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WATER ABSORPTION, THICKNESS SWELLING AND MECHANICAL PROPERTIES OF CEMENT BONDED WOOD COMPOSITE TREATED WITH WATER REPELLENT

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ABSTRACT

In this study, the purpose was to improve outdoor performance of cement bonded wood composite due to their biodegradation and sensitivity to moisture especially in warm and humid climates. Cement bonded wood composites were treated with different concentrations (10 %, 25 %, 50 %, 75 % and 100 %) of water repellent. Water repellent used was an organo-silicon based, nano-sized, eco-friendly, water-based agents. Dipping and pressure systems were applied for composite treatment. Water absorption, thickness swelling, accelerated weathering, color changes and mechanical properties after accelerated weathering were determined for treated and untreated cement-bonded composites. Results showed that treatment of composites with water repellent provided a transparent layer on composite surface. Thus, lower water absorption and thickness swelling results in the beginning of immersion in water. Treated and untreated composites were exposed to an accelerated weathering test for 350 h. Their mechanical strength including modulus of rupture, modulus of elasticity and internal bonding properties were decreased after 350 h of weathering. However, overall results after weathering test showed that all panels' mechanical properties provided minimum modulus of rupture, modulus of elasticity and internal bonding requirements of the EN standards.

Keywords: Accelerated weathering test, cement-bonded wood composites, composites treatment, mechanical properties, water absorption.

INTRODUCTION

Cement-bonded wood composite materials have been studied for more than one hundred years but they were commercially utilized since 1930's (Frybort *et al.* 2008). Cement-bonded wood composites (CBWCs) are made of wood particles mixed with Portland cement (Okino *et al.* 2004, Marzuki *et al.* 2011). Utilization of different fiber sources in making cement-bonded composite material became an alternative material due to concerns related to policies of limiting asbestos (Moslemi 1999, Karade 2010). Large amount of different lignocellulosic materials can be used for composite production. Some of them are generated around the world during various human activities including agro-forestry wastes like rice husk and straw, sunflower stems, wheat-straw, bagasse, oil palm strands, hazel nuts and saw dust (Widyorini *et al.* 2005, Thygesen *et al.* 2005, Yel 2022). Compatibility of wood and cement is the main problem in cement-bonded wood composites due to inhibition effect of wood on cement settings. The inhibitory substances in wood such as hemicelluloses, starches, sugars, phenols and hydroxylated carboxylic acids cause hydration effects when cement is mixed with wood (Papadopoulos 2008, Frybort *et al.* 2008, Tittelein *et al.* 2012). Researchers reported that different wood treatments such as extraction, alkaline hydrolysis and retention of polysaccharides can be applied to minimize inhibition problems. Inhibitory water-soluble compounds in wood can be removed by extraction method while hemicelluloses and sugars can be degraded into non-inhibitory substances by alkaline hydrolysis. In the retention of polysaccarides, inhibitory substances are not released from the wood surface due to formation of thin coating layer on the wood surface (Quiroga *et al.* 2016).

CBWCs are widely preferred in building constructions for both interior and exterior applications due to their good properties on sound attenuation, fire resistance, thermal insulation, and structural performance (Huang and Cooper 2000, Na *et al.* 2014). In addition, cement-bonded wood composites possesses both workability with conventional wood-working tools like sawn, drilled, nailed, sanded, glued, and screwed and durability like masonry construction material (Marzuki *et al.* 2011). However, using CBWC in exterior condition especially in warm and humid climates is limited due to biodegradation and sensitivity to moisture of wood in composites (Wei and Tomita 2001, Kirkpatrick and Barnes 2006). Moreover, the wood composites are susceptible to UV radiation corruption. Wood components such as hemicellulose, lignin and cellulose are the main wood chemical elements affected by the photodegradation; lignin is the most susceptible to weathering. Photodegradation of lignin leads to the staining of wood. The UV radiation causes the formation of free radicals. As a result of this, begin by photochemical reactions in wood. Photochemical reactions induce the degradation of lignin and photooxidation of cellulose and hemicelluloses. This also leads to discoloration of wood and influence negatively on the wood's physical and mechanical properties (Temiz *et al.* 2007, Matuana *et al.* 2011, Durmaz *et al.* 2022).

Treatment of wood-based composites is not easy due to many types of wood-based composites such as particleboard, cement-bonded wood composite, medium density fiber board, wood-plastic composites etc. and manufacturing processes. Wood-based composites can be protected by various methods including pre-treatment of particles, in-process treatment during manufacturing process, post-treatment after manufacturing of composites (Kirkpatrick and Barnes 2006; Taşçıoğlu 2013). The most practical way to protect composites could be post-treatment after manufacturing the composites by dipping, spraying, brushing or vacuum-pressure treatment (Taşçıoğlu 2013). Depending on the desired properties of cement-bonded wood composites, physical and mechanical properties can be improved with several factors such as cement-wood ratio, particle size and geometry, orientation of particles, treatment of particles or treatment composites with water repellent etc. Moisture absorption and dimensional stability could be improved by impregnating water soluble polymers into composite structure after manufacturing the composites. Therefore, improving outdoor performance of CBWC with different treatment methods provides wider potential application of CBWCs for replacing traditional building materials for interior and exterior use.

The objective of the research is to improve the outdoor performance of cement-bonded wood composites treated with water repellent. CBWCs were treated with different concentrations of organo-silicon based, nano-sized chemical and exposed accelerated weathering test. The effects of water repellent on water absorption, dimensional stability and mechanical properties of CBWCs after QUV test were determined.

MATERIAL AND METHODS

Composite Treatment Process

CBWCs used in this study were commercially obtained from TEPE Betopan Co. Inc. in Ankara, Turkey. CBWCs were treated with different concentrations (10 %, 25 %, 50 %, 75 % and 100 %) of water repellent to improve outdoor performance of composites. Water repellent used was an organo-silicon based, nano-sized, eco-friendly, water-based agents. It was obtained from ARDChem in Turkey. Since the size of water repellent less than 3 nm - 6 nm, it penetrated deep into the material pores 3 nm - 5 mm. Therefore, the building material becomes stronger and highly water repellent (Köse *et al.* 2014). Two different treatment processes, dipping and vacuum-pressure systems were applied to treat with water repellent. The first group samples were dipped into solutions for 10 min. Pressure system was conducted in a small-scale impregnation container using a vacuum of 645 mm/Hg for 30 min followed by 6 bar pressure for 30 min. The retentions for each treatment solution were calculated according to ASTM D 1413 (2007) standard by using the following Eq. 1:

$$R_{kg/m^3} = [(G \times C)/V] \times 10 \qquad (1)$$

Where; G is the grams of treating solution absorbed by composite (g), C is the concentration (%), V is the sample volume (cm^3).

Water Absorption and Thickness Swelling Tests

Water absorption (WA) and thickness swelling (TS) tests were performed according to EN 317 (1993). Fifteen replicates of each group with the dimensions of 50 mm (length) x 50 mm (width) x 10 mm (thickness) were conditioned in climate room (20 ºC ± 2 °C temperature and 65 % ± 5 % RH) until they reach constant weigh. Treated and untreated (control) samples were placed into distilled water test tanks and measured water absorption and thickness swelling after 30 min, 2 h, and 24 h. The WA and TS values were calculated according to Eq. 2 and Eq. 3 after each period.

$$\mathrm{WA}_{(\%)} = ((\mathrm{W}_2 - \mathrm{W}_1) / \mathrm{W}_1) \times 100 \quad (2)$$

$$\mathrm{TS}_{(\%)} = ((\mathrm{T}_2 - \mathrm{T}_1) / \mathrm{T}_1) \times 100 \quad (3)$$

Where; W_1 and W_2 are the weight of the boards before and after test, T_2 is the thickness of boards at any given time during water soaked condition and T_1 is the initial thickness of the boards.

Accelerated Weathering Test

The weathering test was performed in a QUV accelerated weathering tester. UVB-313 type lamp was used in QUV. The reason for choosing UV-B light is that the energy level in UV-B zone was enough to break the chemical bonds of carbon-nitrogen in polymer carbon-carbon, nitrogen-hydrogen, carbon-oxygen, carbon-hydrogen compounds. Composites, pressure treated with 25 % and 50 % of concentration water repellent were exposed to QUV due to showed better dimensional stability. Weathering test cycle comprised exposure to 340 nm UVB-313 light irradiation for 4 h followed by condensation for 4 h. The average irradiation was set about 0,71 W/m^2 at 340 nm with temperature of 60 °C while condensation temperature was set to 50 °C. Seven replicates of each treatment were exposed for 50 h, 100 h, 200 h and 350 h to QUV and determined color change according to ISO 7724-1 (1984).

Color Measurement

The surface color of composites was determined according to ISO 7724-1 (1984) standard using a Minolta model color measurement device. CIELab (Commission International de i'Eclairage) system is characterized by three parameters, L*, a* and b*. L* axis represents light stability, a* and b* are the chromatographic coordinates, (+a* for red, -a* for green, +b* for yellow, -b* for blue).

L*, a* and b* values of each group of composites were measured before and 50 h, 100 h, 200 h and 350 h after exposure to QUV. Total color change (ΔE*) was calculated according to Eq. 4-7.

$$\Delta L^* = L_f^* - L_i^* \tag{4}$$

$$\Delta a^* = a_f^* - a_i^* \tag{5}$$

$$\Delta b^* = b_f^* - b_i^* \tag{6}$$

$$\Delta E^* = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \tag{7}$$

Where; ΔL*, Δa*, Δb* are the changes between the initial (i) and in different periods (f). A low ΔE* corresponds to a low color change or a stable color.

Mechanical Properties

Modulus of rupture (MOR), modulus of elasticity (MOE) and internal bonding (IB) of the CBWCs, conditioned at 20 °C and 65 % RH were performed according to EN 310 (1993) and EN 319 (1993) standards, respectively. Rectangular 250 mm (length) x 50 mm (width) x 10 mm (thickness) samples were used to determine three-point bending measurement of MOR and MOE. The flexural properties were detected using a Zwick/Roell Z010 Universal Testing system equipped with a load cell capacity of 10 kN. Specimens of 50 mm (length) x 50 mm (width) x 10 mm (thickness)were used for IB measurement. The samples were tested on Mohr+Federhaff+Losenhause universal testing machine equipped with a load cell capacity of 10 kN. Twenty replicates were tested for each composite formulation. The result of CBWC was analyzed with ANOVA test using SPSS 21.0 software (SPSS

2020). The significance (p<0,05) between the treatments was compared with DUNCAN homogeneity groups.

RESULTS AND DISCUSSION

Water Absorption and Thickness Swelling Ratios

Water absorption and thickness swelling of composites are given in Table 1 with their retention values. According to results, water absorption values of control groups were determined to an increase from 6,22 % after 30 min. to 14,29 % after 24 h of exposure in water. All the samples treated with water repellent significantly reduced water uptake in the beginning of immersion time. Increasing water repellent concentration in pressure system generally decreases water absorption values. After 24 h exposure in water, there were differences between test and control (untreated) groups. Samples pressure treated with 75 % of water repellent showed the lowest water absorption value after 30 min. exposure in water while all water repellent treatment significantly reduced water absorption in the beginning of water exposure. Samples there were treated with the pressure system showed lower water absorption than dipping process due to higher retention values. Pressure treatment system showed lower water absorption than dipping process due to higher retention values. Several researchers have reported that organo-silicon based treatment improved water absorption of wood by means of water repellency system (Köse *et al.* 2014; Glohamiyan 2010).

Regarding the thickness swelling, maximum swelling of control (untreated) composites after 24 h in water was 0,91 %. This value is lower than resin-bonded particleboards subjected to similar conditions due to "encased" nature of wood in the cement, restricting wood from expanding volumetrically (Jorge *et al.* 2004; Yel and Urun 2022). The moisture absorption in composites is mainly due to the presence of lumens, pores, and hydrogen bonding sites in the wood fiber along with voids (English and Falk 1996). Treatment with water repellent provided better dimensional stability of composites than that of untreated (control) groups. Some groups treated with water repellent showed minus values due to creating a transparent coating layer of test chemical on the composite surface. Depending on the exposure time in water, this water repellent layer on the composite surface was washed out with water and samples reached their initial thickness. The lowest thickness swelling was determined on the composites pressure treated with 75 % of WR (-1,14 %). Decreasing WR amount in composites resulted in lower thickness swelling.

Table 1: Water absorption and thickness swelling of the CBWC treated with water repellent.

Concentration		**Water Absorption (%)**			**Thickness Swelling (%)**			**Retention (kg m^{-3})**
		30 min	2 h	24 h	30 min	2 h	24 h	
Water repellent	100 % Dipping	1,67 (0,13)*	3,83 (0,32)	11,63 (0,95)	-0,22 (0,29)	-0,11 (0,32)	0,47 (0,28)	30,40 (3,49)
	75 % Pressure imp.	1,10 (0,48)	3,26 (0,42)	11,12 (0,58)	-0,97 (0,47)	-1,17 (0,37)	-1,14 (0,55)	85,11 (7,15)
	75 % Dipping	1,94 (0,27)	4,32 (0,50)	11,56 (0,86)	-0,87 (0,54)	-0,77 (0,48)	-0,22 (0,54)	28,50 (1,89)
	50 % Pressure imp.	1,73 (0,23)	(3,79) (0,37)	12,14 (0,79)	0,15 (0,16)	0,38 (0,32)	0,76 (0,52)	70,33 (5,82)
	50 % Dipping	2,62 (0,82)	4,84 (0,35)	11,54 (1,18)	-1,11 (1,37)	-0,88 (0,56)	-0,31 (0,60)	22,54 (0,92)
	25 % Pressure imp.	1,80 (0,13)	4,20 (0,34)	11,26 (0,60)	-0,13 (0,28)	-0,11 (0,28)	0,32 (0,34)	80,61 (2,99)
	25 % Dipping	2,63 (0,34)	4,79 (0,56)	11,19 (1,81)	0,21 (0,57)	0,27 (0,52)	0,74 (0,49)	14,77 (1,43)
	10 % Pressure imp.	1,64 (0,11)	4,06 (0,19)	11,43 (0,88)	-0,08 (0,30)	0,08 (0,37)	0,65 (0,51)	33,23 (1,96)
	10 % Dipping	3,39 (0,37)	5,64 (0,47)	11,59 (0,82)	0,43 (0,20)	0,54 (0,26)	0,93 (0,22)	5,94 (0,30)
	Control	6,22 (0,62)	8,87 (0,78)	14,29 (1,10)	0,65 (0,38)	0,68 (0,40)	0,91 (0,47)	-

[*] The values in parenthesis show standard deviation.

The Effect of Accelerated Weathering Test on the Color Change of CBWC

Color changes of the panel groups after 50 h, 100 h, 200 h and 350 h of accelerated weathering are given in Table 2. According to CIELab coordinates, positive Δa* values show red in UV process, on the other hand, negative Δa* values indicates green. Again in Δb* values indicate yellow for positive and blue for negative. Positive ΔL* values represent getting white, negative ΔL* values represent getting grey.

After the 350-h process, the highest color change was observed at the panel group impregnated with 25 % of WR (ΔE: 14,46) while the lowest color change was determined at the group treated with 50 % of WR among the treatment groups. The reason for higher color change for WR groups than control groups could be due to destroying and washing out the coating layer on composite surface, formed by WR treatment. Water absorption results was also showed that this surface layer protected composites against water absorption but with increasing immersion time, composites treated with WR absorbed water, indicates destroying this layer.

Table 2: Color changes of CBWC after accelerated weathering test.

Samples	**After 50 h**				**After 100 h**				**After 200 h**				**After 350 h**			
	ΔL	Δa	Δb	ΔE	ΔL	Δa	Δb	ΔE	ΔL	Δa	Δb	ΔE	ΔL	Δa	ΔB	ΔE
Control	0,65	0,32	-0,2	0,75	1,9	0,29	-0,62	2,02	1,23	0,58	8,77	8,87	7,6	0,43	-0,6	7,64
25 % WR	6,82	-0,06	-3,79	7,8	10,2	0,01	-6,99	12,37	10,47	-0,3	-7,47	12,87	13,7	-0,83	4,54	14,46
50 % WR	2,4	0,31	-2,4	3,41	3,03	0,22	-3,19	4,41	3,37	1,19	-4,16	5,49	5,26	0,99	5,68	7,80

The Effects of Accelerated Weathering Test on Mechanic Properties of CBWC

Treated and untreated wood-cement composites were exposed 350 h to an accelerated weathering test. Mechanical properties including modulus of rupture (MOR), modulus of elasticity (MOE) and internal bonding (IB) of unexposed and exposed to QUV were determined. The results of MOR, MOE, and IB of experimental boards including homogeneity group (Duncan test) values are given in Table 3.

According to results, all wood-cement composites tested in this study provide the minimum MOR and MOE requirement of the EN 634-2 (2007) standard. In addition, the minimum requirements of IB strength in the EN 634-2 (2007) standards are 0,5 N/mm^2 for general usage and 0,3 N/mm^2 after the cyclic test. Therefore, all types of board met the minimum IB requirement of the EN standards.

Changes on the mechanical properties after QUV test are shown in Figure 1.

Table 3: The effect of accelerated weathering test on mechanical properties of CBWC.

Board type	**MOR (MPa)**	**MOE (MPa)**	**IB (MPa)**
Unweathered control	12,97 (1,45)* **A**	5570 (408,70) **A**	0,68 (0,06) **A**
Weathered control	11,73 (0,84) **B**	4855 (490,57) **B**	0,66 (0,04) **B**
Unweathered 25 % WR	10,71 (1,43) **C**	4777 (377,92) **C**	0,60 (0,05) **C**
Weathered 25 % WR	10,20 (1,17) **D**	4678 (252,68) **D**	0,60 (0,03) **C**
Unweathered 50 % WR	11,73 (0,75) **B**	4763 (307,50) **C**	0,64 (0,04) **D**
Weathered 50 % WR	10,51 (1,37) **E**	4508 (258,93) **E**	0,62 (0,04) **E**
The values in parenthesis show standard deviation			

*

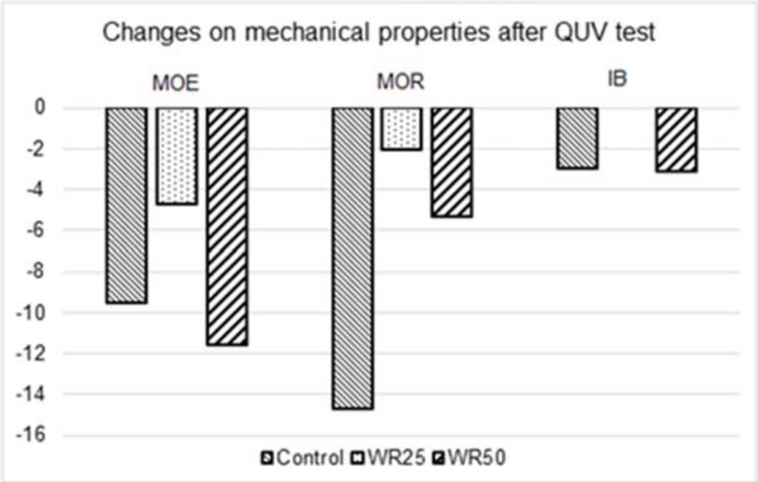

Figure 1: Changes on the mechanical properties after accelerated weathering test.

As expected that, mechanical properties of wood-cement composites decreased after 350 h weathering test. This can be attributed that the weathering test can lead to surface damage due to forming the micro-cracking, resulted in reduction on mechanical properties (Page and Page 2007; Hung *at al.* 2017). The lowest mechanical changes were obtained from the composites treated with 25 % of WR.

Higher concentration of WR increased the mechanical properties losses. This may be related with some negative effect of cement in composite structure and WR.

Strength properties of wood are very dependent on the moisture content of the cell wall. Because of increasing the rate of moisture barrier coated with a population that formed between water and wood panels as a result of decreases. For this reason, wood materials become more fragile and brittle (Rowell 1984; Taşçıoğlu *et al.* 2016; Shang *et al.* 2012). Impregnation of wood decreased flexible properties and shock resistance (Shang *et al.* 2012. When the examination of effect the mechanical properties of accelerated weathering, it was determined that a reduced amount of MOR, MOE and IB resistance compared to Duncan test results. The natural or accelerated weathering of composite materials can change their mechanical and strength properties (Butylina *et al.* 2012). Güntekin and Şahin (2009) defined that significant reduction in mechanical properties with the accelerated weathering test in fiber cement composites. As stated above, photodegradation of lignin adversely affected wood physical and mechanical properties. In addition, the physical and mechanical properties of cement-based material affected the environmental conditions greatly (Kockal and Turker 2007). Wetting–drying cycles had negative effects on strength properties and causes durability problems at concrete.

CONCLUSIONS

Commercially obtained cement-bonded wood composites were treated with water repellent in order to improve outdoor performance. Two different treatment processes (dipping and pressure treatment for water repellent) were applied as post-treatment after manufacturing the composites. Main findings are summarized as follow:

1- Water repellent treatment significantly reduced water absorption in the beginning of water absorption test due to forming a transparent coating layer on the composite surface. However, increasing exposure time decreased water absorption differences between treated and untreated (control) composites.

2- Treatment of composites with water repellent provided better dimensional stability of composites than that of untreated (control) groups.

3- Mechanical properties of wood-cement composites decreased after 350 h weathering test. The lowest mechanical changes were obtained from the composites treated with 25 % of WR. However, the highest color change was observed at the panel group impregnated with 25 % of WR after 350 h weathering test.

AUTHORSHIP CONTRIBUTIONS

S. l.: Project administration, writing – original draft; U. A.: Investigation, formal analysis, writing – review & editing; H. K.: Conceptualization, writing – original draft; A. T.: Conceptualization, investigation, writing – review & editing.

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REFERENCES

American Society for Testing and Materials. ASTM. 2007. Standard Test Method for Wood Preservatives by Laboratory Soil-Block Cultures. ASTM D 1413. Annual Book of ASTM Standards (Vol. 04.10), ASTM International, West Conshohocken, PA., USA.

Butylina, S.; Hyvärinen, M.; Kärki, T. 2012. A study of surface changes of wood-polypropylene composites as the result of exterior weathering. *Polym Degrad Stabil* 97(3): 337-345. https://doi.org/10.1016/j.polymdegradstab.2011.12.014

Durmaz, S.; Erdil, Y. Z.; Ozgenc, O. 2022. Accelerated weathering performance of wood-plastic composites reinforced with carbon and glass fibre-woven fabrics. *Color Technol* 138(1): 71-81. https://doi.org/10.1111/cote.12572

European Committee for Standardization. CEN. 1993. Particleboards and fiberboards, determination of swelling in thickness after immersion. EN 317. Brussels, Belgium.

European Committee for Standardization. CEN. 1993. Particleboards and fiberboards, determination of tensile strength perpendicular to plane of the board. EN 319. Brussels, Belgium.

European Committee for Standardization. CEN. 1993. Wood-based panels, determination of modulus of elasticity in bending and bending strength. EN 310. Brussels, Belgium.

European Committee for Standardization. CEN. 2007. Cement-bonded particleboards - Specifications - part 2: requirements for OPC bonded particleboards for use in dry, humid and external conditions. EN 634-2. Brussels, Belgium.

English, B.W.; Falk, R.H. 1996. Factors that affect the application of woodfiber-plastic composites. In *Proceedings Forest Products Society*. 7293: 189-194.

Frybort, S.; Mauritz, R.; Teischinger, A.; Müller, U. 2008. Cement bonded composites-A mechanical review. *Bioresources* 3(2): 602-626. https://bioresources.cnr.ncsu.edu/BioRes_03/BioRes_03_2_0602_Frybort_MTM_Cement_bonded_composites_Review.pdf

Glohamiyan, H. 2010. The effect of nanoparticles and common furniture paints on water resistance behavior of poplar wood (*P. nigra*). In Proceedings International Convention of Society of Wood Science and Technology and United Nations Economic Commission for Europe -Timber Committee. 82: 1-7. Geneva, Switzerland. https://www.swst.org/wp/meetings/AM10/pdfs/WS-82%20Tarmian%20nano%20paper.pdf

Güntekin, E.; Şahin, H.T. 2009. Accelerated weathering performance of cement bonded fiberboard. *Sci Res Essays* 4(5): 484-492. https://doi.org/10.5897/SRE.9000127

Huang, C.; Cooper, P.A. 2000. Cement-bonded particleboards using CCA-treated wood removed from service. *Forest Prod J* 50(6): 49-56. https://www.proquest.com/docview/214646959/fulltextPDF/F4AFF65BA39A4877PQ/1?accountid=17248

Hung, C.C.; Su, Y.F.; Hung, H.H. 2017. Impact of natural weathering on medium-term self-healing performance of fiber reinforced cementitious composites with intrinsic crack-width control capability. *Cem Concr Compos* 80: 200-209. https://doi.org/10.1016/j.cemconcomp.2017.03.018

International Organization for Standardization. ISO. 1984. Paints and varnishes – colorimetry, ISO 7724-1. Geneva, Switzerland. https://www.iso.org/standard/14557.html

Jorge, F.C.; Pereira, C.; Ferreira, J.M.F. 2004. Wood-cement composites: a review. *Holz Roh Werkst* 62: 370-377. https://doi.org/10.1007/s00107-004-0501-2

Karade, S.R. 2010. Cement-bonded composites from lingo cellulosic wastes. *Constr Build Mater* 24(8): 1323-1330. https://doi.org/10.1016/j.conbuildmat.2010.02.003

Kirkpatrick, J.W.; Barnes, H.M. 2006. Biocide treatments for wood composites- a review. In *Proceedings The International Research Group on Wood Protection, IRG/WP 06-40323.*

Kockal, N.U.; Turker, F. 2007. Effect of environmental conditions on the properties of concretes with different cement types. *Constr Build Mater* 21(3): 634-645. https://doi.org/10.1016/j.conbuildmat.2005.12.004

Köse, G.; Temiz, A.; Demirel S.; Özkan, O. E. 2014. Using commercial water repellent chemicals on wood protection. In Proceedings The International Research Group on Wood Protection, IRG/WP 14-30656.

Marzuki, A.; Rahim, S.; Hamidah, M.; Ruslan, R.A. 2011. Effects of wood: cement ratio on mechanical and physical properties of three-layered cement-bonded particleboards from Leucaena leucocephala. *J Trop For Sci* 23(1): 67-72. https://www.jstor.org/stable/pdf/23616881.pdf

Matuana, L.; Jin M.S.; Stark, N.M. 2011. Ultraviolet weathering of HDPE/wood-flour composites coextruded with a clear HDPE cap layer. *Polym Degrad Stabil* 96(1): 97-106. https://doi.org/10.1016/j.polymdegradstab.2010.10.003

Moslemi, A.A. 1999. Emerging technologies in mineral-bonded wood and fiber composites. *Adv Perform Mater* 6: 161-179. https://doi.org/10.1023/A:1008777812842

Na, B.; Wang, Z.; Wang, H.; Lu, X. 2014. Wood-cement compatibility review. *Wood Res* 59(5): 813-816. http://www.centrumdp.sk/wr/201405/20140510.pdf

Okino, E.Y.A.; Souza, M.R.; Santana, M.A.E.; Alves, M.V.S.; Sousa M.E.S.; Teixeira, D.E. 2004. Cement-bonded wood particleboard with a mixture of eucalypt and rubberwood. *Cement Concr Compos* 26: 729-734. https://doi.org/10.1016/S0958-9465(03)00061-1

Page, C.L.; Page, M.M. 2007. *Durability of concrete and cement composites*. Woodhead Publishing. https://www.sciencedirect.com/book/9781855739406/durability-of-concrete-and-cement-composites#book-description

Papadopoulos, A.N. 2008. Natural durability and performance of hornbeam cement bonded particleboard. *Maderas-Cienc Tecnol* 10(2): 93-98. http://dx.doi.org/10.4067/S0718-221X2008000200002

Quiroga, A.; Marzocchi, V.; Rintoul, I. 2016. Influence of wood treatments on mechanical properties of wood cement composites and of Populus Euroamericana wood fibers. *Compos B Eng* 84: 25-32. https://doi.org/10.1016/j.compositesb.2015.08.069

Rowell, R.M. 1984. *The chemistry of solid wood-American Chemical Society*. ACS Advances in Chemistry Series No. 207, Washington D.C., USA. https://pubs.acs.org/doi/10.1021/ba-1984-0207

Shang, L.; Han, G.; Zhu, F.; Ding, T.S.; Wang; Q, Wu, Q. 2012. High density polyethylene based composites with pressure treated wood fibers. *Bioresources* 7(4): 5181-5189. https://doi.org/10.15376/biores.7.4.5181-5189

SPSS Statistics. 2020. SPSS software version 21.0. IBM. https://www.ibm.com/support/pages/spss-statistics-210-available-download

Taşcıoğlu, C. 2013. Effects of post treatment with alkaline copper quat and copper azole on the mechanical properties of wood-based composites. *Turk J Agric For* 37: 505-510. https://doi.org/10.3906/tar-1208-58

Taşcıoğlu, C.; Tufan, M.; Yalçın, M.; Akçay C.; Şen, S. 2016. Determination of biological performance, dimensional stability, mechanical and thermal properties of wood–plastic composites produced from recycled chromated copper arsenate-treated wood. *J Thermoplast Compos Mater* 29(11): 1461-1478. https://doi.org/10.1177/0892705714565704

Temiz, A.; Terziev, N.; Eikenes, M.; Hafren, J. 2007. Effect of accelerated weathering on surface chemistry of modified wood. *Appl Surf Sci* 253(12): 5355-5362. https://doi.org/10.1016/j.apsusc.2006.12.005

Thygesen, A.; Daniel, G.; Lilholt, H.; Thomsen, A.B. 2005. Hemp fiber microstructure and use of fungal defibration to obtain fibers for composite materials. *J Nat Fibers* 2: 19-37. https://doi.org/10.1300/J395v02n04_02

Tittelein, P.; Cloutier, A.; Bissonnette, B. 2012. Design of a low-density wood cement particleboard for interior wall finish. *Cement Concr Compos* 34: 218-222. https://doi.org/10.1016/j.cemconcomp.2011.09.020

Wei, Y.M.; Tomita, B. 2001. Effects of five additive materials on mechanical and dimensional properties of wood cement-bonded boards. *J Wood Sci* 47: 437-444. https://doi.org/10.1007/BF00767895

Widyorini, R.; Xu, J.; Watanabe T.; Kawai, S. 2005. Chemical changes in steam pressed kenaf core binderless particleboard. *J Wood Sci* 51: 26-32. https://doi.org/10.1007/s10086-003-0608-9

Yel, H. 2022. Effect of alkaline pre-treatment and chemical additives on the performance of wood cement panels manufactured from sunflower stems. *J Build Eng* 52: 104465. https://doi.org/10.1016/j.jobe.2022.104465

Yel, H.; Urun, E. 2022. Performance of cement-bonded wood particleboards produced using fly ash and spruce planer shavings. *Maderas-Cienc Tecnol* 24(44): 1-10. http://dx.doi.org/10.4067/s0718-221x2022000100444