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Research Article

An investigation on the properties of woodcrete exposed to high temperature

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ABSTRACT

By combining wood wastes with various binders, construction materials can be produced. These materials can be used in non-bearing parts such as wall block, insulation panel. In this study, prismatic specimens were taken from the mixtures produced considering the chip-cement ratio as 0.25, 0.5 and 1. The unit weight, ultrasonic pulse velocity, bending and compressive strengths of the specimens were determined by using the results of the experiments on these specimens. In addition, specimens were kept at 200 and 400°C for 3 hours in order to determine its behavior under high temperature, which is one of the most important problems for wood composites. With the experiments carried out on the cooled specimens, weight and strength losses, changes in ultrasonic pulse velocity were examined. As a result of the study, while determining that the chip-cement ratio can be used as 1, it is recommended to use the chip-cement ratio up to 0.5 when the high temperature effect is taken into consideration.

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1. Introduction

Studies for the disposal of wastes generated by the increasing industrial activities in today's technology maintain their importance (Mengeloğlu and Alma, 2002). Depending on the type of the wood, up to 2% sawdust waste can be formed from the processing of wood. A very small part of these wood waste is collected by recycling companies. Some of it is used for heating, some is thrown away (Ateş, 2018). As seen in Fig. 1, sawdust is used as recycling in the production of chipboard and medium density fiberboard (MDF).

In recent years, wood-cement-based composites have been preferred in many countries as environmentally friendly and renewable products in order to reduce the cost of materials in construction works, as seen in Fig. 2 (Şahin, 2019). Wood composites are divided into two main classes; wood composites produced with thermoset adhesives are woodcrete produced with materials such as thermoplastic and cement (Aigbomian and Fan, 2013). The low-density ones of Portland cement composites are made of wood wool and the higher-density ones are made of chip or fiber (Ulusoy and Peker, 2019). Cemented particle boards, one of the cemented wood composites, are defined according to the type, shape, color and surface condition of the cement used in the EN 633 standard (EN 633, 1993). The compatibility of cement with wood is high (Wang, 2018). The fact that cement does not require extra additives for hardening unlike other binders in wood composites makes the products obtained more economical (Aras et al., 2019). Although woodcrete is heavier than resin bonded wood composites, it is lighter than concrete (Jorge et al., 2004; Şahin et al., 2019). Wood-cement composites are also more workable, resistant to water, burning, and rotting than other wood composites (Aras and Kalaycıoğlu, 2016). Woodcrete is also resistant to insects (İstek and Gencer, 2014). Woodcrete has been found to be highly resistant to weather conditions and has no significant changes in dimensional changes (Wolfe and Gjinolli, 1996; Kaya, 2020). It is seen that due to the lignocellulosic material it contains, it has a high sound and more importantly heat insulation (Wei and Tomita, 2001; Kalaycıoğlu et al., 2012). The effects of water-cement ratio, cement-chip

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"ratio and chip type on woodcrete properties are great (Onursal, 1996). In addition, the type of tree from which the chip is obtained is also important (Risbrudt et al., 2010). For example, the wood species being hardwood and softwood affects strength (Na et al., 2014). Not all tree species are equally suitable for obtaining woody building material using cement and chips. Because some tree species delay the setting of cement. Here, water-soluble sugars and phenols in the structure of the chips are effective in the process of setting (Bozkurt, 1982; De la Gree et al., 2014; Miller and Moslemi, 2007). Chip is used as both aggregate and reinforcement material in wood-cement composite production. It is important that the cement used as binder completely surrounds the chip (Simatupang and Geimer, 1990).

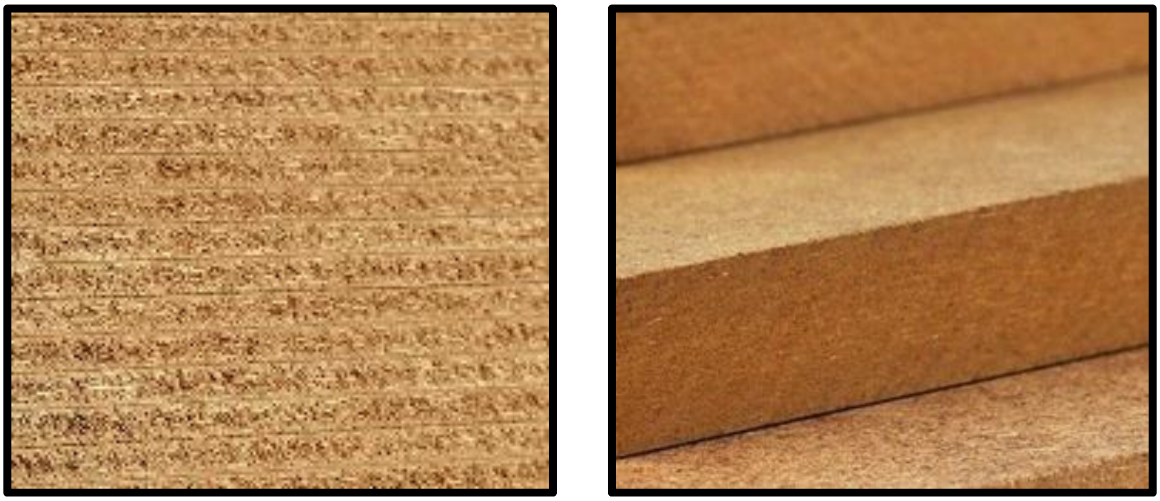

Fig. 1. Partial board and MDF samples.

Fig. 2. Wood-cement based composite specimens.

Although wood waste can be used in the production of wood composites with different resins, mass production of such composites requires a high cost investment. However, since cemented wood composites are easier to produce and their investment costs are lower, a facility to be established where woodworking companies are together has a high potential to transform the waste of these companies into cemented wood composite products. As can be seen from the studies carried out, these products are used as insulation materials due to their lightness and low sound and heat conductivity. Its cement-based nature prevents the wood from being easily flammable. In addition, plasters made on these products make these products more resistant to fire. However, the purpose of this study is to determine the effect of the high temperature that will occur during the fire on the cement-based wood composite properties, unlike other studies. Specimens produced by choosing different ratios of chip-cement were kept at temperatures reaching 400°C and weight and strength losses were determined.

2. Experimental Study

2.1. Materials

The chips shown in Fig. 3, which are the waste of a woodworking company, were used in the study. This company uses Russian fired pine from the Siberian region called North Saphire 117 as its raw material. The unit weight of the chips has been determined as 50 kg/m^3 and its granulometry is given in Table 1. Tap water was used as mixing water and its properties are shown in Table 2. CEM I 42.5 R Portland cement was used as binder and its properties are given in Table 3.

Table 1. Granulometry of pine chips.

Sieve size, mm	16	8	4	2	1
Granulometry, %	100	77	18.4	5.7	0

Table 2. Properties of mixing water.

Chemical Property, mg/l						Physical property	
Al	0.04	Cu	0.016	Ni	5.07	Conductivity, μS/cm	628
NO_3	11.1	Fe	0.007	K	6.8	Hardness, Fd^0	30.11
NH_4	0.06	Mn	0.015	As	1.19	pH	7.35

Table 3. Properties of cement.

Chemical properties				Physical properties	
SiO_2	19,2	K_2O	0,63	Density, g/cm^3	3.09
Al_2O_3	4,56	Na_2O	0,31	Specific surface, cm^2/g	3190
Fe_2O_3	3,09	SO_3	3,21	Setting Time(initial), min	163
CaO	62,9	CI-	0,01	Setting Time(final), min	228
MgO	1,88	LOI	3,8	Expansion, mm	1

Fig. 3. The chip used in the production of woodcrete.

2.2. Method and tests

The chips used as filler in woodcrete production were obtained by mixing with cement paste. Water-cement ratio was kept constant at 0.50 in production. Three different mixtures were made with a chip-cement ratio of 0.25, 0.5 and 1. 4x4x16 cm prismatic specimens were taken from the produced woodcrete mixes and removed from the mold after 1 day and placed in a standard curing environment. Some of the specimens that gained their strength for 28 days were kept at 200°C and some were kept at 400°C for 3 hours according to TS EN 1363-1 (2013) after the oven reached the desired temperature. Left to cool at room temperature. Unit weight, ultrasonic pulse, bending and compressive tests were carried out on these specimens. The effect of high temperature on the specimens was determined by calculating the unit weights, ultrasonic pulse velocity, bending and compressive strengths. Compressive and bending tests were tested in compliance with TS EN 196-1 standard (2016) and ultrasonic pulse velocity in compliance with TS EN 12504-4 standard (2012). At least 3 specimens were used for each test. The bending test was carried out in accordance with TS EN 196-1 (2016), using a single (middle) point loading method. In the bending test, the 4x4x16cm sized specimen was loaded at a speed of 50N/mm^2. At the end of the experiment, the maximum bending load that the specimen can carry was determined. In the compression test, specimens that were divided into two parts as a result of the bending test were used and loaded from their smooth side surfaces. Ultrasonic pulse velocity is determined according to TS EN 12504-4 standard (2012). The experiment is based on determining the transition times of the ultrasonic pulse generated between the receiver and the transmitter within the specimens. For the unit weight test, each of the 4x4x16 cm sized specimens was weighed in the air-dry state. The specimen volume was calculated in cm3 using the dimension measurements made in the specimens according to TS EN 12390-1 (2013). The unit weight was calculated by dividing the specimen weight by the volume. Fig. 4 shows the cross sections of woodcrete specimens with different chip-cement ratios.

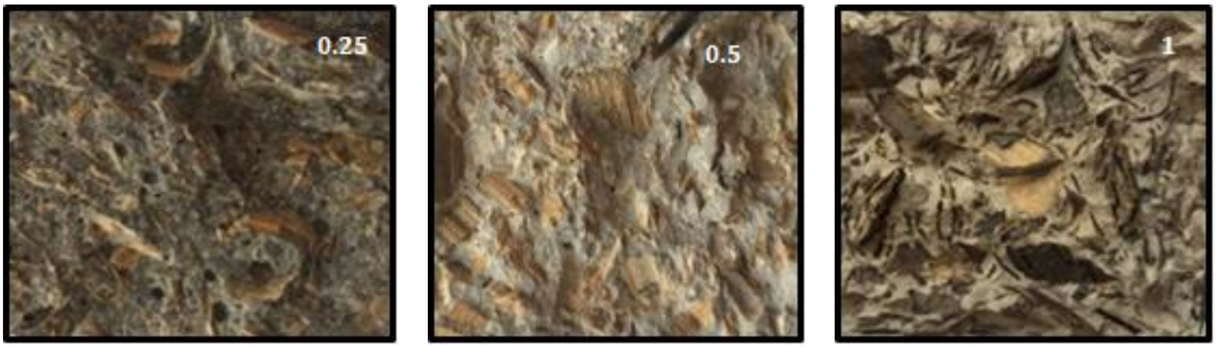

Fig. 4. Woodcrete sections.

3. Discussion

Unit weight, ultrasonic pulse velocity, bending and compressive strength values determined as a result of the experiments on control specimens are given in Table 4. When Table 4 is examined, as the chip-cement ratio increased, unit weight values decreased at rates reaching 12%, ultrasonic pulse velocity values reached 21% and compressive strength values reached 8.4% while bending strength increased by reaching 8.2%. The decrease in the amount of cement, which has a higher density compared to other components, caused a decrease in unit weights. Increasing the rate of chips, that transmit ultrasonic pulses more difficultly, decreased the ultrasonic pulse velocity. The increase in the number of chips, which have a weaker structure than cement, reduced their compressive strength. As a result of the fibrous structure of the chip, the bridging effect on the internal structure caused an increase in the bending strength. According to the strength results obtained, it has been seen that these composites can be used in masonry structures and in reinforced concrete structures as partition wall element. It has been determined that their strength is higher than alternative building materials such as brick and aerated concrete block.

Table 4. Test result of control specimens.

Chip-cement ratio	Ultrasonic pulse velocity, km/sec	Bending strength, MPa	Compressive strength, MPa	Unit weight, kg/dm^3
0.25	3.09	1.85	20.59	2.034
0.5	2.68	1.91	20.03	1.951
1	2.45	2.01	18.86	1.794

The change of unit weights of woodcrete specimens produced with different chip-binder ratios with high temperature is given in Fig. 5. When Fig. 5 is analysed, with increasing chip-cement ratio, cement density is higher than chip. Therefore, it was observed that the unit weights of the specimens decreased. It was observed that unit weights decreased regardless of the chip-cement ratio with increasing temperature. Since the temperature reached 200°C, decreases were observed in unit weights. These values decreased by 1.7% when using 0.25 chip-cement, 1.5% in 0.5 chip-cement, and unit weights decreased by 0.8% when using 1 chip-cement. The reason for this decrease can be explained by the evaporation of the water in the open gaps in the specimens and the decrease in the weight of the material. Since the temperature reached 400°C, unit weights decreased by 16.3% in case of 0.25 chip-cement, 17.5% in case of 0.5 chip-cement, and 13.2% in case of chip-cement ratio of 1. At 400°C, $Ca(OH)_2$, occurred at the end of the hydration reaction of cement, loses the water in its structure and turns into CaO, internal pressure caused by the evaporation of the gel waters trapped in the closed pores created micro cracks in the specimens, and these cracks and deteriorations caused a significant decrease in unit weights.

The change of the ultrasonic pulse velocity of the specimens with the temperature increase is given in Fig. 6. When Fig. 6 is examined, the decrease in the chip rate of the specimens increased the ultrasonic pulse velocity. According to a rigid structure such as cement paste, the low ultrasonic pulse velocity caused this decrease. It was observed that ultrasonic pulse velocity decreased in all specimens with increasing temperature. At 200°C, this decrease rate was 10.8% in the case of using 0.25 chip-cement ratio, 10.4% in the case of 0.5 chip-cement ratio, and 5.2% in the case of 1 chip-cement ratio. At 400°C, the reduction rates were determined as 85.7% in the use of 0.25 chip-cement ratio, 82.6% in the use of chip-cement ratio at 0.5, and 81.2% in the use of chip-cement ratio at 1. The gaps and micro cracks caused by the loss of water at 200°C in the specimens caused a slight decrease in ultrasonic pulse velocity. However, the reason for the considerable decrease in the ultrasonic pulse velocity at 400°C can be explained as the chemical degradation with the increase of cracks in addition to the loss of water and the carbonization of the chip by being affected by the high temperature.

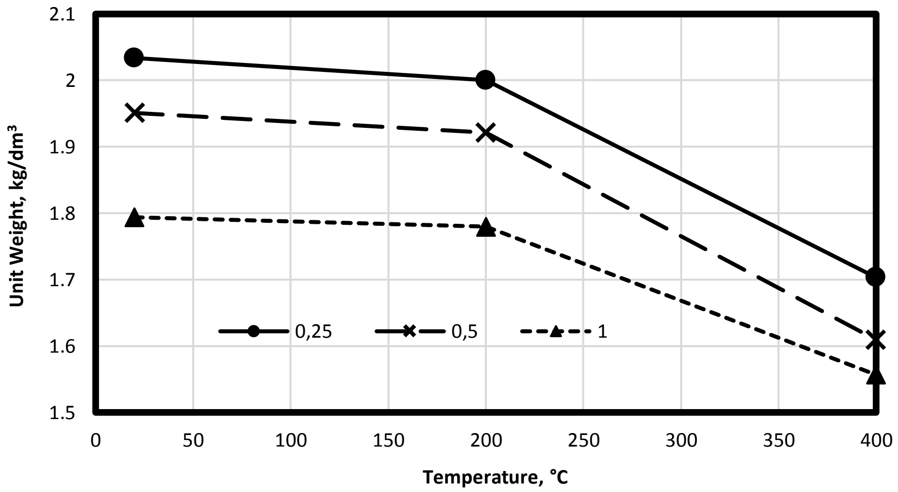

Fig. 5. The effect of high temperature on unit weights of woodcrete specimens.

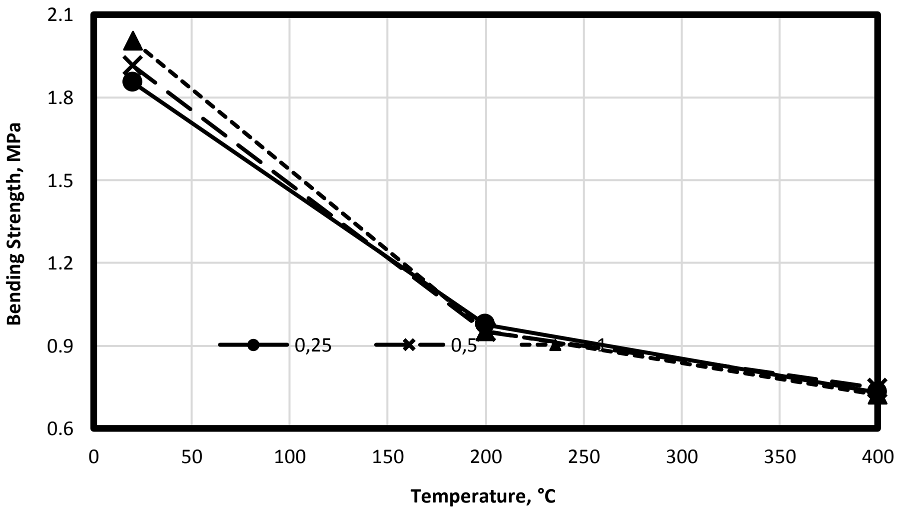

Fig. 6. Effect of high temperature on bending strength of woodcrete specimens.

The bending test results of the specimens are given in Fig. 7. When the bending test results were examined, the increase in the amount of chip due to the fact that the chip behaved like fiber had a positive effect on the bending strength. It was observed that the bending strength values decreased with the increase in temperature under the influence of high temperature. This decrease was 47.4% in the case of using 0.25 chip-cement, 50.3% in the case of using 0.5 chip-cement, and 52.6% in the case of 1 chip-cement at 200°C. At 400°C, there was a 60.6% loss of strength in the use of 0.25 chip-cement, 61% in the use of chip-cement at 0.5, and 64% in the use of chip-cement at a rate of 1. In addition to being effective in the decrease in bending strength of water loss and chemical degradation in the binding phase due to its high temperature, the main effect is thought to be partially carbonized and losing its elasticity by the chips acting as fiber.

The compressive strengths remaining under the high temperature effect of the specimens are shown in Fig. 8. When Fig. 8 is examined, since the binding phase is more rigid than the chip, the increase in chip rate decreased the compressive strength. The increase in temperature negatively affected the compressive strength. The decrease in compressive strength was at 200°C, 4.8% in case 0.25 chip-cement, 12.9% in case 0.5 chip-cement, 49.3% in case 1 chip-cement; 400°C, 46.6% in case 0.25 chip-cement, approximately 50% in case 0.5 and 1 chip-cement found to be. The reason for this decrease can be said as the deterioration of CSH structure, which provides resistance in the binding phase, dehydration of

$Ca(OH)_2$, micro cracks caused by water loss, and the fibrous structure of the chip deteriorate due to the temperature and the chip acts as a gap. Despite these large decreases in the compressive strength of the specimens, the residual strengths are sufficient for masonry structures and non-bearing partition walls elements.

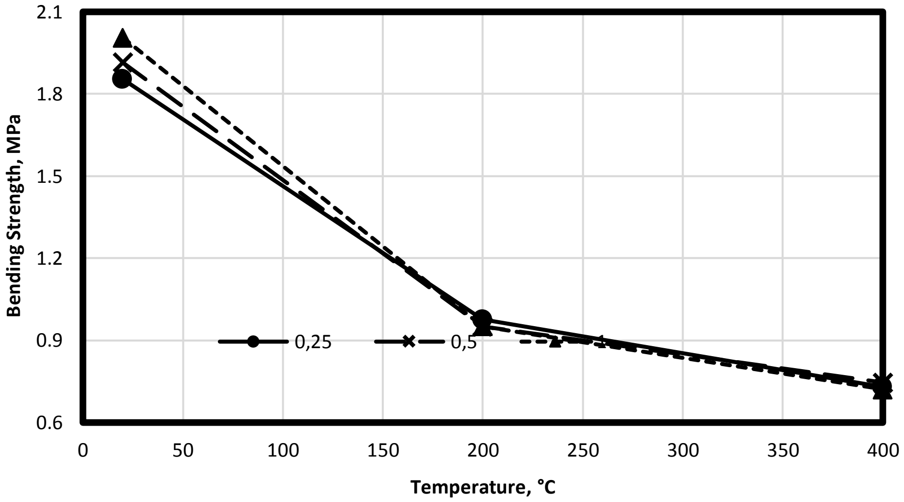

Fig. 7. Effect of high temperature on bending strength of woodcrete specimens.

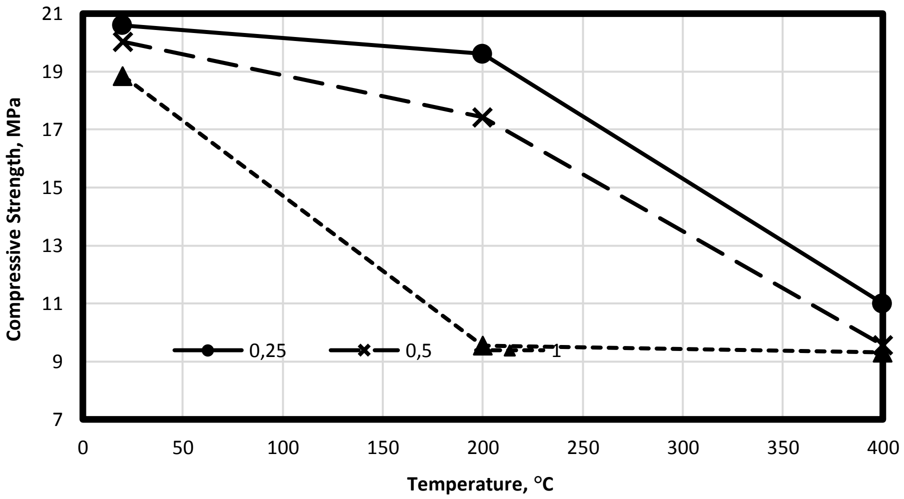

Fig. 8. Compressive strength variation of woodcrete specimens with high temperature.

4. Conclusions

As a result of the experiments conducted in this study, where the effect of high temperature on woodcrete properties was examined, the following results were obtained:

- Increasing the amount of chip decreased unit weight, ultrasonic pulse velocity and compressive strength while increasing bending strength.
- As the temperature increased, the unit weight values, which were 1.9 kg/dm^3 on average, decreased to 1.6 kg/dm^3 depending on the chip rate.
- While the highest losses are observed at ultrasonic pulse velocity with high temperature increase, the ultrasonic pulse velocity that remained as a result of these losses decreased to 0.5 km/sec.
- Despite the positive effect of chip content on bending strength, high temperature effect has been negatively affected by bending strengths and bending strength has decreased to 0.7 MPa.
- Even though there is a decrease in compressive strength with the increase of temperature, it is an important result that the remaining strengths are at an average level of 10 MPa and that this material does not completely lose its bearing strength under the influence of temperature.

As a result of this study, it can be suggested to use the chip waste generated during wood processing in cement-based composites at the ratio of 0.5 chip-cement. However, considering the losses caused by the high-temperature effect, it can be suggested to choose a chip-cement ratio of 0.25 if these products are used in places where they may be affected by high temperatures. In addition, the determination of other physical and chemical durability properties is recommended for other studies.

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