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Wood-wool cement board: potential and challenges

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Abstract

Wood-wool cement boards (WWCB) produced from Ordinary Portland Cement and spruce wood-wool since the beginning of 1920 are still widely applied. However, the question remains if this type of material is still feasible in the current market where both sustainability and durability perceive popularity. One of the reasons is the high CO\textsubscript{2} footprint of cement production which contrasts to the increased environmental concern. This paper describes the potential of the WWCB in the current market, together with the challenges concerning the sustainability. Firstly, the motivation for this study is introduced. Secondly, the production process of the WWCB is reviewed. Thirdly, the available studies on the interaction between wood and cement, are summarized. Finally, the physical influence of an applied binder is discussed.

Key Words: WWCB, Binder, Cement, Wood-wool

1. INTRODUCTION

In around 1920, after the invention of Ordinary Portland Cement, cement was mixed with spruce-wood wool leading to the creation of wood-wool cement board (WWCB) \cite{1}. WWCB became increasingly popular because of their high thermal insulating and sound absorbing properties gained by the high porosity and low density (400-600 kg/m\textsuperscript{3}). Consequently, because of the mineralization of the wood-wool by the applied binder, the boards possess high resistance to bio-degradation \cite{2} and fire \cite{3}. Hence, the boards can be applied in both buildings and constructions as roof and ceiling material or as an exterior wall where a high durability and low maintenance is requested. However, there are certain disadvantages of these products that limit their suitability in the market. The main drawback is that wood and cement do not work well together due to the wood extractives (mainly sugars) that inhibit the cement setting and result in boards with poor mechanical properties. Furthermore, at present, WWCB is still produced, but the question remains if this product is still feasible in the current global market where both sustainability and durability perceive popularity. Therefore, it would be more favorable to lower the environmental impact of a WWCB e.g. by replacing cement with an alternative binder. It is well known that cement production, has a high CO\textsubscript{2} footprint (global warming equivalent is 971 kg CO\textsubscript{2}/ton cement, data originates from life cycle analyses) and therefore contrasts to the increased concern about global warming, air, water, and land pollution.

The need for and the benefits from an optimized mineral-bounded wood composite have already been studied over the past 60 years, by investigating the interactions between wood and cement, and introducing different kinds of wood/plant fibers as substitutes to the usually applied spruce wood \cite{2}–\cite{10}. Nevertheless, there is a lack of implementation of scientific approaches in industry because of practical problems or lack of acceptance. Additionally, in most studies, wood is mainly used for fiberboards fabrication or as a reinforcement agent in concrete, where different parameters apply compared to WWCB.

In this study, an overview to WWCB and an investigation on the influence of the applied binder is performed.

2. WWCB

2.1 Production process

Forest trees such as pine, spruce, poplar, eucalyptus (mostly soft wood species) \cite{1} with diameters between 16-25 cm are harvested at 30-50 cm above the ground level, whereas the first 2 m of the trees are used for the production of WWCB. The branches and bark of the trees are removed on site. After cutting, the wood logs are transported to the WWCB factory and stored on site for 3-6 months depending on the season (winter or summer), and the tree sap, mainly consisting of sugars, is leached out.

Subsequently, WWCB is produced following the flow chart as presented in Fig. 1. First the outside stored wood logs are cut into blocks of 50 cm in length (±2%) so that they can be screened for metal parts and then cut into 25 cm pieces and shredded to wood-wool. The final dimensions of the wood-wool are 25 cm in length, 1-4 mm in width and 0.1-0.5 mm in thickness. Depending on the aesthetic requirements superfine (≤ 1 mm in width), fine (± 1-3 mm in width), course (≥ 3 mm in width) wood-wool is produced.
Then, the wood-wool is dipped in a solution to accelerate the compatibility at the wood-wool-cement paste interface and are afterwards pressed to decrease the water content. The wet wood-wool with 50-65% moisture content, together with cement powder, is fed into a continuous mixer. The irregular flow of wet wood-wool is continuously controlled by an electronic device for a continuous flow of cement. This process is called the mineralization of the wood-wool and takes approximately 2 minutes.

The mixture is then transported to the so-called double distribution machine. This machine spreads two different layers of a continuous mat of wood-wool cement into the molds.

After having passed a hydraulic pre-press roll (with a small force, enough to press the plate together), the molds are separated by a circular saw and moved to the hydraulic stacking press. This machine stacks the molds with fresh material under pressure (the mold height is used as a reference for the pressure). As soon as the stack is full, the stack is moved out and stored under pressure (e.g. by a concrete block of 1500 kilo for 24 hours). After the setting of cement, the boards are taken from the molds for further curing, while the molds can be cleaned and oiled for re-use.

After a storage period of 10 days, the boards are put into an oven at 140-160 °C for 30 minutes to remove the extra water. Finally, the plates are painted, stacked and packed.

2.2 Properties

Color. Based on the aesthetic requirements, the boards can be painted to any desired color. Since grey cement can never be completely invisible, white cement is often used. However, this leads to a significant increase on the cost.

Thermal insulation. The thermal conductivity of the board is stated to be 0.08 W/(m·K) for boards with thicknesses ranging from 15-30 mm. The low thermal conductivity is due to the use of low density wood-wools and low dosage of the cement. The total porosity of the board is 78%.

Sound absorption. Due to its large porosity and open structure with a high contact area, sound waves can easily be absorbed. The absorption is mostly effective for sound frequencies of 500 Hz and higher, but with increasing the board thickness higher absorption in the lower frequency between 125-500 Hz can be achieved (Fig. 2).

Fig. 1: Flow chart of the production of WWCB starting from the wood logs until pressing of the boards.

Fire resistance. Wood is a combustible material that ignites before reaching 300 °C. However, by applying a cementitious coating covering the wood-wool, ignition can be prevented and therefore, the product can meet the stated requirements in EN 13501-1 for a low combustible material (category B2). Furthermore, increasing the amount of binder, will further increase the fire resistance of the board.

3. INHIBITORY EFFECT OF WOOD

The retarding effect of wood components on the cement hydration occurs due to the different reasons: when wood is in contact with water, it starts to absorb the water, mostly by the hydrophilic hemicellulose. Afterwards, cement is added and different mechanisms initialize:

- Firstly, the hemicellulose and other inhibitory substances such as starches, sugars, phenols and hydroxylated carboxylic acids – that are soluble – start to dissolve and leach out from the wood fiber. This is even accelerated by the rapidly increasing alkalinity (caused by the added cement) of the environment that promotes the diffusion of this inhibitory substances;
- Secondly, from the start of migration of inhibitory substances, the alkaline hydrolysis of hemicellulose and other substances result in the formation of calcium salts of lignin, polysaccharides and sugars [11], which will interfere with the cement hydration forming different hydration products and alter crystalline structures;
- Thirdly, because of the absorption phenomena, potassium (K⁺) and calcium (Ca²⁺) ions could be absorbed to some extent by the lignocellulosic particles. Thus, calcium, which is essentially from the hydration products that promotes the cement hardening is removed from the solution, reducing the availability for cement hardening and causing their impairment to some degree;
- Fourthly, lignocellulosic particles can absorb water that otherwise could be used for cement hydration. Hence, they reduce the amount of water used for cement curing [12], [13].
- Fifthly, it was reported that the formation of portlandite (CH) strongly inhibited beyond 48
hours of hydration by natural poplar, while an increasing amount of calcium carbonates was observed [14]. It was found that the inhibition of CH formation is not due to the decrease in water to cement ratio, but more likely due to the alkaline degradation of wood that could induce a carbon dioxide release. This carbon dioxide leads to the carbonation of CH. Consequently, the amount of CaCO₃ in the paste increases.

### 4. Binder

Portland cement is a widely applied mineral binder for wood-wool cement composites. Based on the requirements of the board such as fast hydration and desired mechanical strength, CEM I 52.5 R is used. This cement characterizes itself as a high-quality binder, allowing fast hydration, and acceptable early and late mechanical properties.

The drawbacks of Portland cement in combination with wood have been already addressed by various authors [2], [6], [15], [16] and are often addressed by using accelerators such as waterglass, sodium hydroxide, portlandite, and chlorides.

In order to establish a WWCB with good mechanical properties, the binder needs to meet three crucial criteria. Firstly, to create a good interfacial transition zone between the wood and binder. For this a binder with small particles would be useful since it is able to react fast without substantially being affected by the dissolved sugars. Secondly, to form a protective layer, covering the wood-wool. For this, the cement needs to be well distributed to cover the surface of the wood-wool. A low density binder would have a positive contribution since more material can be added to remain a similar density. Moreover, a binder with a high specific surface is preferable, since it mostly consists of fine particles and will easily distribute around the wood-wool to form a protective layer. One drawback is the high water absorption that will start a competition between the wood (that can absorb water 3 times of its own weight) and the binder. In case there is not enough available water for the binder to hydrate, the quality of the interfacial transition zone between both the wood and binder layer will be poor, but also the binder layers to interconnect the wood-wool will be insufficient during the compressing and will lead to reduced mechanical properties of the board. However, when a large amount of water is added to overcome this problem, the wood-wool will swell and during the curing shrink, creating internal stress. Thirdly, the wood-wool is interconnected by the cement hydrated layer and therefore, the layer should not be too thin or the distance between the wood-wool too large. The third point is not often taken into account but is essential to have a successful binder. In case a too low wood amount is used for a certain volume (e.g. to increase the porosity of the board), the distance between the wood-wool during compression is larger than the thickness of the cement layers, making it impossible to interconnect with each other. Again, this results in reduced mechanical properties. Therefore, particle size distribution, specific surface area and density of the binder are important in addition to the inhibiting effect of the wood-wool.

### CONCLUSIONS

This paper addresses the potential and challenges of WWCB. The following summaries are reached:

- The inhibitory effect of wood on the cement hydration is widely studied by different authors. However, there is a lack of systematic knowledge about the influence and performance of applied binders in WWCB.
- It is found that an applied binder needs to fulfill three important aspects. Firstly, to create a good interfacial transition zone between the wood and binder. Secondly, to create a well distributed layer covering the wood-wool. Thirdly, to create strong matrix interconnections between the wood-wool.

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### REFERENCES


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