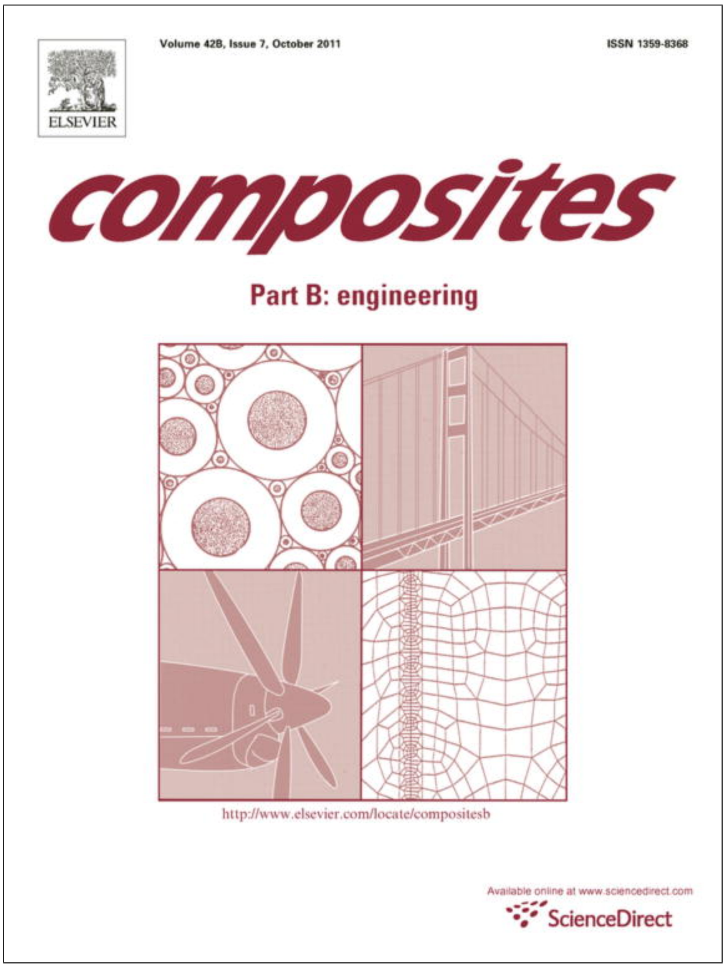
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Performance characterizations of particleboards made with wheat straw and waste veneer splinters

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ABSTRACT

The aim of this study was to determine the performance of three-layer particleboard made from wheat straw and veneer splinters, as waste materials. For the purpose of evaluation, compositions of wheat straw and beech veneer splinters at different mixture rates were compared for some of properties. Physical (thickness swelling and water absorption) and mechanical properties (modulus of rupture, modulus of elasticity, internal bond and impact strength) of the boards were evaluated. Effects of mixing ratios of fibrous material and press temperature on the above-mentioned properties were also investigated. The mixing ratios of beech veneer with wheat straw were 100%:0%, 75%:25%, 50%:50%, 25%:75% and 0%:100%, respectively. A commercial urea–formaldehyde (UF) adhesive was used as binder. A total of 10 experimental boards with an average target density of 0.70 g cm^{-3} across all mixtures were fabricated. All the mechanical and physical properties of the boards were improved when the press temperature was increased from 140 to 170 °C. Analysis of data revealed that the mechanical properties were significantly different among the board types. With the exception of modulus of elasticity, the other properties were decreased by the addition of wheat straw particles. In general, water absorption and thickness swelling decreased with the increase of wheat straw content. The presence of wheat straw in the particleboards resulted in higher water absorption and thickness swelling. Finally, it can be stated that wheat straw and beech veneer splinters have potential as supplement fibrous materials, in combination with wood particles for particleboard manufacturing and indoor applications.

1. Introduction

Iran has poor natural forest resources that cover only about 7% of the country's land area. Similar to many developing Asian countries, deforestation and over-harvesting in Iran have created environmental issues. On the other hand, increasing demand for forest resources in various applications has led to the shortages of wood supply. Thus, there is a need to look for innovative ways of using non-traditional forest resources such as non-woods, agro residues, wood wastes, to substitute wood raw material for wood based industries [1,2]. Agro residues and wood wastes are potentially usable in different ways. According to the end uses, wood wastes could be sorted, processed and provided as raw materials for manufacture of pulp, fiberboard and particleboard. Manufacturing value added panel products may be the most efficient use of such waste materials. The manufacture of particleboard from recycled wood-based wastes is the most common way to reuse such waste materials [3].

Particleboards are widely used because they enable wood particles from relatively useless small size and/or low grade timber to be transformed into useful large wooden panels. Particleboards are manufactured from particles of wood or other fibrous materials, which are formed and pressed together using an organic binder together with one or more of agents, such as heat, pressure, catalyst, and so on. Properties of the board depend, among other things, on the form and amount of fibrous material used. The basic materials from which particleboards are made include (a) chips, which are wood particles typically used in pulp manufacture, (b) flakes, which are mechanically sliced wood particles, (c) ribbons, wood particles of specific thickness but varied length, (d) shavings, thin, of short length and consisting of ruptured fibers, and (e) splinters, wood particles greater in length compared to width. Particleboard retains many of the properties of the wood from which it is made [4].

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 composites particularly for particleboards [5]. The objective of this study is to use the mixture of wheat straw and waste veneer splinters as raw material

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for laboratory made three-layer particleboard, and to test selected properties of the boards to determine if they have the required levels of properties for general uses. The effects of two variables in terms of mixing ratio of fibrous materials and press temperature on the physical and mechanical properties were also investigated.

2. Materials and methods

2.1. Materials

Two different types of fibrous materials were used in this study: wheat straw (WS) and beech veneer (BV). The WS was obtained from farms in the northern part of Iran. The BV was received from local veneer plant residues. Air-dried straw was cut by hand into pieces of 30–40 cm and then reduced further with a hammer mill to approximately 15 mm in length, 2 mm in width and 0.4 mm in thickness. The BV splinters were chipped by hand into small particles. They ranged from 3 to 4 cm long and 2 cm wide. Particles were oven-dried at 103 °C for 5 h to a moisture content of less than 4% prior to processing.

Urea–formaldehyde (UF) adhesive with a solid content of 67%, density of 1.265 g cm^{-3}, viscosity of 61 cp, gelation time of 45 s, and pH of 7.5 was applied. As a hardener, ammonium chloride (NH_4Cl) solution (solid content: 20%) was added to the adhesive.

2.2. Lab production of boards

Five different ratios of two fibrous types, namely 75%, 50%, 25% BV were mixed with WS to manufacture the boards in addition to boards produced 100% of each species. Experimental schedule is shown in Table 1. As it can be seen, two variable factors were mixture of fibrous materials and press temperature (140 and 170 °C). Other parameters such as resin content (core layer: 9% and face layer: 11%), hardener content (1%), press closing rate (5 mm s^{-1}), press pressure (35 kg cm^{-2}), board thickness (10 mm), and target density (0.70 g cm^{-3}) were held constant. For each treatment (formulation), three boards were fabricated.

Dried particles for the face and core layers were separately blended with UF adhesive in a rotating drum-type mixer fitted with a pneumatic spray gun. The materials were placed in a molding frame and spread to fill evenly. The resinated particles were then pressed into panel mat using a laboratory scale hydraulic hot press (OTT, Germany). The nominal dimensions of the boards were $420 \times 420 \times 25$ mm^3. Stop bars were used in the press to allow the same board thickness to be achieved for all the test runs. No wax or any other hydrophobic substance was applied for manufacturing of the boards. After pressing, all boards were trimmed to a final size of 400×400 mm^2. Consequently, the board samples were conditioned for 2 weeks at 65% RH and 25 °C.

Table 1
The mixing ratios of raw materials and their abbreviations used in this study.

Run	Fibrous mixture (%)			Press temperature (°C)		Board type
	WS	BV	Abb.	Tem.	Abb.	
1	0	100	A_1	140	B_1	A_1 B_1
2	0	100	A_1	170	B_2	A_1 B_2
3	25	75	A_2	140	B_1	A_2 B_1
4	25	75	A_2	170	B_2	A_2 B_2
5	50	50	A_3	140	B_1	A_3 B_1
6	50	50	A_3	170	B_2	A_3 B_2
7	75	25	A_4	140	B_1	A_4 B_1
8	75	25	A_4	170	B_2	A_4 B_2
9	100	0	A_5	140	B_1	A_5 B_1
10	100	0	A_5	170	B_2	A_5 B_2

2.3. Testing methods

All tests were carried out in accordance with DIN 68763 standard. The mechanical and physical tests performed on the specimens were: static bending [modulus of rupture (MOR) and modulus of elasticity (MOE)], internal bond strength (IB), impact strength (IS), water absorption (WA), and thickness swelling (TS). The WA and TS samples were fully immersed in distilled water at 25 °C for 2 h and 24 h period of time.

2.4. Statistical analysis

The data were evaluated using an analysis of variance procedure for a completely randomized design. The experimental design consisted of two treatments and their interactions. Duncan's Multiple Range Test (DMRT) was performed to permit separation of means. Results were considered significant at 95% and 99% confidence levels.

3. Results and discussion

3.1. Mechanical properties

In general, statistical analyses showed that the mechanical properties in terms of MOR, MOE, IB and IS of the experimental boards were significantly influenced by the mixing ratio of fibrous materials and press temperature (Tables 2 and 3). All boards made with 170 °C press temperature had the highest values among the other types of specimens. In other words, all mechanical properties of the boards were improved when the press temperature was increased from 140 to 170 °C, which clearly shows that at 140 °C sufficient heat is not transferred to the core section of the mat.

3.1.1. MOR and MOE

Based on EN Standards, the minimum requirements for MOR and MOE of particleboard for general uses are 11.5 and 1600 MPa [6]. The range of data in the MOR was from 3.4 to 28.5 MPa. As can be seen from Fig. 1a, only boards of types A_1 and A_2 could meet the minimum MOR requirement of the EN Standards for general uses. Addition of WS particles in the produced boards displayed different behavior. The increase in WS content substantially reduced the MOR of the produced boards, but improved the MOE. Similar results were also found by Kalaycıoğlu and Nemli [7] that the substitution of WS with wood chips resulted in decrease in MOR property. This behavior can be explained by the weak interfacial interaction between WS and UF resin. Boquillon et al. [8] reported that wheat straw has an outer silica and waxy layer with very low porosity, which disrupts resin penetration and consequently reduces the bondability between UF resin and the particles. The bondability of a straw particleboard could be improved by removing the waxy layers. Chemical treatment could remove the waxy layer and produce a rough and hydrophilic surface [9].

3.1.2. IB and IS

As mentioned earlier, all mechanical properties particularly IB and IS of the boards were markedly improved when the press temperature was increased from 140 to 170 °C (Table 2). The WS loading was found to have significant effect on the IB and IS properties at 95% confidence level (Table 2). Like MOR, addition of WS could not improve those properties (Fig. 1b). The significant negative influence of WS on IB and IS can be explained by the reduced bonding ability due to the fact that WS particles are weaker than BV. In addition, it should be mentioned that WS particles have more surface area than the BV particles; therefore the resin coverage and consequently the bondability is less.

Table 2
ANOVA table of mixture of fibrous materials (A) and press temperature (B) in relation to mechanical properties.

Source of variations	df	MOR			MOE			IS			IB		
		SS	MS	*F*	SS	MS	*F*	SS	MS	*F*	SS	MS	*F*
A	4	1584.1	396	49.2**	532,10,975	133,02,743	83.5**	1862.2	465.5	112.4**	0.40	0.10	15.3**
B	1	36.6	36.6	4.5*	27,87,481	27,87,481	17.5**	35.8	35.8	8.6*	0	0	0.07ns
A × B	4	39.7	9.2	1.2ns	17,75,701	443,925	2.8ns	73.4	18.3	4.4*	0.12	0.025	3.82*
Error	20	161	8.1		31,86,331	159,316		82.8	4.14		0.13	0.007	
Total	30	6641			2917,13,692			27809.4			1.80		

Note: df = degree of freedom; MS = mean of squares; SS = sum of squares; *F* = *F* value; ns = not significant.
** Significant difference at the 1% level ($p \leqslant 0.01\%$);
* Significant difference at the 5% level ($p \leqslant 0.05\%$).

Table 3
DMRT of the percentage of fibrous mixture and temperature on the mechanical and physical properties.

Board type	Property							
	MOR (MPa)	MOE (MPa)	IB (MPa)	IS (J m^{-1})	TS 2 h (%)	TS 24 h (%)	WA 2 h (%)	WA 24 h (%)
A_1 B_1	24.1 (A)	1077 (D)	0.32 (AB)	39.1 (A)	23 (BC)	31 (CD)	75 (D)	85 (C)
A_1 B_2	28.5 (A)	1463 (D)	0.49 (A)	40.6 (A)	16 (D)	24 (D)	55 (E)	70 (C)
A_2 B_1	12.6 (B)	1777 (CD)	0.14 (AB)	33.9 (B)	63 (A)	45 (BC)	95 (DE)	83 (BC)
A_2 B_2	14.6 (B)	2161 (BC)	0.33 (C)	37.4 (AB)	34 (B)	30 (CD)	76 (CD)	87 (BC)
A_3 B_1	11.2 (CD)	2588 (B)	0.09 (C)	28.8 (C)	67 (A)	74 (AB)	99 (CD)	108 (B)
A_3 B_2	14.2 (BC)	2634 (B)	0.12 (C)	30.9 (C)	48 (AB)	51 (B)	86 (CD)	106 (B)
A_4 B_1	8.0 (D)	2299 (BC)	0.10 (C)	21.5 (D)	68 (A)	85 (A)	123 (AB)	130 (AB)
A_4 B_2	8.8 (CD)	3315 (B)	0.16 (BC)	22.3 (D)	48 (AB)	63 (AB)	125 (A)	127 (AB)
A_5 B_1	3.4 (D)	4556 (A)	0.09 (C)	15.5 (E)	69 (A)	90 (A)	124 (A)	160 (A)
A_5 B_2	7.8 (D)	5864 (A)	0.11 (C)	22. 8 (D)	48 (AB)	70 (AB)	125 (A)	140 (A)

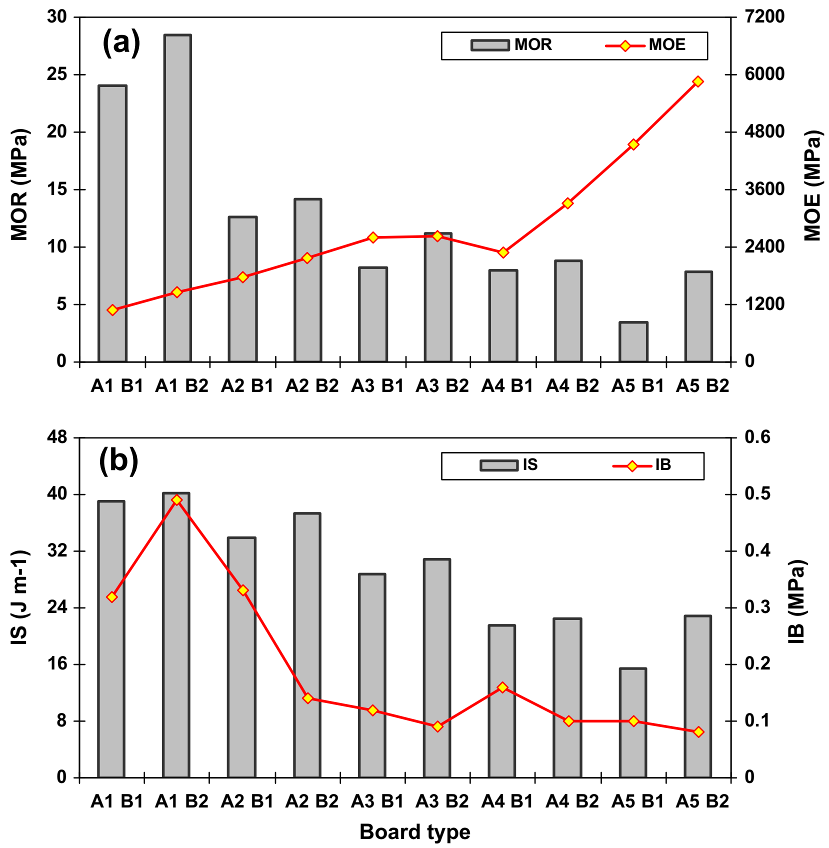

Fig. 1. Mechanical properties of various board types.

IB values ranged from 0.08 to 0.49 MPa. The minimal requirement of IB strength for general purpose is 0.24 MPa [10]. According to the test results, some produced boards showed higher values than the EN requirements. Fig. 1b shows that all boards containing BV particles and made with 170 °C exceed the EN Standard.

Similar trend was observed for IS. Variation of IS with increasing ratio of WS/BV and press temperature is also shown in Fig. 1b. As

Table 4
ANOVA table of mixture of fibrous materials (A) and press temperature (B) in relation to physical properties.

Source of variations	df	WA 2 h			WA 24 h			TS 2 h			TS 24 h		
		SS	MS	*F*	SS	MS	*F*	SS	MS	*F*	SS	MS	*F*
A	4	18,080	4520	222.7**	16,178	4044	48.3**	7735	1933.8	27.3**	11054.9	2763.5	59.5**
B	1	71.02	71	3.5ns	12.3	12.3	0.15ns	259	259.8	3.67*	108.6	108.6	2.33ns
A × B	4	5197	1299	64**	4159.9	1039.9	12.4**	2724	681	9.62**	4862.8	1215.7	26.2**
Error	20	851.8	20.29		1675	83.7		1415.6	70.8		929.3	46.5	
Total	30	75,040			42,118			86039.9			107,117		

Note: df = degree of freedom; MS = mean of squares; SS = sum of squares; *F* = *F* value; ns = not significant.
** Significant difference at the 1% level ($p \leqslant 0.01\%$).
* Significant difference at the 5% level ($p \leqslant 0.05\%$).

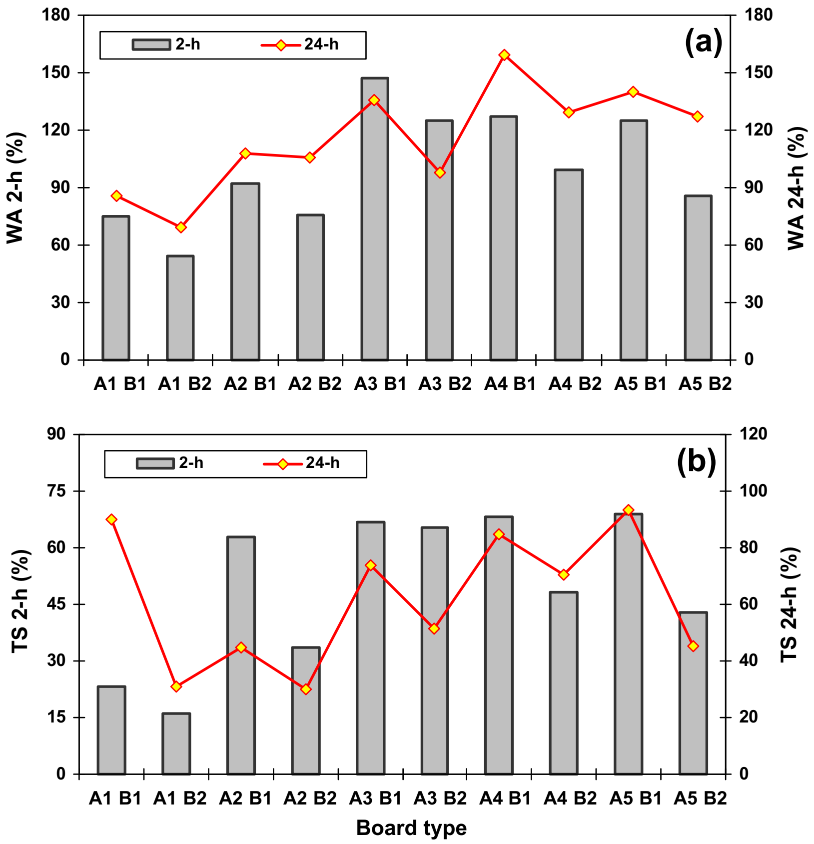

Fig. 2. Physical properties of various board types.

noted, increase in the WS loading significantly reduced the IS of the boards. IS of boards containing BV was 76% and 66% higher than those of the boards which had 25%, 75% WS (board type B_2), respectively. Interfacial interaction between particles and UF resin plays a major role in determining the crack initiation process [9]. An optimum interaction between the particles and the UF resin is essential to have good IS.

3.2. Physical properties

3.2.1. WA and TS

The statistical results are shown in Tables 3 and 4 and demonstrate the influences of type of fibrous materials and press temperature on the WA and TS properties of produced boards. Results indicate that as the amount of WS particles increases, the WA of the boards increases significantly. Average WA of the samples ranged from 54% to 147% and 69% to 159% for 2 h and 24 h immersion, respectively (Fig. 2a). The TS is affected by bond quality and adhesive properties [11]. It is obvious that WS particles have higher thickness swelling as a result of the larger surface area. This is attributed to the fact that WS particles are more bulky than BV and consequently have much larger surface area per weight unit than BV particles. Another reason is the lack of water repellent agents in board furnish.

The TS values of boards made with different amounts of WN and their statistical comparison are shown in Tables 3 and 4. Based on EN Standards, particleboard should have a maximum TS value of 8% for 2 h immersion. In addition, the maximum TS for 24 h requirement EN 312-4 [10] is 15%. The mean TS data of the particleboards obtained vary from 16% to 69% and 30% to 94% for 2 h and 24 h immersion, respectively (Fig. 2b). In general, all boards did not satisfy the TS requirement for general uses. The results indicate that as the WS content increased, the TS of the boards increased significantly. It is obvious that WS particles cause higher board swelling, which is the result of the lower adhesive content per surface area of WS particles in comparison to BV particles. This is due to the fact that WS particles are wider and considerably thinner, and consequently have a much larger surface area per weight unit than BV particles. This may be also due to not using hydrophobic substance in particleboard manufacturing. Nemli [12] believed that the panels require additional treatments such as the coating of particleboard surfaces with melamine-resin impregnated papers or laminates or high press temperature usage to become more stable products.

4. Conclusions

In this research work, the potential of two waste fibrous materials for particleboard manufacturing was studied. Ratio of fibrous materials content and press temperature were the main parameters influencing the physical and mechanical properties of the boards. Increasing of press temperature improved the MOR, MOE, IS, WA and TS of the boards, significantly. This may be due to interference in the curing of UF adhesive, reduced wettability of the particle surface or limitation of diffusion and/or spreading of the adhesive within the particles and over the particle surface. Most produced boards with BV particles were found to comply with MOR, MOE and IB requirements for general uses stated in the EN Standards. Furthermore, the highest MOR, MOE, IB and the lowest WA and TS were reached with BV particles and at 170 °C press temperature. However, the WA and TS of the boards were very poor (i.e. high), since no hydrophobic substance was used during the board manufacturing. Based on the findings of this study, it can be concluded that WS is rather feasible as a supplement fibrous material, in combination with wood particles for particleboard manufacturing and indoor applications.

References

[1] Xing C, Deng J, Zhang SY, Riedl B, Cloutier A. Properties of MDF from black spruce tops as affected by thermomechanical refining conditions. Holz Roh Werkst 2006;64(6):507–12.
[2] Akgül M, Çamlibel O. Manufacture of medium density fiberboard (MDF) panels from rhododendron (*R. ponticum* L.) biomass. Build Environ 2008;43(4):438–43.
[3] Ashori A, Nourbakhsh A, Karegarfard A. Properties of medium density fiberboard based on bagasse fibers. J Compos Mater 2009;43(18):1927–34.
[4] Lubi CM, Thachil ET. Particleboard from cashew nut shell liquid. Polym-Plast Technol Eng 2007;46(4):393–400.
[5] Panthapulakkal S, Sain M. Agro-residue reinforced high-density polyethylene composites: fiber characterization and analysis of composite properties. Compos Part A 2007;38(6):1445–54.
[6] EN 312-2. Particleboards-specifications. Part 2. Requirements for general purpose boards for use in dry conditions. Brussels, Belgium: European committee for standardization; 1996.
[7] Kalaycıoğlu H, Nemli G. Producing composite particleboard from kenaf (*Hibiscus cannabinus* L.) stalks. Ind Crops Prod 2006;24(2):177–80.
[8] Boquillon N, Elbez G, Schönfeld U. Properties of wheat straw particleboards bonded with different types of resin. J Wood Sci 2004;50(3):230–5.
[9] Tabarsa T, Jahanshahi S, Ashori A. Mechanical and physical properties of wheat straw boards bonded with a tannin modified phenol–formaldehyde adhesive. Compos Part B 2011;42(2):176–80.
[10] EN 312-4. Particleboards-specifications. Part 4. Requirements for load-bearing boards for use in dry conditions. Brussels, Belgium: European committee for standardization; 1996.
[11] Zheng Y, Pan Z, Zhang R, Jenkins BM, Blunk S. Properties of medium-density particleboard from saline Athel wood. Ind Crops Prod 2006;23(3):318–26.
[12] Nemli G. Effects of some manufacturing factors on the properties of particleboard manufactured from alder (*Alnus glutinosa subsp*. Barbata). J Agr Forestry 2003;27(2):99–104.