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Fiberglass Plaster Mesh as Reinforcement for Cement Bonded Particleboard

Učinci ojačanja cementom vezane iverice primjenom fasadne mrežice od stakloplastike

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ABSTRACT • *The effects of fiberglass plaster mesh (FPM) as reinforcement on some physical and mechanical properties of cement bonded particleboard (CBP) were examined. Experimental CBP with and without FPM were manufactured in laboratory conditions using wood particles, cement, tap water and chemical accelerators. Two plies of FPM, manufactured using fiberglass and polyester resin, were laid within the experimental CBP. The target density of CBP was 1300 kg/m^3 in the study. Three different types of chemical accelerators ($CaCl_2$, KCl, DARASET® 580) were used in the experiments. Properties of CBP evaluated include 2- and 24-hour - thickness swelling (TS), 2- and 24-hour - water absorption (WA) and bending stiffness (MOE) and strength (MOR). The results indicate that all the board properties tested were significantly improved by FPM application. The average MOE values of the CBP boards with FPM was two times higher than those of the boards without FPM. Dimensional stability and MOR of the CBP boards were also significantly improved with the use of FPM. FPM can be used to improve inferior properties of the CBP, so as to make it more compatible with other wood based construction materials.*

Keywords: *cement bonded particleboard; fiberglass plaster mesh; physical and mechanical properties*

SAŽETAK • *U radu su ispitani učinci fasadne mrežice od stakloplastike kao ojačanja cementom vezanih iverica na neka njihova fizička i mehanička svojstva. Eksperimentalne cementom vezane iverice proizvedene su s fasadnom mrežicom od stakloplastike i bez nje u laboratorijskim uvjetima, i to upotrebom drvnog iverja, cementa, vode iz slavine i kemijskih ubrzivača. Dva sloja fasadne mrežice od stakloplastike, izrađene od staklenih vlakana i poliesterske smole, položena su u eksperimentalnu cementom vezanu ivericu. U istraživanju je ciljana gustoća cementom vezane iverice bila 1300 kg/m^3. U pokusima su upotrijebljene tri različite vrste kemijskih ubrzivača ($CaCl_2$, KCl, DARASET® 580). Proučavana su ova svojstva cementom vezane iverice: debljinsko bubrenje nakon 2 i 24 sata, upijanje vode nakon 2 i 24 sata, modul elastičnosti i modul loma. Rezultati pokazuju da su upotrebom fasadne mrežice od stakloplastike sva proučavana svojstva znatno poboljšana. Prosječne vrijednosti modula elastičnosti cementom vezane iverice s dodatkom fasadne mrežice od stakloplastike bile su dva puta veće od vrijednosti iverice bez dodatka takve mrežice. Dimenzijska stabilnost i modul loma cementom vezane iverice također su znatno poboljšani primjenom fasadne mrežice od stakloplastike. Fasadna mrežica od stakloplastike može se rabiti za poboljšanje lošijih svojstava cementom vezane iverice kako bi ona bila kompatibilnija s drugim građevnim materijalima na bazi drva.*

Ključne riječi: *cementom vezana iverica; fasadna mrežica od stakloplastike; fizička i mehanička svojstva*

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1 INTRODUCTION
1. UVOD

Cement bonded boards, which are a mixture of wood particles with cement, water and some additives (Marteinsson and Gudmundsson, 2018), have been in use for almost a century. Compared to organic bonded wood products, some advantages such as durability, dimensional stability, acoustic and thermal insulation properties and low production cost make them desirable in the construction industry (Lee, 1984; Ramirez-Coretti *et al*., 1998; Savastano *et al*., 2003; Okino *et al*., 2005; Del Menezzi *et al*., 2007). Despite the advantageous properties of CBP, its flexural properties are mostly inferior compared to other wood-based composites. The properties of CBP are significantly influenced by the amount of the cement, woody material and density (Youngquist, 2010). Thus, flexural properties are mostly controlled by the amount of cement. Utilization of alternative woody materials also lower its flexural properties and worsen its dimensional stability.

In order to improve flexural properties of CBP, some pretreatments such as cold or hot water soaking of the particles were found promising (Frybort *et al*. 2008). During the last few decades, fiberglass has been used with a variety of materials in order to improve strength and stiffness properties (İlhan and Feyzullahoğlu, 2019). Solid wood and wood-based materials are also reinforced with fiberglass and remarkable improvements in bending and other properties were observed (Smulski and Ifju, 1987). Christoforo *et al*. (2016) obtained doubled bending properties for particleboard by applying fiberglass. Cassidy (2002) observed a 39 % increase in bending strength of oriented strand board (OSB) when reinforced with fiberglass. Fonseca *et al*. (2011) evaluated the influence of fiberglass reinforcement in plywood panels. Their results showed a 58 % and 43 % increase in bending strength for both longitudinal and transverse directions, respectively. Medium density fiberboard (Cai, 2006) and hardwood panels (Smulski and Ifju, 1987) were also reinforced and significant enhancement was achieved in bending properties.

Reinforcement of CBP with some natural fibers such as bagasse (Aggarwal, 1995) and jute (Deng and Furuno, 2002) were investigated and some improvements in physical and mechanical properties were observed. The literature concerning fiberglass reinforcement of CBP is scarce. A study by Wei and Tomita (2001) investigated the effects of discontinuous glass fiber on cement bonded boards and reported an increasing *MOR* and internal bond strength but also a decreasing *TS* and *WA*.

The use of fiberglass reinforcement may help reducing the use of wood material for large and heavy structural wood members as well as minimize mechanical property variability (Rowlands et al. 1986). In this study, FPM was used as reinforcement, and its effects on some physical and mechanical properties of the CBP manufactured were investigated.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Experimental CBPs with the size of 500 mm × 500 mm, a thickness of 12 mm and an average target density of 1300 kg/m^3 were prepared in laboratory conditions. Wood particles were mixed with commercial cement (CEM I 42.5), water and accelerator. Wood/cement ratio was 1:2 and 1:3; water/cement ratio was 1/2.5. Coarse particles of Red pine wood (*Pinus brutia*), which are used in the core layer of commercial three layer particleboard, were provided from a local particleboard factory. *MC* of wood particles was 12 %. The size distribution of wood particles used in the production of experimental CBP is given in Table 1.

Table 1 Size distribution of wood particles used in the study
Tablica 1. Raspodjela drvnog iverja upotrijebljenog u istraživanju

Particle size, mm / *Veličina iverja,* mm	%
6.3	0.6
4	4.5
2	29
1	49
0.85	6.6
0.5	8.5
0.25	1.3
0.125	0.5

The amount of 5 % of chemical additives ($CaCl_2$, KCl, DARASET® 580) based on cement mass was added to the water before mixing. $CaCl_2$ is one of the most known accelerators used in wood cement composites. KCl is usually added to cement mixtures in order to improve the cement/formation bond. DARASET® 580 is an admixture for concrete, used to accelerate cement hydration, which causes shortened setting times and increased early compressive strength. FPM (FileTex160 brand) used in the study was woven glass fiber fabric at 4 mm intervals. Bidirectional FPM weighed 160 g/m^2 and consisted of 80 % fiberglass (E-glass) and 20 % polyester resin binder. In general, FPM is used in exterior plastering, where it helps to prevent stress caused by humidity and extreme temperature changes. It also has the features of anti-corrosion and resistance to alkalis.

Experimental CBP were prepared with and without FPM (Table 2) as follows: first, wood particles were sprayed with water that contains previously dissolved accelerator. Then, cement was added to the mixture until a homogeneous distribution was obtained. The experiment was carried out by spreading the mixture on the steel plate. In the production of experimental CBP with FPM, two plies of FPM were embedded approximately 3 mm below the board surface. The mixture was placed between steel plates and left for curing under the pressure of 1.8 N/mm^2 - 2.0 N/mm^2. Wax paper was used between cement mixture and steel plates. The cured boards were conditioned in the laboratory climate at approximately +20 °C and relative humidity (RH) of 65 %. After curing, samples were

Table 2 Experimental design used in the study
Tablica 2. Dizajn eksperimenta

Wood - cement ratio *Omjer drvo – cement*	**Accelerator used** *Dodani ubrzivač*	**FPM**
33 % wood	$CaCl_2$	yes
		no
	KCl	yes
		no
	Daraset	yes
		no
50 % wood	$CaCl_2$	yes
		no
	KCl	yes
		no
	Daraset	yes
		no

prepared in order to determine *WA*, *TS* and bending properties.

WA and *TS* values after 2 and 24 hours of immersion in water were determined according to TS EN 317. *MOR* and *MOE* of the boards were determined according to TS EN 310. 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. The obtained results were also compared to standard values of TS EN 634-2.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Table 3 and 4 show *TS* and *WA* values of the laboratory manufactured CBP samples. Density of the experimental CBP ranges from 1221 to 1345 kg/m^3 and was not significantly different among the tested group. The use of FPM did not significantly alter the density of the CBP manufactured. 2- and 24-hour *TS* values of the CBP vary between 2.39 % - 12.39 % and 2.6 % - 16.57 %, respectively.

Overall, *TS* values of CBP were significantly affected by all the variables involved in the study ($p < 0.001$, $R^2 = 0.83; 0.96$). The average 2-hour - *TS* values (3.66 %) of 33% wood boards were increased to 5.425 % when the amount of wood particles was increased to 50 %. $CaCl_2$ and KCl seemed to yield lower 2-hour - *TS* values (3.5 % and 4.09 %, respectively) compared to the DARASET (6.028 %). The use of FPM remarkably dropped the average 2- hour *TS* values from 5.5 % to 3.5 %.

The increase in the amount of wood volume resulted in higher 24-hour *TS* values as expected (4.69 % to 7.5 5%). Results are compatible with the literature. 24–hour *TS* values of boards manufactured using KCl (4.2 %) were lower than those manufactured using $CaCl_2$ and DARASET (5.8 % and 8.35 %). The use of FPM remarkably dropped the average 24-hour *TS* values from 7.8 % to 4.3 % (80 %).

In general, *WA* values of CBP were significantly affected by all the variables involved in the study ($p < 0.001$, $R^2 = 0.96; 0.97$). *F*-values indicate that FPM had the greatest influence on *WA* values than other variables involved. The average 2-hour *WA* values (9.33 %) of 33 % wood boards were increased to 12 % when the amount of wood particles was increased to 50 %. $CaCl_2$ seemed to yield lower 2-hour *WA* values (5.3 %) compared to KCl and DARASET (13.1 % and 13.4 %, respectively). The use of FPM drastically decreased the average 2-hour *WA* values from 15.54 % to 5.78 %. The average 24-hour *WA* values (11.83 %) of 33 % wood boards were increased to 16.5 % when the amount of wood particles was increased to 50 %. $CaCl_2$ seemed to yield lower 24-hour *WA* values (9.5 %) compared to KCl and DARASET (14.6 % and 18.3 %, respectively). The use of FPM drastically decreased the average 24-hour *WA* values from 20 % to 8.3 %.

In general, dimensional stability of the CBP is measured with *TS* and *WA,* which are dependent on wood particle content (Moslemi and Pfister, 1987; Savastano *et al.*, 2003; Olorunnisola, 2009). Higher wood particle content means lower dimensional stability. In addition to higher particle content, dimensional stability can also be affected by the type of chemical

Table 3 Thickness swelling values after 2 and 24 hours
Tablica 3. Vrijednosti debljinskog bubrenja nakon 2 i 24 sata

Wood – cement ratio *Omjer drvo – cement*	**Accelerator used** *Dodani ubrzivač*	**Plaster net** *Fasadna mrežica*	***TS* (2 hours), %**	***TS* (24 hours), %**
33 % wood	$CaCl_2$	yes	4.50 (0.35)*	5.55 (0.43)
		no	2.97 (0.46)	4.93 (0.46)
	KCl	yes	4.14 (2.36)	2.60 (0.96)
		no	3.35 (0.55)	4.10 (1.09)
	Daraset	yes	2.39 (0.33)	4.50 (0.35)
		no	4.61 (0.29)	6.46 (0.35)
50 % wood	$CaCl_2$	yes	2.74 (0.36)	5.04 (0.73)
		no	3.81 (0.63)	7.71 (0.76)
	KCl	yes	3.73 (1.26)	5.47 (1.02)
		no	5.94 (3.33)	7.39 (1.2)
	Daraset	yes	4.71 (1.02)	5.89 (1.16)
		no	12.39 (0.6)	16.57 (0.11)

*Values in parenthesis are standard deviations. / *U zagradama su standardne devijacije.*

Table 4 Water absorption values after 2 and 24 hours
Tablica 4. Vrijednosti upijanja vode nakon 2 i 24 sata

Wood – cement ratio *Omjer drvo – cement*	**Accelerator used** *Dodani ubrzivač*	**Plaster net** *Fasadna mrežica*	***WA* (2 hours), %**	***WA* (24 hours), %**
33 % wood	$CaCl_2$	yes	6.28 (2.17)*	7.85 (0.18)
		no	2.81 (1.02)	6.47 (0.78)
	KCl	yes	5.46 (1.27)	7.14 (1.34)
		no	17.79 (0.91)	17.80 (1.03)
	Daraset	yes	5.48 (1.24)	8.41 (0.2)
		no	18.15 (0.54)	23.33 (0.69)
50 % wood	$CaCl_2$	yes	7.23 (1.1)	12.38 (4.02)
		no	4.89 (1.18)	11.39 (1.19)
	KCl	yes	5.92 (1.56)	9.65 (3.94)
		no	23.88 (4.15)	26.43 (1.22)
	Daraset	yes	4.61 (0.12)	6.92 (0.18)
		no	25.73 (0.79)	34.68 (0.97)

*Values in parenthesis are standard deviations. / *U zagradama su standardne devijacije.*

accelerators, which are highly hygroscopic, and type of wood particles (Olorunnisola, 2009) and (Moslemi and Pfister, 1987). It seems that *TS* values of all experimental boards were higher than 1.5 % as required by the standard, while most of the *WA* values were less than 32 % (TS EN 634-2). Application of pre-treatment or using smaller particles in the board production may help lowering *TS* and *WA* values (Moslemi *et al*., 1983; Lee, 1984; Zhengtian and Moslemi, 1985; Badejo, 1988; Lee and Short, 1989). Compared to 10.4 % - 19.2 % decrease in TS values obtained by the use of discontinuous glass fiber (Wei and Tomita, 2001), FPM causes a significant decrease of 80 % in TS. Compared to 14.1 % - 19.9 % decrease in *WA* values obtained by the use of discontinuous glass fiber (Wei and Tomita, 2001), FPM resulted in a remarkable decrease of 140 % in *WA*. It seems that embedded FPM, 3 mm below the surface, plays an important role in control of dimensional stability. Improved dimensional stability may be attributed to higher surface area of bonding between FPM and cement thus blocking the penetration of water molecules through to wood particles of the CBP (Wei and Tomita, 2001).

The bending properties of CBP manufactured in the study are presented in Table 5. *MOR* and *MOE* of the experimental CBP were significantly affected by the variables involved in the study ($p < 0.001$, $R^2 = 0.94, 0.98$). FPM seemed to have a serious effect on bending properties of CBP manufactured. Lowering the amount of wood in the mixture increases the *MOE* and *MOR* of the boards from 2485 N/mm² to 3241 N/mm² and 10.2 N/mm² to 11.9 N/mm², respectively. Since stiffness of the CBP is dependent on the amount of cement, which is more rigid than wood, it is expected to achieve higher *MOE* values with lower wood particle content (Moslemi and Pfister, 1987). The use of FPM resulted in an overall increase of 105 % in bending MOE (1876 N/mm² to 3850) of the manufactured boards. The use of different chemical accelerators also showed significantly different results in *MOE* values of CBP manufactured. The use of $CaCl_2$ yielded higher average *MOE* values than other chemicals used.

In general, lowering cement–wood ratio results higher *MOR* (Moslemi and Pfister, 1987; Papadopoulos *et al*., 2006), which is contrary to the findings of the present study. This may be a result of interactions of

Table 5 Bending properties of boards
Tablica 5. Savojna svojstva ploča

Wood – cement ratio *Omjer drvo – cement*	**Accelerator used** *Dodani ubrzivač*	**Plaster net** *Fasadna mrežica*	***MOR*, N/mm²**	***MOE*, N/mm²**
33 % wood	$CaCl_2$	yes	15.45 (0.35)*	3903 (276)
		no	10.95 (0.12)	3353 (276)
	KCl	yes	17.11 (0.33)	4235 (234)
		no	5.95 (0.66)	1354 (26)
	Daraset	yes	11.52 (0.17)	4457 (637)
		no	10.71 (0.72)	2145 (119)
50 % wood	$CaCl_2$	yes	15.54 (0.74)	3322 (112)
		no	9.86 (0.33)	3073 (907)
	KCl	yes	11.88 (0.121)	3660 (881)
		no	7.05 (0.65)	633 (30)
	Daraset	yes	13.15 (0.15)	4247 (253)
		no	3.72 (0.33)	702 (24)

*Values in parenthesis are standard deviations. / *U zagradama su standardne devijacije.*

the variables used in the study. The use of FPM created an overall increase of 75 % in bending *MOR* (8.04 N/mm^2 to 14.1 N/mm^2). The use of different chemical accelerators also resulted in significantly deviating results in *MOR* values of CBP manufactured. The use of $CaCl_2$ yielded higher average *MOR* (12.95 N/mm^2) values than other chemicals used.

Compared to 15.6 % - 23.2 % *MOR* increase obtained by the use of discontinuous glass fiber (Wei and Tomita, 2001) and 52 % increase of bagasse (Aggarwal, 1995), FPM provides superior bending resistance.

The average *MOR* values of the experimental CBP with FPM satisfy the minimum standard value of 9 N/mm^2 required by the standard (TS EN 634-2). *MOR* values of CBP without FPM are mostly inferior. *MOR* values are satisfied when $CaCl_2$ is used as accelerator. No experimental CBP resulted in an acceptable *MOE* value required by the standards (TS EN 634-2), although *MOE* values were increased with the use of FPM. Higher *MOE* may be achieved with lower particle content for cement bonded boards (Al Rim *et al*., 1999) or with higher density (Moslemi and Pfister, 1987; Oyagade, 1990). According to Bejo *et al*. (2005), mechanical properties of CBP may be increased when densification is increased. Since fiberglass in general has superior tensile strength and stiffness, two plies of FPM make great contribution to the bending properties of CBP.

The main reason behind the inadequate physical and mechanical properties of the boards manufactured in the study could be the use of only coarse wood particles. Coarse particles could not be easily compressed as fine particles, which resulted in some gaps or voids during manufacturing, thus yielding undesirable board properties. Bending properties of the CBP may also be improved by the application of pretreatments, which were found acceptable for many lingo-cellulosic materials (Moslemi *et al*., 1983; Lee, 1984; Zhengtian and Moslemi, 1985; Lee and Short, 1989).

4 CONCLUSIONS
4. ZAKLJUČAK

The effects of FPM as reinforcement on selected mechanical and physical properties of CBP were studied. The results indicated that embedment of two plies of FPM near the surface of CBP improves *MOE* and *MOR* as well as resistance to *TS* and *WA*. An application of two plies of FPM increased *MOE* and *MOR* of CBP by 75 % and 105 %, respectively, reduced *WA* up to 140 % percent, and reduced TS up to 80 %. FPM could be used for improvement of CBP properties, as an alternative to other pretreatments, chemical additives or reinforcing materials. Besides improving inadequate board properties, the application of FPM may help lowering the weight of the CBP, which is a disadvantage compared to similar wood base composites. Furthermore, utilization of agricultural residues, which usually result in inferior board properties in the manufacture of CBP, may be facilitated.

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