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Properties of Three-layer Particleboard Made from Wood of Athel (*Tamarix aphylla*) and Pruning Particles of Almond (*Amygdalus communis*) and Pistachio (*Pistacia vera*)

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ABSTRACT

This study investigated the effects of particle sizes of Athel wood, Almond and Pistachio pruning shavings used in surface layers and also them mixture ratios with poplar (*Populus deltoids*) particles used in core layer on some of the physical and mechanical properties of three-layer particleboard. Commercial urea formaldehyde (UF) adhesive was used as binder. The results showed that slenderness and compaction ratios increased and instead bulk density and specific surface decreased with increment of particle size and also proportion of poplar to other particles. Significant differences found between the values of all properties of the panels ($P < 0.05$). The thickness swelling and mechanical properties of boards improved with the increase of slenderness and compaction ratio and decrease of bulk density and specific surface area, but instead water absorption of boards increased. Decreasing of particle sizes usage in the surface and increasing of Almond and Pistachio pruning particles usage in the core negatively affect the thickness swelling and mechanical properties of board. Decreasing of particle sizes improved water absorption of board. The optimized panel properties was obtained with 80-90 percent poplar particles and 10-20 percent Athel, Almond or Pistachio pruning particles in core with fraction size of 4pass/on2 mm in surface, exceeded the EN Standard for Wood Particleboard.

KEY WORDS: Pruning particles; Particleboard; Physical properties; Mechanical properties.

INTRODUCTION

The raw wood material demand of the forest product industry increases annually. Enhance, attention can be toward the utilization of non-wood fiber supplies such as agricultural residues (bagasse and wheat straw) not only in forest deficient countries but also in forest rich countries [1-9]. Environmentally, useful lignocellulosic resources are available in different forms of non-wood based on agricultural residues [10].

At the same time, the feasibility of using fast-growing trees as raw materials for particleboard production has been explored by a number of researchers [11]. Pugel et al. [12-13] reported that the overall strength property and water resistance of the wood composite made from southern pine (*Dendroctonus frontalis* Z.) juvenile trees were similar to or better than those of mature wood composites. Red pine (*Pinus resinosa*) thinning had similar properties to aspen when it was used as a raw material for laboratory waferboards bond with phenolic resin [14]. Zheng et al. [15] reported that saline Athel wood was an appropriate material for manufacturing particleboards.

There are several particleboard factories in the north of Iran. However, limitations in forest area and available volume of trees make the provision of raw materials for the particleboard industries a special challenge in Iran [16]. Pistachio and Almond prunings are two types of lignocellulosic agricultural residues which could replace wood as the raw material for particleboard production. These species are traditionally cultivated plants in the different regions of Iran. They cover large areas of land and are cultivated for fruit production. Large quantities of lignocellulosic prunings remain in the fields every year in February after pruning.

The Athel tree as a fast-growing tree is an evergreen tree that grows in the center and south of Iran. Athel has high ash (30–40%) and salt content which make difficulty to burn it even when it is dry [17]. This indicates that the Athel based particleboard have superior fire retardant and other beneficial characteristics. Silica, phenol and some oxidants, i.e: CuO, CrO_3, and As_2O_5 in Athel have been reported to have significant effects on improving the mechanical properties, water resistance properties, and decay resistance of particleboard [18-21]. To our knowledge, there is no literature on the feasibility of using saline Athel, Almond and Pistachio pruning as a raw material with Poplar wood for particleboard. Therefore, the aim of this study is to investigate the potential utilization of Pistachio and Almond prunings and Athel

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wood with Poplar wood in tree-layer particleboard production as supplement and to alleviate the shortage of raw material in forest industry.

METHODOLOGY

The Pistachio and Almond prunings were collected from Yazd (Yazd province, Iran), Athel wood particles from Zabol (Sistan and bluchestan province, Iran) and Poplar wood from the west of Iran. A commercial hacker was used to initially break the Poplar wood down and then hand tools were used to produce small slivers. Pistachio, Almond and Athel logs were cut into short logs of approximately 30 cm length using belt saw. Short logs then were reduced to small shavings using a planer. Poplar slivers, Pistachio, Almond and Athel planer shavings were then classified by using a sieve with screen aperture of 4 mm; wood particles remaining on this sieve were used to form core layer of the boards. Pistachio, Almond and Athel planer shavings were used in the ratios of 10:90, 20:80 and 30:70 to Poplar slivers in core layer. The Pistachio, Almond and Athel planer shavings which remained on 2 and 0.5 mm sieves, respectively, were used in surface of three-layer panel production. After these processes, all of the particles were dried with a laboratory made hot air dryer from moisture ranged between 40 and 50% down to 3% moisture content.

The slenderness ratio (SR) of the particles used in core and surface layers was calculated by the simple equation taken from Moslemi [22], shown in Equation:

$$SR = \frac{length}{thickness} \quad (1)$$

The specific surface area, S_p, of poplar, Athel, Almond and Pistachio particles with different sizes were determined using following equation:

$$S_p = \frac{\sum_{i=0}^{n} F_{out}\, i}{\sum_{i=0}^{n} mi} \quad (2)$$

where F_{out}i, is the total surface area of the particles, and *m*i is the weight of particles.

Then, bulk density (BD) of the particles used in core layer and surface layers was determined by filling them in a beaker of volume of 500 cm^3 with occasional tapping and weighing them. The weight of particles was measured with moisture content at 25 ± 2 °C at 60 ± 10% humidity. Three measurements were made for each sample.

In the production of experimental panels; urea formaldehyde (UF) resin, at 60% solids, was used as a binder. Based on oven dry particle weight, 7% and 11% UF resin were applied by atomizing spray gun for the core and surface layers, respectively. Average resin content used for each board was approximately 8%. As a hardener, 35% of ammonium chloride solution, which was 1% of the oven dry weight of particles, was used.

The mat configuration was three-layers and formed by hand distribution after adhesive application. The shelling ratio (outers : core) was 40:60%. The target board thickness (19 mm) was achieved in 5 min under pressure of 25-30 kg/cm^2 at 140 ± 5ºC. Experimental panels were then trimmed and kept in the condition of 20 ± 3ºC and 65 ±5% relative humidity for 48h. The target board density was 0.65 g/cm^3. After conditioning, test samples were cut from the particleboards and the following properties were determined in accordance with appropriate EN standards: static bending MOR, MOE (EN 310, 1993), IB (EN 319, 1993), TS and WA (EN 317, 1993) [23-25]. 18 board formulations with three replications were manufactured based on above-mentioned variables.

Statistical analysis: Multifactor analysis of variance was used "($P \leq 0.05$)"to test for significance between factors and levels. When the variance analysis indicated a significant difference among factors and levels, a multiple comparison of the means was performed employing a Tukey's test to identify which groups were significantly different.

RESULTS AND DISCUSSION

Table 1 gives the bulk density, compaction ratio, slenderness ratio and specific surface of the particles collected from each sieve. The larger particles in length and width gave the lowest bulk density in the present study. Adverse relation between bulk density and particle size has been reported by Olorunnisola [26]. The compaction ratio gives an index of assessing the effect of wood species and particle size on the bulk density of the particles produced in the same way. According to this, finest Almond and Pistachio particles had much lower compaction ratio (2.5 and 2.6, respectively) than Athel particles and the others coarser particles. The slenderness ratio increased with the increase of particle size (from 57 to 109). The slenderness ratio of particles remained on sieve with aperture 4 mm and passed through sieve with aperture 4 mm was higher than particle passed through sieve with aperture 2 mm. Also, the specific surface area of course particles was lower than fine particles of the same species.

The average values of mechanical properties (modulus of elasticity, modulus of ruptures, internal bonding) and physical properties of panels (water absorption and thickness swelling after 2 and 24h water soaking) are shown in Table

2. Multifactor analysis of variance on the effects of wood species, ratio of particles in core layer and particle size in surface layers on the static bending, modulus of elasticity, internal bonding, thickness swelling and water absorption of the particleboards are given in Table 3. Also, Table 4 displays the results of statistical analysis for different variables.

Table 1. Bulk density, compaction ratio, slenderness ratio and specific surface of wood particles

Species	Particle size (mm)	BD (kg/m^3)	Compaction ratio in core	surface	SR	S_p (m^2/g)
Athel	4-2	148	-	5.4	73	1.75
	2-0.5	198	-	4	62	2.53
	>4	113	3.2	-	71	0.56
Almond	4-2	234	-	3.4	69	1.56
	2-0.5	321	-	2.5	57	2.35
	>4	178	2.8	-	64	0.62
Pistachio	4-2	225	-	3.5	69	1.61
	2-0.5	308	-	2.6	57	2.41
	>4	163	3	-	64	0.59
Poplar	>4	40	12.5	-	109	0.74

Table 2: Mechanical and physical properties of experimental panels

Panel type	Species	Ratio of particles in core layer (%)	Particle size in surface layers (mm)	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	TS (%) 2h	TS (%) 24h	WA (%) 2h	WA (%) 24h
A1	Athel	10	2	15.71	2823	0.66	4.23	9.41	35.41	46.67
A2	Athel	20	2	13.24	2741	0.51	5.65	10.98	28.72	40.12
A3	Athel	30	2	11.35	2474	0.42	6.33	11.67	20.47	29.34
A4	Athel	10	0.5	14.74	2431	0.65	5.03	10.34	29.54	40.34
A5	Athel	20	0.5	13.18	2274	0.53	5.97	11.78	23.74	32.12
A6	Athel	30	0.5	10.12	1823	0.41	6.59	12.34	17.63	26.89
B1	Almond	10	2	14.83	2743	0.48	7.04	15.47	47.43	59.56
B2	Almond	20	2	12.21	2534	0.41	7.56	15.89	42.01	52.23
B3	Almond	30	2	9.75	2429	0.32	7.97	17.23	38.53	46.42
B4	Almond	10	0.5	12.54	2527	0.49	7.35	17.98	41.74	55.19
B5	Almond	20	0.5	10.95	2175	0.38	8.24	18.00	36.47	49.12
B6	Almond	30	0.5	7.84	1733	0.29	9.46	19.21	29.69	42.23
C1	Pistachio	10	2	13.65	2785	0.52	7.21	15.78	46.56	57.98
C2	Pistachio	20	2	11.98	2542	0.39	7.96	16.34	41.48	53.34
C3	Pistachio	30	2	9.84	2336	0.31	8.00	17.67	34.73	46.11
C4	Pistachio	10	0.5	11.95	2574	0.49	7.87	16.43	39.52	51.39
C5	Pistachio	20	0.5	9.68	2171	0.38	9.91	18.98	31.41	45.67
C6	Pistachio	30	0.5	7.94	1723	0.27	10.4	19.56	27.77	40.11

Table 3. Multifactor analysis of variance own to effects of wood species, ratio of particles in core layer and particle size in surface layers on the physical and mechanical properties.

Tests	Source of variation	F-Ratio	Significant Level
Modulus of rupture	Wood species	33.45	*
	Ratio of particles in core layer	21.45	*
	Particle size in surface layers	143.56	**
Modulus of elasticity	Wood species	26.34	*
	Ratio of particles in core layer	35.13	*
	Particle size in surface layers	146.23	**
Internal bonding	Wood species	45.67	**
	Ratio of particles in core layer	112.34	**
	Particle size in surface layers	23.56	*
Thickness swelling (TS2)	Wood species	54.35	**
	Ratio of particles in core layer	83.98	**
	Particle size in surface layers	51.34	**
Thickness swelling (TS24)	Wood species	48.23	**
	Ratio of particles in core layer	103.48	**
	Particle size in surface layers	63.45	**
Water absorption (WA2)	Wood species	34.56	*
	Ratio of particles in core layer	145.23	**
	Particle size in surface layers	93.45	**
Water absorption (WA24)	Wood species	26.34	*
	Ratio of particles in core layer	151.34	**
	Particle size in surface layers	74.34	**

** = $p \leq 0.01$, * = $p \leq 0.05$

Based on EN Standards, 11.5, 13 and 1600 N/mm^2 are the minimum requirements for MOR and MOE of particleboard panels for general uses and furniture manufacturing, respectively (EN 312-2; EN 312-3) [27-28]. Experiment panels had higher MOR than the general purpose requirements with exception of A3, A6, B3, B5, B6, C3, C5 and C6. The range of data in the MOR and MOE was from 7.94 to 15.71 and 1723 to 2823 N/mm^2, respectively. As can be seen from Table 2, all type of panels met the minimum MOE requirement of the EN Standards for general uses.

Table 4. The statistical analysis of the properties for different variables.

Variables		MOR (MPa)	MOE (MPa)	IB (MPa)	TS (%)		WA (%)	
					2h	24h	2h	24h
Wood species:	Athel	13.06a	2427a	0.53a	6.00a	11.09a	25.92a	35.91a
	Almond	11.35b	2356b	0.39b	7.94b	17.30b	39.31b	50.79b
	Pistachio	10.84b	2355b	0.39b	8.56c	17.46b	36.91c	49.10b
Ratio of particles in core layer:	10:90%	13.9c	2647c	0.55c	6.45d	14.23c	39.99d	51.85c
	20:80%	11.87d	2406d	0.43d	7.55e	15.33d	33.97e	45.43d
	30:70%	9.47e	2086e	0.37e	8.13f	16.28e	28.14f	38.52e
Particle size in surface layers:	2 mm	12.51f	2601f	0.47f	6.88g	14.49f	37.26g	49.33f
	0.5 mm	11g	2159g	0.43g	7.87h	16.07f	30.83h	43.88g

Different letters represent statistical significance.

The range of data in IB was from 0.27 to 0.66 N/mm^2 (Table 2). The IB requirements are 0.24 N/mm^2 for general purpose boards, 0.35 N/mm^2 for interior fitments, load-bearing boards and 0.50 N/mm^2 for heavy duty load bearing boards according to EN 312-2 (1996), EN 312-3 (1996), EN 312-4 (1996) [29], EN 312-6 (1996) [30], respectively. All of the particleboards produced from Athel wood particles, Almond and Pistachio prunings particles had higher IB than the requirement for general purpose. The A1, A2, A4, A5 and C1 type panels satisfied the EN 312-6 (1996) requirement for heavy duty load bearing boards.

In addition, the results showed that mechanical properties (MOR, MOE and IB) statistically (P <0.05) decreased as the ratio of Athel wood particles, Almond and Pistachio prunings particles increased in the core layer. Results also showed a statistically reduction in MOR, MOE and IB when applied particle size in surface layers decreased from >2 mm to > 0.5 mm (Table 4).

This result supports the conclusions reached by Mottet [31] and Brumbaugh [32], which reported that fine particles decrease the modulus of rupture and modulus of elasticity due to low amount of woody cells and short fibers. In fact, the slenderness ratio of longer particles (poplar particles in core layer and Athel, Almond or Pistachio particles with dimension of > 2 mm in surface layers) was relatively higher than others wood particles in core and surface layers. As the load was applied perpendicular to the board surface, it creates compression stress on the top side of the board which transformed into tension stress at the bottom after exceeding the middle portion. Since load stresses are transferred from one particle to another, the length of particles functions as a medium for load transfer. Longer particles will be able to support greater stress, thus, resulting in greater MOR. With increasing the ratio of poplar slivers in core layer and increasing in length of Athel, Almond and Pistachio particles in surface layers, slenderness ratio increased, so that boards made from these particles had higher MOR (Tables 2 and 4). These particles had better inter-particle bonding which resulted in high MOR values. Barnes [33] and Yadama [34] determined that particles have to be sufficiently long to allow adequate overlap for transfer of applied stress from one particle to the next. The effect of particle size on strength properties has also been investigated by Liiri et al. [35] and Niemz et al. [36]. They mentioned that the best bending strengths can be achieved when longer and thicker particles are used.

Adcock and Irle [37] and Jossifov [38] mentioned that the compaction ratio and specific gravity are important variables that affect the bending strength. They concluded that with the increasing compaction ratio, the bending strength increases as well. The higher the proportion of shorter particles, the higher the bulk density is. This is due to the fact that shorter particles make denser structures between particles. On the other hand, a higher proportion of coarse particles would result in a lower bulk density due to the abundance of longer particles, which makes looser structures between particles [39]. In this study, modulus of rupture, modulus of elasticity and internal bonding of panels increased with decreasing in particle bulk density used in surface layers. This could be due to a compaction of longer particles that could create larger bond area between particles and subsequently produce a larger contact surface which finally results in higher board strength. The specific surface area for finer particles (> 0.5 mm) is larger than that of coarser particles (<4 mm) due to the much larger fiber cross sections. It is well known that resin consumption is mostly affected by the specific surface area of wood particles. In addition, decreasing surface area usually increases the resin content per unit surface area and will generally result in better mechanical properties of panels. According to formula No. 2, it is assumed that the particles shape in lateral and cross section is square and lateral and end surfaces of particles do not contribute significantly to the adhesion. Xing et al. [40] suggested that the specific surface area (m^2/g) for longer fibers is lower than that of shorter fibers for the same species due to the much larger fiber cross sections.

The WA and TS values observed in the composites are shown in Table 2. Based on EN Standards, particleboard should have a maximum TS value of 8% for 2h immersion. The maximum thickness swelling values for 24h according to EN 312-4 (1996) is 15%. Average thickness swelling of the specimens for 2 and 24h immersion ranged from 4.23% to 10.43% and from 9.41% to 19.56%, respectively. Except for board types B1 - C6, other boards satisfied the thickness swelling requirement of EN 312-4 (1996). The board made from 10% Almond shavings in core layer and >2 mm shavings in surface layers (B1), absorbed higher water at 2 and 24h than others. Decreasing in ratio of Almond, Pistachio or Athel particles in core layer and also increasing in particle size in surface layers statistically (P<0.05) improved thickness swelling, but enhanced values of water absorption (Table 4).

This could be attributed to their lower bulk density of coarser poplar particles (>4 mm) used in core and particles used in surface layers (>2 mm), hence, higher porosity already alluded to. In fact, the highly porous structure allows easy penetration and uptake of water. Particleboards consisting 30% Almond and Pistachio shavings in core layer and <2 mm particles in surface layers had lower internal bond strength and higher thickness swelling values than those panels consisting of lower amount of the these shavings and particles. This could be related to more resin absorbing of shavings than long poplar slivers in core layer. The same results have been reported by Wang and Sun [4]. According to their study, the surface areas of coarser particles were too large to be adequately covered by the adhesives when the same mass ratio of adhesives and particles was used.

Finer and shorter Athel, Almond and Pistachio shavings fill the pores between the thick and long poplar slivers in the core layer. Consequently contacts between the blended particles in this layer increase [41]. Generally, finer particles have low amount of woody cells. For this reason, they absorb less water than thick particles.

CONCLUSIONS

Based on the results of this study, the following conclusions can be drawn.
The particleboards met the minimum modulus of rupture and modulus of elasticity of EN standards except for panels A3, A6, B3, B5, B6, C2, C3, C5 and C6. The internal bond strength values were higher than the values reported by the standards. All of the particleboards satisfied the thickness swelling requirement with the exception of panels B5, B6, C5 and C6.

The bulk density, compaction ratio, specific surface and slenderness ratio of the particles are believed to have been the main cause of change in mechanical and physical properties of boards. With increase of compaction ratio and slenderness ratio in core and surface layers, mechanical properties and thickness swelling of particleboard improved. Increasing the mean bulk density and specific surface of particles in core and surface layers, the mechanical properties of board decreased.

Wood species had significant effects on the strengths and physical properties of the composites. The boards made from Poplar + Athal particles in core layer with ratio of 90:10 (by weight) and 2pass/on0.5 fraction size of Athel particles in surface layers had the highest modulus of rupture, modulus of elasticity, internal bonding strengths, and the lowest thickness swelling.

Addition of 30% Athel wood particles in core and 2pass/on0.5 fraction size of Athel particles in surface layers had the most significant positive effects on the water absorption of composite.
In addition, increasing of particle sizes in surface layers and decreasing of amount of Athel, Almond and Pistachio wood particles in core layer improved the thickness swelling and mechanical properties, but increased water absorption of particleboards, significantly. Modulus of rupture, modulus of elasticity, internal bonding, water absorption and thickness swelling of boards were significantly (P<0.05) affected by wood species, quantity of wood species in core and particle size in surface layers.

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