ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 11 N° 4 2015
pp. 130-137

EVALUATION POSSIBILITIES OF RICE STRAW IN PARTICLEBOARD INDUSTRY

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Abstract

Technological developments have been continued rapidly in the forest products industry as in the other industries. Both Turkey and the world forest recourses are not enough in spite of this velocity and increasing the demand for wood products. Utilization of fibrous agricultural plants increases year by year. Either the agricultural residues are burned on site so cause air pollution or left to decay on harvesting area so the content and the value are lost forever. Rice is a renewable lignocellulosic source used as both food and fiber for humans and animals.

In this study, some of the technological properties of particleboard produced from rice straw and husks for general purpose under the laboratory conditions were investigated. For production of particleboard, urea formaldehyde resin (60% solid content) and as hardening agent ammonium chloride (20% solid content) were used. The press conditions and production plan of particleboards were as follows; press temperature: 180°C, pressing time 10 minutes, press pressure 24kg cm^{-2}, outer layers 35% and middle layer 65% of the boards thickness. Rice straw and husk particleboards were produced at 400, and 600kg m^{-3} density and 460x460x20mm dimension at six different producing conditions totally 36 boards. The determination of moisture content, density, thickness swelling, bending strength and modulus of elasticity, and internal bond strength of the rice straw particleboards were performed according to Turkish (TS EN) standards. Thus, optimum production condition was determined according to usage areas.

Key words: *agricultural wastes; rice straw; husk; particleboard; physical properties; mechanical properties.*

INTRODUCTION

In particleboard production, use of agricultural residues and annual plants as a source of alternative raw materials instead of wood due to insufficient wood or problems in the supply of wood raw materials will contribute to solve the problems. The use of lignosellulosic biomass resources outside the wood raw material has a great importance in terms of economic. However, the use of lignocellulosic biomass resources will gain new properties for particleboard.

Annual plant stems have some negative aspects although they have a lot of positive aspect due to their low density such as harvest, collection, transport and storage (Özen et al. 2002; Barbu et al. 2014).

In particleboard production, cereal straw, sugar cane, corn stalks, sunflower stalks, cotton stalks, vine wood, kenaf are the sometime commonly used (or added to wood) lignocellulosic biomass.

Rice plant is a renewable lignosellulosic resource and it has similar properties to wood because of its fibrous structure and chemical properties (Table 1) (Tutuş et al. 2002).

Table 1

Chemical contents and fibrous properties of some lignosellulosic materials

Types	Holocellulose %	Cellulose %	Lignin %	Ash content %	Pentosan %	Cilica content (%)	Fibre length mm	Fibre width µm
Coniferous	63-74	55-61	25-32	0.2-1	8-13	0.1-0.3	3-7	32-43
Deciduous	76-85	58-64	17-26	0.2-1	18-25	0.1-0.3	0.7-2	20-40
Wheat stem	73-77	48-52	15-19	5-8	27-30	3-7	0.82	16.07
Rice straw	71.5	47.3	11.9	16.1	24.5	12-18	1.5	8.5

Particleboards produced with cereal straw have been stated that they will be resistant to fire due to higher silica content of cereals (Opel 1992). Rice straw will be significantly contributed to resistance to fire of particleboards because it has high silica content (Younquist et al. 1993). In addition, it was reported that rice straw is more resistant than the other raw materials against bacterial malfunctions when they used as building materials (Anonymous 2006).

It has been reported that particleboard produced for the general purposes from sunflower stalks and it can be alternative raw material instead of wood (Kalaycıoğlu 1992-a; Bektaş et al. 2002; Kalaycıoğlu 1992-b; Bektaş et al. 2005). In addition, particleboard has been produced in laboratories from the mixture of poplar and sunflower header, poplar and sunflower stalks and reported that the resistance values of the produced particleboards are appropriate to standards (Gertjejansen et al. 1977; Gertjejansen 1972).

Some physical and mechanical properties of particleboards produced from cotton stalks with urea formaldehyde have similar values specified in the standards and they can be used for indoor and in building as an insulation board and packaging industry (Güler and Özen 2002; Güler et al. 2001; Güler and Özen 2004).

It has been stated that tea waste is appropriate for production of particleboard according to experimental results of their physical and mechanical properties. Thus, end of the this study was received a patent and it has been expressed that they are used for production of furniture by covering its surface, door interior, ceiling materials, wall panelling in the indoor (Örs and Kalaycıoğlu 1991; Kalaycıoğlu 1993; Kalaycıoğlu 1992-b). In addition, Nemliand Kalaycıoğlu (1997) and Yalınkılıç et al. (1998) stated that these lab panels are resistant to decay and termite damage.

Maritime pine, tobacco stalks, sunflower stalks and tea factory waste (Kalaycıoğlu, 1992-b), palm stems (Nemli et al. 2001), kenaf (Kalaycıoğlu and Nemli 2006), corn stalks (Chow 1974) and nut shells (Çöpür et al. 2007) have been reported to be suitable for the production of particleboard at laboratory scale. Three layered particleboard has been produced from corn stalks and it has been used by covering its surface after II. World War (Younquist et al.1993).

It has been emphasized that vine stems mixed with wood chips can be evaluated in the production of particleboard but only vine stem is not suitable for particleboard production (Örs et al. 2000).

Low density particleboards (250kg m^{-3}) made from cereals straw but other resins than UF has been expressed that can be used especially in the construction of prefabricated houses (Rowell et al. 1997).

Rice plant cultivation area is 110.592 ha (1.105.920 da) and 900.000 tons rice are produced from this areasaccording to data of 2013 in Turkey (Anonymous 2015). 18-20% of harvested paddy is husks so husk amount is about 162.000 – 180.000 tons and rice plant gives straw about 2000 or 2400 kg per acre so rice straw amount is 552.960–663.552 ton in a year in Turkey. A large amount of rice straws and husks are being burned or abandoned to rot in the fields.

OBJECTIVE

The main objective of the present research was to determine optimal production conditions of particleboards produced from rice straw mixed wood chips in compliance with standards.

MATERIAL AND METHOD

To produce of particleboard from rice straw, husk and wood chips, rice straws and husks were obtained from Kargıin Çorum and wood chips, used commercially in production of particleboard, were obtained from a factory that produces particleboard in Kastamonu.

The rice straw is cut into 1-3cm length and is rend the Wiley mill to be used in outer and middle layer.Straw width depends upon natural width of rice straw stem. The mixture of wood chips was used as obtained from factory. Rice straws, husks and wood chips are used after drying to moisture content of 3-4% before gluing. Experimental design was given in Table 2.

Table 2

Experimental design

Panel type	Raw materials mixture rate	Layer number	Urea formaldehyde (%)		Density (kg m^{-3})		Pressure (kg cm^{-2})	Time (min)
			Outer	Middle	0,400	0,600		
1-control	100% wood chips	3	12	10	x	x	24	10
2	Outer wood chips Middle rice straw+husk (70/30%)	3	12	10	x	x		
3	100% rice straw	Mono	10		x	x		
4	20% rice straw+80% wood chips	Mono	10		x	x		
5	30% rice straw +70% wood chips	Mono	10		x	x		
6	40% rice straw +60% wood chips	Mono	10		x	x		

For production of particleboard, urea formaldehyde (UF) resin (60% solid content) and as hardening agent ammonium chloride (20% solid content) were used. UF resin was applied in 12% and 10% based on the weight of oven dry wood chips, rice straws and husks for outers and middle layers, respectively. Ammonium chloride was applied in 1% based on the weight of oven dry chip weight. The mixing time to ensure homogenous distribution of the glue was set to at least 5 minutes.

The press conditions and production properties of particleboards were as follows; press temperature: 180°C, pressing time 10 minutes, press pressure 24kg cm^{-2}, outer layers 35% and middle layer 65% of the boards thickness. Rice straw and husk particleboards were produced at 0.4, and 600kg m^{-3} density and 460x460x20mm dimensions at six different producing condition totally 36 boards. Shims were used in 2cm thickness.

After pressing the boards were conditioned to constant weight at 65±5% relative humidity and a temperature of 20±2°C until they reach stabile weight (TS 642-ISO 554 1997) and samples were taken from boards in compliance with TS EN 326-1 (1999).

The determination of moisture content (MC) (TS EN 322 1999), density (D) (TS EN 323 1999), thickness swelling (TS) (TS EN 317 1999) after 24-h water absorption (WA) and bending strength (BS) and modulus of elasticity (MOE) (TS EN 310 1999) and internal bond (IB) (TS EN 319 1999) strength of the rice straw particleboards were performed according to standards. In measurement of IB, BS and MOE values, Shimadzu universal test device with capacity of 5000kg was used.

Data analysis

Statistical differences in the mean values of parameters carried out in this paper were estimated with analyses of variance (ANOVA). When significant differences were detected with ANOVA, the Duncan test was used to evaluate the relationship between the density and board types. All statistical analyses were performed using SPSS ® 20.0 for Windows ® software. Means were considered to be significantly different when $p \leq 0.05$.

RESULTS AND DISCUSSION

The moisture content and density of panels were measured according to TS EN 322 (1999) and TS EN 323 (1999). The average MC and D values were determined 10.1%, 9.7% and 428kg m^{-3}, 624kg m^{-3}, respectively.

The average values and standard deviation in parenthesis of bending strength (BS), modulus of elasticity (MOE), internal bond (IB) and thickness swelling (TS) are given in Table 3 according to panel groups.

For density of 400kg m^{-3}, thickness swelling rate after 24 hours water absorption, bending strength, MOE and internal bond varied between 16.58% and 62.90%, 0.84 $Nmm^{-2}$and 2.38 Nmm^{-2}, 173.14 Nmm^{-2} and 544.06 Nmm^{-2}, 0.0014 Nmm^{-2} and 0.1114 Nmm^{-2}, respectively. For density of 600kg m^{-3}, thickness swelling rate after 24 hours water absorption, bending strength, MOE and internal bond varied between32.74% and 87.00%, 1.81 Nmm^{-2} and 6.83 Nmm^{-2}, 661.36 Nmm^{-2} and 1599.51 Nmm^{-2}, 0.0038 Nmm^{-2} and 0.3223 Nmm^{-2} for density of 600kg m^{-3} (Table 3).

Table 3

The average values and standard deviation values of BS, MOE, IB and TS

Panel type / Density	Bending strength ($N\ mm^{-2}$)		Modulus of Elasticity ($N\ mm^{-2}$)		Internal bond ($N\ mm^{-2}$)		Thickness Swelling after 24h (%)	
	428	624	428	624	428	624	428	624
1-control	1.96 (0.51)	6.83 (0.77)	510.86 (140.61)	1599.51 (297.30)	0.1114 (0.01)	0.3223 (0.077)	16.58 (1.69)	32.74 (3.57)
2	0.84 (0.07)	1.81 (0.33)	173.14 (21.23)	661.36 (141.48)	0.0014 (0.00)	0.0038 (0.00)	55.98 (3.79)	71.74 (6.09)
3	1.48 (0.13)	3.27 (0.68)	380.43 (40.06)	698.82 (145.94)	0.0059 (0.00)	0.0073 (0.00)	62.90 (7.85)	87.00 (9.34)
4	2.19 (0.65)	5.84 (1.05)	514.78 (175.73)	1433.25 (186.42)	0.0798 (0.02)	0.0976 (0.02)	21.52 (2.06)	37.30 (3.92)
5	2.38 (0.51)	6.70 (1.20)	535.96 (126.78)	1548.21 (384.48)	0.0445 (0.01)	0.0851 (0.01)	27.48 (1.90)	38.76 (5.50)
6	2.33 (0.41)	6.34 (1.17)	544.06 (60.79)	1247.47 (212.18)	0.0360 (0.02)	0.0506 (0.00)	23.82 (1.39)	50.26 (6.34)

As a result of the statistical analysis, it is determined that production conditions (density and panel types) have an effect on the BS, MOE, IB and TS. The values of BS, MOE, IB and TS increased depend on increasing of density (Table 3). And also, the effect of changing in density are statistically significant ($p<0.05$) (Table 4, 6, 8 and 10).

Results of multiple variance analyses for impact of density and panel types for bending strength are given in Table 4.

Table 4

Multiple variance analysis for impact of density and panel type for bending strength

Source	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1392,165[a]	11	126,560	244,989	0,000
Intercept	3665,012	1	3665,012	7094,540	0,000
Panel type	442,810	5	88,562	171,434	0,000
Density	801,601	1	801,601	1551,698	0,000
Interaction Panel type x Density	147,755	5	29,551	57,203	0,000
Error	148,780	288	0,517		
Total	5205,958	300			
Corrected Total	1540,945	299			

a. R Squared = ,903 (Adjusted R Squared = ,900)

It is determined that the factor of density and panel type and interaction of factors had an effect on bending strength (Table 4). Duncan test results done to determine the impact and homogenous groups (HG) are given in Table 5.

Table 5

Duncan test results and homogenous group for bending strength

Panel type	N	Homogenous group			
		1	2	3	4
2	50	1,3193			
3	50		2,3735		
4	50			4,0160	
6	50				4,3341
1	50				4,3920
5	50				4,5365

The highest bending strength were obtained at 5th panel type although the lowest BS were obtained at 2nd panel type. 5th and 6th panel type are in the same homogenous group with control group and there is no statistically differences among them (Table 5). Bending strength increased with increasing of density (Table 3) and it has been approached the standard values expressed in the TSEN 312 (2012). In the literature, it is stated that BS has increased with increasing of adhesive ratio and press pressure (Bektaş et al. 2002; Goker and Akbulut 1992).

Results of multiple variance analyses for impact of density and panel types for modulus of elasticity are given in Table 6.

It was determined that the factor of density and panel type and interaction of both factor had an effect on modulus of elasticity (Table 6). Duncan test results done to determine the impact and homogenous groups (HG) are given in Table 7.

Table 6

Multiple variance analysis for impact of density and panel type for modulus of elasticity

Source	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	67344513,976[a]	11	6122228,543	170,940	0,000
Intercept	2,020E8	1	2,020E8	5641,244	0,000
Panel type	18745669,429	5	3749133,886	104,680	0,000
Density	42740266,908	1	42740266,908	1193,357	0,000
Interaction Panel type x Density	5858577,639	5	1171715,528	32,716	0,000
Error	10314763,487	288	35815,151		
Total	2,797E8	300			
Corrected Total	77659277,463	299			

a. R Squared = ,867 (Adjusted R Squared = ,862)

Table 7

Duncan test results and homogenous group for modulus of elasticity

Panel type	N	Homogenous group				
		1	2	3	4	5
2	50	417,2488				
3	50		539,6219			
6	50			895,7688		
4	50				974,0153	
5	50				1042,0824	1042,0824
1	50					1055,1879

According to Table 7, while the highest MOE were obtained at control group (1055,19 Nmm^{-2}), 5th group panel type (1042, 1 Nmm^{-2}) was at the same homogeneity group with the control. 4th panel type (974, 02 Nmm^{-2}), it was in the same homogeneity group with 5th panel type, followed them. The lowest MOE value were obtained at 2nd group panel type with 417,2 Nmm^{-2}. The values of BS increased depend on increasing of density (Table 3). The values expressed in the standard (TSEN 312) has been reached at 5th panel type at density of 600kg m^{-3}.

Results of multiple variance analyses for impact of density and panel types for internal bond strength are given in Table 8.

Table 8

Multiple variance analysis for impact of density and panel type for internal bond strength

Source	Sum ofSquares	df	Mean Square	F	Sig.
Corrected Model	2,144[a]	11	0,195	323,306	0,000
Intercept	1,490	1	1,490	2470,957	0,000
Panel type	1,561	5	0,312	517,781	0,000
Density	0,172	1	0,172	286,009	0,000
Interaction Panel type x Density	0,411	5	0,082	136,290	0,000
Error	0,174	288	0,001		
Total	3,808	300			
Corrected Total	2,318	299			

a. R Squared = ,925 (Adjusted R Squared = ,922)

The factor of density and panel type and interaction of factors had an effect on internal bond strength (Table 8). Duncan test results done to determine the impact and homogenous groups (HG) are given in Table 9.

Table 9

Duncan test results and homogenous group for internal bond

Panel type	N	Homogenous group				
		1	2	3	4	5
2	50	0,00262				
3	50	0,00656				
6	50		0,04333			
5	50			0,06477		
4	50				0,08870	
1	50					0,21686

The highest IB bond strength were determined at control group as 0,22N mm^{-2}. For particleboards, IB strength should be at least 0,24N mm^{-2} according to TSEN 312 (2012) standard.

The best value obtained in this study was 0,09N mm^{-2} at 4th group panel type after control group and this value was significantly lower than the value of control group. This can be explained with high silica content of rice straw (Table 1). And also, it is said that rice straw particle dimensions affect on the bond.

Results of multiple variance analyses for impact of density and panel types for thickness swelling are given in Table 10.

Table 10

Multiple variance analysis for impact of density and panel type for thickness swelling

Source	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	132365,080[a]	11	12033,189	463,810	0,000
Intercept	576583,680	1	576583,680	22223,961	0,000
Panel type	105294,410	5	21058,882	811,698	0,000
Density	24988,813	1	24988,813	963,174	0,000
Interaction Panel type x Density	2081,857	5	416,371	16,049	0,000
Error	7471,940	288	25,944		
Total	716420,700	300			
Corrected Total	139837,020	299			

a. R Squared = ,947 (Adjusted R Squared = ,945)

The factor of density and panel type and interaction of factors had an effect on thickness swelling (Table 10). Duncan test results done to determine the impact and homogenous groups (HG) are given in Table 11.

Table 11

Duncan test results and homogenous group for thickness swelling

Panel type	N	Homogenous group					
		1	2	3	4	5	6
1	50	24,660					
4	50		29,410				
5	50			33,120			
6	50				37,040		
2	50					63,860	
3	50						74,950

The lowest TS was determined at control group panel as 24,7% while the highest TS was obtained at 3rd group panel type as 74,9%. The second increase in the TS was determined at 4th group panel type as 29,4%. According to TSEN 312 (2012), TS is not necessary for "general purpose boards used in dry conditions" but for "non-load-bearing panels for use in humid conditions" is 14% for 24 hours. The values obtained in this study are higher than the values expressed in the standard. It is indicated in the literature that using of hydrophobic substance such as paraffin cause reduction on the TS. Furthermore, it was stated that TS decreases with increase in utilization ratio of adhesive and pres pressure (Bektaş et al. 2002).

All values increased depending on the increase in density (Table 3) and also, it was determined that the effect of density on the values was statistically significant (Table 4, 6, 8 and 10).
When the data were analyzed, the values obtained have not reached the value in the standard. However, compared with control boards produced at the same conditions in the laboratory, control board were in the same homogenous groups with 5 and 6 in terms of bending strength (Table 5). Almost the same results were obtained for MOE (Table 7). While the standard value for internal bond was obtained at density of 600kg m^{-3}, the values of density of 400kg m^{-3} and all other groups is far below the standard value (Table 3) and all groups are different homogeneity groups (Table 9). For thickness swelling, while all groups take place different homogeneous groups, group of 4 and 5 have the nearest value according to the control group (Table 11).

CONCLUSIONS

As the density of panels increased, values of bending strength, MOE, internal bond and thickness swelling increased. Density has statistically significant effect on the BS, MOE, IB and TS.

According to TS EN 312 (2012) standard, value of BS, MOE, IB and TS are respectively given as; 10N mm^{-2}, 1600N mm^{-2}, 0.24N mm^{-2}, and 14%.

While the fifth group (%30 rice straw +%70 wood chips) gave the best result for BS and MOE, the fourth group (%20 rice straw +%80 wood chips) gave the best result for TS EN, although they had lower values than the standard value. So, mixture of rice straw ratio of 20% or 30% can be used in particleboard production. However, IB strength values were quite low. It may be explained that the rice straw dimensions are bigger than normal dimensions. After the rice straw dimensions are reduced, IB values can be improved.

Consequently, rice straw can be used in the particleboard production after its dimensions are reduced and added some additional chemicals such as paraffin. Furthermore, low density panels (400kg m^{-3}) may be used as insulation board after examining of its thermal and sound insulation properties.

ACKNOWLEDGEMENT

This paper is supported by Scientific Research Projects Committee of Kastamonu University with the project number KUBAP-01/2012-41, 2015.

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