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POSSIBILITY OF USING CRUDE AND EXPANDED VERMICULITE IN CEMENT-BONDED PARTICLEBOARD PRODUCTION

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ABSTRACT

The aim of this study is to investigate the effect of using vermiculite on the thermal, physical and mechanical properties of cement-bonded particleboards. For this purpose, single-layer cementitious particle boards with a final density of 1200 kg/m^3 and a size of 550 x 550 x 10 mm were produced using 2 type vermiculites (crude and expanded**)** at three different ratios (5%, 10% and 15%). The produced boards were examined in terms of thermal (TGA/DTG), physical (moisture content, density, water absorption and thickness swelling), mechanical (modulus of rupture, modulus of elasticity, internal bond strength and screw withdrawal resistance) properties. According to the TGA results, using both types of vermiculite caused an increase in cement hydration products in the boards and increased the thermal resistance. While the use of vermiculite did not significant effect on the density and moisture content of the boards, it increased the dimensional stability of the boards. The values of modulus of rupture and modulus of elasticity increased when the low amount of vermiculite was added. However, with the use of vermiculite in the boards, there was a decrease in the internal bond strength and screw withdrawal resistance values in general. All boards produced using vermiculite met the values specified in EN standards.

Keywords: Cement-bonded particleboard, vermiculite, physico-mechanical properties, thermal resistance.

INTRODUCTION

Traditionally, wood has been used as a building material for many years, and its application areas have decreased with the discovery of reinforced concrete. Recently, interest in wood used to produce low-cost building materials has increased (Soroushian et al. 2004, Franek et al. 2011). Composite materials have superior properties compared to their constituents, which makes them more attractive and enhances their usability (Durmaz 2022). Wood-cement composites have been used as building materials for over 100 years and represent significant potential in building applications. The development of wood-cement composites increases their attractiveness in building materials (Okino et al. 2004). Typically, wood-cement composites are produced with the addition of some chemicals along with wood particles (fiber, chip) and Portland cement mix. These products are generally produced from 10-70% wood and 90-30% binder (cement), depending on the property expected from the material (Jorge et al. 2004). The wood-cement composites provide high dimensional stability and toughness, excellent acoustic properties, fire and biological resistance compared to other wood composites (Quirogaa et al. 2016, Yel and Urun 2022). Compared to conventional concrete, products with low costs and high insulation properties can be produced (Cabral et al. 2018). On the other hand, wood material selection constitutes an essential criterion in wood cement composite production. Choosing wood material with high sugar, phenolic substance, and hemicellulose negatively affects the hardening of the cement. For this reason, wood species with low extractive content are generally preferred (Frybort et al. 2008, Na et al. 2014).

Recently, the use of low-density lightweight aggregates such as pumice, perlite, vermiculite, and zeolite in cement-based materials has been increasing. These materials significantly increase thermal insulation and high-temperature resistance performances (Mo et al. 2018). However, few studies have used these aggregates in cemented particleboard production. Vermiculite is a magnesium alumina silicate clay mineral formed by the natural erosion of mica (Kumari and Mohan 2021). It has high cation exchange and adsorption capacity (Zhang et al. 2016). When the vermiculite is heated to about 900-1000°C, the water between the layers turns into water vapor and damages the vermiculite silicate layer. Thus, expansion occurs, and porous light material is formed. The newly formed expanded vermiculite is heat resistant and exhibits good insulating properties (Marcos and Rodriguez 2011, Mo et al. 2018).

Therefore, this study aims to explore the possibility of adding crude and expanded vermiculite in cement-bonded particleboard (CBPB) production and focuses on the physico-mechanical properties and thermal performances of the boards.

MATERIAL AND METHODS

Materials

In this study, poplar (*Populus tremula* L.) veneer residues were used as wood material. CEM II B-M (P-LL) 32.5 R type portland cement used in the study was supplied from ASKALE cement Co. Calcium chloride ($CaCl_2$) (10% solids content) used at the rate of 5% of the cement weight to increase the compatibility between wood and cement were purchased in a solid form from TEKKIM Co, Turkey. The crude (CV) and expanded vermiculites (EV) used in production were obtained from Organic Mining Co, Turkey in super fine size (<1.4 mm)

Methods

Poplar veneer wastes were first chipped and then sieved and 1.5-3 mm particles were used in production. The homogeneously mixed wood-cement-water mixture was laid on the aluminum plate using a 500 x 500 x 10 mm^3 wooden mold. The target density of the boards produced in a single layer is 1200 kg/m^3 and the cement/wood ratio is 3. The board draft was kept under a pressure of 18-20 kg/cm^2 for 24 hours using a laboratory-type cold press. A total of 14 boards were produced, with two repetitions of each board. Then, due to the continued hydration reaction of the cement, the boards were kept in the climatized room at 20±2℃ and 65 ±5% relative humidity for 28 days. After this process, the boards were cut to the dimensions specified in the relevant standards for mechanical, physical, and thermal tests. Density, moisture content, water absorption, thickness swelling, modulus of rupture, modulus of elasticity, internal bond strength, and screw withdrawal resistance test values are determined according to EN 323 (1999), ASTM D1037 (2006), EN 317 (1993), EN 310 (1993), EN 319 (1993) standards, respectively. The results assessed in accordance with EN 634-2 (2009). ANOVA analysis was performed on the produced boards using IBM SPSS 20.0 software. TUKEY HSD homogeneity test was performed to determine the significance ($p<0.05$) between the board groups. The raw materials used in the mixture with the board production process are given in Tab. 1.

Tab. 1: Board production process.

Board type	K	C5	C10	C15	E5	E10	E15
Poplar wood (%)	100	95	90	85	95	90	85
Crude vermiculites (%)	-	5	10	15	-	-	-
Expanded vermiculites (%)	-	-	-	-	5	10	15

RESULT AND DISCUSSION

Thermal properties

Thermogravimetric analysis (TGA-DTG) results of the boards are given in Fig. 1 and Tab. 2. It was observed that four endothermic peaks occurred in the thermal analysis in which the board samples were heated up to 900°C. The first peaks (75-104℃) occur because of water separation from calcium silicate hydrate (C-S-H), ettringite and wood particles in the boards (Wang et al. 2020). The second peak (290-325℃) occurred because of the degradation of wood components: cellulose (275-350℃), hemicellulose (180-350℃), lignin (250-500℃) in the board (Fabiyi et al. 2010). As the substitution rate of both vermiculite types increased, the weight losses in the second peak decreased proportionally due to the decrease in the amount of wood in the board. The third peak is formed because of the decomposition of calcium hydroxide, which is formed because of the cement hydration reaction. It is seen that the weight loss in the third peak decreased with the use of vermiculite. The fourth peak occurs due to the degradation of calcium carbonate formed by the reaction of CaOH with CO_2 (Yel 2022). The use of vermiculite appears to increase the formation of calcium carbonate in the slabs. Therefore, the amount of calcium hydroxide (CaOH) in the boards decreased with vermiculite substitution. When the third and fourth peaks were examined, it was understood that using vermiculite (due to the decrease in the amount of wood) positively affected the cement hydration in the boards. As the amount of inorganic material in the board increased because of the increase in vermiculite usage, the amount of residue at 900℃ also increased. Vermiculite is a heat-resistant material with an inorganic composition and flaky structure. This flaky structure can reduce the rate of flame and oxygen diffusion into the coal layer. In addition, inorganic substances increase the thermal stability of the coal layer. The use of vermiculite has an inhibitory effect on thermal oxidation at high temperatures (Zhang et al. 2009, Xue et al. 2015). The flaky nature of vermiculite makes it have high lubricating properties for wide temperature ranges (Gedeonov 1991). This adds non-flammability to the material. The material's degradation decreases and increases the thermal resistance by providing a heat and flame barrier with the low thermal expansion provided by vermiculite (Hodhod et al. 2019, Rashad 2016).

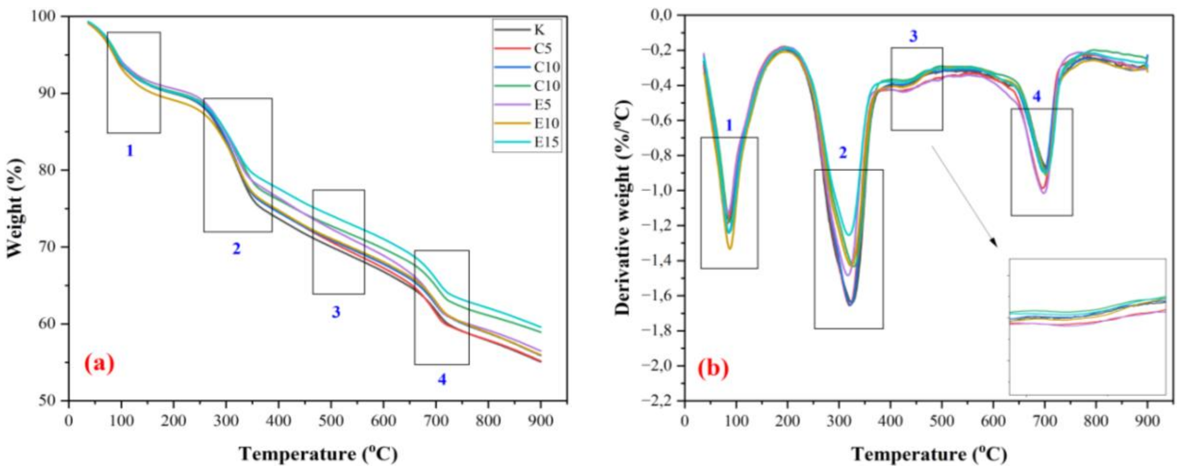

Fig. 1: The effect of vermiculite usage on the TGA (a) and DTG (b) curves (1 - water dehydration; 2 - wood material decomposition; 3 - portlandite decomposition; 4 - $CaCO_3$ decarbonisation.

Tab. 2: TGA results of cement-based particleboards.

Board types	1st peak		2nd peak		3rd peak		4th peak		Residue at 900°C
	Temp. (°C)	Weight loss %	Temp. (°C)	Weight loss %	Temp. (°C)	Weight loss %	Temp. (°C)	Weight loss %	
K	90	4.58	320	10.21	460	0.69	695	2.78	55.077
C5	84	4.32	323	9.74	395	0.60	693	4.45	55.168
C10	83	4.93	320	9.55	400	0.54	700	3.29	55.895
C15	91	4.39	329	9.03	396	0.53	701	3.66	58.933
E5	90	4.77	328	8.69	404	0.67	704	3.33	55,967
E10	82	4.60	318	8.47	494	0.34	700	4.40	56.474
E15	88	5.03	318	7.12	432	0.65	704	3.89	59.587

Physical and mechanical properties

The physical properties of the boards and the results of statistical analysis are given in Fig. 2 and Tab. 3, respectively. The density values of the boards were found to be between 1222 to 1290 kg/m^3. The moisture content values were found to be between 11.5 to 12.8%. The results of the density and moisture content of the CBPB showed no difference between the means according to the one-way analysis of variance at the 5% significance level. The thickness swelling (TS) values of the boards were found to be between 0.5% and 1.2%, and the water absorption (WA) values were between 10.8% and 14.6%. The TS values of all boards met the standard required by EN 634-2 (1.5%). There was a decrease in the TS values in all board groups. The highest decrease in TS values was obtained in the board group using 15% CV. The highest decrease in TS values was obtained in the board group using 15% CV.

The highest decrease in TS values was obtained in the board group using 15% CV. There was a 100% decrease in the TS values using 5% EV. The use of CV had a more positive effect on the TS values. The use of vermiculite as a substitute for wood particles may have resulted in better interlocking and increased dimensional stability. Although the WA values are generally close to each other, there was a statistically significant decrease in the board group using 5% CV.

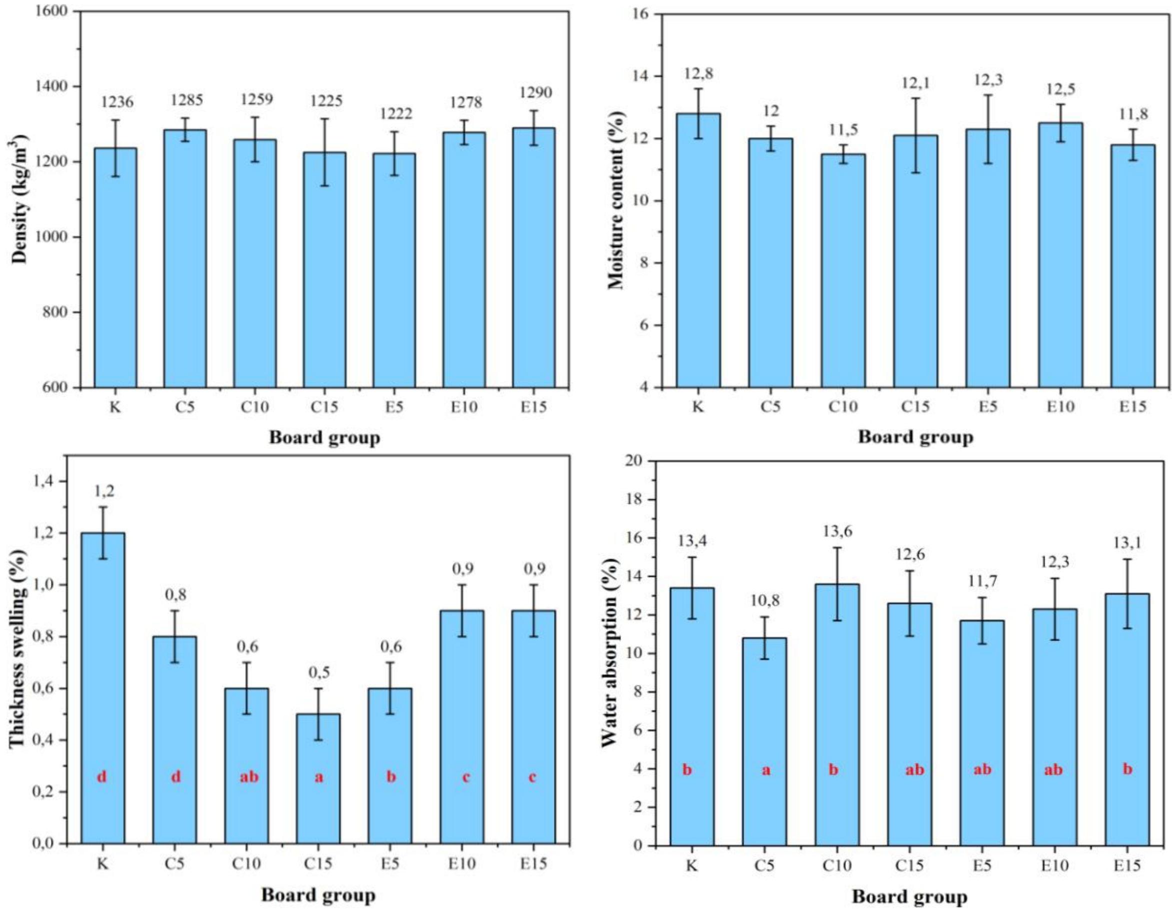

Fig. 2: The effect of vermiculite usage on the physical properties of the boards.

Kozlowski et al. (1999) determined that the use of vermiculite in lignocellulosic-based composites had a positive effect on dimensional stability. In case of an increase in the ratio of particles used in wood cement composites, a decrease in dimensional stability occurs due to the tendency of the particles to absorb more water (Savastano et al. 2003). Therefore, using vermiculite instead of the particle may have increased the dimensional stability. The free hydroxyl groups of wood carbohydrates (especially hemicelluloses) have an essential share in the tendency to absorb water in wood-based composites (Yeh et al. 2013, Li et al. 2013). Decreased wood in the composite may have increased the dimensional stability by creating a better bond between the cement and the matrix.

The results of the effect on the mechanical properties of CBPB produced by using vermiculite and the results of the statistical analysis are given in Fig. 3 and Tab. 3, respectively. According to the results of the analysis of variance, it has been determined that the rate of vermiculite usage has a significant effect on the mechanical properties of CBPB. It has been determined that the use of 5% CV and EV has a positive effect on the modulus of rupture (MOR) values of the board but a decrease in the bending resistance values at higher usage rates. The highest MOR values were found in the boards produced using 5% CV (14.4 N/mm^2), and the lowest in the boards produced using 15% CV (11.6 N/mm^2). The use of 5% CV and 10% EV caused an increase in the modulus of elasticity (MOE) values of the boards, while a decrease in MOE values occurred in the board group using 15% CV.

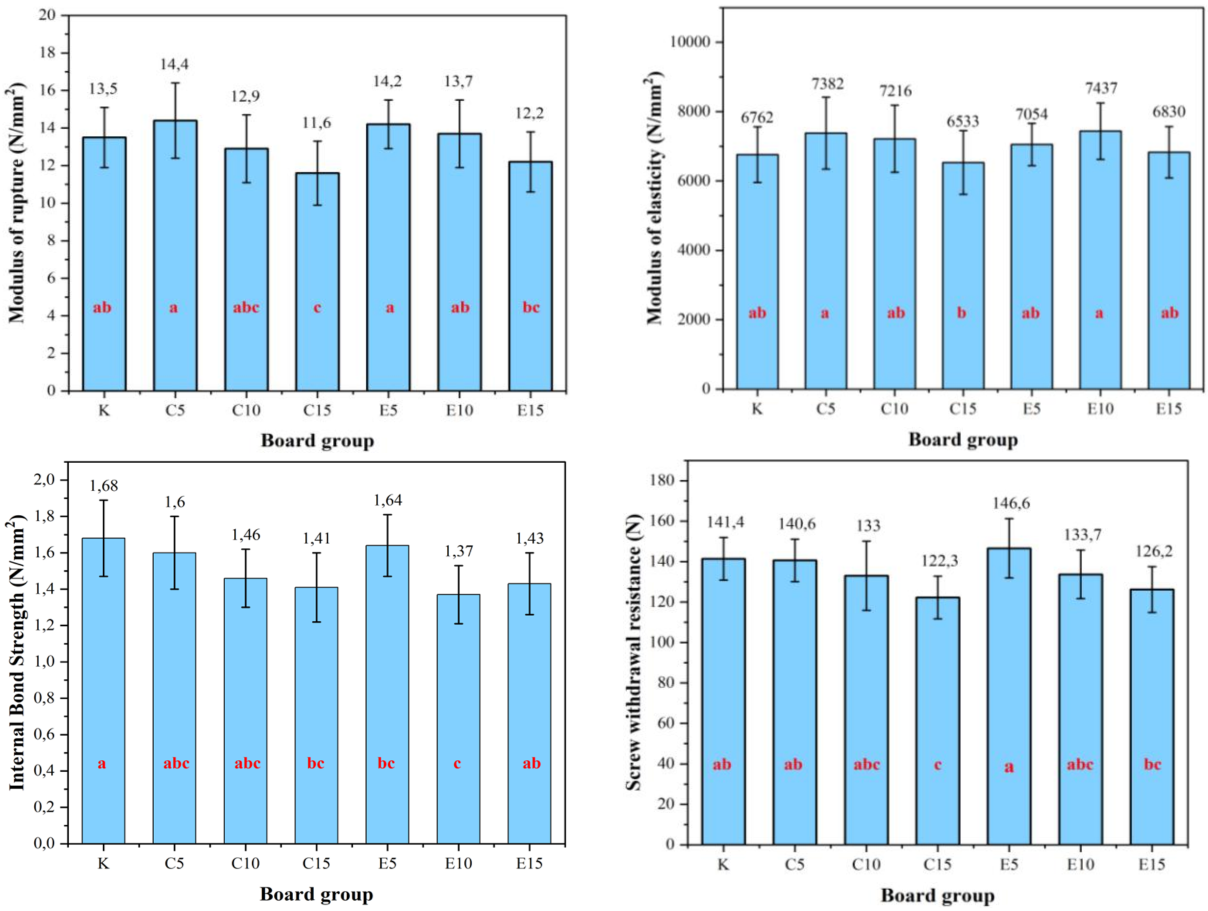

Fig. 3: The effect of vermiculite usage on the mechanical properties of the boards.

The highest MOE values were found in the boards produced using 10% EV (7437 N/mm^2), and the lowest in the boards produced using 5% CV (7382 N/mm^2). The increase in flexural strength properties with low ratios of vermiculite may be associated with increased hydration. An increase in the degree of hydration in cement-based products leads to an increase in strength properties (Szostak and Golewski 2020, Çavdar et al. 2022). The TGA results have also supported this hypothesis. The TGA results also support the increase in the degree of hydration. In addition, the wood ratio in the composite matrix decreases with the use of vermiculite. Increasing the cement/wood ratio increases the hydration temperature and reaction rate (Lee et al. 1987, Mayer et al. 2022). In the EN 634-2 (2009) standard, the minimum MOR and MOE values of cement-bonded particleboards are given as 9 N/mm^2 and 4500 N/mm^2, respectively. All board groups meet standard values. Internal bond strength (IB) results showed a decrease with the use of vermiculite. In the two types of vermiculite, a slight decrease occurred at 5% usage rate, while the highest resistance loss occurred at 20% usage rate. However, the EN 634-2

(2009) requirement for CBPB is an IB value of 0,5 N/mm^2. All experimental types of boards had IB values below the standard. There was a slight increase in screw withdrawal resistance (SWR) values compared to the control board using 5% EV. In other usage rates, the use of vermiculite affected the values negatively. Despite the compatibility between vermiculite and cement, as the use of higher density vermiculite increased, the wood volume in the cemented particleboard and the contact area between the chips decreased. This may have caused a decrease in the IB and SWR values of the CBPBs. Another important reason for the decrease in the resistance of CBPBs is the chip geometry. The chip geometry is an important factor affecting the internal bonding in CBPB (Frybort et al. 2008, Tas et al. 2021). Increasing the chip size causes better internal bonding in the boards (Semple and Evans 2004). Another reason for the decrease in bond strength values may be that the water requirement for the completion of the hydration process cannot be met due to the higher water demand of the vermiculite (Köksal et al. 2015, Benli et al. 2020). In general, the effect on the mechanical properties of the two vermiculite types was similar.

Tab. 3: Tukey HSD statistical analysis of physical and mechanical properties.

Boards	**D**	**MC**	**TS**	**WA**	**MOR**	**MOR**	**IB**	**SWD**
ANOVA results	0.059^{ns}	0.076^{ns}	0.008**	0.001**	0.0001***	0.025**	0.002**	0.018*

Note: ns- not significant, *- significant on p < 0.05, **- significant on p < 0.01, ***- significant on p < 0.001.

CONCLUSIONS

In this study, the effect of vermiculite usage on thermal, physical, and mechanical properties was investigated. Based on the findings of the study, the use of vermiculite positively affected the thermal properties of the boards. The amount of char yield also increased, with the increase in the amount of vermiculite. The use of vermiculite appears to increase the formation of calcium carbonate in the slabs. It has been understood that the increase in vermiculite usage ratio has a positive effect on cement hydration. There was no significant change in the D and MC values of the board. The use of small amount of vermiculite also had a reducing effect on the amount of WA values, while there was a decrease in TS values. It was determined that the addition of a small amount of vermiculite in CBPBs production improves the MOR and MOE values. It was determined that as the use of vermiculite increased, the IB and SWR values of CBPBs decreased. However, all board groups have met the minimum values specified in the standard for physical and mechanical properties. In general, no significant difference was found between the effects of the two vermiculite types on the board properties. Further investigations are, the effect of other factors such as different wood/cement ratio, hardener type, wood type and amount of water on CBPBs produced using vermiculite should be investigated. In addition, the possibility of using vermiculite as a substitute for cement should be investigated to produce more environmentally friendly and low carbon emission composites.

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