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ORIGINAL ARTICLE

Surface characteristics and physical properties of wheat straw particleboard with UF resin

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Abstract Agricultural fibers, such as straw and plant stalks, have been considered as renewable alternatives for making particleboard, which would ease the huge demand for wood. The objective of this study was to investigate surface characteristic (surface roughness and wettability) and physical properties (thickness swelling and water absorption) of wheat straw (*Triticum aestivum* L.)/poplar wood particleboard with UF resin and silane coupling agent. The effects of the silane coupling agent content and straw/poplar wood particles ratio on the surface characteristic and physical properties were examined. The ratios of the mixture of straw and poplar wood particles were 100:0, 85:15, 70:30 and 55:45. Silane coupling agent content was chosen at three levels of 0, 5 and 10 %. The experimental panels were tested for their physical properties according to the procedure in DIN 68763 (Determination of values of surface roughness parameters Ra, Rz, R max using electrical contact(stylus) instruments, concepts and measuring conditions, Berlin, Deutsches institut für Norming, 1982) roughness measurements, average roughness (R_a), mean peak-to-valley height (R_z), root mean square roughness (R_q), were taken from the unsanded samples using a fine stylus tracing technique. Contact angle measurements were obtained by using a goniometer connected with a digital camera and computer system. Results indicated that physical properties (thickness swelling and water absorption (were improved by the addition of silane coupling agent, but use of poplar wood particles has a negative effect on physical properties (thickness swelling and water absorption). Statistical analysis showed that boards consisting of a greater amount of poplar particles exhibited lower wettability. Furthermore, panels made with higher amount of silane level, showed lower Rq values.

Keywords Wheat straw particleboard · Poplar wood · Surface properties · Physical properties · Wettability · Silane coupling agent

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Introduction

One of the main potential utilizations of these agro-based materials is conversion to composite products (Han et al. 1998). In view of the global decline in the forest resources and population growth, agro-based resources have been exploited in recent years to supplement the supply of wood materials from the existing forest resources. Cereal straw is annually-renewable in abundant volumes in many regions of world; the worldwide production of cereal straw is estimated at 1.5 billion m^3 annually (Grigoriou 2000). It has been reported that, in the last two decades, use of straw has been gaining much research attention as a potential alternative fibrous raw material replacing wood for making particleboards (Azizi et al. 2011).

However, some problems still exist with seasonality, storage, scattering sources, and bondability. Among these problems, bondability remains a major unsolved technical problem, especially when urea-based resins are applied (Han et al. 1998). Morphologically, straw is more complicated than wood. Straw contains a relatively large number of elements, including the actual fibers, parenchyma cells, vessel elements, and epiderma cells, which contain a high amount of ash and silica. The epidermal cells of straw are the outermost surface cells, that are covered by a thin wax layer.

This surface layer deteriorates the moisture absorbance of straw from water-based adhesives such as urea–formaldehyde (UF) resin (Markessini et al. 1997). It therefore acts as a barrier to the gluing of straw with UF resin. Removing this bonding barrier layer from straw materials has been a technical problem for performance enhancement of straw panels (Markessini et al. 1997; Han et al. 1999). Isocyanate is an alternative resin that can be used to improve the properties of these strawboards, but the application of isocyanate is hindered by its high cost; hence, it is not commonly utilized, especially in developing countries (Han et al. 1998). In this regard, silane coupling agents are used to modify the characteristics of the inorganic surface by fixing some organic functional groups onto it. There are at least two functional groups in their molecules: one is methoxyl or ethoxyl group, which decomposed in water or reacts with some groups of inorganic materials. Another is amino or epoxy group, which can react wheat organic material. Roughness is a measure of the fine irregularities on a surface. The surface roughness of particleboard plays an important role since any surface irregularities. It may show through thin overlays reducing the final quality of the panel. When particleboard is used as substrate for surface coating, its surfaces must be capable of having resistance stresses to peeling. Fine irregularities on the board surface will show through overlays and, this affects products grade, quality, finishing and gluing. Wettability is crucial for good adhesion in bonding between particleboard and coating. Wettability is defined as a condition of a surface that determines how fast a liquid will wet and spread on the surface or whether it will be repelled and not spread on the surface. Liquid surface coatings or adhesives have to wet and penetrate the cellular structure of wood in order to establish intimate contact between molecules of composite surface and coating. Contact angle (CA) method has been commonly used to determine wettability of particleboard. When the CA is zero, perfect wetting of a surface occurs. Liquids wet surfaces when the CA is less than 90° (Baharoglu et al. 2011). The objective of this study was to investigate the influence of silane coupling agent and poplar wood particles percentage on the surface roughness, wettability and physical property of UF-bonded wheat straw (*Triticum aestivum L.*)/poplar wood particleboards.

Materials and methods

Materials

Preparing of wheat straw and poplar wood particles

Poplar logs were prepared from the forest in the north of Iran. The agricultural lignocellulosic fiber used in this study was wheat straws (*Triticum aestivum* L.) that were obtained from the Karaj city. Straw and polar particles then were prepared using a Pallmann knife ring flakers. All particles used were air-dried to about 3 % moisture content. Subsequently, they were screened by handle sieve and oversize and undersize particles were removed. The average size of straw particles was 34 mm by 2.56 mm by 0.33 mm and poplar particles averaged 23 mm by 5.6 mm by 0.85 mm. Slenderness ratio for wheat straw and poplar particles were calculate 80 and 27, respectively. Table 1 presents the fraction analysis of straw particles in compression to poplar particles.

Silane coupling agent

Amino silane coupling agent NH_2-C_3H_6-$Si(OC_2H_5)_3$, was used for improving the properties of the straw/poplar wood particleboards. Some properties of the used silane coupling agents (Merck Chemistry Company, Germany) are shown in Table 2.

UF resin

The commercial UF resin used in this study was supplied by Tiran chemistry Company, Iran. This resin was water dispersed with a solid content of 62 %, a viscosity of 125 cp, gelation time of 54 s, pH of 7.5 and a density of 1.28 g/cm^3.

Manufacturing of board

The UF resin was sprayed onto the particles in a blender at 10 % resin content based on the oven-dried weight of particles. Silane coupling agent was mixed with the UF resin prior to blending, based on the weight of the resin solid. One percent of NH_4CL based on the weight of the resin solid, was added as the curing catalyst. The hand-formed mats were pressed into 14 mm thick boards using distance bars at 180 °C for 5 min. The mats were pressed under a pressure of 35 kg/cm^2. The board size was 400 × 400 × 14 mm with targeted density of 0.70 g/cm ^{3}. In an attempt to optimize straw/Poplar particle ratio, the

Table 1 Fractional (%) per weight of straw and poplar wood particles

Screen mesh width (mm)	Poplar wood particles (%)	Straw particles (%)
>2 < 4	24.83	–
>1 < 2	22.29	10.9
>0.5 < 1	36.40	9.70
<0.5	16.29	78.60

Table 2 Properties of used silane coupling agent

Properties	Unite	Value
Molar mass	(g/mol)	221.37
Density at 20 ċ	(g/cm^3)	0.95
Boiling point	(ċ)	217
Flash point	(ċ)	93
PH value (20 g/mol, H_2O, 20 ċ)	–	11
Solubility temperature	(ċ)	20
Ignitions temperature	(ċ)	300

following four ratios were tested:100/0, 85/15, 70/30, and 55/45. Also coupling agent amount was chosen at three levels of 0, 5 and 10 %. Experimental schedule is shown in Table 3.

Physical testing

Prior to testing the physical properties, the boards were conditioned at 20 ± 1 ċ and 65 ± 5 % relative humidity (RH) until they reached a constant weight. Based on these variables 12 board were manufactured with three boards of each type resulting in 36 boards in total. The water absorbtion (WA) thickness swelling (TS) after 2 and 24 h water soaking of samples was measured according to DIN 68763 (1982). The surface properties of the samples were determined by employing a fine stylus profilometer (Mitutoyo SJ-201P). Three samples were used from each type of the panel for the surface roughness measurements. Three roughness parameters characterized by DIN 4768 standard (1990), respectively, average roughness (R_a), mean peak-to-valley height (R_z), and root mean square roughness (R_q) were considered to evaluate the surface properties of the panels (1990). The surface roughness parameters were calculated from the digital information. The vertical displacement of the stylus is converted into electrical signals by a linear displacement detector before the signal is amplified and converted into digital information. R_a is the arithmetic mean of the absolute values of the profile deviations from the mean line. It is by far the most commonly used parameter in surface finish measurement. The surface roughness of the samples was measured with a sensitivity of 0.5 μm. Measuring speed, pin diameter and pin top angle of the tool were 0.5 mm/sec, 4 μm and 90, respectively. The length of tracing line (L_t) and cut-off were 12.5 and 2.5 mm (γ), respectively. Measuring force of the scanning arm on the samples was 4 mN (0.4 gf). Measurements were done at room temperature and pin was calibrated before the tests.

Table 3 The mixing ratios of raw materials and their abbreviations used in this study

Silane content (% by Wight)	Fibrous mixture (%)		Repetition
	Wheat straw	Poplar	
0	100	0	3
0	85	15	3
0	70	30	3
0	55	45	3
5	100	0	3
5	85	15	3
5	70	30	3
5	55	45	3
10	100	0	3
10	85	15	3
10	70	30	3
10	55	45	3

The wetting behavior of the particleboard samples was characterized by the contact angle method (goniometer technique). The contact angles were obtained with a KSV Cam-101 and sessile drop method, which is the most widely used procedure. It is determined simply by aligning a tangent with the sessile drop profile at the point of contact with the solid surface. The drop image was stored by a video camera and an image analysis system calculated the contact angle (h) from the shape of the distilled water drop at room temperature. An imaging system was used to measure contact angle and shape and size of water droplets for the tested surfaces of the particleboard samples. The image of the liquid drop was captured by a video camera and the contact angle was measured by digital image analysis software. After the 5 μL droplet of the distilled water was placed on the sample surface, contact angles from the images were measured at fifth second. Three samples with dimension of 50 mm × 50 mm × 14 mm were used from each type of formulation for the contact angle measurements (Azizi et al. 2011).

Statistical analysis

The experiment designed as factorial using completely randomized design arrangement. Duncan method was used to compare means ($P < 0.05$). Statistical analysis was conducted in SPSS (version 18).

Results and discussion

Surface characteristics

Surface roughness

Figures 1, 2 and 3 show that the effects of poplar particles and silane coupling agents level on the surface quality of the particleboards were statistically significant.

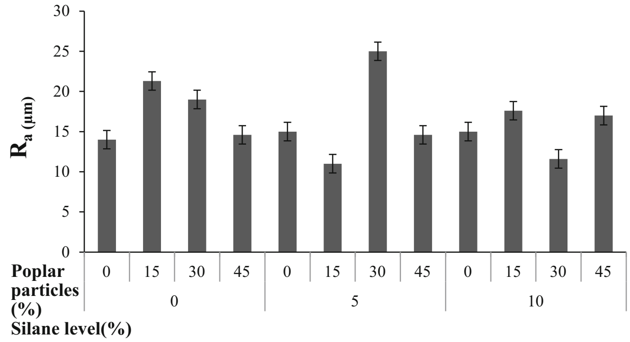

Fig. 1 The surface roughness (R_a) of boards

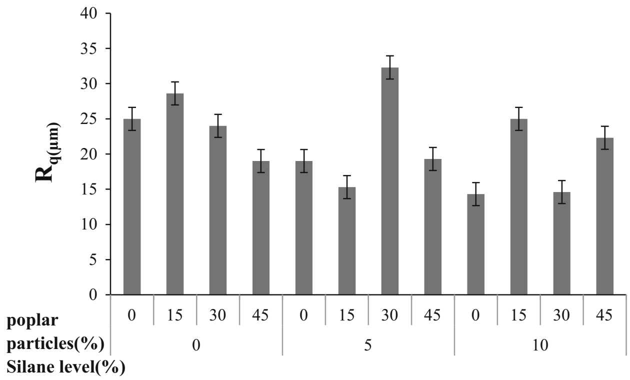

Fig. 2 The surface roughness (R_q) of boards

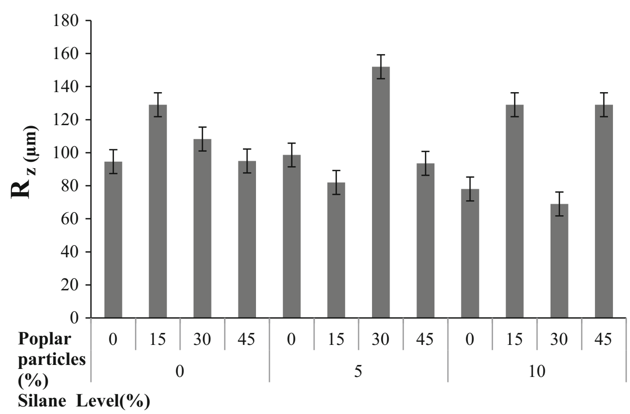

Fig. 3 The surface roughness (R_z) of boards

Increasing silane coupling agents level showed a positive effect on the surface roughness in Rq. This may be due to better interfacial interaction between wheat straw and UF resin and subsequently smoother panel surface. The boards made with 10 % Silane coupling agent level and 30 % poplar particles had the smoothest surface values among the other types of specimens. A typical commercially manufactured particleboard could have Ra values ranging from 3 to 6 µm (Hiziroglu 1996). It appears therefore that, surface quality of all the panels is very rough and not ideal for overlaying applications as substrate without any sanding process. However, if the panels were sanded with a sequence of 150, 180, and 220 grit sandpaper, their surface roughness could have been improved and such panels would be used as substrate for these overlays without any problems (Hiziroglu and Holcomb 2005).

Wettability

As could be seen in Fig. 4 The panels made from 15 % poplar particles and 10 % silane coupling agent level had the highest contact angle. This may be due to the decrease bonding between the wheat straw particles in 100 % straw board and increases the water diffusion into this type of panel. Adding poplar particles until 30 % had a positive effect on wettability, This may be due to better bonding between poplar particles in comparison with straw particles because of their waxy layer and better compression in press stage. decrease The contact between the wood particles cannot be proved due to presence of roughest particles and poorest wettability compared high level of moisture content (Hiziroglu 1996).

Physical properties

Thickness swelling and water absorption

Figures 5, 6, 7 and 8 show that the effects of poplar particles and silane coupling agents level on the TS and WA for 2 and 24 h immersion of the particleboards were statistically significant.

Generally, the thickness swelling of boards decreased with adding and increasing the silane coupling agent level. This reduction in thickness swelling was significant when the silane coupling agent content was 5 %, and no significant reduction was observed when the silane coupling agent content was above 5 %. Speculated that amido

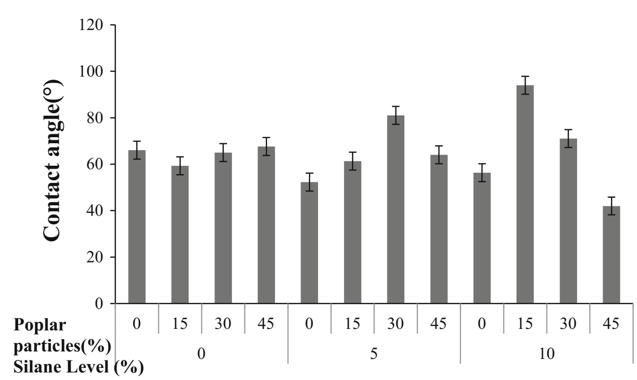

Fig. 4 The wettability (Contact angle) of boards

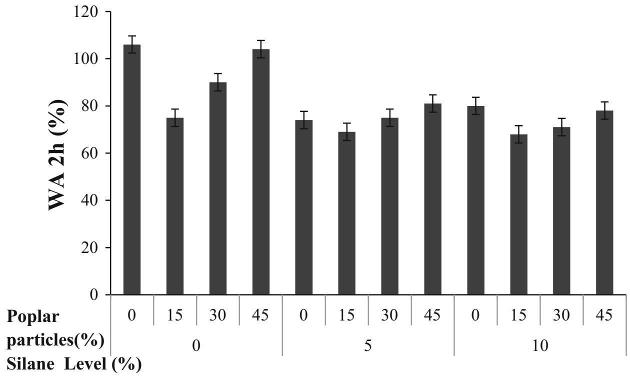

Fig. 5 The water absorption (WA) after 2 h immersion of boards

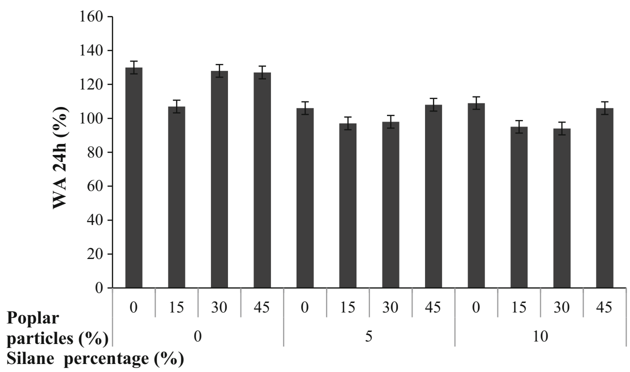

Fig. 6 The water absorption (WA) after 24 h immersion of boards

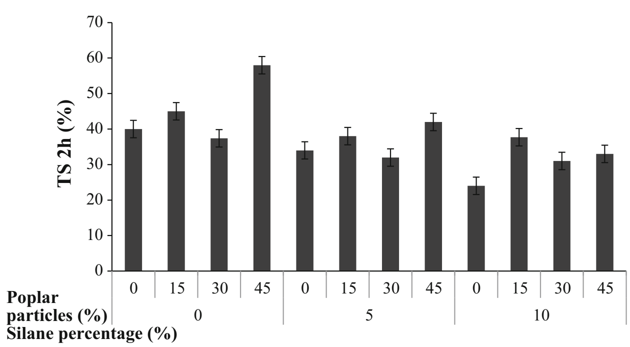

Fig. 7 The thickness swell (TS) after 2 h immersion of boards

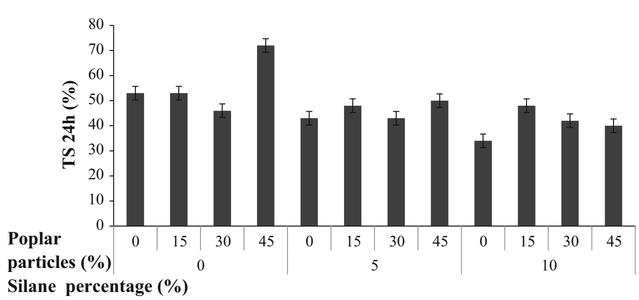

Fig. 8 The thickness swell (TS) after 24 h immersion of boards

formed is capable of reacting whit the hydrate of formaldehyde. Ethoxysilane may experience a reaction between amino and hydroxyl group in UF resin may accure (Han et al. 1998). Similar result was also found by (Han et al. 2001). The mean TS of the particleboards varied from 24 to 58 % and 34 to 72 % for 2 and 24 h immersion, respectively. The thickness swelling of boards was found to increase with an increase in poplar particles percentage and the boards with 15 % poplar particles have lower TS. This is related to the inherent characteristics of the raw materials, where wheat straw is more water-resistant than poplar particle. This superior water resistance property of wheat straw is due to its higher silica content. Furthermore, the straw particles are longer and thinner than the wood particles, resulting in lower swelling (Grigoriou 2000). Average water absorption of the samples ranged from 68 to 106 % and 94 to 130 % for 2 and 24 h immersion, respectively.

Conclusions

These preliminary findings indicated that the wettability of particleboard was significantly affected by the adding poplar particles and increasing levels of silane coupling agents ($P < 0.05$ in both cases). Adding poplar particles and silane coupling agent caused smoother surfaces.

In general, results showed that the both wheat straw/poplar particle ratio and the silane adding can influence the physical properties and surface properties of the boards. Adding silane coupling agents reduced the WA and TS of the boards, significantly. However, all boards did not satisfy the TS requirement of EN standards for general uses. According to EN 312-4 (1996) standard, particleboard should have a maximum TS value of 8 and 15 % for 2 and 24 h immersion, respectively. Thus, it is recommened to use some suitable hydrophobic additives during such board manufacturing. On the whole, wheat straw particleboard with 5 % silane coupling agent and 30 % poplar particles gave superior physical performance and had better properties in surface roughness but panels made with 15 % poplar particles and 10 % silane coupling agent level had less wettability.

References

Azizi Kh, Tabarsa T, Ashori A (2011) Performance characterizations of particleboards made with wheat straw and waste veneer splinters. Compos J Part B 42:2085–2089

Baharoglu M, Gökay N, Sarı B, Bardak S, Ayrılmıs N (2011) The influence of moisture content of raw material on the physical and mechanical properties, surface roughness, wettability, and formaldehyde emission of particleboard composite. Compos J Part B 42:2085–2089. doi:10.1016/10.020

DIN (1982) particleboard. DIN 68763-1982. Chipboard for special purposes in building construction; concepts, requirements, testing. 1982–1983, p 4

DIN (1990) particleboard. DIN 4768-1990. Determination of values of surface roughness parameters Ra, R_z, R_{max} using electrical contact(stylus) instruments, concepts and measuring conditions. Deutsches institut für Norming, Berlin, Germany

European Standard EN 312-4 (1996) Particleboards-specifications. Part 4. Requirements for load-bearing boards for use in dry conditions. European committee for standardization, Brussels, Belgium

Grigoriou AH (2000) Straw-wood composites bonded with various adhesive systems. Wood Sci Technol J 34:355–365

Han G, Umemura K, Zhang D, Zhang CH, Kawai Sh (1998) Upgrding of urea formaldehyde-bonded reed and wheat straw particle boards using silane coupling agents. Wood Sci Technol J 44(4):282–286

Han G, Umemura K, Kawai Sh, Kajita H (1999) Improvment mechanism of bond ability in UF bonded reed and wheat straw boards by silane coupling agent and extraction treatments. Wood Sci Technol J 45:299–305

Han G, Umemura K, Wong E, Zhang M, Kawai Sh (2001) Effect of silane coupling agent level and extraction treatment on properties of UF bonded reed and wheat straw particleboard. Wood Sci Technol J 47:18–23

Hızıroglu S (1996) Surface roughness analysis of wood composites: a stylus method. For Prod J 46:67–72

Hızıroglu S, Holcomb R (2005) Some of the properties of the three-layer particleboard made of eastern red cedar. Build Environ J 40:719–723

Markessini E, Roffael E, Rigal L (1997) Panels from annual plant fibers bonded with urea-formaldehyde resins. In: Proceedings of the 31st international particleboard/composite materials symposium, April 8–10, Washington State University, Pullman, p 147–160