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Evaluation of the mechanical and physical properties of particleboards manufactured from rice husk

Pirinç kabuğundan üretilen yongalevhaların bazı fiziksel ve mekanik özelliklerinin değerlendirilmesi

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Abstract
The effect of rice husk ratios on some physical and mechanical properties of particleboard was investigated. To meet this objective, particleboards with different proportions of wood, rice husk, urea-formaldehyde glue, and other chemicals were produced. The density, moisture content, water absorption, thickness swelling, modulus of rupture (MOR), modulus of elasticity (MOE), internal bond strength, and screw withdrawal resistance of the particleboards were determined. Experimental results indicated that using rice husk in particleboard production improved the dimensional properties of the particleboards. Also, it was found that mechanical properties decreased as the amount of rice husk increased in particleboard production. This is thought to be due to the fact that silica, which is one of the main components of rice husk, weakens the bonding between lignocellulosic raw materials and glue used in particleboard production.

Özet
Bu çalışmada pirinç kabuğu oranlarının yonga levhanın bazı fiziksel ve mekanik özellikleri üzerindeki etkisi araştırılmıştır. Bu amaçla, farklı oranlarda odun karışımı, pirinç kavuzu, üre-formaldehit tutkalı ve diğer kimyasallar içeren yonga levhalar üretilmiştir. Yonga levhaların yoğunluğu, nem içeriği, su emme, kalınlık şişmesi, eğilme direnç (MOR), eğilmede elastikiyet modülü (MOE), yüzeye dik çekme direnci ve vida çekme direnci belirlenmiştir. Deneysel sonuçlar, yongalevha üretiminde pirinç kabuğu kullanımının yongalevhaların boyutsal stabilitesini iyileştirdiğini göstermiştir. Ayrıca, yongalevha üretiminde pirinç kavuzu miktarı arttıkça mekanik özelliklerin azaldığı tespit edilmiştir. Bu durumun, pirinç kavuzunun ana bileşenlerinden biri olan silikanın, lignoselülozik hammaddeler ile yongalevha üretiminde kullanılan tutkal arasındaki bağı zayıflatmasından kaynaklandığı düşünülmektedir.

INTRODUCTION

Particleboard is a group of materials obtained by mixing raw materials and binders and forming the mixture into a sheet or panel. Particleboard is used extensively in many sectors, especially construction, and furniture. Particleboard, a constantly growing market, is considered a great alternative to traditional wood material. However, panel demand for construction, furniture, and other application is creating deforestation pressures in the forestry industry. Many studies have been done to eliminate this problem. Using renewable materials can contribute significantly to the solution of raw material shortage for the particleboard industry. As our society becomes aware of the harmful consequences of using standard practices in industrial production, using environmentally friendly or green building materials more widely is gaining importance. These materials are non-toxic and can be obtained from renewable or recyclable sources. For this purpose, many agricultural wastes such as rice husks, wheat stalks, hemp wastes, tea leaves, and sunflower stalks have the potential to be used successfully in the particleboard industry (Vasisth and Chandramouli 1975, Nemli and Kalaycioglu 1997, Khristova et al. 1998, Muruganandam et al. 2016).

The usability of rice husk in the wood based panel industry depends on two factors: the production process and the husk to paddy ratio. About 20% of the rice paddy is husk, and about 120 million tons of husk are produced annually (Giddel and Jivan 2007). In most rice-producing countries, most of the husk left over from rice milling is underutilized, either incinerated or left as waste. When incinerated in the ambient atmosphere, rice husk leaves ash residue. Mathematically, about 200 kg (20%) of husk is produced from every 1000 kg of paddy, and about 55 kg (25%) of rice husk ash is produced from husk burned in boilers (Kumar et al., 2013). There have been many publications by researchers on using agricultural wastes in the forestry products industry. Particleboard has been produced from agricultural waste such as sunflower stalks (Bektas et al. 2005), rice husks (Ayrilmis et al. 2012), bagasse (Nonaka et al. 2013), tobacco stalks (Li et al.

2014), canola straws (Kord et al. 2016) and grapevine waste (Wong et al. 2020). Due to the increasing demand for wood composites today, the need for alternative raw materials used in producing wood composites has increased. It is essential to know the properties of alternative materials that have the potential to be used in wood composite production. This research was carried out to examine some physical and mechanical properties of particleboard containing rice husk particles at different usage rates.

MATERIALS AND METHODS

Materials

Wood particles, urea-formaldehyde adhesive, hardener, and paraffin were supplied by Kastamonu Integrated Wood Industry and Trade Inc., located in Kastamonu, Türkiye. The rice husk was obtained from a rice mill in Kastamonu, Türkiye. Before particleboard production, the moisture content of the rice husk particles was prepared to be 3-5% by oven-dry weight.

Particleboard Manufacturing

In the production of particleboards, black pine (%30), yellow pine (%10), Calabrian pine (%20), sessile oak (%20), white poplar (%20) wood, rice husk and urea formaldehyde adhesive were used. The experimental design determined for particleboard production is shown in Table 1.

Table 1: Production parameters of particleboard

Composite codes	Core layer (%) (CL)	Face layer (%) (FL)	Wood mixture (WM)
A	0	0	100
B	10	10	80
C	10	20	70
D	10	30	60
E	20	10	70
F	20	20	60
G	20	30	50
H	30	10	60
I	30	20	50
J	30	30	40

Commercial-sized particleboards (2800 mm x 2100 mm x 18 mm) were produced in Kastamonu Integrated Wood Industry and Trade Inc., located in Kastamonu, according to the above production parameters. The average thickness of the particleboard was determined as 18 mm. The press temperature, time, and pressure were set to 180-200 °C, 145 s, and 230 bar to achieve this result, respectively. Three particle boards and a set of control panels were made from each experimental design, resulting in 30 boards for evaluation. Samples of the produced samples are shown in Figures 1 and 2.

Figure 1. Layers of particleboard made from rice husk

Figure 2. surfaces of particleboards made of rice husk

Testing of Particleboards

Density (TS EN 323-1- 1999), moisture content (TS EN 322- 1999), thickness swelling (TS EN 317- 1999), and water absorption (TS EN 317- 1999) tests were carried out according to related standards. Ten replicate specimens of 50 mm×50 mm×18 mm of each particleboard type were used for density, thickness swelling, and water absorption properties.

The mechanical properties such as modulus of rupture (MOR) (TS EN 310- 1999, modulus of elasticity (MOE) (TS EN 310- 1999, internal bond strength (TS EN 319- 1999), and screw withdrawal resistance (TS EN 320- 2011) of the particleboards were determined with the relevant standards.

Prior to the physical and mechanical tests, all samples were kept in a climate-controlled room with 65% relative humidity and a temperature of 20°C until they reached equilibrium moisture content.

RESULT AND DISCUSSION

Physical Properties

Density

The density values of particleboards produced using rice husk are shown in Table 2.

Table 2. Density of particleboards

Composite codes	Core layer (%) (CL)	Face layers (%) (FL)	Wood mixture (WM)	Density (kg/m³)
A	0	0	100	634 (10.82)*
B	10	10	80	634 (12.16)
C	10	20	70	635 (13.02)
D	10	30	60	633 (13.34)
E	20	10	70	628 (15.67)
F	20	20	60	629 (11.82)
G	20	30	50	633 (13.18)
H	30	10	60	628 (10.13)
I	30	20	50	628 (10.59)
J	30	30	40	625 (16.54)

*Values in parentheses are standard deviations

The target density of the boards produced within the scope of the study is 630 kg/m^3. Densities varied due to the forming process being a mechanical method. According to TS EN 312- 2005, the average density deviation in the board is specified as ±10%. Accordingly, the minimum and maximum density values should be 567- 695 kg/m^3. It was found that the density value of the boards decreased when the board groups in which the ratios of the core layer and face layers were similar were examined. Some researchers have obtained similar results to those obtained in this study. For example, Kwon et al., (2013) stated in their study that the use of rice husk in particleboard production decreased the density. It is seen that the board density values decrease as the rice husk ratio increases. This indicated that the bonding performance between rice husk and wood mixture was poor.

Moisture Content

The moisture content values of particleboards produced using rice husk are shown in Table 3.

According to TS EN 312 (2005), the moisture content of particleboard should be between 5-13%. According to the results given in Table 3, it can be seen that all values related to the board groups are between the values required by the standards.

Table 3. Moisture content of particleboards

Composite codes	Core layer (%) (CL)	Face layers (%) (FL)	Wood mixture (WM)	Moisture (%)
A	0	0	100	5.5
B	10	10	80	5.7
C	10	20	70	5.4
D	10	30	60	6.1
E	20	10	70	5.3
F	20	20	60	5.2
G	20	30	50	6.2
H	30	10	60	5.6
I	30	20	50	5.6
J	30	30	40	6.6

Dimensional Stability

The thickness swelling and water absorption ratios of particleboards produced using rice husk are shown in Table 4.

According to Table 4, it is determined that the highest value of thickness swelling is found in the board groups produced using 100% wood mixture (Group A), and the lowest value is found in the board groups produced using 60% rice husk and 40% (Group J) wood mixture. According to the data in Table 4, it was determined that using rice husk in particleboard production improved the thickness swelling properties of the particleboards. Also, it was determined that using rice husk in the core and face layers of particleboard production improved the thickness swelling ratios of particleboard. At a constant rate, the thickness swelling ratio of particleboards using 30% rice husk in the core and face layers (Group J) is 32.50% less than that of particleboards produced using 100% wood mixture (Group A). The water absorption ratios of the produced particleboards varied from 83.2% to 63.3%. According to Table 4, it is determined that the highest value of water absorption is found in the board groups produced using 100% wood mixture (Group A), and the lowest value is found in the board groups produced using 60% rice husk and 40% (Group J) wood mixture. Using rice husk in particleboard production improved the water absorption properties of the particleboards. Also, it was determined that using rice husk in the core and face layers of particleboard production improves the thickness swelling ratios of particleboard. At a constant rate, the water absorption ratio of particleboards using 30% rice husk in the core and face layers (Group J) is 23.91% less than that of particleboards produced using 100% wood mixture (Group A). The high dimensional stability of particleboards produced using rice husk has been attributed to the high extractive content of RH particles such as silica and wax, high pH and buffering capacity compared to wood, and low thermal conductivity (Kwon et al. 2013).

Table 4. Some physical properties of particleboards

Composite codes	Core layer (%) (CL)	Face layers (%) (FL)	Wood mixture (%) (WM)	Thickness swelling (%)	Water absorption (%)
A	0	0	100	19.7	83.2
B	10	10	80	17.0	76.0
C	10	20	70	17.0	76.2
D	10	30	60	16.1	74.1
E	20	10	70	16.3	74.4
F	20	20	60	16.0	74.2
G	20	30	50	15.8	74.1
H	30	10	60	15.0	69.0
I	30	20	50	14.7	68.8
J	30	30	40	13.3	63.3

Mechanical Properties

Table 5 shows the mechanical properties of the produced panels. The results indicated that an increase in rice husk percentage in the mixture generally diminished the mechanical properties of the particleboards.

The average MOR of the obtained particleboards varied between 11.9 and 14.2 N/mm^2. Results indicated that increasing the rice husk ratio had a negative effect on the bending strength of the particleboards. Table 5 shows that the board groups produced using 100% wood mixture (Group A) had the highest bending strength value, and the board groups produced using a combination of 60% rice husk and 40% wood (Group J) had the lowest bending strength value. At a constant rate, the bending strength of particleboards using 30% rice husk in the core and face layers (Group J) is 16.20% less than that of particleboards produced using 100% wood mixture (Group A). Similar findings were observed for the modulus of elasticity (MOE) values. Table 5 shows that the board groups produced using 100% wood mixture (Group A) had the highest MOE value, and the board groups produced using a combination of 60% rice husk and 40% wood (Group J) had the lowest MOE value. The MOR and MOE properties of the particleboards made of a mixture of wood particles (100wt%) were higher than those of the rice husk (100wt%) particleboards (Kwon et al. 2013) but lower than wood particleboards (Lockwood and Cardamone 2002).

Table 5. Some mechanical properties of particleboards

Composite codes	Core layer (%) (CL)	Face layers (%) (FL)	Wood mixture (%) (WM)	MOR (N/mm^2)	MOE (N/mm^2)	Internal bond strength (N/mm^2)	Screw withdrawal resistance (N)
A	0	0	100	14.2	2714	0.52	844
B	10	10	80	13.6	2487	0.44	723
C	10	20	70	12.9	2365	0.40	751
D	10	30	60	12.3	2177	0.39	746
E	20	10	70	13.0	2332	0.33	656
F	20	20	60	12.4	2283	0.31	677
G	20	30	50	12.8	2204	0.32	671
H	30	10	60	12.2	2267	0.27	613
I	30	20	50	12.4	2317	0.30	596
J	30	30	40	11.9	2165	0.28	615

The average internal bond strength of particleboards varies between 0.28 and 0.52 N/mm^2. Results indicated that increasing the rice husk ratio had a negative effect on the internal bond strength of the particleboards. The lower mechanical properties of the 100% wood mixture produced samples than the rice husk and wood mixture produced samples could be explained by the lower cross-linking ratio. The principal components of rice husk are holocellulose (43-56%), lignin (26-31%), silica (15-17%), and soluble substances (2-5%) (Luduena et al. 2011). The waxy and silica coating surrounding the rice husk surface prevents sufficient direct contact between the adhesive and the rice husk particle, which is a negative characteristic for the binding ability of rice husk particles.

Table 5 also shows the screw withdrawal resistance properties of the produced boards. The average screw withdrawal resistance of the particleboards obtained varies from 615 to 844 N. Table 4 demonstrates that the highest screw withdrawal resistance was achieved by the board groups manufactured using a mixture of 100% wood mixture (Group A). In contrast, the board groups produced the lowest screw withdrawal resistance utilizing a mixture of 60% rice husk and 40% wood (Group J). Some researchers have obtained similar results to those obtained in this study (Calegari et al. 2007, Melo et al. 2014). For example, Melo et al. (2014) investigated the use of bamboo wood and rice husk in particleboard production. According to the data obtained, it was determined that the internal adhesion resistance of particleboards decreased when rice husk was used.

CONCLUSIONS

This study investigated the possibility of using a mixture of rice husk and wood in the production of three-layer particleboard. From the findings of this study, the following major conclusions can be drawn:

- When the board groups with similar core layer and face layer ratios (CL:10 FC:10, CL:20 FC:20, and CL:30 FC:30) were examined, it was observed that the density value of the boards decreased as the rice husk ratio increased.
- It was determined that using rice husk in particleboard production improved the dimensional properties of the particleboards. Also, it was determined that using rice husk in the core and face layers of particleboard production improves the dimensional properties of particleboard.
- It was found that mechanical properties decreased as the amount of rice husk increased in particleboard production. This is thought to be due to the fact that silica, which is one of the main components of rice husk, weakens the bonding between lignocellulosic raw materials and glue used in particleboard production.
- The face layer particles from rice husk are larger than those from wood particles. Therefore, the surface quality of particleboards can be negatively affected. For this reason, it is not appropriate to use more than 20% rice husk in the face layers. Board costs can be reduced by using rice husk up to 10% in the core layer and up to 20% in the face layers.

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