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Citation for published version (APA):

Kochova, K., Schollbach, K., & Brouwers, H. J. H. (2015). Use of alternative fibres in Wood Wool cement boards and their influence on cement hydration. In *19th International Conference on Building Materials (Ibautil 2015)* (pp. 1375-1382). Article 2 Bauhaus-Universität Weimar.

Document status and date:

Published: 01/01/2015

Document Version:

Accepted manuscript including changes made at the peer-review stage

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

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1. Introduction

Wood wool cement boards (WWCB) were developed in the 1920s and have been used since then as building materials [1]. Uses have focused primarily on the advantages of these composites: resistance to decay and insects, good acoustical and thermal insulating properties, low density from 300 to 500 kg/m³ [1]. WWCB are mostly used in parking decks, basement ceilings, floor units, loft conversion, timber frame construction, as sound barriers and for acoustic absorption [2].

The most used wood for creating WWCB is spruce and poplar wood, obtained from regional forestry. Spruce wood is classified as a soft wood and poplar wood is classified as hard wood [3]. Binder is generally ordinary Portland cement, but MgSO₄ and caustic calcined magnesia (Sorell cement) can be found as a binder as well. Due to the reduction of price and economic benefits additives, such as lime can be used [2].

The use of wood particles in cement has increased rapidly over the past decade, primarily because of improvements in process technology, economic factors and increased concerns sustainability, renewability and recycling of wood and less consumption of cement [4].

Moreover, large amounts of organic and inorganic waste are generated around the globe from various human activities, such as producing electricity or food (rice husk, wheat straw, bagasse) and the demolition of old structures (buildings, railways) [5,6]. WWCB offer a good opportunity to replace wood and cement with waste products. Cement can be replaced with fly ash, rice husk ash and wood can be replaced with organic waste fibres, like coconut fibres, rice straw, oil palm fibres or fibers intended directly for processing such as hemp or jute [7]. In this way, new sustainable WWCB can be created with economic benefits by taking advantage of waste products.

The production process of WWCB is shown in Fig. 1. An important part of the WWCB production is minimizing the influence of sugar in the wood on cement hydration. For that reason the raw material (wood) is stored in the form of 2 m long logs for 6 - 12 months, depending on the climatic conditions. The next step is to cut the wood to pieces in 50 cm. These blocks are processed on planing machines to get wood wool approximately 1 - 3 mm in width, 0.1 - 0.5 in thickness and 25 cm in length. Then the wood wool is mixed with cement at a ratio of approximately 0.4 to 0.75 by weight [1]. The water:cement ratio is around 0.5 to 0.8. Before the wood wool is mixed with cement, it is wetted in a salt solution. After the mixing process the wood wool is poured into a mould and concrete weights are placed on the stacked moulds to compress them. The filled moulds are dried between 12 and 24 hours and demoulded. The finished boards pass through a dryer again, which removes the moisture from the surface and the boards are cut to the required format. Pigment can be added as per the customers specifications [2].

The main problem for production of wood cement composites, such as WWCB, is the incompatibility between cement and organic fibres, due to the carbohydrates in the fibres which may hinder or stop the hydration of cement. The biggest influence can be sucrose, glucose, fructose [8]. These components are soluble especially in an alkali

environment and react with the cement paste to slow down hydration. This can cause lower mechanical strength of wood cement composites compared to the neat cement. Nevertheless, not all types of carbohydrates have the same effect. Glucose and sucrose are observed to have the biggest inhibitory influence. Sucrose has a greater retarding effect than glucose at the same concentration. The quality and quantity of the leached carbohydrates depend on the type of wood fibres and their growing condition. They need to be investigated to fully understand the compatibility of cement with wood and organic fibres in order to produce wood wool cement boards with new fibres alternatives [8,9,10].

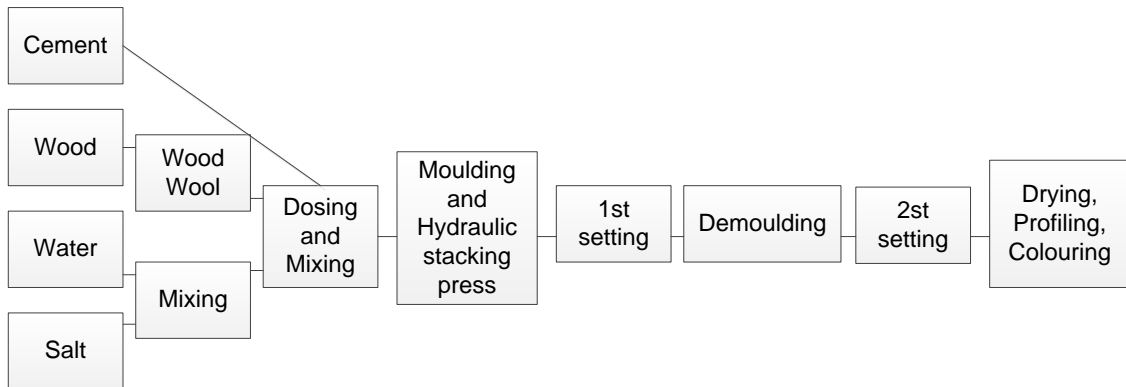


Fig. 1: Production process of WWCB

This paper presents the current research situation in wood wool cement boards. The purpose is to summarize the applicability of alternative materials for the production of WWCB and the influence factors and assessment methods of wood cement compatibility.

2. Alternative materials for the production of WWCB

Worldwide lignocellulose waste has three main sources: agricultural by-products, wood waste from construction/demolition and waste from the wood processing industry [5,7].



Fig. 2: Organic fibres – from left to right spruce wood, rice fibres and coconut fibres

In the agricultural industry a considerable quantity of waste is generated. The waste contains different parts of the plant, such as wheat straw, rice straw and husk, sugarcane bagasse, coconut husk and many parts of the oil palm like fibres or shells [5]. For example, production of cereal straw is around 2 billion tons worldwide [11].

Wheat is one of the major cereals grown in the world. Nowadays, worldwide production is about 709 million tons per year [5]. Due to this fact, the material is an attractive

possibility for producing new products. Wheat straw and wood materials contain almost equivalent amounts of cellulose, but the hemicellulose content is higher and the lignin content is lower in wheat in comparison to wood [12], as can be seen in Tab. 1. Replacement of wood with the aid of wheat straw is feasible due to the size, shape and mechanical characteristics of wheat straw. The application of wheat straw in wood wool cement boards may be a problem due to the higher hemicellulose content which can be responsible for an increased retarding effect on cement hydration. Another problem is the higher water absorption compared to poplar or spruce wood. However, accelerated processing techniques can help with the cement reactions [5,11,13].

Rice is as important as wheat. Worldwide generation is about 673 million tons [5]. Rice provides two types of waste, rice straw (Fig. 2) and rice husks. Both materials are used in different ways. Rice straw is mainly used as a replacement for wood in wood wool cement boards [5,13]. However, rice husks contain high levels of silica and the ash, rice husk ash (RHA), can be used as a supplementary cementitious material to replace cement. The use of RHA can bring benefits; firstly as a cement replacement in wood wool cement boards product and secondly, it has been shown to improve durability of the final product [5].

Coconut husk fibres (Fig. 2) are located between the husk and outer shell of the coconut. The fibres have a relatively low cellulose content and a high lignin content as shown in Tab. 1. These fibres are very resistant and durable. Nevertheless, the pre-treatment (boiling and washing) of fibres is important before their application [5,13,14].

Sugarcane bagasse is produced after extraction of juice from the sugarcane. It is composed of about 50% fibres, 30% pith including moisture and about 20% soluble solids [5] (Tab. 1.).

Oil palm trees have a production life about of 25-30 years and each tree generates about 500 - 600 kg waste (fibre, shells and pulp). This waste material can be used in different ways – for example for energy production, and subsequently the ash can be used for road constructions or fertiliser. A new way to take advantage of the fibres and ash is to create boards [5].

Table 1:
Chemical composition of some natural fibres

Fibres	Cellulose (wt%)	Hemicellulose (wt%)	Lignin (wt%)
Wheat straw	38-45	15-31	20-20
Rice straw	41-57	33	8-19
Rice husk	35-45	19-25	20
Coconut husk	32-43	0,15-0,25	40-45
Sugarcane bagasse	55,2	16,8	25,3
Oil palm	65	-	29
Spruce wood	40-45	20-30	20-30
Poplar wood	42	17	19

3. Cement compatibility

3.1. Wood cement compatibility factors

Compatibility or incompatibility between organic fibres and cement is linked to the soluble carbohydrates, which are found to hinder or stop the hydration of cement. The critical compounds are sugar and starch, but not all types of sugar or starch have the same inhibitory effect [8], as can be seen in Fig. 3. The graph shows the addition of 1 wt% of sucrose, glucose, fructose, cellulose or lignin to the cement paste (CEM 52.5R) with a w/c ratio of 0.5. During the first five days no hydration is visible for the samples prepared with sucrose, glucose, fructose. The effect of lignin is less pronounced while cellulose has no measurable effect.

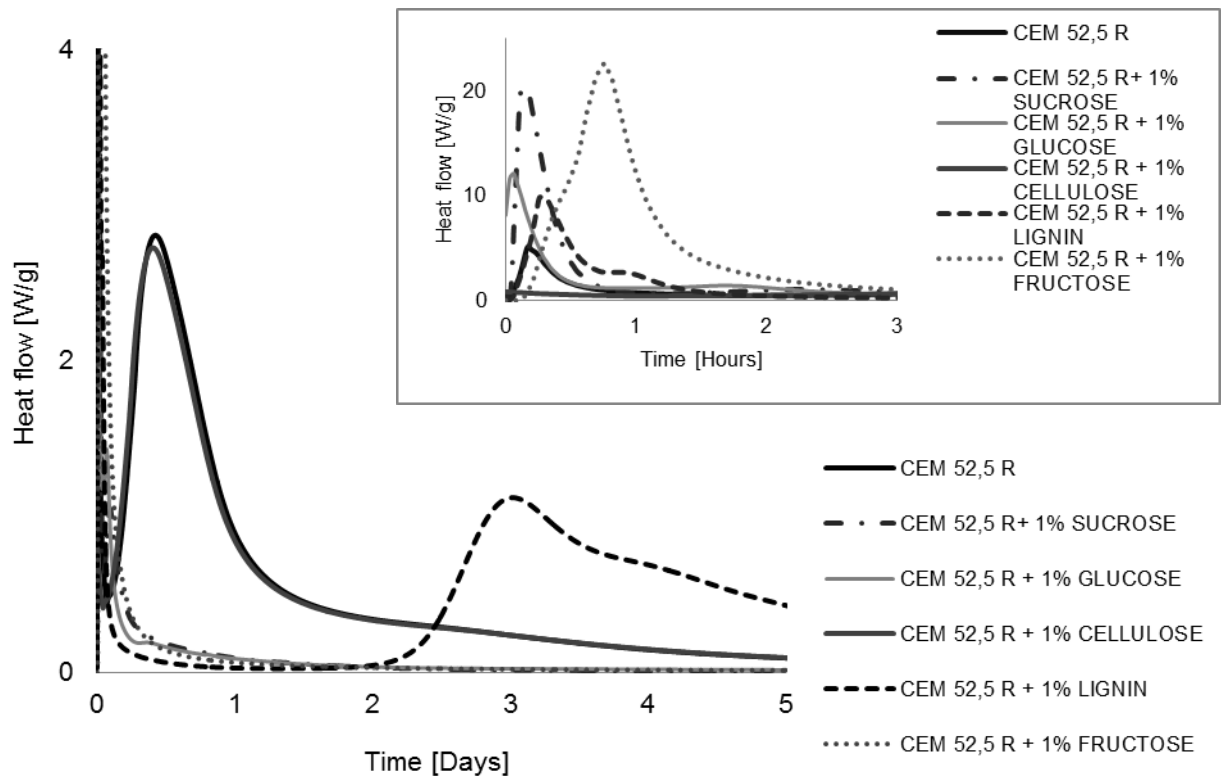


Fig. 3: The effect of 1% sucrose, glucose, fructose, cellulose and lignin on the hydration of cement measured using isothermal calorimetry

Several studies [10,15,16] have shown the effect of carbohydrates on the hydration of cement paste. Juenger and Jennings [15] compared cement with 1% sugar and cement without sugar using calorimetry. They found that an addition of 1% of sugar to the cement paste causes the retarding of cement hydration for several months. Bishop and Barron [10] presented cement hydration inhibition with sucrose and lignosulfonate (products from the production of wood pulp). Both materials stopped cement hydration, but each material acted through a different mechanism. Sucrose acted through nucleation poisoning/surface adsorption while lignosulfonates involved the formation of a semipermeable layer on the cement grains. Peschard et.al. [16] have shown effects of polysaccharides (starch ether, native starch, white dextrin) on cement hydration. This study indicated that a strong modification of cement hydration. C_3A hydration was restricted to the growth of hydrates and not to nucleation.

Several methods exist to improve the compatibility between wood and cement, for example pre-treatment of wood or addition of cement set accelerators (metal salts). Pre-treatment is meant to remove soluble carbohydrates before mixing cement with wood. Hot or cold water and NaOH solution is used [8]. In the production of WWCB Na_2SiO_3 (water glass) is also extensively used as a pre-treatment [2]. Fibres are encased, sugar cannot be leached out and the structure of WWCB is not disrupted. As an addition of the cement set accelerators are used metal salts, such as $\text{Al}_2(\text{SO}_4)_3$, FeCl_3 and CaCl_2 which can improve the strength properties of WWCB or bring economic benefits [8,3].

3.2. Measurement of compatibility

Various methods can be used to measure wood (fibres) cement compatibility. The measurement of hydration with calorimetry is frequently used. The basic principle is measuring the maximum temperature (T_{max}) of hydration and the time (t_{max}) required to reach this temperature with the assistance of calorimetry [8]. Wei et.al. [9] divided the compatibility of 10 wood species into three categories – ‘least’ ($T_{\text{max}} > 50^\circ\text{C}$ and $t_{\text{max}} < 10\text{h}$), ‘intermediate’ ($T_{\text{max}} > 40^\circ\text{C}$ and $t_{\text{max}} < 15\text{h}$) and ‘highly’ ($T_{\text{max}} < 40^\circ\text{C}$ or $t_{\text{max}} > 15\text{h}$) inhibitory. Another method uses the inhibitor index (I), which is calculated from T_{max} and t_{max} and the maximum slope of the exothermic curve for evaluation and classification of the compatibility of the wood, cement and water mixture. Depending on the inhibitory index (I), there are four grades: ‘low inhibition’ ($I < 10$), moderate inhibition ($I = 10-50$), ‘high inhibition’ ($I = 50-100$) and ‘extreme inhibition’ ($I > 100$) [17]. Hachmi et.al. [18] presented a different classification than studies before. It has alternative indicators, such as C_T (weighted maximum temperature rate ratio), C_H (maximum heat rate ratio) and C_A (the ratio of the amount of heat released from a wood cement mixture in 3.5-24 h interval). This study recommended the C_A factor over the C_T and C_H for the measurement wood cement compatibility. Three classes of compatibility are given: ‘compatible’ ($C_A > 68\%$), ‘moderately compatible’ ($28\% < C_A < 68\%$) and ‘not compatible’ ($C_A < 28\%$) [8].

4. Conclusion

This study is focused on WWCB production and the chemical incompatibility between wood, cement and alternative materials. A number of fibres are selected from literatures and reviews, due to the effects on the cement hydration. These effects are caused by carbohydrates, that influence the hydration mechanism. Several methods from literature are proposed for the analysis of calorimetric data. This study will be continued by following methods: FT-IR, SEM, XRD, TG, ion chromatography and calorimetry. Qualitative and quantitative analysis for polysaccharides which can be leached out from fibres under different conditions (different pH or leaching time) will be investigated.

References

- [1] R. W. Wolfe and A. Gjinolli, "Cement-Bonded Wood Composites as an Engineering Material," *use Recycl. wood Pap. Build. Appl. Proc. a 1996 Symp. Spons. by U.S. Dep. Agric. For. Serv. For. Prod. Lab. For. Prod. Soc. Coop. with Natl. Assoc.*, pp. 84 – 91, 1997.
- [2] Knauf Insulation, "Wood Wool Boards Environmental Product Declaration," 2012.
- [3] N. Thaler, B. Lesar, M. Kariž, and M. Humar, "Bioincising of Norway spruce wood using wood inhabiting fungi," *Int. Biodeterior. Biodegrad.*, vol. 68, pp. 51–55, 2012.
- [4] A. Ashori, T. Tabarsa, K. Azizi, and R. Mirzabeygi, "Wood-wool cement board using mixture of eucalypt and poplar," *Ind. Crops Prod.*, vol. 34, no. 1, pp. 1146–1149, 2011.
- [5] S. R. Karade, "Cement-bonded composites from lignocellulosic wastes," *Constr. Build. Mater.*, vol. 24, no. 8, pp. 1323–1330, Aug. 2010.
- [6] B. Belhadj, M. Bederina, N. Montrelay, J. Houessou, and M. Quéneudec, "Effect of substitution of wood shavings by barley straws on the physico-mechanical properties of lightweight sand concrete," *Constr. Build. Mater.*, vol. 66, pp. 247–258, Sep. 2014.
- [7] M. John and S. Thomas, "Biofibres and biocomposites," *Carbohydr. Polym.*, vol. 71, no. 3, pp. 343–364, Feb. 2008.
- [8] B. Na, Z. Wang, H. Wang, and X. Lu, "Wood-cement compatibility review," vol. 59, no. 5, pp. 813–826, 2014.
- [9] Y. M. Wei, Y. Guang Zhou, and B. Tomita, "Hydration behavior of wood cement-based composite I: evaluation of wood species effects on compatibility and strength with ordinary portland cement," *J. Wood Sci.*, vol. 46, no. 4, pp. 296–302, 2000.
- [10] M. Bishop and a R. Barron, "Cement Hydration Inhibition with Sucrose, Tartaric Acid, and Ligninsulfonate: Analytical and Spectroscopic Study," *Ind. Eng. Chem. Res.*, vol. 45, pp. 7042–7049, 2006.
- [11] P. Soroushian, F. Aouadi, H. Chowdhury, A. Nossoni, and G. Sarwar, "Cement-bonded straw board subjected to accelerated processing," *Cem. Concr. Compos.*, vol. 26, no. 7, pp. 797–802, 2004.
- [12] P. Bekhta, S. Korkut, and S. Hiziroglu, "com Effect of Pretreatment of Raw Material on Properties of Particleboard Panels Made from Wheat Straw," vol. 8, no. Grigoriou 2000, pp. 4766–4774, 2013.
- [13] O. Faruk, A. K. Bledzki, H.-P. Fink, and M. Sain, "Biocomposites reinforced with natural fibers: 2000–2010," *Prog. Polym. Sci.*, vol. 37, no. 11, pp. 1552–1596, Nov. 2012.
- [14] C. Asasutjarit, J. Hirunlabh, J. Khedari, S. Charoenvai, B. Zeghmami, and U. C. Shin, "Development of coconut coir-based lightweight cement board," *Constr. Build. Mater.*, vol. 21, no. 2, pp. 277–288, Feb. 2007.
- [15] M. C. Garci Juenger and H. M. Jennings, "New insights into the effects of sugar on the hydration and microstructure of cement pastes," *Cem. Concr. Res.*, vol. 32, no. 3, pp. 393–399, Mar. 2002.
- [16] a. Peschard, a. Govin, P. Grosseau, B. Guilhot, and R. Guyonnet, "Effect of polysaccharides on the hydration of cement paste at early ages," *Cem. Concr. Res.*, vol. 34, pp. 2153–2158, 2004.
- [17] E. Y. a Okino, M. R. De Souza, M. a E. Santana, M. V. D. S. Alves, M. E. De Sousa, and D. E. Teixeira, "Physico-mechanical properties and decay resistance

- of Cupressus spp. cement-bonded particleboards,” *Cem. Concr. Compos.*, vol. 27, no. 3, pp. 333–338, 2005.
- [18] M. Hachmi, a. a. Moslemi, and a. G. Campbell, “A new technique to classify the compatibility of wood with cement,” *Wood Sci. Technol.*, vol. 24, no. 4, pp. 345–354, 1990.

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