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Investigation of the usability of apple tree pruning chips as an alternative raw material to produce cement-bonded particleboard

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Abstract: The utilization of apple tree pruning as an alternative raw material to produce cement-bonded particleboard was investigated. Experimental cement-bonded particleboards measuring 500×500×12 mm with a nominal density of 1400 kg/m³ were prepared in laboratory conditions using different ratios (100/0,75/25,50/50,25/75,0/100) of apple tree pruning chips mixed Red Pine wood chips. The following basic properties required by the TS EN 312 standards were evaluated; water absorption, thickness swelling, bending properties, and screw withdrawal strength. Results of the study indicate that the addition of apple pruning in the mix of cement-bonded particleboard significantly influences the properties tested. Mechanical properties of the tested boards decreased while absorption and thickness swelling values of the cement-bonded particleboard were increased as the portion of apple pruning in the mixture was increased. Experimental boards which include apple tree pruning up to 25 % still meet properties required by the standards for general purpose-use cement-bonded particleboards. Apple tree pruning chips may be an alternative raw material for the manufacturing of cement-bonded particleboard.

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Elma ağacı budama yongalarının çimentolu yonga levha üretimi için alternatif ham malzeme olarak kullanılabilirliğinin incelenmesi

Anahtar Kelimeler
Elma budaması
Çimentolu yonga levhalar
Fiziksel ve mekaniksel özellikler

Makale geçmişi:
Geliş Tarihi: 04.11.2022
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Öz: Elma ağacı budamasının, çimentolu yonga levha üretiminde alternatif ham malzeme olarak kullanımı araştırılmıştır. Nominal yoğunluğu 1400 kg/m³ ve ölçüleri 500×500×12 mm olan deneysel çimentolu yonga levhalar, Kızılçam ahşabı ile elma ağacı budama yongalarının farklı karışım oranlarını (100/0,75/25,50/50,25/75,0/100) kullanılarak laboratuvar şartlarında hazırlanmıştır. Temel özellikler; su emme, kalınlığa şişme, eğilme özellikleri ve vida çekme direnci TS-EN-312 standardının gerekliliklerine göre incelenerek değerlendirilmiştir. Çalışma sonuçları, çimentolu yonga levha karışımına elma budama yongası eklenmesinin test edilen özellikleri önemli ölçüde etkilediğini göstermiştir. Karışım içndeki elma budama oranının artışı, çimentolu yonga levhaların kalınlığa şişme ve emme değerlerini arttırırken mekanik özelliklerini azaltmıştır. %25 elma budaması içeren deney levhaları ise genel kullanım amaçlı çimentolu yonga levhalar için standartların gerektirdiği özellikleri sağlamaktadır. Elma ağacı budama yongaları çimentolu yonga levha üretimi için alternatif bir hammadde olabilir.

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1. Introduction

Cement-bonded particleboard (CBP) is a composite that combines wood and cement in order to achieve the advantageous properties of both constituents. While inorganic bonded wood-based panels have been used since the 1900s, CBP was first produced by Switzerland-based Durisol in 1970 under the trade name Duripanel. CBP is fire, moisture, impact, and decay-resistant. It is also cheaper but heavier than particleboard which is produced using organic resins [1]-[5]. The compatibility of wood and cement is the main issue for the physical and mechanical performance of CBP [6] Chemical composition of wood, particularly, water-soluble compounds may cause inhibition of cement hydration [7]. Pretreatments such as cold and/or hot water applied to the wood particles, the addition of some chemicals such as $CaCl_2$, the use of CO_2, and the addition of superplasticizers may accelerate setting or lowers inhibition. Studies have shown that mechanical interlocking and hydrogen bridges mostly control the bonding, thus the properties of the cement-bonded wood products [7].

The decline of wood resources forces researchers to investigate alternative raw materials which may be utilized in the wood composite industry. A wide variety of materials such as agricultural residues, plantation of fast-growing and annual plants, and recycled wood products were subjected to investigations in order to find technically and economically feasible, ecologically friendly alternative raw materials which can be used in the manufacturing of wood-based composites. During the last few decades, properties of composites manufactured from a wide variety of plant-based raw materials have been technically found sufficient [8]. Although the availability and low density of agricultural residues seem to be advantageous, composites manufactured from these materials inherit inferior properties [9]. The collection and transport of these materials are major obstacles to the utilization of these raw materials in the composite industry [10].

Literature concerning the utilization of woody materials in the production of cement-bonded particleboard is scarce. Grapevine stalks [11] pruning of Acacia salicina, Ficus altissimo, Pithecellobium dulce, and Tamarix aphylla [12] date palm fronds and pruning of buttonwood [13], oil palm veins [14], sunflower stalks [15] have been investigated for their suitability for the production of cement bonded particleboard and found technically appropriate. Most of the references given above-used pretreatments such as cold or hot water to the particles in order to overcome inhibition. Titanium oxide nanoparticles [16] and nano SiO2 [17] were also found promising in order to improve the physical and mechanical properties of cement-bonded particleboard produced from agricultural waste.

According to [18] apple pruning is one of the most abundant biomass available in Turkey and is usually less efficiently utilized by burning. Utilization of apple pruning in the production of organic bonded particleboard was the subject of several investigations [19], [13], [16], [20] and found technically suitable in the manufacture of particleboard, but their use in the cement bonded particleboard has been never investigated. In this study, the use of particles produced from apple pruning with or without wood particles was investigated in the production of cement-bonded particleboard.

2. Materials and Methods

The study consisted of two consecutive stages. In the first stage, experimental cement-bonded particleboards measuring 12 mm x 500 mm x 500 mm were produced in laboratory conditions using coarse particles, commercial cement (CEM I 42.5), tap water, and an accelerator. The ratio of apple pruning particles mixed with the wood particles was 0, 25, 50, 75, and 100 % based on the wood particle weight. The following parameters were used for the board production; wood particles/cement ratio was 1:2 and 1:3; water/cement ratio was 1:2.5 and target density was 1.4 g/cm^3. 5% of calcium chloride ($CaCl_2$) additive based on cement mass was dissolved in the tap water before mixing.

Coarse particles of Red pine (*Pinus brutia*) wood which were utilized as core layers of particleboard were supplied from a local particleboard factory. Apple pruning which was gathered from a close field was dried and passed through a hammer mill and screened. Pruning particles remaining between 3-5 mm sieves were used in the experiments.

In order to prepare experimental cement bonded boards; First, wood and pruning particles were mixed and sprayed with tap water which include a previously dissolved accelerator. Then, cement was added to the mixture until a homogeneous distribution was obtained. After 10 minutes of mixing, the fresh paste was spread in a steel frame by hand. The mixture placed between steel plates was allowed for curing for 24 hours under the pressure of 1.8-2.0 N/mm^2. The hardened boards were conditioned in the laboratory climate at approximately +20 °C, RH 65%. Samples were cut after conditioning to the required size in order to determine some physical and mechanical properties.

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In the second stage, some physical and mechanical properties of the experimental boards were obtained. Apparent density, water absorption (WA) after 24 hours of immersion in water [21], thickness swelling (TS) after 24 hours of immersion in water [21], modulus of elasticity [22], and modulus of rupture [22] in bending (MOE and MOR) and screw withdraw strength (WS) were determined according to conforming standards.

Five replicates were tested for each property and obtained data were subjected to statistical analysis. Experimental results were analyzed using ANOVA tests to identify their statistical significance. DUNCAN's multiple range tests were performed in order to find the least significant difference between all the variables. The obtained results were also confronted with standard values of TS EN 634-2[23].

3. Results and Discussions

Table 1. shows some physical properties of the laboratory manufactured cement bonded particleboard samples as changing with different wood/cement ratios and wood/pruning ratios. The density of the experimental boards ranges from 1258 kg/m^3 to 1407 kg/m^3 and is not significantly different among the tested group.

Test results indicate that the addition of apple pruning to the wood cement mixture significantly influences the water absorption capacity of the cement-bonded particleboards ($P<0.001$; R Squared = 0.92). WA values (%) of the manufactured boards after 24 hours of immersion in water were significantly increased as the amount of apple pruning particles used in the mixture is increased ($P<0.001$; R Squared = 0.92). Experimental boards without apple pruning had the lowest WA values than other groups. The addition of apple pruning increases WA (%) properties almost linearly (Figure 1). TS values (%) of the manufactured boards were significantly affected by the proportion of apple pruning used in the study ($P<0.001$; R Squared = 0.93). Experimental boards made of 100% apple pruning had the highest TS values after 24 hours of water immersion. Higher WA and TS values may be attributed to the chemical composition of the apple pruning. According to Sahin and Arslan [19] apple pruning has similar chemical properties as softwood/hardwood, but they contain higher percentages of short-chain carbohydrates and higher solubility values compared with softwood/hardwood. Higher solubility may interfere with the cement-water interaction, and thus may cause inhibition.

Table 1. Some physical properties of the cement-bonded particle boards manufactured

Cement/particle ratio	Wood/pruning ratio	Density (kg/m^3)	WA (%)	TS (%)
1/2	100/0	1258 (18.3)	10.9 D (0.29)	6.78 D (0.54)
	75/25	1291 (37)	16.99 C (1.01)	7.67 D (0.9)
	50/50	1307 (52.16)	19.79 C (2.34)	11.13 C (1.05)
	25/75	1325 (25.65)	23.29 B (4.02)	13.03 B (1.53)
	0/100	1349 (36.87)	31.03 A (2.53)	17.55 A (1.15)
1/3	100/0	1407 (7.46)	9.02 D (0.99)	4.53 D (0.43)
	75/25	1399 (27.82)	14.1 C (0.77)	4.68 D (0.54)
	50/50	1388 (34.26)	14.25 C (1.19)	6.39 C (0.72)
	25/75	1384 (48.88)	15.21 B (1.55)	7.22 B (1.4)
	0/100	1375 (69.43)	20.55 A (2.09)	9.51 A (2.08)

Values in parenthesis are standard deviations and capital letters are representing Duncan's Groups

In general, higher WA and TS values are the result of higher particle content [24], [25], [26]. Some chemical additives besides the type of wood particle and wood-cement ratio may also influence WA capacity [26] and higher cement content in the mixture diminishes TS of cement-bonded particleboard [24]. A high swelling rate may also be due to the higher density [27] because of the higher compression exposed during production. A higher TS ratio may be also attributed to the high amount of $CaCl_2$ used which is highly hygroscopic [28]. It seems that none of the tested boards fulfills the TS requirement of the standard [23]. It should be mentioned that the tested boards were manufactured with coarse particles which had not been subjected to any type of pre-treatments. Industrial scale production of the boards or application of any pre-treatments may result in boards with standard properties for TS.

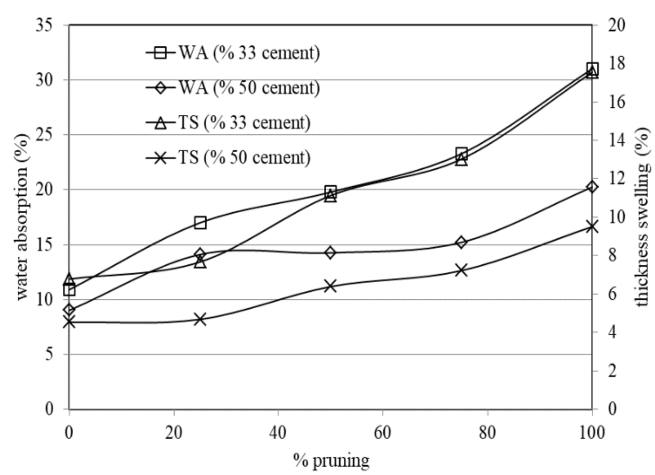

Figure 1. WA and TS values of the experimental boards with respect to the apple pruning ratio

The bending properties and screw withdrawal strength of cement-bonded particleboard are presented in Table 2. A higher cement ratio seemed to yield better mechanical properties for the boards tested. In general, the MOE of the cement-bonded particleboards was significantly reduced by the addition of apple pruning (P<0.001; R Squared = 0.83). The addition of apple pruning also significantly drops the MOR of the cement-bonded particleboards (P<0.001; R Squared = 0.913). The decrease in both properties with the addition of apple pruning is almost linear (Figure 2). The addition of apple pruning to the mixture lowers both stiffness and strength, but boards still carry the minimum bending properties required by the standards [23] when they are used in a higher cement ratio. Mechanical properties of the cement-bonded particleboards manufactured with 100% apple pruning particles were inferior to other groups tested.

Table 2. Some mechanical properties of the cement-bonded particle boards manufactured

Cement/particle ratio	Wood / running ratio	Density (kg/m³)	MOE (N/mm²)	MOR (N/mm²)	WS (N)
1/3	100/0	1258 (18.3)	4205 A (291)	11.21 A (0.56)	1395 A (85)
	75/25	1291 (37)	3962 AB (283)	10.82 AB (0.35)	1366 AB (62)
	50/50	1307 (52.16)	3664 BC (187)	9.64 BC (0.85)	1225 BC (59)
	25/75	1325 (25.65)	2733 C (180)	8.11 CD (0.66)	1149 CD (123)
	0/100	1349 (36.87)	1669 D (175)	6 D (0.46)	732 D (90)
1/2	100/0	1407 (7.46)	5152 A (1001)	11.18 A (2.02)	1376 A (256)
	75/25	1399 (27.82)	4857 AB (628)	10.41 AB (1.21)	1300 AB (200)
	50/50	1388 (34.26)	4296 BC (255)	10.24 BC (1.21)	1122 BC (128)
	25/75	1384 (48.88)	4234 C (538)	8.48 CD (1.67)	823 CD (241)
	0/100	1375 (69.43)	3529 D (523)	7.12 D (0.67)	760 D (340)

Values in parenthesis are standard deviations and capital letters are representing Duncan's Groups

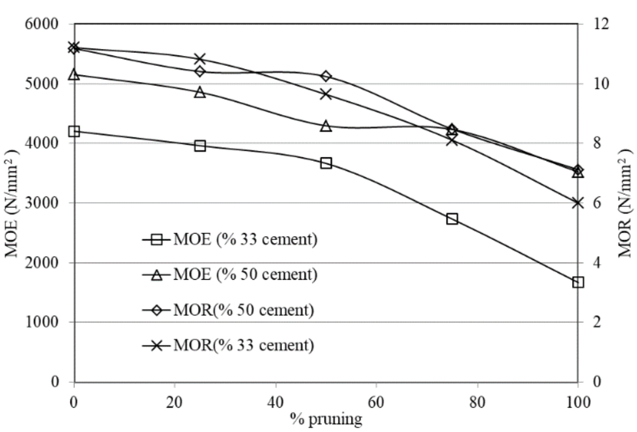

Figure 2. Effects of apple pruning on the bending properties of cement-bonded particleboard

In general, stiffer cement-bonded boards may be obtained with decreasing particle content [29] or density increase, and higher MOR may be achieved using lower cement content [24],[30]. According to Bejo et al. [31], improved bonding between cement matrix and wood, thus better mechanical properties may be attained when the densification of the board increases. A possible contributory factor to the relatively low bending properties of the boards could be higher percentages of short-chain carbohydrates and higher solubility values [19]. Kochova et al. [32] also hold carbohydrates, especially the amount of sucrose, glucose, and fructose responsible for the lower mechanical properties. Liu and Moslemi [33] also mentioned that decreasing strength is a result of sugars. Olorunnisola [34] and Ashori et al. [35] claims that water-soluble extractives play an important role in the inhibition of cement thus, low strength. Reduction in mechanical properties with the addition of apple pruning particles may be prevented by the application of pre-treatments which were found adequate for many lingo-cellulosic materials [36], [1],[37], [38].

In the study, the WS of the cement-bonded particleboards was significantly reduced by the addition of apple pruning (P<0.001; R Squared = 0.899) as seen in Figure 3. WS is an index of internal bond strength and can be influenced by density, water/cement ratio, type of cement, use and ratio of accelerators, and type and dimensions of the wood particles [35], [28]. The decrease in WS could be an indication of poor bonding between apple pruning particles and cement. As shown in Table 2, the strength and stiffness values of all-wood boards meet the minimum requirements set by the standard [23]. and experimental boards containing 25% of apple pruning also fulfill the standard requirements. Dimensional stability and bending properties of adhesively bonded particleboard which contains apple pruning showed similar tendencies [19].

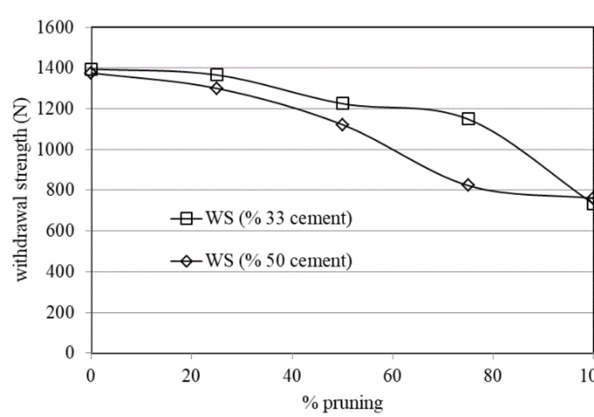

Figure 3. Effects of apple pruning on the withdrawal strength of the cement-bonded particleboards

4. Conclusions

This study explored the possible utilization of apple pruning in cement-bonded particleboard production, under laboratory conditions. Based on the results of the study, the addition of apple pruning to wood cement mixture significantly increases WA and TS properties and reduces the mechanical properties of cement bonded particleboard tested. Short-chain carbohydrates or extractives may be responsible for higher water uptake and lower mechanical properties. Undesirable board properties may be improved by some pretreatments such as hot or cold water applied to the pruning particles. The utilization of fine particles in the production may also improve the board's properties. Utilization of pruning in the manufacturing of value-added products such as cement-bonded particleboard may reduce pressure on deforestation, increase the value of pruning by utilization instead of burning and reduce the amount of waste deposited in the environment or reduce pollution.

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