Effect of Wheat Straw Pretreatments and Glue Formulations on Particle Board Properties

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Summary: In this paper, the effect of wheat straw (WS) pretreatments and glue formulations on mechanical (i.e. Compressive Strength (CS) and Impact Strength (IS)) and water resistance properties (i.e. Thickness Swelling (TS) and water absorption (WA)) of particle board have been investigated and the results have been compared with conventional wooden particleboard . Wheat straw was treated with steam available at 110°C and 20 psig, for the retention time of 5, 10 and 15 min. The solution of 10% HCl was also used for removing the lignin. Particleboard was prepared by bonding treated WS with four types of glue recipes of synthetic and natural binders like urea formaldehyde (UF), polyvinyl acetate (PVA), corn flour (CF) and wheat flour (WF). The particle board was formed at the hydraulic pressure and temperature of 2800 psig and 80°C respectively. It was observed that WS particleboard has low mechanical strength and high water resistance in comparison with conventional board. The particle board prepared with HCl cured wheat straw and glue having high urea formaldehyde and corn flour has higher CS and IS as well as low TS and WA. It may be concluded that wheat straw is a good substitute of wood for particle board while using HCl as a modifying chemical and strong binders like urea formaldehyde and corn flour.

Keywords: Particle board, wheat straw pretreatments, glue recipes, mechanical and water resistance properties, chipboard

Introduction

One of the ways to combat with deforestation is to reduce the consumption of wood. The wood finds its common application in home fixtures, furniture and fuel; therefore investigating the wood substitutes in these cases would be most advantageous [1]. Amongst the applications of wood, particle board is one instance. Particleboard is a composite material made by gluing lignocellulosic fibers of biomass or wood shavings with binder [2-5]. Particleboard is generally known as chipboard in Pakistan or fiberboard worldwide. It is popular because of its uniform appearance, low cost, strength and ease of tooling.

As the fiberboard is produced from bark and hardwood in Pakistan, the dependency on wood availability makes it an uneconomical choice. The present study was undertaken to address this issue by employing agricultural waste for particleboard manufacturing. Agricultural crop waste is an economical and rich source of lignocellulose [6-8]. The commonly occurring agricultural waste materials in Pakistan are wheat straw, rice husk, cotton stalks, corn cubs and barely stems.

In Pakistan, 23.8 million tons of wheat was produced in 2010, where three tons of straw was produced from every two tons of wheat grains. This leads to an estimated production of 35.8 million tons of wheat straw per year [6]. Wheat straw is generally utilized in paper industry, and as livestock feed. Huge quantity of wheat straw is futile and burnt in open atmosphere, leading to release of poisonous gases. The objective of the present study has been to check the possibility of substituting wood, the basic raw material of particleboard, with wheat straw (WS).

Mechanical Thermal Compression Process

The particleboard manufacturing process comprises of various chemical, thermal and mechanical treatments to remove the naturally occurring waxy material on straw; this is necessary to make it feasible for particle board production. The process is collectively called as Mechanical Thermal Compression.

Pretreatment of wheat straw is done by thermal and chemical processes. In thermal process, WS is water logged at high temperature for 4 hrs to soften the waxy layer followed by steam treatment at 110°C and 20 psig for retention period of 5, 10 and 15 min. In chemical process, WS is soaked in 10% HCl solution for 24 hrs and washed with water repeatedly to remove acid contents. The pretreatment steps remove the hemicellulose and waxy layer from WS, resulting in an increase in lignin and moisture content [9]. To decrease the moisture content and for the formation of board, mechanical process is carried out in two stages. Initially, pre-pressing is done to reduce the moisture content of pretreated WS, followed by drying in an oven at 105°C for 24 hrs. Oven dried WS is mixed with four types of glue

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formulations and hot pressed at 80°C and 2800 psig for 7 min in a mechanical thermal compression plant [10]. After compression, drying and conditioning, the wheat straw particleboards were evaluated for their mechanical and water resistance properties.

Results and Discussion

The impact strength of 10.28 MPa, compressive strength 14.25 MPa, Thickness Swelling 13.7 % and water absorption of 51 % was established by testing, for commercial particle board.

Mechanical Properties

The Compressive Strength (CS) and Impact Strength (IS) of the wheat straw particle board of various types are shown in Fig. 1. From the results after testing, it is observed that board IS ranges between 1.02 – 5.61 MPa. The conventional particleboard has Impact Strength of 10.28 MPa [11]. Thus the WS particle board has considerable low impact strength as compared with commercial board. The untreated wheat straw boards (A, B, C and D) exhibit higher IS than that of steam and acid treated WS pellets. It can be observed that highest Impact Strength (5.61MPa) is that of panel type B whereas the lowest of panel C3 (1.02MPa). The Compressive Strength of boards lie in the range 0.4 – 4.60 (MPa) and observed to be low as compared with commercial board i.e. (14.25 MPa). The board produced by acid treated WS show higher CS than that of steam treated and untreated straw boards i.e. 4.1 MPa. The highest Compressive Strength has been attained by panel type B4 (4.60 MPa) while the lowest by panel C (0.40MPa).

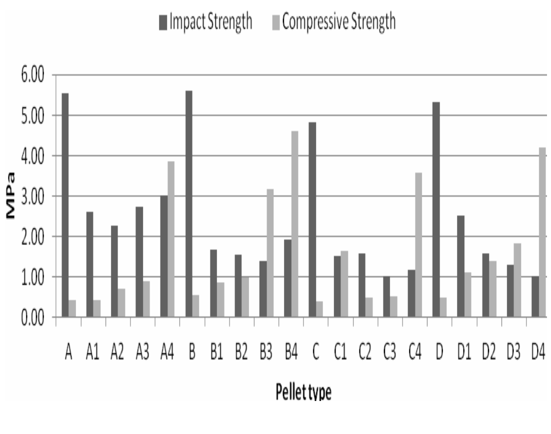

Fig. 1: Compressive Strength and Impact Strength of experimental pellets of Particle Board

The Compressive Strength and Impact Strength of wheat straw boards with steam and acid treatment are shown in Fig. 2. It may be observed after testing that untreated WS has average Impact strength of 5.3MPa which is higher than the boards produced by steam treated WS (1.6 – 2.1MPa) and acid treated WS (1.7MPa). It indicates that steam and acid treatment of WS make the panels vulnerable to damage when exposed to sudden load. The Compressive Strength of boards made of HCl treated WS is 4.1 MPa which is higher than that of untreated and stream treated WS boards. The Compressive Strength of steam treated WS pellets lie in the range 0.9 – 1.6 MPa and that of untreated WS Pellets is 0.47 MPa, which is extremely low.

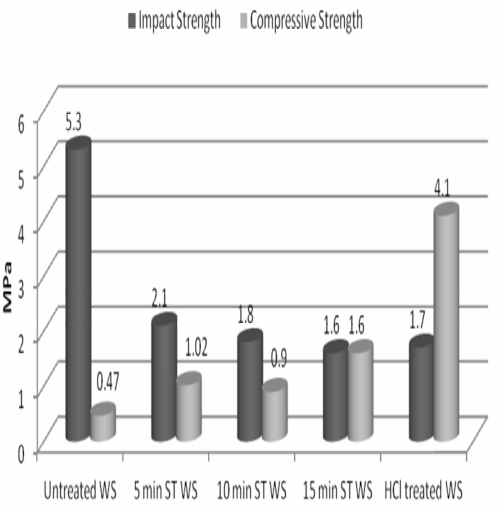

Fig. 2: Effect of wheat straw pretreatment on Impact Strength and Compressive Strength of experimental pellets of Particle Board.

The effect of glue recipes on Impact Strength and Compressive Strength of experimental samples have been shown in Fig. 3. Glue recipe no. 1 and 2 contain higher concentration of urea formaldehyde (UF) and low concentration of poly vinyl acetate (PVA), while recipe no. 3 and 4 contain higher concentration of PVA and lower UF. Moreover, glue recipes 1 and 3 have been primarily prepared from approximately 60% wheat paste (WP) whereas, recipe 2 and 4 from 60% corn paste (CP). The use of recipe 1 resulted in higher impact strength (3.2MPa) as compared with other recipes. Glue no. 2 and 4 indicated intermediate strength while 3rd indicated low strength. The difference between recipe 1 and 3 is the concentrations of urea formaldehyde and poly vinyl acetate. The higher UF concentration results in improved Impact Strength.

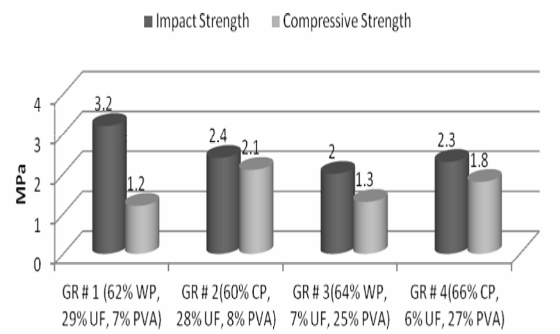

Fig. 3: Effect of glue recipes on Impact Strength and Compressive Strength of experimental pellets of Particle Board.

High compressive strength is achieved by the use of recipe no. 2 while low strength is shown by recipe no. 1. It can also be observed that recipes 2 and 4 (2.1 and 1.8MPa) result in better CS than recipe 1 and 3 (1.2 and 1.3MPa), which infers that glues containing corn flour along with UF imparts good compressive strength.

Water Resistance Properties

The Thickness Swelling and Water Absorption Percentage of boards when soaked for 1 hr in water are presented in Fig. 4. From the results it was observed that thickness swelling of boards lie in the range (0.5 – 5.4%), which is lower than conventional particleboard (13.7%) [12]. Generally, water absorption of boards vary in the range (22 – 69%) and that of commercial board is 51%.The boards prepared from HCl treated WS (A4, B4, C4 and D4) have much less water absorption (22 – 27%) compared with that of commercial board. The lowest thickness swelling and water absorption has been observed for pellet types C4 and D4 while the highest values are exhibited by boards A3 and A.

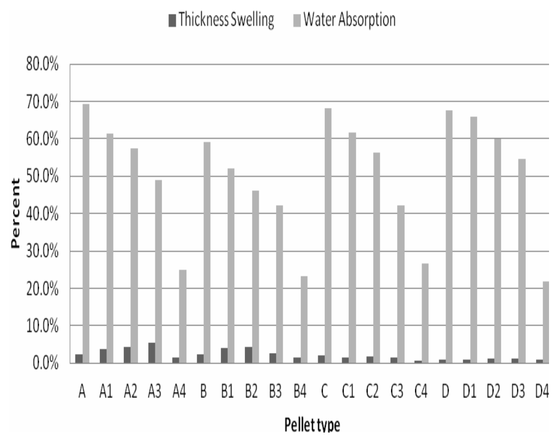

Fig. 4: Thickness Swelling and Water Absorption of experimental pellets of Particle Board.

The effect of wheat straw pretreatment on thickness swelling and water absorption of pellets has been presented in Fig. 5. The thickness swelling of pellets produced from untreated and acid treated WS is 1.9% and 1%, whilst that of steam treated WS pellets vary in the range 2.5 – 2.9%. Thus, it may be concluded that acid treatment of WS enhances the water resistive properties of the particleboard.

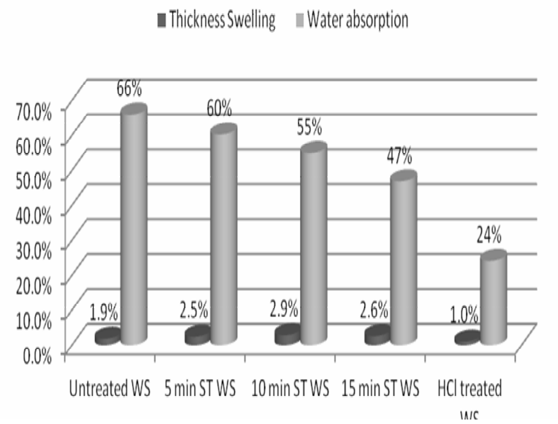

Fig. 5: Effect of Wheat Straw pretreatment on Thickness Swelling and Water Absorption of experimental pellets of Particle Board.

It was observed that untreated wheat straw pellets have highest water absorption while acid treated WS pellets have lowest (66% and 24%). The water absorption of pellets formed with steam treated WS decreases from 60 to 47% as the retention time of steam increases from 5 to 15min. The use of acid treated wheat straw has resulted in minimum thickness swelling and water absorption i.e. 1% and 24% respectively.

The effect of varying Glue recipes on thickness swelling and water absorption of boards is shown in Fig. 6. The thickness swelling drops from 3.4 to 1% as the UF concentration in glue decreases and PVA concentration increases. The glues containing corn paste (2 and 4) exhibited TS of 2.9 and 1%, whereas, wheat paste containing glue formulations (1 and 3) resulted in thickness swelling of 3.4 and 1.4%. This indicates that corn content of glue reduces the thickness swelling of particle board. Also higher concentration of PVA results in low thickness swelling. Water absorption produced by individual glue recipes lie in the range 45 – 54% while that of commercial particleboard is 51%. From Fig. 5, it may be observed that water absorption of first two recipes is comparatively lower than the other two. This indicates that high UF concentration glues resulted in less water absorption than high PVA concentration glues.

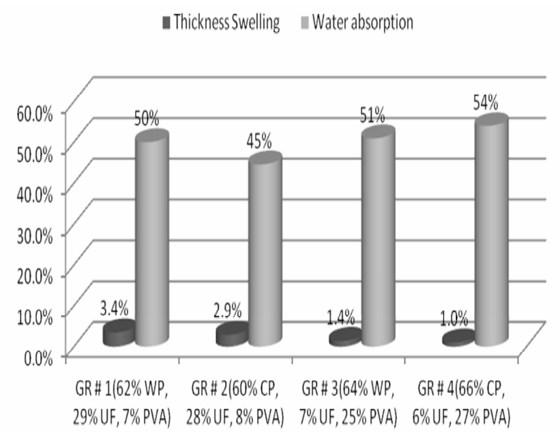

Fig. 6: Effect of glue recipes on Thickness Swelling and Water Absorption of experimental pellets of Particle Board.

Experimental

Materials

Chipped wheat straw with average particle size of 1–15 mm was purchased from the local market. It was air dried at room temperature and screened through a 16 mesh sieve to get undersize particles in the range 1–5 mm. The moisture content was found to be 19% based on oven dried weight of fibers. Glue components like Poly vinyl acetate, Urea Formaldehyde, paraffin wax (PW) and pellet hardener (PH) were purchased from the FAKT International cooperation. Four recipes of binders with varying concentration of wheat paste (WP), corn paste (CP), UF and PVA were prepared. Table-1 shows the glue recipes.

Pellets Manufacturing Process

Wheat straw was soaked in boiling water for 4 hrs followed by steam treatment (ST) in thermal compression rig where steam was injected in die at 110°C and 20 psig for retention time of 5, 10 and 15 min. It was then dried in an oven at 105°C for 24 hrs and remaining moisture was found to be 8%. Oven dried WS was mixed with glue and compressed at 2800 psig and 80°C for press time of 7 min. The mechanical thermal compression was achieved in the experimental facility shown in Fig. 7. The process was repeated with WS pretreated with 10% HCl soln. for 24hrs. Various pellets as shown in Fig. 8 were prepared, each with different feed condition and recipe, the experimental sequence is tabulated in Table-2.

Table-1: Glue Recipes.

Ingredients	Recipe 1		Recipe 2		Recipe 3		Recipe 4	
	Amount (g)	Composition (%)	Amount (g)	Composition (%)	Amount (g)	Composition (%)	Amount (g)	Composition (%)
WP	540	62	0.0	0.0	600	64	0.0	0.0
CP	0.0	0.0	625	60	0.0	0.0	700	66
UF	250	29	300	28	60	7	60	6
PVA	60	7	85	8	250	25	250	27
PH	10	1.1	10	0.9	10	1.1	10	0.97
PW	10	1.1	10	0.9	10	1.1	10	0.97

Table-2: Experimental sequence of Pellets production of Particle Board.

Pellet type.	Water soaking (◦C/hr)	Steam temp./ Retention Time (◦C/min)	10% HCl treatment for 24 hrs	Drying temp. / time(◦C/hr)	Glue Recipe no.
A	-	-	-	-	1
A1	100/4	110/5	-	104/24	1
A2	100/4	110/10	-	104/24	1
A3	100/4	110/15	-	104/24	1
A4	-	-	Yes	104/24	1
B	-	-	-	-	2
B1	100/4	110/5	-	104/24	2
B2	100/4	110/10	-	104/24	2
B3	100/4	110/15	-	104/24	2
B4	-	-	Yes	104/24	2
C	-	-	-	-	3
C1	100/4	110/5	-	104/24	3
C2	100/4	110/10	-	104/24	3
C3	100/4	110/15	-	104/24	3
C4	-	-	Yes	104/24	3
D	-	-	-	-	4
D1	100/4	110/5	-	104/24	4
D2	100/4	110/10	-	104/24	4
D3	100/4	110/15	-	104/24	4
D4	-	-	Yes	104/24	4

Fig. 7: Mechanical Thermal Compression Rig.

Fig. 8: Particle Board Pellets produced with different feed conditions and glue recipe

Sample Preparation and Testing

The pellets were dried at room temperature after compression to achieve the required moisture content of 6%. After conditioning, the straw particle boards were tested for the properties shown in table 3. For each property determination, boards were reduced to definite sizes according to respective ASTM standards. Specimen sizes for various tests are shown in Table-3. The tests were also conducted for commercial particleboard sample for comparison with WS particleboard.

Table-3: Sample sizes for testing.

Property	ASTM Standard	Size (mm)
Impact Strength	D-256	63.5 x 3.2 x 12.7
Compressive Strength	D-3501-05a (2011)	20 x 20
Thickness Swelling	1037-99	50 x 50
Water Absorption	D7433 – 08	50 x 50

Conclusion

The wheat straw particle boards of all types exhibit weaker mechanical strength and stronger water resistance properties in comparison with conventional particleboard properties. 10% HCl treatment of wheat straw resulted in improvement of compressive strength, thickness swelling and water absorption with the exception of impact strength, which is lower for HCl modified panels. The impact strength is improved with the increase in UF and wheat content of glue, compressive strength is improved by increasing UF and corn content. The thickness swelling is reduced by increasing PVA and corn content while, water absorption is reduced when UF and corn content of glue is enhanced. Reasonable mechanical strength can be achieved by using high urea formaldehyde and corn concentration in glue. The study suggests that it is feasible to produce particle board using wheat straw pretreated with acid and bonded with urea formaldehyde modified adhesive. The use of higher pressure to form the board may be investigated.

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