VALORIZATION OF CORN HUSK (*ZEA MAYS*) AND CORN SILK IN POLYMER PARTICLEBOARD MANUFACTURE AND EFFECT OF WASTE COLEMANITE ON THE MECHANICAL PERFORMANCE OF PARTICLEBOARDS

MELİH ŞAHİNÖZ,[*] METİN GÜRÜ[**] and HÜSEYİN YILMAZ ARUNTAŞ[***]

[*] *Department of Civil Engineering, Graduate School of Natural and Applied Sciences, Gazi University, Teknikokullar, 06560, Ankara, Türkiye*
[**] *Department of Chemical Engineering, Faculty of Engineering, Gazi University, 06570, Ankara, Türkiye*
[***] *Department of Civil Engineering, Faculty of Technology, Gazi University, Teknikokullar, 06560, Ankara, Türkiye*
✉ *Corresponding author: M. Şahinöz, melihsahinoz2691@gmail.com*

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In this experimental study, the usability of waste corn husk was investigated as a source of reinforcement material for the first time in eco-friendly particleboard manufacture. For this purpose, the effect of the most appropriate filler/binder (f/b) ratio and pressing temperature manufacturing conditions on three-point flexural strength in particleboard manufacture was examined. To improve the mechanical properties, the water resistance and combustion resistance of the manufactured particleboards, different amounts of corn silk fiber (0~1.50% by weight) and waste colemanite (0~20% by weight) were added. According to the experimental results, the most appropriate manufacturing conditions for the manufacture of corn husk-based particleboard were determined as f/b ratio of 0.75, pressing temperature of 100 °C, and corn silk fiber loading of 0.75 wt%. Additionally, synthetic binders and beet molasses were used together in particleboard manufacture. The particleboards manufactured comply with the specifications of the EN 312 standard, being below the maximum limit values in terms of thickness swelling, and water absorption rates. In addition, by increasing the waste colemanite content in the board composition, the limiting oxygen index (LOI) values and combustion resistance of the boards were increased. However, the use of waste colemanite in particleboard manufacture reduced the flexural strength of the boards. When 5% waste colemanite was added to the particleboards, the boards manufactured met the minimum limit value requirement for P1 type board, according to EN 312. The dimensional stability of the manufactured particleboards, according to the determined manufacturing conditions, is quite good. Particleboards manufactured from corn husks can be used in interior and exterior applications as eco-friendly building materials.

Keywords: particleboard, corn husk, waste colemanite, manufacturing conditions, mechanical performance, combustion resistance

INTRODUCTION

Particleboard is a wood-based composite board material manufactured by combining sawdust obtained from wood or lignocellulosic materials with polymeric binders, such as phenol-formaldehyde (PF), polyvinyl-acetate (PVAc), urea-formaldehyde (UF), and melamine-formaldehyde (MF), under different hot pressing or pressing.[1-3] Fiberboard (FB), medium density fiberboard (MDF), oriented strand board (OSB), plywood (PLY), and particleboard (PB) are examples of different types of wood composite boards.[4,5] Generally, wood composite boards are used in construction, design elements, packaging, shipbuilding, furniture manufacture, and flooring works.[6,7]

The wood industry is growing worldwide, and the demand for wood and wood composite materials is constantly increasing.[8] According to

2020 data, a total of 250 million m^3 of PB, OSB, and FB wood boards were manufactured on a global scale. This wood board manufacturing amount is ~109% more than the wood board manufacturing amount in 2000.[9] However, the increasing global demand for wooden materials causes raw material shortages, deforestation, price increases in wood materials, and logistical difficulties.[7,10] In this case, agro-wastes and agricultural by-products can be used instead of wood as alternative raw material sources, thus protecting forests, reducing the cost of wood material manufacture, and meeting the increasing demand for wood.[11]

As agro-wastes are local raw material sources, which are abundant, low-cost, and renewable,[12,13] agro-wastes, such as stalks, straws, branches, husks, seeds, bagasse, and leaves, which are generated when processing an industrial agricultural plant, can be used instead of wood.[11] For example, in PB manufacture, instead of wood particles, various industrial agro-wastes, such as groundnut shells,[14] tea oil camellia shells,[15] cardoon leaves,[16] breadfruit leaves,[17] sunflower stalks,[18] sesame stalks,[19] sugarcane bagasse,[20] bagasse fibers,[21] olive tree prunings[22] and rice husks,[23] are used as raw material sources. The chemical structure of wood and agro-waste particles mostly contains hemicelluloses, lignin, and cellulose components.[24] These cellulosic-based wood particles are generally combined with formaldehyde-based synthetic resin adhesives, such as melamine, urea, and phenolic formaldehyde, to manufacture composite boards.[25,26] However, formaldehyde is an organic compound that is toxic, carcinogenic, and very harmful to the environment and human health.[27,28] In European Council regulations, the formaldehyde emission value for furniture and wooden elements used in indoor environments is limited to 0.080 mg/m^3.[29] Formaldehyde limit values vary in different countries and regions. These limit value differences make wood manufacturing difficult in the wood industry. It is also estimated that consumers' demands for products with low formaldehyde emissions will increase in the future.[30]

It is very difficult to reduce harmful emissions, especially in the PB industry, where formaldehyde-based resins are frequently used.[31] In wood-based board manufacture, one of the most common methods to reduce both the amount of chemical adhesive and harmful gas emissions is to use alternative organic adhesive materials instead of synthetic adhesives. On the other hand, when wooden boards are manufactured entirely with organic adhesive, the strength and water resistance of the boards decrease.[32] In recent years, the number of studies to reduce formaldehyde emissions in wood products has been increasing.[33,34] In different studies, wood composite panels were prepared by substituting synthetic resins with organic adhesives, such as sucrose, tannin, starch, casein, egg white, blood, soybean protein, and wheat gluten.[35]

In this experimental study, the use of industrial agro-wastes, such as corn husks, corn silks, and beet molasses, as raw material sources in PB manufacture was investigated.

Corn (*Zea mays*) is the second most harvested agricultural crop globally. In addition, a large amount of corn stover is generated when corn products are processed.[36]

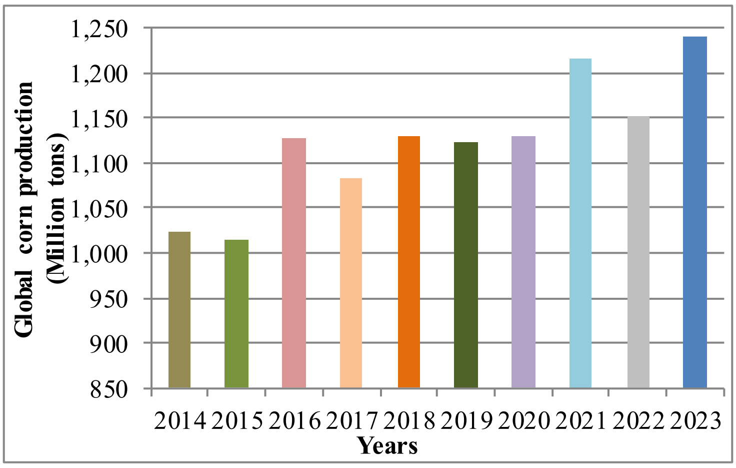

Figure 1: Annual global corn production (million tons)[37,38]

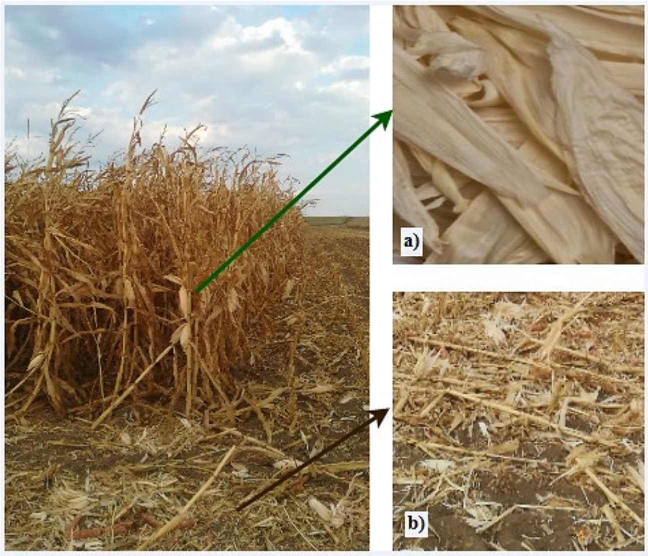

Figure 2: A harvested corn field; a) corn husk and b) corn stover

Figure 1 shows the annual global corn production from 2014 to 2022, according to Statista data.[37] According to the United States Department of Agriculture (USDA) data, ~1.24 million tons of corn was produced in the world in 2023. Approximately half of this amount was produced in the USA and China.[38]

During the corn harvest process, leaves, roots, silks, cobs, and husks of the corn plant emerge as agro-waste. Waste corn husk can potentially be used in the manufacture of bioplastics, paper, electrochemicals, medical materials, nanocomposites, and wood plastic composite materials.[39] Figure 2 shows corn stover and husk in a corn field.

On the other hand, beet molasses is a dark brown liquid by-product obtained from sugar beets during the sugar manufacturing process.[40] In sugar manufacturing, ~40 kg of molasses are obtained from 1 ton of sugar beet.[41] The sugar density of beet molasses (sucrose, glucose, fructose, and raffinose) is between 66~46%.[42,43] Globally, approximately 50 million metric tons of molasses are manufactured annually.[44] In general, molasses is used in the manufacture of alcohol, acid, animal feed, parasite medicine, and as a concrete additive.[45,46]

PBs used in construction have some drawbacks, such as water absorption (WA), swelling, and low combustion resistance.[47] To overcome these drawbacks, the binding resin, filling material, and manufacturing processes of PBs are modified.[48] Thanks to the use of hydrophobic synthetic resins in PB manufacture, the water resistance of particleboard has increased.[49] For example, PF resin, which is most frequently used as an adhesive in the manufacture of wood composite materials, increases the wood material's resistance to water, fungi and termites.[50,51] On the other hand, inorganic materials such as nano-wollastonite powder,[52] pumice,[53] calcium carbonate ($CaCO_3$),[54] zeolite,[55] calcium hydrogen phosphate,[56] fly ash,[57] zinc borate[58] and boron,[59] are added to PBs to increase the combustion resistance of PB materials. These incombustible inorganic materials increase the combustion resistance by preventing the flame from spreading on the wood.[60] Türkiye has the largest boron reserves (73.6%) and the largest boron manufacturing capacity in the world.[61,62] In Türkiye, the most abundant boron mineral types are borax, colemanite, and ulexite.[63] In Türkiye, the annual amount of boron waste generated in boron facilities is higher than the boron reserve amount of many countries. Storage of these wastes in tailings dams causes environmental pollution and groundwater contamination.[61]

Boron components are used to increase the combustion resistance of wood composite materials.[64,65] In this study, increasing the combustion resistance of PBs by using waste colemanite in PB manufacture was investigated.

There are many experimental studies in the literature examining the mechanical and physical properties of PBs prepared with various agro-wastes under different manufacturing conditions. Syahfitri *et al.*[66] investigated the use of sorghum bagasse and molasses in the manufacture of PB. In their studies, it was determined that when molasses was used up to 20% in board manufacture, the flexural strength (FS), modulus of elasticity, and internal bonding force of the samples increased. In addition, it was determined that as the molasses content in the samples increased, the WA and thickness swelling (TS) rates of the samples decreased. It has been explained that, as the molasses content increases, the mechanical properties and dimensional stability of the samples also increase. As a result, it was stated that the manufactured PB could be used as lightweight roof tiles. Ferrandez-Villena *et al.*[67] investigated the utilization of waste vine prunings in PB manufacture. In their work, it was determined that using fine-grained material, high molding pressing, and long pressing times increased the mechanical properties of the samples in PB manufacture. However, it has been explained that the increase in pressing time does not affect the density, thermal conductivity, flexural strength, TS and WA rates of the samples. In conclusion, it has been stated that it is appropriate to manufacture PB from waste vine prunings and that the manufactured PBs can be used as indoor decoration, furniture, and load-bearing boards. Jimenez Jr. *et al.*[68] studied the physico-mechanical properties of PBs obtained from a mixture of waste tobacco stalk and paper mulberry wood sawdust. It was explained that tobacco stalks created large gaps and poor bonding in PBs. According to their test results, it was detected that, as the tobacco stalk content in PBs increased, the WA and TS rates of PB samples increased, while FS, internal bonding force, and formaldehyde concentration decreased. Additionally, the 75:25 tobacco stalk:paper mulberry wood sawdust ratio was found to be the most appropriate one. Betené *et al.*[69] researched the mechanical performance of PBs manufactured from doum palm and balanite fruit shells. In their study, PB samples were prepared with different doum palm:balanite shell ratios. As a result, it was determined that as the content of balanite shell increased in PBs, porosity, moisture content, WA, and TS values decreased. It has been declared that the mechanical performance of PBs manufactured with a mixture of equal amounts of doum palm and balanit fruit shells is in accordance with the literature. Lusiani *et al.*[70] examined the effect of using different types of sawdust and plants in PBs on the mechanical properties of PBs. As a result, it has been explained that the type of filling material and the particle properties of the filling material affect the properties of particleboard. Additionally, it has been determined that the most appropriate chipboards are manufactured with mahogany wood sawdust. Tasdemir *et al.*[71] investigated the manufacturing of PB with waste orange peel and polymer binder mixture (95% UF+5% PF). In the study, PB samples were manufactured at binder mixture:orange peel ratios of 1:4, 1:3, 1:2, and 1:1. In conclusion, it was determined that, as the polymer binder content in particleboard samples increased, the tensile strength, hardness, and LOI values of PBs increased. It has been stated that PF resin reduces the WA rate of PBs. It was concluded that the highest tensile strength (15 MPa) and the highest mechanical properties were obtained from samples manufactured with 1:1 binder mixture:orange peel ratios.

In this study, the use of corn husk as a filling material in eco-friendly PB manufacture was investigated experimentally. PB was manufactured for the first time with a combination of corn husk and corn silk. Our study is innovative in this respect and contributes to the literature. In our study, corn silk fibers and waste colemanite were used to increase the mechanical performance of PBs manufactured with corn husk. Thanks to waste colemanite, PBs are more resistant to combusting. In this case, waste colemanite-based particleboards have been made to be safer against fire. The mechanical properties of the manufactured PBs were compared with the relevant standards and literature. Manufacturing corn husk-based particleboards with low pressing temperatures can provide a significant advantage in terms of reducing energy consumption.

EXPERIMENTAL

Materials

The corn husk and corn silk used in this study were collected from a corn field in Eskişehir, Türkiye. The husk and silk were dried in the air in an open area. The density of ground corn husk was determined as 0.27 g/cm^3. The average length of dried corn silk was measured as 4 cm. PF resin was provided by Polisan Chemical Plant (Kocaeli province, Türkiye) and PVAc resin was provided by a glue plant (Eskişehir province, Türkiye). These resins were maintained at +17 °C. PVAc resin has the following properties: density 1.20

g/cm^3, solid content 49%, pH 3.5~4 and milky white color. The physical properties of the PF resin used in PB manufacture are given in Table 1. Sugar beet molasses was obtained from Ankara Sugar Factory (Ankara province, Türkiye) and kept in a laboratory environment. The characteristic properties of sugar beet molasses are presented in Table 2. Waste colemanite was taken from the tailings dam of Eti Mining Plants (Emet district, Türkiye). The oxide components of waste colemanite material are demonstrated in Table 3.

Table 1
Physical properties of PF resin

Parameter	Unit	Value
Gel time	(min, 105 °C)	10 ~ 20
Viscosity	(cPs, 20 °C)	300 ~ 700
Density	(g/cm^3)	1.21
Solid	(wt%)	47

Table 2
Characteristic properties of sugar beet molasses

Parameter	Unit	Value
Total sucrose	(wt%)	52
Invert sugar	(wt%)	0.09
pH	-	8.9
Density	(g/cm^3)	1.18

Table 3
Oxide components of waste colemanite material (wt%)

Oxide	Value	Oxide	Value
B_2O_3	34.4	Fe_2O_3	1.41
SiO_2	23.7	SrO	1.0
CaO	18.7	TiO_2	0.24
Al_2O_3	9.7	SO_4	0.21
MgO	8.83	Na_2O	0.13
K_2O	1.67	P_2O_5	0.01

Particleboard manufacturing

In this experimental study, all PB samples were designed and manufactured as single-layer under laboratory conditions. The hot pressing method was used in the manufacture of PB. The experimental study was carried out in two stages. In the first stage, the most appropriate filler/binder ratio (f/b ratio) and the most appropriate pressing temperature manufacturing conditions for PBs were determined according to the samples' flexural strength. The manufacturing conditions where the highest FS was achieved were considered as the most appropriate PB manufacturing conditions. In the second stage, corn silk and waste colemanite were added to the sample mixtures to improve the mechanical properties of PB samples. The parameters of different f/b ratio and pressing temperature in the first stage of the PB manufacture process are given in Table 4, and the contents of corn silk fiber and waste colemanite in the second stage of the manufacture process are given in Table 5.

Dried corn husks were ground into powder with a Retsch grinding device. The average grain diameter of the ground corn husk material is $\bar{d}$: 525 µm. The binder mixture was prepared by mixing 45% polyvinyl acetate, 35% beet molasses, and 20% phenol formaldehyde by weight, based on our previous experimental work.[72] Hardener catalyst sulphuric acid (0.10 milliliters) was added to the binder mixture. A homogeneous mixture was prepared by manually mixing the ground corn husk and binder mixture in a container for 5 minutes. Corn silk was added to these sample mixtures at rates between 0.5~1.5% by binder weight. In addition, waste colemanite was substituted for corn husk at rates between 0~20%. The prepared board sample mixtures were poured into a stainless steel mold measuring 120 × 60 mm. To prevent the samples from sticking to the steel mold, the inside of the mold was covered with foil paper.

After determining the most appropriate f/b ratio for PB manufacturing, all the sample mixtures were prepared at a fixed weight of 80 g. The target density of the boards based on fixed weight is 820 kg/m^3. PB samples were manufactured at different pressing temperatures using a hot press device, and during production, both pressing force and pressing time were kept constant at 3.5 Mton and 15 minutes. The manufactured board samples were cured in an oven at a fixed 70 °C temperature for 24 hours after being removed from the mold. The manufactured board samples were maintained in the laboratory environment during the testing process. Figure 3 shows the manufacturing stages of corn husk-based PB samples.

Particleboard testing

After curing, the PB samples were cut with a saw, and the samples were sized for flexural strength, WA, TS, and LOI tests according to relevant standards. The FS values of the boards are very important in determining the usage areas of the board samples. FS was determined by the 3-point flexural strength test method in accordance with European Standard EN 310:1993.[73] Samples with dimensions of 60 × 15 × (sample thickness) mm were used to calculate the FS value. The 3-flexural strength test was carried out using a 5 kN Autograph Shimadzu AG-I device at a test speed of 10 mm/min and an effective span of 40 mm. FS values were recorded from the test device display. The average of the FS values of 6 test samples was taken. FS was calculated according to Equation (1):

$$\sigma_f = \frac{3\ x\ P_{max}\ x\ l_1}{2\ x\ \mathrm{b}\ x\ h^2} \quad (1)$$

where P_{max} is the maximum load, l is the support clearance, b is the sample width, h is the sample thickness.

TS and WA experiments were carried out to determine the dimensional change of board samples of 50 × 50 × (sample thickness) mm size exposed to wetting. The resistance of the boards to TS and WA greatly affects the usage performance of the boards. In accordance with the EN 317 standard,[74] 12 test samples for each sample mixture were soaked in water for 24 hours. The dry and wet weights of the samples were weighed on a precision scale. On the other hand, the dry and wet thicknesses of the samples were determined with a caliper.

Table 4
Filler/binder ratio (f/b) and pressing temperature parameters for PB manufacture

Parameter	f/b ratio (g/g)	Pressing temperature (°C)
First stage	0.50	100
	0.75	100
	1.00	100
	1.25	100
	0.75	80
	0.75	90
	0.75	110
	0.75	120

Table 5
Contents of corn silk fiber and waste colemanite for PB manufacture

Parameter	Corn silk fiber (wt%)	Waste colemanite (wt%)
Second stage	0	-
	0.25	-
	0.50	-
	0.75	-
	1.00	-
	1.25	-
	1.50	-
	0.75	5
	0.75	10
	0.75	20

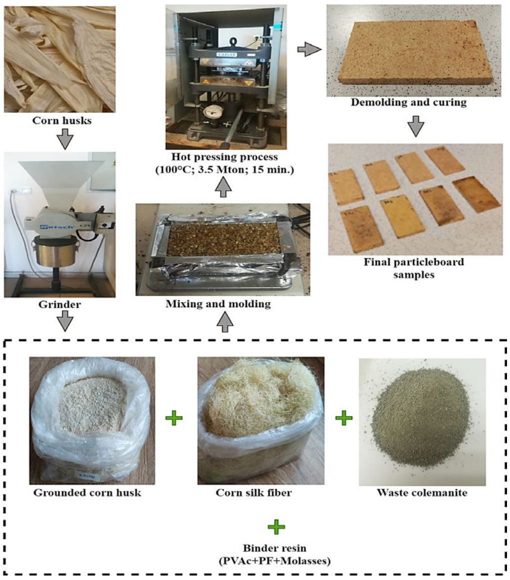

Figure 3: Manufacturing stages of corn husk-based eco-friendly PB samples

The TS and WA rates of the board samples were calculated according to Equations (2) and (3), respectively:

$$TS_{(24\,h)} = \frac{T_2 - T_1}{T_1} \times 100 \tag{2}$$

where T_1 is the initial dry board thickness, T_2 is the final wet board thickness;

$$WA_{(24\,h)} = \frac{W_2 - W_1}{W_1} \times 100 \tag{3}$$

where W_1 is the initial dry board weight, W_2 is the final wet board weight.

The limit oxygen index (LOI) test was used to analyze the combustion of the board samples. A Dynisco test device was used in the LOI experiment. According to the ASTM D 2863-1951 standard,[75] samples with a size of 100 × 10 × (sample thickness) mm were fitted vertically in a glass cylindrical column. A continuous flow of nitrogen (N) and oxygen (O_2) gases was provided in the glass column. The continuous combustion condition of the samples was observed. The N and O_2 gas rates at which the test samples combusted continuously for the first time were recorded. LOI tests were performed 10 times for each colemanite-based board sample.

RESULTS AND DISCUSSION

Determining the most appropriate filler/binder (f/b) ratio

Figure 4 shows the FS values of PBs as a function of the increase in the filler rate in the sample content. The thickness of the boards prepared with different f/b ratios was between 6.5 and 7.2 mm. According to Figure 4, the highest FS (~7.40 MPa) was obtained from the boards manufactured with a f/b ratio of 0.75. The thickness of the boards prepared with an f/b ratio of 0.75 was measured as 6.8 mm. Keeping the binder ratio constant and increasing the filler content significantly affects the FS of the samples. It was determined that the FS of the samples decreased beyond the 0.75 f/b ratio. This decrease can be explained by the inability of the filler material particles to transfer the stress from the binder matrix and the formation of weak surface bonds among the particles. Similar results were observed in the studies of Shakuntala *et al*.[76] and Nourbakhsh *et al*.[77] In these two experimental studies, it was determined that, while the FS of the board samples increased up to a certain filler content, the FS values of the boards decreased after a certain threshold. As a result, the ratio of 0.75 f/b, which provides the highest FS, was chosen as the most appropriate preparation condition for the board samples.

Effect of pressing temperature

PB samples were manufactured at pressing temperatures between 80 and 120 °C. The FS values of the boards manufactured at different pressing temperatures are shown in Figure 5. According to Figure 5, the highest FS (~7.40 MPa) was obtained in the boards manufactured with a pressing temperature of 100 °C. Additionally, it has been determined that the FS of boards manufactured at temperatures above 100 °C decreases. This decrease can be explained by the high temperature degradation of molasses, which contain ~52% sucrose by weight. Similarly, Zhao *et al.*[78] stated that at high temperatures, the chemical structure of sucrose deteriorates, it caramelizes, and its adhesion properties decrease. On the other hand, Iswanto *et al.*[79] explained that the strength of the binder material used in PB manufacture may decrease at different pressing temperatures. Accordingly, in their studies, the FS of particleboards manufactured with a pressing temperature above 140 °C decreased due to the binder material structure. In a previous experimental study, it was determined that the FS values of the boards decreased beyond a certain waste molasses content and pressing temperature in board manufacture.[72] As a result, the experimental results of this study are compatible with different literature studies. The pressing temperature has a significant impact on the FS of board samples. In PB manufacture, the pressing temperature of 100 °C, which provides the highest FS, was found as the most appropriate board preparation condition.

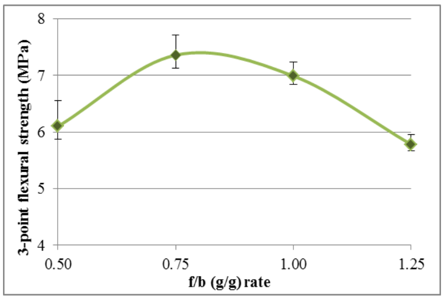

Figure 4: Flexural strength of particleboards prepared with different f/b ratio

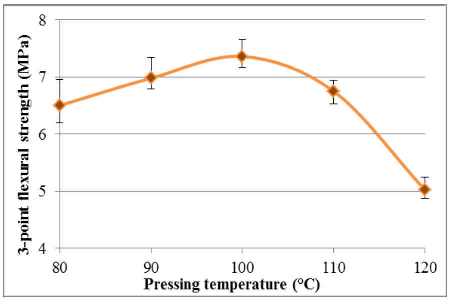

Figure 5: Variation of flexural strength of particleboards as a function of pressing temperature

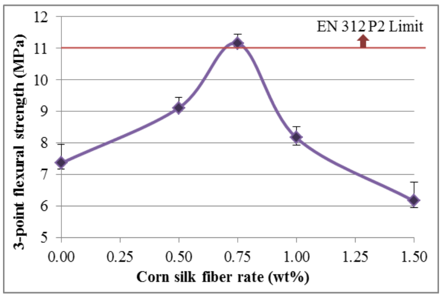

Figure 6: Flexural strength of particleboards containing different amounts of corn silk fiber

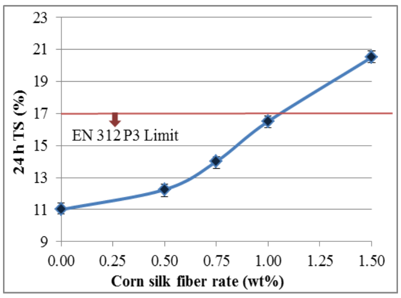

Figure 7: 24-hour TS rates of particleboards manufactured with different loadings of corn silk fiber

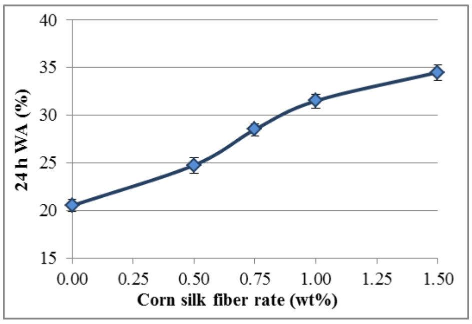

Figure 8: 24-hour WA rates of particleboards manufactured with different loadings of corn silk fiber

Optimization of corn silk fiber loading

Different fiber loadings have a significant effect on the FS values of PBs. The FS values of the boards prepared by adding 0~1.5% corn silk fiber by weight are shown in Figure 6. When Figure 6 is examined, it can be determined that the FS of the boards increases up to a fiber addition of 0.75 wt%. However, the FS of the boards prepared with fiber content higher than 0.75 wt% decreased. This decrease can be explained by the fibers creating gaps in the board. A similar situation has been observed in different previous studies. Reddy *et al.*[80] stated that, after a certain fiber amount, the FS of the boards decreases because of the increase in the gaps inside the board samples. In another study, it was stated that, when a high amount of fiber was used in board manufacture, the adhesion between the fiber and the matrix decreased.[81] As a result, it is concluded that the experimental results of this study are compatible with the others reported previously. Thanks to the addition of corn silk fiber to the boards, the boards manufactured with a loading of 0.75 wt% fiber comply with the P2 type board (for furniture material) limit value, according to the FS value of the EN 312 standard.[82] In PB manufacture, 0.75 wt% fiber loading, which provides the highest FS, has been determined as the most appropriate board preparation condition.

Thickness swelling (TS) and water absorption (WA)

According to the EN 312 standard,[82] PBs must have a maximum TS rate of 17% for the P3 type board class. On the other hand, in the EN 312 standard, there is no WA and TS limit value for P1 and P2 type classes. The TS and WA rates of corn silk PB samples after 24 hours are shown in Figure 7 and Figure 8. It was observed that the dimensional stability of the board samples did not deteriorate during the 24-hour TS and WA experiments. In Figure 7, the TS rate of 0.75 wt% fibrous boards is determined as ~14%. Accordingly, it has been determined that 0.75 wt% fibrous PBs are suitable for P3 type board class in terms of TS. On the other hand, according to Figure 8, the WA rate of 0.75 wt% fibrous boards was determined as ~28%. Due to the increase in the amount of corn silk fiber in the board, an increase in both swelling and WA rates of the boards was detected. This increase can be explained by the fibers creating gaps in the board. In addition, it is considered that the WA and TS rates of the boards increase due to the fact that corn silk fibers also absorb water. Other authors have reported similar experimental results.[81,83]

Effect of waste colemanite on combustion resistance

By using PBs with high combustion resistance in a structure, the combustion risk of the structure can be reduced. LOI is a widely used parameter to measure the combustibility performance of materials. In general, materials with a LOI value ≤27% are considered highly combustible, and as the LOI value increases, the materials become more difficult to ignite.[84] Ercan *et al.*[85] stated that the combustion resistance of the boards can be increased by adding fireproof material to composite boards. In our study, waste colemanite material was used instead of corn husk at rates between 0~20% by weight to increase the combustion resistance of the boards. Figure 9 shows the LOI values of the boards prepared with different contents of waste colemanite. According to Figure 9, it was determined that the LOI value of the boards increased as the waste colemanite content in the boards increased. In this case, the combustion resistance of corn husk-based particleboards increases thanks to waste colemanite. This increase is due to the fact that waste colemanite material is a fireproof material. Similarly, in the study of Aras,[53] it was explained that the LOI values of wood composites with the addition of pumice powder increased by up to 35%. Consequently, the experimental results determined are similar to those in the literature.

However, the LOI test alone is not sufficient to determine the most appropriate waste colemanite content in the preparation of PBs. The binder type used in our study generally bonds organic particles. However, waste colemanite is an inorganic-based material. In this respect, the FSs of the manufactured boards were detected in order to determine the most appropriate waste colemanite rate. Figure 10 shows the flexural strengths of PBs manufactured with waste colemanite at rates between 0~20%. When Figure 10 is examined, the boards containing only 5% waste colemanite meet the EN 312[82] P1 type board (general use) limit value, with a FS value of 10.54 MPa. Additionally, it has been determined that, as the amount of waste colemanite in the PB content increases, the FS of the boards decreases considerably. Similar experimental results were reported in the studies of Şahinöz *et al.*[86] As a result, it was determined that 5% waste colemanite should be used as the most appropriate PB preparation condition. The LOI value of PB samples containing 5% colemanite is 32% (Fig. 10). In addition, very good dimensional stability was provided in all PBs containing waste colemanite.

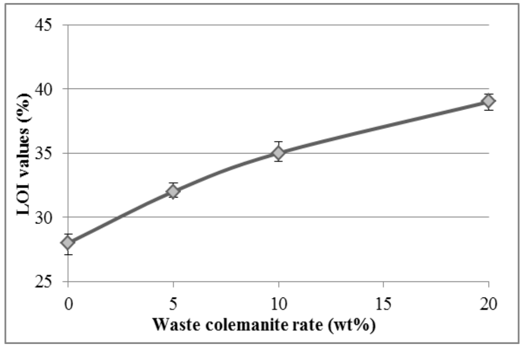

Figure 9: LOI values of particleboards containing different loadings of waste colemanite

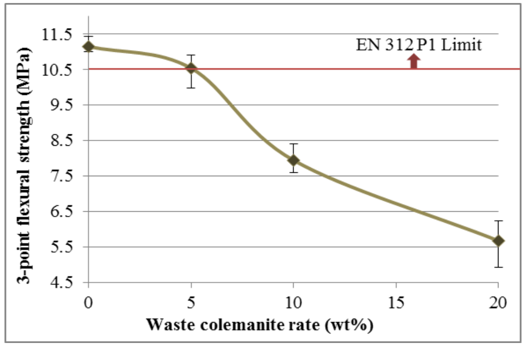

Figure 10: Flexural strength of particleboards containing different loadings of waste colemanite

Table 6
Comparison of properties of particleboards based on corn husks and other agro-waste based particleboards

Agro-waste raw materials	Binder type	Pressing temperature (°C)	Density (kg/m^3)	WA, 24 h (%)	TS, 24 h (%)	Flexural strength (MPa)	LOI (%)	Refs
Corn husk	Molasses+PVAc+PF	100	820	28.5	14	10.54	32	This study
Tea oil camellia shells	Polymeric MDI	180	720	40~60	17	13.4	-	[15]
Bagasse	Phenol urea formaldehyde	185	706	85.6	46.5	15.38	-	[21]
Olive tree prunings	UF	220	630	-	34	8	-	[22]
Poplar wood+pumice powder	PF	150	692~680	66.26	16.56	13.95	33	[53]
Oil palm trunk+$CaCO_3$	Poly(vinyl) alcohol	160	700	70	61.8	1.6	33.5	[54]
Sorghum bagasse	Molasses	200	800	30~40	4~6	7~8	-	[66]
Tobacco stalks	UF	150	791	96	40~45	10~12	-	[68]
Doum-Balanite	Polyester resin	150	714	35.9	7.9	4.32	-	[69]
Sengon wood	UF+Isocyanate	140	750	40~50	10~15	8~10	-	[79]
Eucalyptus wood+coconut fiber	UF	130	689~545	54.55	10.72	19.65	-	[83]

In Table 6, the properties of PBs manufactured from corn husk and PBs manufactured from other agricultural wastes are compared. Accordingly, Table 6 gives the physical and mechanical properties of PBs obtained in other experimental studies. When Table 6 is examined, it can be noted that the corn husk-based particleboards in our study were manufactured at a lower pressing temperature, and have the lowest WA rate. In general, the TS rates and flexural strengths of the PBs manufactured in this study are better than or close to the TS rates and flexural strengths of other PBs in the literature. On the other hand, thanks to the waste colemanite additive, the LOI values of the PBs manufactured are in accordance with the literature.

CONCLUSION

Experimental results demonstrated that corn husk waste as a raw material source can be used to manufacture eco-friendly PB. The most appropriate manufacturing conditions in corn husk-based particleboard manufacture were determined as f/b ratio of 0.75, pressing temperature of 100 °C and corn silk fiber loading of 0.75 wt%. In particular, manufacturing boards at relatively lower pressing temperatures is important in reducing the cost of board manufacturing in terms of energy consumption. On the other hand, the low TS and WA rates of these PBs increase the usage potential of these boards. By adding waste colemanite to the PB content, the combustion resistance of boards has increased. These PBs, which have higher combustion resistance, are safer against combustion risks in buildings and for general use. Although waste colemanite material reduces the flexural strength of PBs, PBs with 5% waste colemanite provide the EN 312 P1 type flexural strength limit value. Different combinations of agro-wastes, various types of fibers, and different synthetic binders can be used to improve the flexural strength values of corn husk-based polymer particleboards. These eco-friendly PBs are recommended to be used for interior and exterior applications, for example, as decoration material, wall and furniture covering, office partition, roof panel, molding, ceiling tile, and roof panel. In addition, by using agro-waste in PB manufacture, forests can be protected and environmental pollution problems can be reduced. A low-cost particleboard can be manufactured by using waste corn husks in the particleboard industry.

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