wt% in the core layer, the TS values decreased from 60.2 to 40.4%. A similar trend was observed for the WA values (Table 2). The decrement in the amount of rice husk particles in the core layer improved the dimensional stability of the particleboard. The TS and WA of the particleboard with a high content of the rice husk were higher than those of the particleboard made from the wood particles. This was mainly due to high amount of silica and wax in the rice husk as compared to the wood (Mohanty et al., 2005). The adverse influence of the silica and wax components on the water resistance of wood-based panels such as particleboard and fiberboard was reported in previous studies (Ciannamea et al., 2010; Lee et al., 2003; Yasin et al., 2010). In the phase II, the water resistance of the particleboard was greatly improved by the incorporation of the LDPE powder into the core layer at the same content of the UF adhesive. The LDPE has very negligible or no WA because of its hydrophobic character. The TS values of particleboard decreased from 48.4 to 42.5% as 5 wt% the LDPE powder was incorporated into the core layer, and then decreased to 15.6% as the LDPE content increased up to 30 wt%. Similarly, the WA value of the particleboard decreased from 85.8 to 43.5% as 30 wt% the LDPE was incorporated into the core layer. The TS and WA values of the particleboard containing 5 wt% the LDPE were lower than those of the control particleboard made with 8 wt% the UF adhesive. This is mainly due to the fact that the surface area of the hygroscopic wood and rice husk particles in the core layer is covered by the hydrophobic LDPE, which decrease the movement of water into the cell walls.

Another explanation of higher water resistance of the particleboard containing the LDPE is that the LDPE can decrease the porosity of the core layer due to its low melting temperature which is around 105 °C as compared to the hot pressing temperature of particleboard (180 °C). As the amount of the LDPE increased from 5 to 30 wt%, the average TS of the particleboard decreased from 42.5 to 15.6%. Similarly, the average WA value decreased from 82.4 to 43.5% as the LDPE was incorporated into the core layer. In the phase III, the LDPE content was fixed at 15 wt% and then the amount of the UF adhesive was gradually decreased from 8 to 0 wt% (Fig. 2). As expected, the TS and WA values of the particleboard increased with decreasing the UF adhesive content. As the UF adhesive content decreased from 8 to 0% at the same content of the LDPE (15 wt%), the TS values increased from 32.8 to 43.8%. A similar trend was observed for the WA values (Table 2). The stress resulted from swelling of the core layer particles, in particular wood particles, can cause the failure of adhesive bond between the particles, which increases the TS value of particleboard.

However, the TS and WA values of the particleboard having a core layer bonded with a mixture of 1 wt% UF adhesive and 15 wt% LDPE were lower than those of the control board having a core layer bonded with 8 wt% UF adhesive. The formaldehyde emission of the particleboard core layer bonded with a mixture of 1% UF adhesive and 15 wt% LDPE could be lower than that of the control board due to the low amount of the UF adhesive in the core layer.

The LDPE has no formaldehyde emission. Formaldehyde has been known as a major irritant in indoor air for many years and it is important for wood-based panels used in indoor furniture (Gunnarsen et al., 2008). In the phase IV, the water resistance of the particleboard was considerably improved by the incorporation of the MAPE compatibilizer into the polymer matrix. For example, as 1.5 wt% MAPE was incorporated into the core layer, the TS of particleboard decreased from 36.4 to 29.6%. Further increment in the MAPE content (6 wt%) greatly decreased the TS value (18.8%).

Table 2. The physical and mechanical properties of particleboard

Particle board code	*Density, g/cm³*	*Water absorption, %*	*Thickness swelling, %*	*Bending strength, N/mm²*	*Modulus of elasticity in bending, N/mm²*	*Internal bond strength, N/mm²*
1	0.72 (0.04)	99.2 (4.3)	60.2 (3.8)	8.79 (1.16)	1249 (75)	0.11 (0.01)
2	0.71 (0.03)	92.6 (3.8)	52.7 (2.6)	9.34 (2.11)	1490 (115)	0.13 (0.02)
3	0.74 (0.03)	85.4 (4.6)	48.4 (3.2)	10.66 (0.8)	1560 (109)	0.14 (0.02)
4	0.74 (0.01)	80.3 (2.7)	44.2 (2.2)	11.66 (1.3)	1746 (122)	0.18 (0.03)
5	0.75 (0.02)	74.1 (3.3)	40.4 (2.9)	12.70 (1.32)	1925 (135)	0.24 (0.04)
6	0.73 (0.02)	82.4 (5.0)	42.5 (1.9)	10.16 (0.9)	1683 (98)	0.17 (0.02)
7	0.76 (0.03)	77.4 (4.1)	39.2 (2.5)	10.85 (0.76)	1720 (107)	0.19 (0.02)
8	0.75 (0.04)	66.7 (3.5)	32.8 (1.7)	11.63 (1.1)	1812 (118)	0.24 (0.02)
9	0.74 (0.04)	57.1 (2.9)	26.4 (2.0)	12.94 (0.69)	1944 (82)	0.27 (0.04)
10	0.76 (0.02)	50.9 (3.7)	22.5 (1.8)	12.32 (2.31)	1903 (161)	0.35 (0.03)
11	0.75 a.(0.01)	43.5 (2.5)	15.6 (1.4)	11.89 (1.7)	1868 (115)	0.45 (0.04)
12	0.76 (0.04)	70.7 (5.1)	33.6 (2.7)	10.94 (1.4)	1710 (123)	0.23 (0.03)
13	0.74 (0.03)	72.8 (4.5)	35.4 (3.3)	10.12 (1.2)	1675 (93)	0.20 (0.02)
14	0.74 (0.01)	78.5 (3.6)	39.6 (2.9)	9.48 (0.9)	1540 (104)	0.19 (0.02)
15	0.74 (0.02)	83.6 (4.0)	41.4 (2.5)	8.16 (1.3)	1440 (87)	0.17 (0.009)
16	0.69 (0.03)	85.0 (3.9)	43.8 (3.7)	7.75 (0.7)	1355 (68)	0.15 (0.006)
17	0.74 (0.02)	61.7 (2.7)	36.4 (3.4)	10.23 (0.8)	1615 (76)	0.20 (0.01)
18	0.75 (0.02)	60.1 (3.4)	29.6 (2.6)	10.65 (1.1)	1665 (83)	0.28 (0.02)
19	0.78 (0.03)	49.8 (2.5)	26.6 (2.1)	11.06 (0.6)	1733 (70)	0.36 (0.02)
20	0.77 (0.02)	51.3 (3.1)	22.0 (1.8)	11.23 (0.7)	1810 (98)	0.47 (0.03)
21	0.75 (0.03)	46.6 (2.9)	18.8 (1.4)	12.23 (1.2)	1851 (108)	0.52 (0.04)

The values in the parentheses are standard deviations.

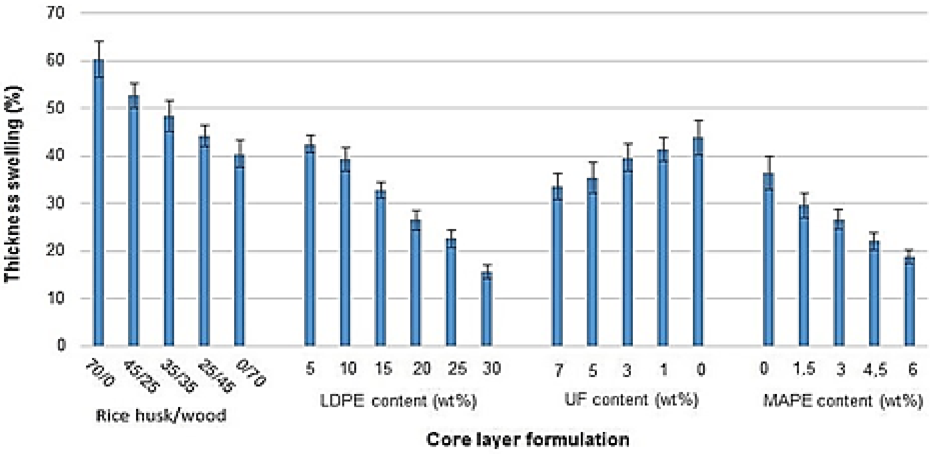

Fig. 2. Effect of core layer formulation on the thickness swelling of the hybrid particleboard

Similar results were observed for the WA values. Compatibilizers have been extensively used in wood plastic composites to improve the quality of adhesion between wood and plastic to reduce the gaps in the interfacial region (Youngquist, 1999; Clemons, 2002). The presence of the MAPE reduces the voids sizes and turns the surface more homogeneous confirming its effect on promoting adhesion in the interfacial region (Adhikary, 2008).

3.2. Mechanical properties of particleboard

The mechanical properties of the particleboard are presented in Table 2. The IB strength of the particleboard increased with increasing the wood particle content in the core layer. In the phase I, as the amount of rice husk in the core layer was decreased from 70 to 0 wt%, the IB value increased from 0.11 to 0.24 N/mm^2. The extractives, such as waxes, can interfere with the direct adhesive contact, leading to a chemically weak boundary effect and poor bond strength (Frihart and Hunt, 2010). The lower IB strength of the particleboard having a rice husk core was mainly due to the fact that high amounts of the silica and waxes in the rice husk decreased the bonding and mechanical interlocking of the UF adhesive.

In the phase II, the IB strength of particleboard was greatly improved by the incorporation of LDPE powder into the core layer at the same content of the UF adhesive. As the amount of LDPE used in the core layer was increased up to 30 wt%, the IB strength increased from 0.17 to 0.45 N/mm^2. The IB strength of the particleboard made from a mixture of the rice husk and the wood particles (rice husk/wood: 35/35 wt%) with 20 wt% the LDPE was better than that of the particleboard made from the wood particles. The incorporation of the 20 wt% LDPE into the core layer more increased the amount of binding between the wood and rice particles as compared to the UF adhesive in the control board. The IB results showed that the LDPE increased the mechanical performance of adhesive bonds between the core layer particles, in particular humid conditions. The observations of the fracture surface of the IB specimens showed that a high amount of the wood and rice husk particles was encapsulated by the hydrophobic the LDPE polymer.

In the phase III, the IB strength of the particleboard decreased as a function of decreasing the UF adhesive content in the core layer (Fig. 3). The IB strength decreased from 0.24 to 0.15 N/mm^2 as the amount of the UF adhesive was decreased from 8 to 0 wt% at the same LDPE content which was 15 wt%. The IB strength of the particleboard (code: 21) with 15 wt% the LDPE in the core layer was higher than that of the particleboard having a rice husk core layer produced with 8 wt% the UF adhesive (particleboard codes: 1 and 2).

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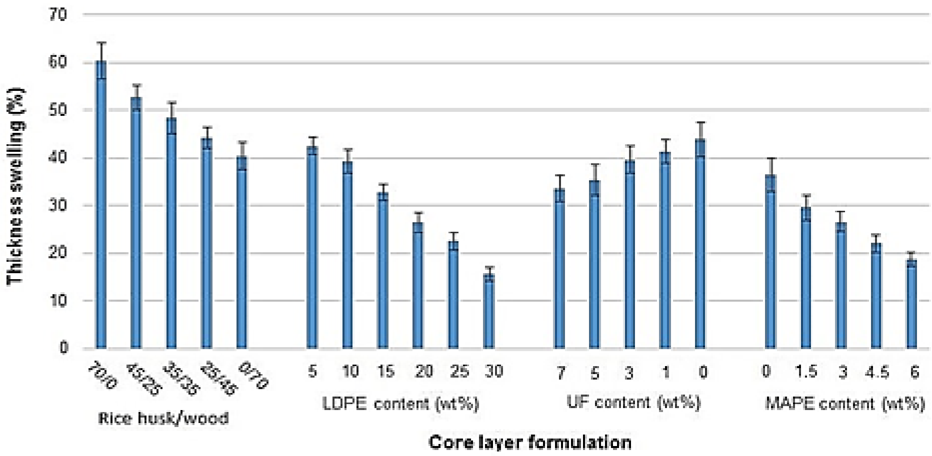

Fig. 3. Effect of core layer formulation on the internal bond strength of the hybrid particleboard

The incorporation of the 20 wt% LDPE into the core layer more increased the amount of binding between the wood and rice particles as compared to the UF adhesive in the control board. The IB results showed that the LDPE increased the mechanical performance of adhesive bonds between the core layer particles, in particular humid conditions. The observations of the fracture surface of the IB specimens showed that a high amount of the wood and rice husk particles was encapsulated by the hydrophobic the LDPE polymer.

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The MOR and MOE of the particleboard increased with increasing the wood particle content in the core layer. The MOR and MOE of the particleboard having a rice husk core (70 wt%) were found to be 8.79 N/mm^2 and 1249 N/mm^2 while these properties were found to be 12.70 N/mm^2 and 1925 N/mm^2 for the particleboard having a wood particle core (70 wt%), respectively. At the same manufacturing conditions, the particle size has a significant effect on the bending properties. The rice husk particles had lower slenderness ratio (the ratio of length to thickness) in comparison to the wood particles. The bending properties of particleboard increase with increasing slenderness ratio of wood particles. Longer particles increase the network system by themselves in the core layer and result in increased bending properties of particleboard (Maloney, 1977). In the phase II, as compared to the control board (code: 3), the MOR and MOE of particleboard were improved by the incorporation of 20 wt% LDPE into the core layer (Table 2). Further increment in the LDPE content slightly decreased the MOR and MOE. The improvement in the bending properties was not same the IB strength. As 20 wt% LDPE was added into the core layer, the MOR and MOE increased by 27% and 25%, respectively. The MOR and MOE of the particleboard decreased as the amount of LDPE was above 20 wt% because the MOE of LDPE was much lower than that of the wood.

In the phase III, the MOR and MOE of the particleboard containing 15 wt% the LDPE decreased as the UF adhesive content decreased from 8 to 0 wt% in the core layer (Table 2). As the amount of the UF adhesive in the core layer decreased from 8 to 0 wt%, the MOR and MOE decreased by 31% and 15%, respectively.

The bonding performance between the core layer particles decreased with decreasing the UF adhesive content, which resulted in lower the MOR and MOE. Adhesives transfer and distribute loads between components, thereby increasing the strength and stiffness of wood products (Frihart and Hunt, 2010). Thus, the decrement in the adhesive content adversely affected the stress transfer between the core layer particles, which resulted in lower the MOR and MOE. In the phase IV, the addition of the MAPE into the core layer improved the MOR and MOE of the particleboard.

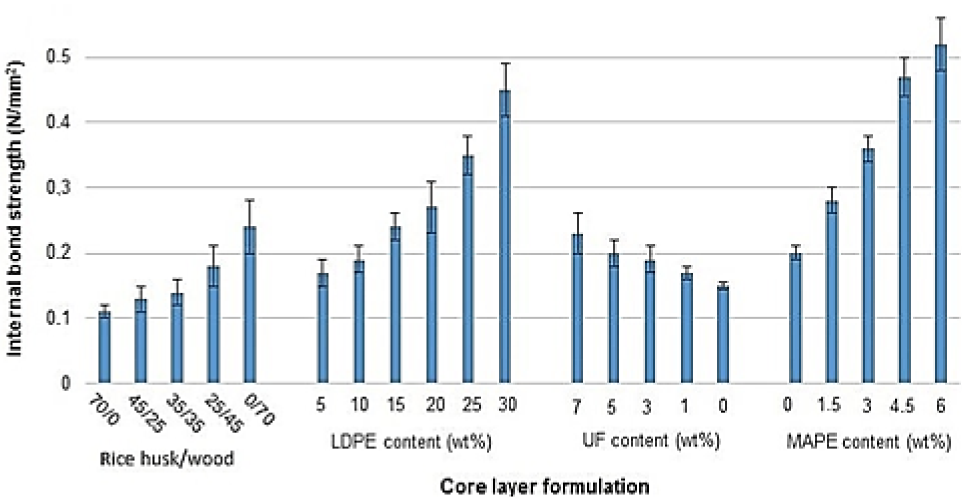

Fig. 3. Effect of core layer formulation on the internal bond strength of the hybrid particleboard

For example, the MOR and MOE of the particleboard (code: 19) increased by 13% and 7%, respectively, as 3 wt% the MAPE was incorporated into the core layer. An increase in the MOR and MOE of particleboard with the LDPE coupled with the MAPE compared to the uncoupled LDPE can once again be attributed to the effect of strong adhesion and wettability of the in the core layer.

4. Conclusions

The following conclusions were drawn from the results of the present study:

1. The water resistance and mechanical properties of the particleboard having a core with a mixture of the wood and rice husk decreased with increasing the rice husk particle content in the core layer. This was mainly due to the fact the wax and silica layer encirculating the rice husk particle inhibited sufficient direct contact between the adhesive and the rice husk particles.
2. The TS and WA values of the particleboard having a core layer produced with a mixture of 1 wt% the UF adhesive and 15 wt% the LDPE were lower than those of the control board produced with 8 wt% the UF adhesive. The formaldehyde emission of the particleboard containing the LDPE could be lower than that of the particleboard produced with the UF adhesive due to the low amount of the UF adhesive in the core layer. As the LDPE is a good barrier to water due to its hydrophobic character, by replacing the UF by the LDPE, the TS and WA can be significantly reduced.
3. The water resistance and IB strength of the particleboard were greatly improved by the incorporation of the LDPE powder into the core layer at the same content of the UF adhesive. The incorporation of the MAPE compatibilizer into the polymer matrix considerably improved the water resistance and IB strength of the particleboard. The water resistance and mechanical properties of the particleboard (code: 19) produced with 30 wt% the LDPE powder and 3 wt% the MAPE powder were better than those of the particleboard (code: 7) produced with 8 wt% the UF and 10 wt% the LDPE powder.
4. Based on the findings obtained from the present study, it can be said that the water resistance and mechanical properties of particleboard having a rice husk core can be considerably improved by the incorporation of the LDPE powder and MAPE into the core layer.

Acknowledgements

This study was supported by the Research Fund of Istanbul University-Cerrahpasa, Project number: 39588.

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