Challenge Journal of Structural Mechanics

Research Article

Effect of high temperature on the mechanical behavior of cement-bonded wood composite produced with wood waste

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ABSTRACT

The increase in the population day by day and urbanization has led to a rapid increase in the construction sector. With the increase in demand in construction, the product types of building materials are increasing. It is seen that wastes are formed during and after the production of the materials used in the building. This highlights studies on waste management and recycling of waste. After construction activities, wastes are recycled or converted to secondary products. One of these is wood waste, a traditional building material. In addition to the production of wood furniture, it is used in various areas from the beginning of construction to the end of the building. In this study, sawdust, which is the waste of a woodworking company, was used. Utilizing the advantages of wood, recyclable and sustainable cement bonded wood composite production practices have been explored. It is aimed to produce nature and environment friendly, ecological and economic and durable composite materials. In this research, it is aimed to determine the optimum ratio by using different ratios of sawdust-cement while keeping the water-cement ratio constant in production. The specimens taken from the production were exposed to high temperature after gaining strength. The strength results, unit weights and ultrasonic pulse velocity results of cement bonded wood composite samples exposed to high temperature were examined. Although cement bonded wood composites are exposed to high temperatures such as 400°C, it has been observed that strength is achieved. With this study, an alternative area was proposed for the evaluation of these wastes.

ARTICLE INFO

Article history:
Received 28 August 2020
Revised 31 October 2020
Accepted 10 December 2020

Keywords:
Wood
Cement-bonded
Sawdust
Composite
High temperature

1. Introduction

Composite material is defined as the combination of two or more materials that give superior properties compared to the use of its components individually. Each material composing the composite materials composition retains its physical, chemical and mechanical properties (Campbell, 2010; Aras and Kalaycıoğlu, 2016). In wood-based composite materials, they typically coexist with cement and wood or its derivatives (sawdust, chip, fiber, etc.) in the binding of matrix cement. These materials are suitable for building and construction works as they provide easy production, as well as improved biodegradation and are produced from sustainable sources (Şahin et al., 2019).

With the decreasing forest presence and rising wood prices worldwide, it has increased the tendency towards wood composite materials (Kaya, 2018). Wood waste is produced worldwide. Recycling and reuse of wood waste as aggregate in concrete or mortar becomes a sustainable and developed solution for building materials (Li et al., 2019a). As an alternative to traditional construction materials, wastes such as bio-sourced wood fibers combined with cement matrix have been used. These materials, which are cheap and environmentally friendly to manufacture, provide economic and ecological solutions. Wood cement composites have low weight, thermal and acoustic properties, ease of recycling and less energy requirements (Li et al., 2019b).

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ISSN: 2149-8024 / DOI: https://doi.org/10.20528/cjsmec.2021.01.005

Cement bonded wood composites is the name given to the material with high specific gravity and smooth surface, which is formed by combining wood chips or agricultural plants with cement, water and various chemical substances in appropriate proportions (Kalaycıoğlu, 2016). The compatibility of water, sawdust and cement in wood composites significantly affects the hardening and strength properties of cement (Yel, 2020). Water / cement ratio is important for cementitious composites. It is also possible for wood to absorb the water required for hydration of the cement. In this case, some of the cement cannot be hydrated and the composite causes low strength (Caprai et al., 2018; Kochova et al., 2020). Since wood is a natural material, its properties can change even within the same type. This case is an important factor for lignocellulosic composite (Gauvin et al., 2019). For the production of high quality cement bonded wood composite, woods such as spruce, fir and pine with the lowest water solubility are recommended. Depending on the type of wood, the water-soluble substances change and affect the setting time of the wood-cement mixture (Sanaev et al., 2016). Hemicelluloses in Wood decompose, form monosaccharides and polysaccharides and can delay cement hydration (Berger, 2020).

Cement bonded woodcretes can be versatile lightweight building materials such as interior panels, noise barriers, and partition walls (Hossain et al., 2018). The combination of cement and wood offers advantages such as strength performance, structural durability, lightness, heat / sound insulation and fire resistance in wood cement composites (Wang, 2017). Cement bonded wood composites have high resistance and dimensional stability against external weather conditions or rapid aging. These materials have high fire, sound and heat insulation as well as high resistance to biological factors. Although they are heavier than resin-based boards, they are lighter than concrete. For this reason, it is preferred especially in the sections that are not exposed to load in the prefabricated building sector (Kaya, 2018). Cemented chipboards, one of the cemented wood composites, are defined according to the type, shape, color and surface condition of the cement used in the TS EN 633 standard (TS EN 633). Examples of wood-cement composites used in practice are shown in Fig. 1.

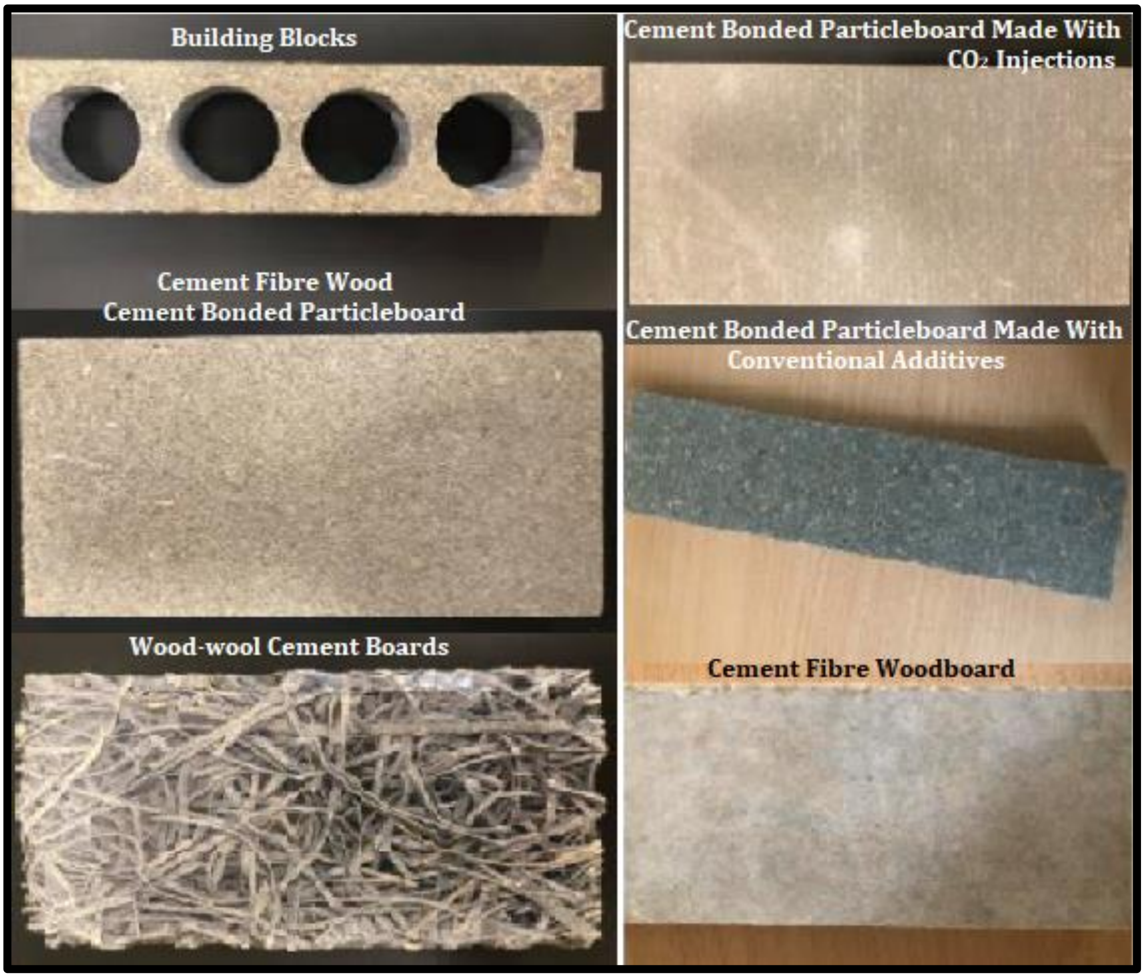

Fig. 1. Wood-cement composite types used in the application (Brahmia et al., 2020).

Although up to 2% waste is generated during the processing of wood, very few of them are used as recycling in chipboard production (Ateş, 2018). With the applied standards, it is seen that various composite building materials researches are increased in order to take advantage of the wood such as insulation. Researches on the use of these products as insulation materials, especially since they are not flammable, are still up-to-date. Unlike these studies, the negative effect of high temperature on the mechanical properties of cement-bonded wood composites was investigated in this study. For this purpose, specimens produced with different sawdust-cement ratios were exposed to temperatures reaching 400°C, and losses in physical and mechanical properties were determined.

2. Experimental Study

2.1. Materials

Sawdust, which are the waste of a firm that carries out woodworks, were used in the study. The type of wood used is the baked Russian pine, called north Saphire 117, taken from the Siberian region. The sawdust shown in Fig. 2 appeared during timber production. The unit weight of the chips is found as 230 kg/m^3 and its granulometry is given in Table 1. As mixing water, mains water which property is given in Table 2, is used. CEM I.42.5 R Portland cement, the properties of which are given in Table 3, was used as binder.

Fig. 2. The sawdust used in the production of cement-bonded composite.

Table 1. Granulometry of sawdust.

Sieve size, mm	4	2	1	0.5	0.25
Granulometry, %	100	99.5	88.7	44.9	15.2

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	Soundness, mm	1

2.2. Method and tests

The sawdust was used as filler in cement-bonded wood composite production. Water-cement ratio was kept constant at 0.50 in production. Three different mixtures were made with a sawdust-cement ratio of 0.4, 0.8 and 1.25. 4x4x16 cm prismatic specimens were taken from the produced composite mixtures 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 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 the specimens. Also, at least 3 specimens were used for each test. The three-point bending test is carried out in accordance with TS EN 196-1. Specimens that are divided into two parts in the bending test are tested for compressive strength. Compressive strength test was carried out on these parts by using 4x4 cm^2 metal plates. According to the TS EN 12504-4 Standard, it is based on the determination of the transition times of the ultrasonic sound waves generated between the receiver and the transmitter in the specimen. The unit weight was calculated according to TS EN 12390-1 by dividing the specimen weight by volume. Cement-sawdust mixtures and compressive test were shown in Fig. 3. Since the wood becomes charred at temperatures above 280 degrees (Vural, 2013) and loses its properties, the temperature before carbonization was chosen as 200°C, and the temperature after carbonization was 400°C.

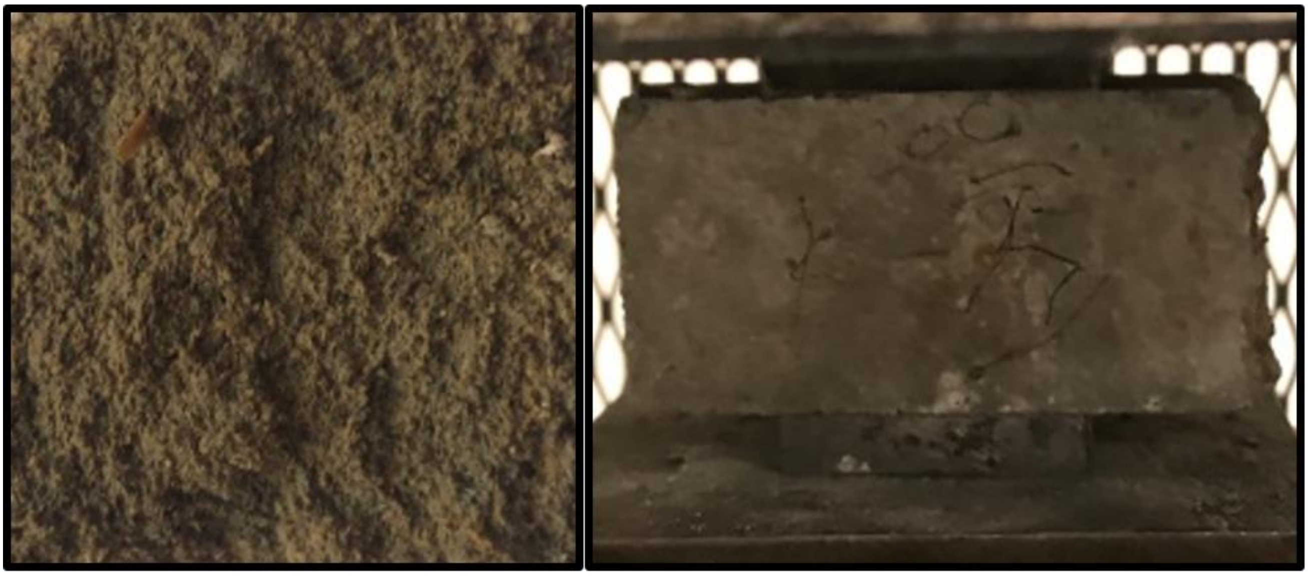

Fig. 3. Cement-bonded wood mixtures and compressive test.

3. Results and Discussion

Unit weight test results were given in Fig. 4. As the sawdust-cement ratio decreased, the unit weights increased by 6%. Similar to other studies (Oliveira et al., 2020), it can be stated that a very light composite is obtained since the unit weights of the specimens are around 1.3 kg/dm^3. Depending on the evaporation of the water contained in the specimens kept at a temperature of 200°C, losses were observed in the rates up to 2% in unit weights. When the temperature reached 400°C, unit weights decreased at the rate of low sawdust-cement by 7.4% while this decrease rate was 4.3% at the rate of high sawdust-cement. It can be said that the reason for the relatively higher losses in unit weight at 400 °C is carbonization (Vural, 2013) of the sawdust by partial burning.

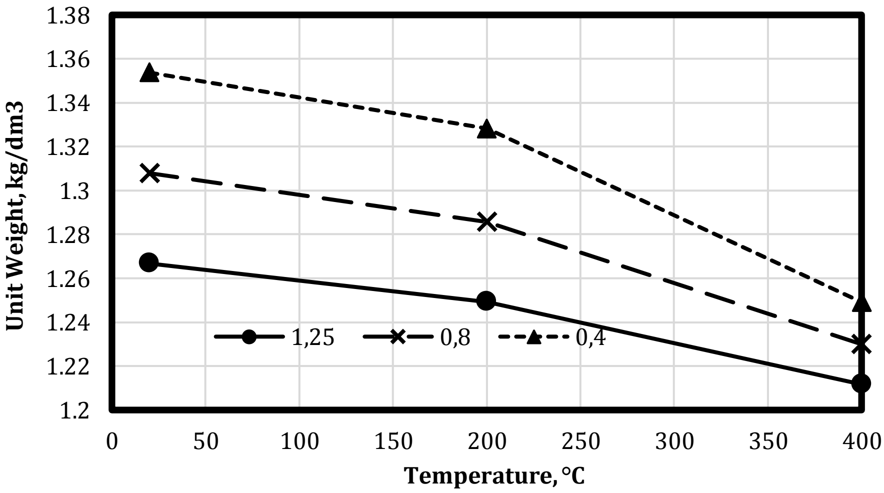

Fig. 4. The effect of high temperature on unit weights of composite specimens.

Ultrasonic pulse velocity losses occurring under the influence of high temperature were shown in Fig. 5. As shown in Fig. 3, when the sawdust-cement ratio increased, ultrasonic pulse velocity decreased by 14%. Increasing the amount of sawdust causes gaps to increase. In addition, since the hardened cement paste and sawdust create different media, the transmission of the vibration movement is slower in the sawdust, resulting in the reduction of the ultrasonic pulse velocity. When the temperature increased from 20°C to 200°C, micro cracks caused by the evaporation of water trapped in the interior and the application of pressure caused a decrease in the rate of ultrasonic pulse velocity reaching 13%. When the temperature was 400°C, sawdust was partially burned and the gases formed as a result of this burning applied pressure to the inner walls, as a result of the propagation and branching of micro-cracks that occurred earlier, caused a decrease in the ultrasonic pulse velocity reaching 67%.

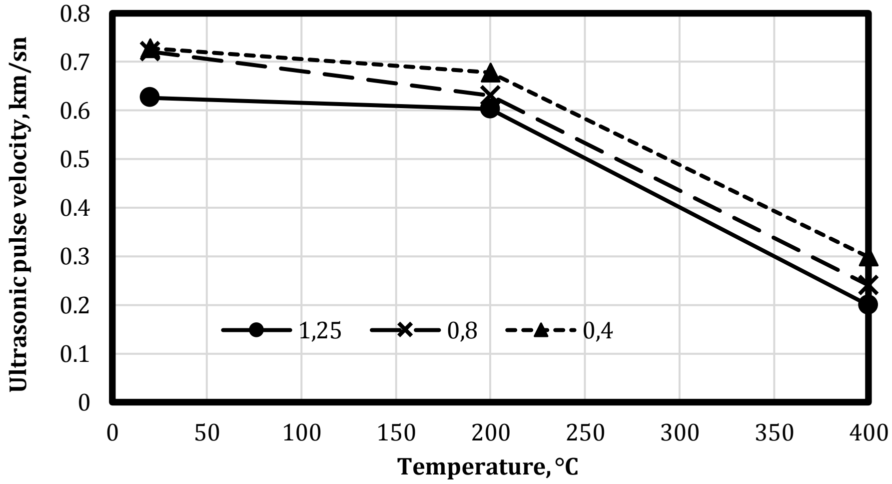

Fig. 5. Ultrasonic pulse velocity rate change of composite specimens with high temperature.

Variation of bending strength with temperature and sawdust-cement ratio were shown in Fig. 6. The increase in the sawdust content of the composite caused the bending strength to decrease by 13%. Since Sawdust is in powder form and not long enough to form a fibrous structure, it did not affect bending strength positively. In addition, sawdust being less rigid than cement caused decreases in bending strength. With increasing ambient temperature, bending strength decreased linearly. The rate of decrease has reached 25%. Micro cracks caused by dehydration and burning can be cited as the reason for these significant decreases in bending strength.

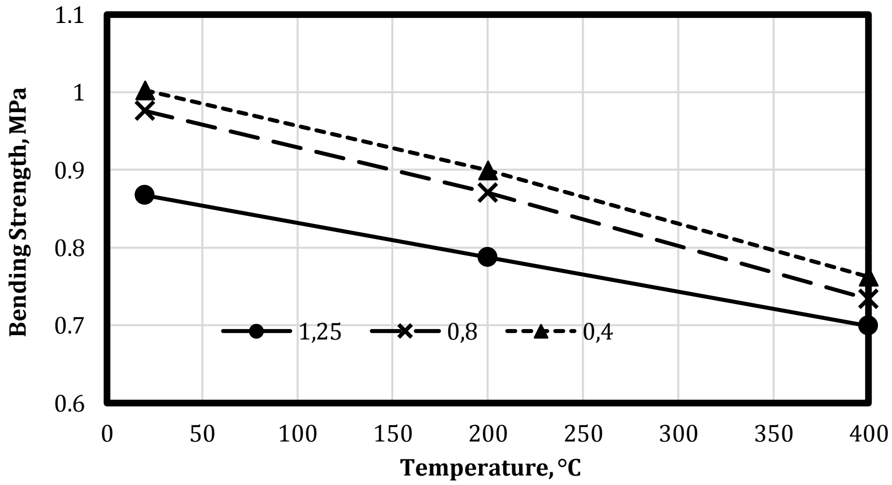

Fig. 6. Effect of high temperature on bending strength of composite specimens.

Compressive strength test results on cement-bonded wood composite specimens were shown in Fig. 7. Strengths were determined to be below 10 MPa, similar to other studies in the literature (Oliveira et al., 2020). İllustrated in Fig. 7. When the sawdust-cement ratio increased from 0.4 to 0.8, the compressive strength decreased by 7%. When the sawdust-cement ratio reached 1.25, compressive strengths remained nearly the same. When the effect of high temperature on compressive strength is examined, compressive strength has decreased due to the increase in temperature. When the temperature reached 400°C, specimens with sawdust-cement ratio of 0.4 experienced 23% strength loss. When the sawdust-cement ratio is 0.8, the strength loss is 25%, while when the sawdust-cement ratio reaches 1.25, the strength loss has reached 26%. Sawdust is being more viscous than cement and lack of binding properties caused a decrease in strength in specimens where sawdust was high. $Ca(OH)_2$, which is a hydration product with high temperature in cementitious structures, loses water and turns into CaO, causing shrinkage and cracks. This situation shows that sawdust is effective in the decrease in strength together with the inward burning. The high residual strengths can be interpreted as the deterioration of calcium silicate hydrate gels, which are among the hydration products and provide a solid structure, has not yet started.

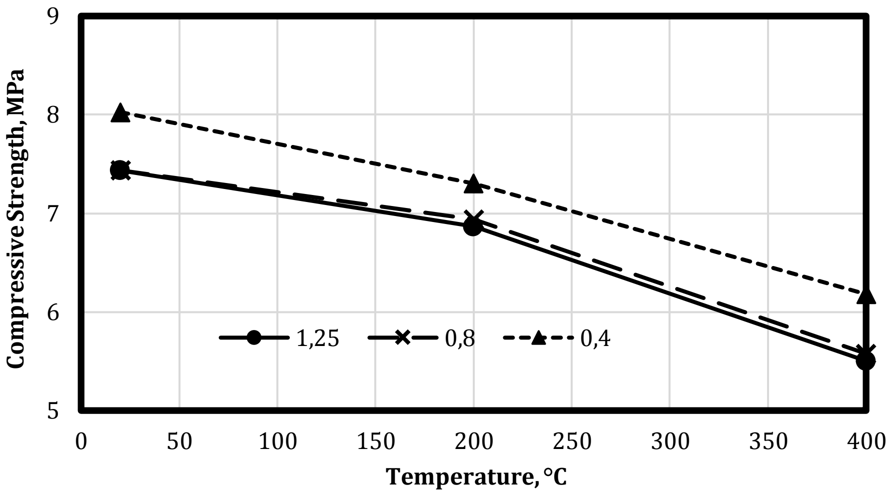

Fig. 7. Compressive strength variation of composite specimens with high temperature.

During the reactions of the main components of cement with water, they interact with components such as cellulose and lignin in the sawdust structure and dissolve in alkaline environments caused by Ca $(OH)_2$. Although more than one reaction occurs at the same time, the formation of hydrogen bridges between cement and sawdust is primarily effective on the bond. Due to the large number of hydroxyl groups in Sawdust's structure, the strength of the composite matrix largely depends on its hydrogen binding potential. Fig. 8 shows the bond structure of sawdust and cement (Şahin et al., 2019).

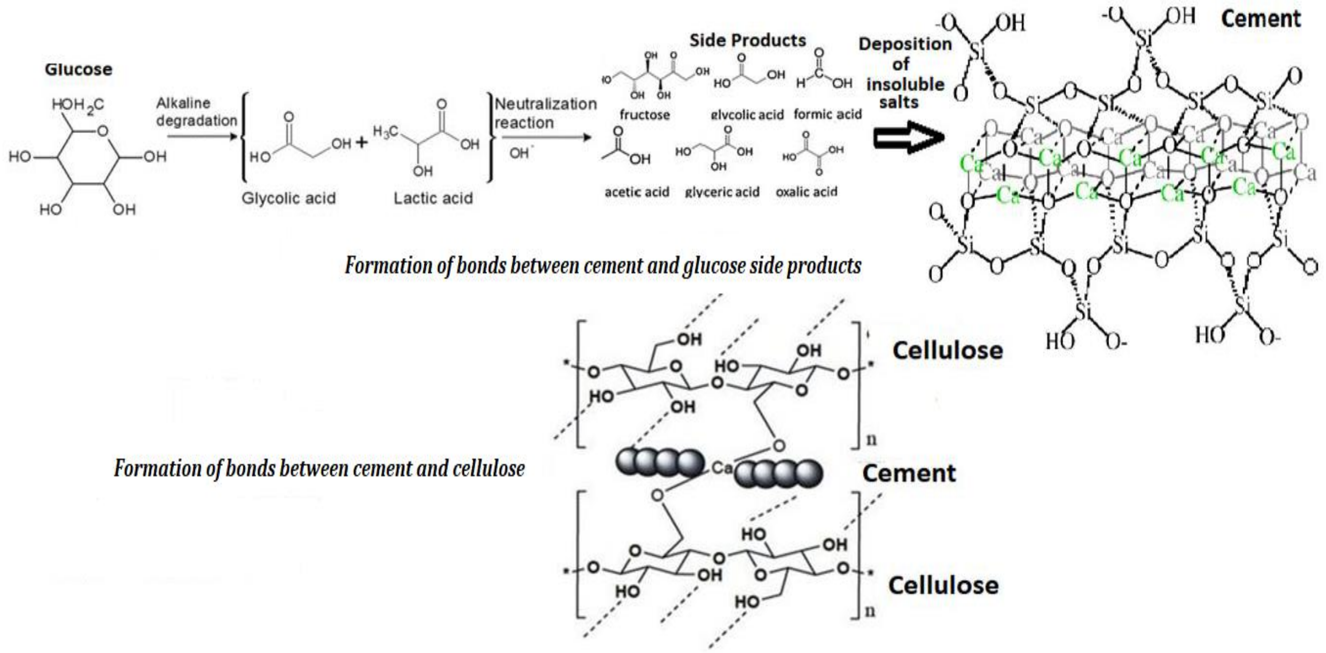

Fig. 8. Chemical structures of cement-bonded wood composite.

4. Conclusions

The following results have been achieved with the experimental study conducted:

- The unit weights of the produced cement-bonded wood composites were found to vary between 1.26-1.36 kg/dm³, ultrasonic pulse velocity of 0.6-0.8 km/sec, flexural strengths of 0.8-1 MPa, and compressive strengths of 7-8 MPa. The values found indicate that a fairly light block can be produced for masonry structures or partition walls with this material or this material can be used for insulation purposes by turning it into a plate. Especially when considering strength, sawdust-cement ratio is recommended as 0.4.
- When the properties that remained under the influence of high temperature were examined, it was observed that the unit weights decreased by 7% and dropped to 1.21 kg/dm³. It is noteworthy that ultrasonic pulse velocity decreased to 0.2 km/sec and decreased by 0.7 MPa with a loss of 25% in flexural strength. In addition, it was observed that the com-

pressive strength losses reached 26%, and the remaining strength decreased by 5.5 MPa. Despite the decreases in physical and mechanical properties, it shows that the specimens do not disintegrate at high temperatures such as 400°C and residual strengths still do not lose their carrier properties. It is recommended to use cement-bonded wood composite products, especially because of the insufficient high temperature and fire performance of composite products produced using sawdust-resin. When residual strengths were examined, it was found that the optimum sawdust-cement ratio was 0.4.

- Wood is one of the most widely used building materials with its wide usage area. Recycling of waste generated during wood processing is not sufficient. With this study, an alternative field is proposed for the evaluation of these wastes. Thus, products with sufficient mechanical properties can be produced for the structure. However, it is recommended to investigate other durability properties that can disrupt the cement structure, especially for cement-bonded wood composite. In addition, it is recommended to investigate the changes in the mechanical and physical properties of this product when used at temperatures above 400°C.

References

Aras U, Kalaycıoğlu H (2016). Wood Based Composites and Usage Areas. *International Refereed Journal of Engineering and Science*, 120-136.

Ateş E (2018). Determination of the amount of the waste wood dust and its energy value in the city center of Balıkesir. *Technological Applied Sciences*, 13(4), 329-346.

Berger F, Gauvin F, Brouwers HJH (2020). The recycling potential of wood waste into wood-wool/cement composite. *Construction and Building Materials*, 260, 119786.

Brahmia FZ, Horváth PG, Alpár TL (2020). Effect of pre-treatments and additives on the improvement of cement wood composite: a review. *BioResources*, 15(3), 7288-7308.

Campbell FC (2010). Structural Composite Materials. ASM International, 612 p., USA.

Caprai V, Gauvin F, Schollbach K, Brouwers HJH (2018). Influence of the spruce strands hygroscopic behaviour on the performances of wood-cement composites. Construction and Building Materials, 166, 522-530.

Gauvin F, Kochova K, Caprai V, Schollbach K, Brouwers HJH (2019). Study of different spruce strands and their effect on the properties of wood-cement composites. *Academic Journal of Civil Engineering*, 37(2), 37-41.

Hossain MU, Wang L, Iris KM, Tsang DC, Poon CS (2018). Environmental and technical feasibility study of upcycling wood waste into cement-bonded particleboard. *Construction and Building Materials*, 173, 474-480.

Kaya Aİ (2018). Some wood based composite materials. Turkchem News Portal. http://www.turkchem.net/ahsap-esasli-bazi-kompozit-malzemeler.html Downloaded on 26.07.2020

Kochova K, Caprai V, Gauvin F, Schollbach K, Brouwers HJH (2020). Investigation of local degradation in wood stands and its effect on cement wood composites. Construction and Building Materials, 231, 117201.

Li M, Nicolas V, Khelifa M, El Ganaoui M, Fierro V, Celzard A (2019a). Modelling the hygrothermal behaviour of cement-bonded wood composite panels as permanent formwork. *Industrial Crops and Products*, 142, 111784.

Li M, Khelifa M, Khennane A, El Ganaoui M (2019b). Structural response of cement-bonded wood composite panels as permanent formwork. *Composite Structures*, 209, 13-22.

Oliveira CA, Silva JV, Bianchi NA, Campos CI, Oliveira KA, Galdino DS, Bertolini MS, Morais CAG, Souza AJD, Molina JC (2020). Influence of Indian cedar particle pretreatments on cement-wood composite properties. *BioResources*, 15(1), 1656-1664.

Sanaev VG, Zaprudnov VI, Gorbacheva GA, Oblivin AN (2016). Factors affecting the quality of wood-cement composites. *Bulletin of the Transilvania University of Brasov*. *Forestry, Wood Industry, Agricultural Food Engineering. Series II*, 9(2), 63.

Şahin HT, Kaya Aİ, Yalçin ÖÜ, Kilinçarslan Ş, Şimşek Y, Mantanis Gİ (2019). A study on the production process and properties of cement-based wood composite materials. *The Journal of Graduate School of Natural and Applied Sciences of Mehmet Akif Ersoy University*, 10(2), 219-228.

TS EN 196-1 (2016). Methods of testing cement - Part 1: Determination of strength. Turkish Standardization Institute, Ankara, Turkey.

TS EN 633 (1999). Cement-Bonded particleboards- Definition and classification. Turkish Standardization Institute, Ankara, Turkey.

TS EN 12390-1 (2013). Testing hardened concrete - Part 1: Shape, dimensions and other requirements for specimens and moulds. Turkish Standardization Institute, Ankara, Turkey.

TS EN 12504-4 (2012). Testing concrete - Part 4: Determination of ultrasonic pulse velocity. Turkish Standardization Institute, Ankara, Turkey.

Vural S (2013). Species of charcoal used in Konya region and its effects on charcoal quality. *M.Sc. thesis*, Süleyman Demirel University, Isparta, Turkey.

Wang L (2018). Value-added recycling of construction waste wood into eco-friendly cement-bonded particleboards. *Ph.D. thesis*, Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong.

Yel H, Cavdar AD, Torun SB (2020). Effect of press temperature on some properties of cement bonded particleboard. *Maderas. Ciencia y tecnología*, 22(1), 83-92.