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Sunflower (*Helianthus Annuus*) Stalks as Alternative Raw Material for Cement Bonded Particleboard

Suncokretove stabljike (*Helianthus annuus*) kao alternativna sirovina za cementom vezane ploče iverice

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ABSTRACT • *Sunflower stalks (Helianthus annuus) were studied as an alternative raw material for cement bonded particleboard. Experimental cement bonded particleboards measuring 500 mm × 500 mm × 12 mm with nominal density of 1300 kg/m³ were produced using different ratios of sunflower stalk particles with wood. Properties of the cement bonded particleboards evaluated include water absorption, thickness swelling, screw withdrawal strength and bending properties. Results of the study showed that the addition of small amount of sunflower stalks in the production of cement bonded particleboard does not significantly influence the properties tested. Inclusion of more stalks in the mixture significantly decreases mechanical properties and raises thickness swelling and water absorption values of the cement bonded particleboard. Results indicate that boards which include a small amount of sunflower stalks provide properties required by the standards for general purpose-use cement bonded particleboards.*

Keywords: *cement-bonded particleboard; physical and mechanical properties; sunflower stalks*

SAŽETAK • *U radu se opisuje istraživanje stabljike suncokreta (Helianthus annuus) kao alternativne sirovine za proizvodnju cementom vezanih ploča iverica. Eksperimentalne cementom vezane ploče iverice dimenzija 500 mm × 500 mm × 12 mm i gustoće 1300 kg/m³ izrađene su s različitim omjerima iverja od suncokretovih stabljika i drva. Pritom su istraživana ova svojstva tih ploča iverica: sposobnost upijanja vode, debljinsko bubrenje, izvlačna sila vijaka i savijanje. Rezultati istraživanja pokazali su da mali dodatak suncokretovih stabljika u proizvodnji cementom vezanih ploča iverica ne utječe znatnije na ispitivana svojstva. Dodavanjem veće količine stabljika u smjesu bitno slabe mehanička svojstva te se povećava debljinsko bubrenje i upojnost cementom vezanih ploča iverica. Rezultati pokazuju da ploče s malom količinom suncokretovih stabljika zadovoljavaju propisane zahtjeve za opću uporabu cementom vezanih ploča iverica.*

Ključne riječi: *cementom vezana ploča iverica; fizička i mehanička svojstva; suncokretove stabljike*

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1 INTRODUCTION
1. UVOD

The increasing demand for wood based products, due to the growth of world population and deforestation, requires development of more ecologically friendly building materials based on natural renewable raw materials. A wide variety of resources such as agricultural residues, plantation of fast growing and annual plants and recycling of wood products may be an alternative to wood. Thus, lately attention has been increasingly focused on the research for the development of new biosourced materials. During the last few decades, utilization of plant fibers such as flax, hemp, jute, corn stalks, etc. in the production of particleboard, medium density fiberboard, wood plastic composites, etc. has been widely investigated (Klimek and Wimmer, 2017). Although agricultural residues have some advantages such as availability, low density, etc., most of their properties are mostly inferior to other resources (Sun *et al*., 2013).

Wood-cement boards are usually made of wood fibers or particles mixed with cement, water and some additives in order to speed up the bonding process (Marteinsson and Gudmundsson, 2018). They have been already used almost everywhere in the world mainly for roofs, floors and walls (Nazerian *et al*., 2018). Their advantages compared to composites produced with organic resins including durability, dimensional stability, acoustic and thermal insulation properties and low production cost make them attractive (Lee, 1984; Ramirez-Coretti *et al*., 1998; Savastano *et al*., 2003; Okino *et al*., 2005; Del Menezzi *et al*., 2007).

Many alternative raw materials have been studied for suitability of possible use in manufacturing cement bonded particleboard for the last few decades. These include resources from those widely available such as wheat straw (Soroushian *et al*., 2004), to local ones such as tea residue (Yel *et al*., 2011). Most of these lignocellulosic raw materials, however, contain soluble sugars that inhibit cement hydration, thus resulting in undesirable board properties. According to Del Menezzi *et al*. (2007), extractives and polysaccharides inhibit the reaction between wood and cement. To overcome inhibition effects, several physical, chemical, and biological pretreatment methods (Moslemi *et al*., 1983; Lee, 1984; Zhengtian and Moslemi, 1985; Lee and Short, 1989) applicable on the woody particles have been developed, making possible the utilization of a wider variety of plant-based materials for cement bonded particleboard production.

According to Klimek and Wimmer (2017), sunflower stalks are one of the most abundant biomass available. Utilization of sunflower stalks in the production of organic bonded particleboard was the subject of several investigations (Gertjejansen *et al*., 1972; Gertjejansen, 1977; Khristova *et al*., 1996; Bektas *et al*., 2005; Güler *et al*., 2006) and sunflower stalks were 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 sunflower stalks with or without wood particles was investigated in the production of cement bonded particleboard.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Wood-cement composites measuring 12 mm × 500 mm × 500 mm with target density of 1300 kg/m^3 were prepared in the laboratory conditions. The amount of sunflower stalk particles added to wood particles was 0, 25, 50, 75 and 100 % based on the wood particle weight. The ratio between the wood/stalk particles and cement by mass were 1:3 and 1:2. Additional material as cement setting accelerator, $CaCl_2$, was used at the ratio of 5 % based on the cement weight. Water sprayed on to the mix was 40 % of the cement weight.

The cement used in the mixture was commercial Portland cement (CEM I 42.5). Red pine (*Pinus brutia*) coarse particles which, were used as core layers of commercial organic bonded particleboard, were obtained from a local particleboard factory. The size distribution of the wood particles used in the production of experimental panels is given in Table 1. Sunflower stalks were collected from Kahramanmaraş province. They were dried and passed through a hammer mill and screened. Stalk particles left between 3-5 mm sieves were used in the experiments.

Table 1 Size distribution of wood particles used in the study
Tablica 1. Udio pojedine veličine iverja upotrijebljenoga u istraživanju

Particle size, mm *Veličina iverja,* mm	%
6.3	0.62
4	4.53
2	28.55
1	48.86
0.85	6.5
0.5	8.35
0.25	1.76
0.125	0.83

The mixing of all samples was carried out as follow: First, wood and sunflower particles were mixed and sprayed with water containing accelerator. Then, cement was added and mixing continued until a homogeneous distribution. After mixing, fresh mixtures were cast to the forms and cured for 2 days. The amount of pressure provided during curing of the mixture was 1.8-2.0 N/mm^2. The cured boards were then left for conditioning in the laboratory climate at approximately 20 °C, relative humidity (RH) of 65 %. Cement bonded particleboards were cut down after curing to required size in order to determine some physical and mechanical properties.

The effects of sunflower stalks on water absorption and thickness swelling tests were determined on 50 mm × 50 mm samples according to TS EN 317, which is similar to ASTM D 1037. Water absorption and thickness swelling tests were conducted by submerging specimens horizontally in water at room temperature for 24 hours. After each submersion period, samples were drained of excess water and measured for change in thickness and amount of water absorbed.

The effects of sunflower stalks on modulus of elasticity and modulus of rupture (*MOE* and *MOR*) were evaluated using a three point bending test following TS EN 310. *MOE* and *MOR* were determined for each specimen using load–deformation curves. Screw withdrawal strength of the 50 mm × 50 mm samples was also determined. Five replicates were used for each test and the obtained data were subjected to an analysis of variance. 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.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Table 2 shows some physical properties of the laboratory manufactured cement bonded particleboard samples. Density of the manufactured boards ranged from 1257 to 1407 kg/m^3 and varied with the amount of the addition of stalk as well as wood to cement ratio.

The dimensional stability of the boards produced was measured using water absorption (*WA*) and thickness swelling (*TS*) tests. *WA* (%) values after 24 hours of soaking of the manufactured boards were significantly increased as the amount of sunflower particles used in the mixture increased (P<0.001; R Squared = 0.935). Boards containing no sunflower stalks had lower *WA* values than other groups.

Test results indicate that sunflower stalks significantly influence the *WA* capacity of the cement bonded particleboards (P<0.001; R Squared = 0.935). Since sunflower stalks have lower density than wood, increase of proportion in the mixture means more particles and thus more space for water molecules to bond. Addition of sunflower stalks creates more surfaces for potential engagement of water, thus yielding higher water absorption. According to Savastano *et al*. (2003), *WA* is increased by particle content increase. In general, *WA* capacity of cement-bonded particleboards decreased with the increase in cement content (Moslemi and Pfister, 1987; Olorunnisola, 2009). Some chemical additives besides type of wood particle and wood-cement ratio may also influence *WA* capacity (Olorunnisola, 2009).

24 hour *TS* (%) values of the manufactured boards were significantly affected by the proportion of sunflower stalks used in the study (P<0.001; R Squared = 0.696). *TS* values after 24 hours of soaking were the highest for the group containing 100 % sunflower stalks. Compared to the boards manufactured using 100 % wood particles with wood to cement ratio of 1:2, the addition of sunflower stalks to the mixture slightly lowers *TS* rate. Boards manufactured using 100 % sunflower stalks are an exception. In general, higher cement content in the mixture diminishes *TS* of cement bonded particleboard (Moslemi and Pfister, 1987). Boards manufactured with 1:3 wood/cement ratio, in comparison with 2:1 wood / cement ratio, seemed to cause increasing *TS* after 24 hours immersion in water. Higher swelling rate may be due to the higher density. Huang and Cooper (2000) claim that *TS* rate may be higher for denser boards because they are exposed to higher compression during production. Higher *TS* rate may also be attributed to a high amount of $CaCl_2$ used, which is highly hygroscopic (Davies and Davies, 2017).

The mechanical test results including the bending properties and screw withdrawal strength of cement bonded particleboard are presented in Table 3. While the addition of a small amount of stalks seems to increases the mechanical properties, the addition of more stalks significantly diminishes the properties. Higher cement ratio seemed to yield better mechanical properties for the boards tested. In general, *MOE* of the cement bonded particleboards was significantly affected by the addition of sunflower stalks (P<0.001; R Squared = 0.888). Addition of sunflower stalks also significantly influences the *MOR* of the cement bonded particleboards (P<0.001; R Squared = 0.913). There is no significant difference between the bending properties of control groups and those which contain 25 % stalk particles. Both groups have higher bending properties than required by the standards (TS EN 634-2).

Table 2 Physical properties of manufactured cement bonded particleboards
Tablica 2. Fizička svojstva proizvedenih cementom vezanih ploča iverica

Particle / cement ratio *Omjer iverja i cementa*	**Wood / stalk particle ratio** *Omjer iverja drva i stabljika suncokreta*	**Density, kg/m^3** *Gustoća,* kg/m^3	***WA*, %**	***TS*, %**
1:2	100/0	1257 (18.47)	10.90 (0.29) A	6.78 (0.54) BC
	75/25	1356 (26.32)	14.29 (0.85) B	5.71 (0.14) B
	50/50	1278 (32.00)	16.21 (0.8) B	5.7 (0.62) B
	25/75	1341 (18.28)	16.42 (0.86) B	5.13 (0.89) B
	0/100	1263 (36.84)	26.7 (3.64) D	7.7 (0.74) BC
1:3	100/0	1407 (7.46)	9.02 (0.99) A	4.53 (0.43) A
	75/25	1398 (15.93)	10.25 (0.75) A	5.14 (1.43) B
	50/50	1358 (37.52)	21.9 (2.92) C	7.1 (1.07) BC
	25/75	1267 (40.13)	22.06 (1.49) C	7.14 (0.73) BC
	0/100	1395 (17.36)	23.4 (1.24) CD	7.79 (0.85) BC

Values in parenthesis are standard deviations, capital letters indicate Duncan grouping. / *Vrijednosti u zagradama standardne su devijacije, a velika slova označuju grupiranje prema Duncanovu testu.*

Table 3 Mechanical properties of manufactured cement bonded particleboards
Tablica 3. Mehanička svojstva proizvedenih cementom vezanih ploča iverica

Particle / cement ratio *Omjer iverja i cementa*	**Wood / stalk particle ratio** *Omjer iverja drva i stabljika suncokreta*	**Density, kg/m³** *Gustoća,* kg/m³	***MOE*, N/mm²**	***MOR*, N/mm²**	**Withdrawal strength, N** *Izvlačna sila,* N
1:2	100/0	1257 (18.47)	4205 (291) C	11.21 (0.56) C	1395 (85) C
	75/25	1356 (26.32)	3274 (864) C	9.42 (0.35) C	1184 (66.6) C
	50/50	1278 (32.00)	2628 (235) B	6.44 (0.41) B	909 (64.4) B
	25/75	1341 (18.28)	3063 (183) C	7.01 (0.54) B	1058 (26.1) C
	0/100	1263 (36.84)	1364 (210) A	5.79 (0.79) B	654 (61) A
1:3	100/0	1407 (7.46)	5152 (1001) CD	11.18 (2.02) C	1376 (256) C
	75/25	1398 (15.93)	6317 (1322) D	12.11 (1.61) C	1463 (186) C
	50/50	1358 (37.52)	2205 (345) B	5.61 (0.82) B	815 (80) B
	25/75	1267 (40.13)	1442 (192) A	3.83 (0.47) A	538 (40) A
	0/100	1395 (17.36)	1645 (138) A	5.26 (0.38) B	838 (58) B

Values in parenthesis are standard deviations, capital letters indicate Duncan grouping. / *Vrijednosti u zagradama standardne su devijacije, a velika slova označuju grupiranje prema Duncanovu testu.*

MOE of the cement bonded particleboards manufactured with 100 % stalk particles were inferior to other groups tested.

The average *MOE* of wood boards for higher cement ratio was 5152 N/mm², while the highest average *MOE* of 6317 N/mm² was obtained with the addition of 25 % sunflower stalks. An increase of 22 % in *MOE* was reached with the addition of stalk particle although the difference between the densities of the corresponding boards was less than 1 %. When considering an increase of 8 % for bending strength and of 6 % for withdrawal strength of the corresponding boards, it can be concluded that the addition of a small amount of sunflower stalks increases the board performance. In general, the *MOE* of cement bonded boards increase with decreasing wood content (Al Rim *et al*., 1999) or density increase and higher cement content lower *MOR* (Moslemi and Pfister, 1987; Oyagade, 1990). According to Bejo *et al*. (2005), higher wood densification means improved bonding between cement matrix and wood, and thus also better mechanical properties. Sun *et al.* (2013) claim that although natural resources may have some advantages, their mechanical properties are usually inferior as a result of lower cellulose content. A

Table 4 Properties of cement bonded boards manufactured from alternative raw materials
Tablica 4. Svojstva cementom vezanih ploča iverica proizvedenih od alternativne sirovine

Source *Izvor*	**Density, kg/m³** *Gustoća,* kg/m³	***MOE*, N/mm²**	***MOR*, N/mm²**	***WA*, %**	***TS*, %**	**References** *Literatura*
Red iron wood sawdust and palm kernel shell *Piljevina crvenog drva i ljuske palmine jezgre*	1051-1639	82-428	2.1-8.8	4.9-1.92	0.5-6.84	Atoyebi *et al*., 2018
Jerusalem artichoke *Jeruzalemska artičoka (*čičoka*)*	1250	3390-4710	9.09-11.01	8.86-14.80	0.35-1.38	Cabral *et al*., 2018
Bamboo / *Bambus*	-	-	6-9.7	-	-	Ranjan *et al*., 2017
Lantana camara	-	-	10-12.47	-	-	Ranjan *et al*., 2017
Grapevine / *vinova loza*	1200	1702-3185	2.71-9.1	-	1.09-7.72	Wang *et al*., 2013
Rattan waste *ostaci ratana*	1050-1200	480-3563	0.5-1.6	31-51	1.1-8.6	Olorunnisola and Adefisan, 2002
Abaca fiber / *vlakna abaka*	-	-	2.4-6.9	-	-	Cabalo, 2015
Coco coir / *kokosovo vlakno*	-	-	2.1-7.6	-	-	Cabalo, 2015
Rice husk / *rižina ljuska*	1020-1530	391-1339	4.56-11.52	1.65-6.47	2.94-6.82	Bamisaye, 2007
Eucalyptus oil waste *ostaci proizvodnje ulja eukalipta*	1200-1310	1893-2467	22.84-47.82	22-28	0.13-0.38	Setiadji and Husin, 2012
Date palm midribs *središnja vlakna lista datulje*	1100-1300	3146-4142	9.87-12.28	21.42-24.70	0.91-1.54	Nasser, 2014
C. erectus prunings *granje C. erectus*	1100-1300	4562-5645	9.60-13.95	15.67-21.06	0.31-0.38	Nasser, 2014
Oil palm veins *žile palme uljarice*	1100	2399-7656	4.24-8.01	4.3-8.2	3.3-5	Ayrılmış *et al*., 2017
Coir *kokosovo vlakno*	1040-1790	4171-13063	28.1-80.3	23.4-61.8	2.9-12.3	Erakhrumen *et al*., 2008
Tea residue / *ostaci biljke čaja*	800-1200	254-2979	0.8-10.99	28-43.5	1.3-8.08	Yel *et al*., 2011

possible contributory factor to the relatively low bending properties of the boards could be low stiffness of sunflower stalks (Sun *et al*., 2013).

Generally, withdrawal strength of the cement bonded particleboards significantly altered by the addition of sunflower stalks (P<0.001; R Squared = 0.899). There is no significant difference between the withdrawal strength of control groups and those that contain 25 % stalk particles. Other groups had similar withdrawal strength properties. Withdrawal strength is an indicator of internal bond strength and can be affected by several factors as follows; density, water/cement ratio, type of cement, use and ratio of accelerators, type and dimensions of wood particles (Ashori *et al*., 2012; Davies and Davies, 2017). The decrease in withdrawal strength could be attributed to poor bonding between sunflower stalk particles and cement.

The mechanical properties of the cement bonded particleboard manufactured in this study are usually higher than most of the tested alternative materials (Table 4). Mechanical properties of cement bonded products manufactured from agricultural waste or residual are highly variable mostly depending upon the anatomical and chemical structure. According to Sun *et al*. (2013), lower cellulose content is responsible for lower mechanical properties. Klimek and Wimmer (2017) also claim that conventional particleboards manufactured from agricultural residues display lower mechanical properties.

The main reason for the lower mechanical properties, as explained by Kochova *et al*. (2015), is carbohydrates, especially the amount of sucrose, glucose and fructose. Liu and Moslemi (1986) also mentioned that the presence of sugars causes decreasing strength. Decrease in mechanical properties with the addition of sunflower stalk particles may be minimized by the application of pretreatments, which were found effective for many lignocellulosic materials (Moslemi *et al*., 1983; Lee, 1984; Zhengtian and Moslemi, 1985; Simatupang *et al*., 1987; Lee and Short, 1989).

4 CONCLUSIONS
4. ZAKLJUČAK

This study explored the feasibility of sunflower stalks in cement-bonded particleboard production, under laboratory conditions. Based on the results of their physical and mechanical properties, it is evident that the addition of 25 % of sunflower stalks to wood cement mixture does not alter the properties of cement bonded particleboard tested. The inclusion of higher percentage of stalk particles in the mixture significantly drops the mechanical properties and increases water affinity, and thus also *WA* and *TS* of the boards tested. Undesirable board properties may be improved by some pretreatments applied to the stalk particles. The use of fine particles in the production may also enhance the board properties. The alternative resources such as sunflower stalks could serve as the balance between supply and demand for the manufacturing of cement bonded particleboards.

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