PROPOSING WOOD LIGHTWEIGHT CONCRETE FOR CO_2 SEQUESTRATION

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Abstract. Building materials made from renewable raw materials can help to improve the CO_2 balance of building components or even serve as a CO_2 sink (by including CO_2 binding during plant growth). In so-called wood lightweight concretes (WLC) wood residues and sawdust are utilized. However, the high cement content required for this process has so far hardly resulted in any advantages regarding the CO_2 balance of this building material. Intermediate results from an ongoing project on the development of lightweight wood concrete mixtures with an improved carbon footprint are presented.

Keywords: wood lightweight concrete, CO_2 sequestration, renewable building materials

1 INTRODUCTION

Concrete is by far the most widely used building material worldwide. Regarding the goal of a climate-neutral circular economy, however, the concrete industry faces substantial problems with high CO_2 emissions from cement production. Most concrete produced today is based on water, cement, and mineral aggregates (sand and gravel). In addition to these purely mineral based concretes, cement-bound materials with components of plant origin (especially wood chips and saw-dust in so-called wood lightweight concretes, WLC) have also been developed and used since the beginning of concrete technology.

The use of organic materials (such as wood or straw) for construction offers potential advantages regarding the CO_2 balance of the building sector, since CO_2 bound by plant growth is withdrawn from the cycle and is only released again after use, e.g., when burnt during thermal recycling. To maximize the effect of this plant-based CO_2 sequestration, it is necessary to prolong the life cycle of plant-based materials as much as possible – e.g., by using them in buildings (which usually have longer lifespans).

Within an ongoing research project, the possibilities of optimizing WLC mixtures regarding their strength properties, workability, and global warming potential (GWP) are determined. Most wood concrete composite recipes given in the literature show comparatively high cement contents, which leads to a main research question: are there mixtures for WLC that are carbon neutral or even carbon negative (considering the sequestration effect of wood content) and still deliver compression strengths feasible for load bearing components? Due to related research work in progress, the focus of this work lies on pourable concrete mixtures, ideally facilitating a workability of the fresh concrete that is suitable for self-compacting concrete.

2 METHODS

As foundation for the experimental studies described, a state of the art research was carried out, focusing on wood concrete recipes in general as well as best practice examples in other areas of concrete technology (without wood aggregates), namely recipes for cement reduced concrete (so called eco-concrete), self-compacting concrete and lightweight concrete. Selected recipes from the literature shall be experimentally verified and will be adapted in ongoing work to reduce the overall GWP of selected mixtures.

2.1 STATE OF THE ART

Historic development of compound products made from cement and wood reach back into early 20th century, overviews can be found in [1], [2]. Today, mineral-bound wood wool panels and formwork are among the most common applications. While these products are prefabricated, have a rather low density, a rather large-pored structure, and are mainly used for nonstructural components, the present work focuses on WLC that have ideally a pourable consistency suitable for cast-in-place (or even self-compacting) structural applications. A more recent survey including mineralogical, chemical, and physical analysis of such wood aggregate concretes can be found in [3].

3D printing of WLC is described in [4], which poses even more specific requirements on the material (e.g., regarding curing times and early strengths). Nevertheless, this work includes details on concrete recipes as well as experimental results with miscellaneous admixtures that might be transferable for other purposes. Improvement of the chemical compatibility between wood and cement by torrefaction (heat treatment of wood chips) was examined in [5]. Investigation on developments towards cement reduced concretes [6–8] and self-compacting lightweight concretes [9] has also been made, but not yet been comprised in the work described here.

2.2 EXPERIMENTS

A comprehensive comparison of various mixtures for WLC is given by Klatt in [2], including detailed information on ratio of components and mixing procedures. Given the fact, that the achieved strength values are the highest within the literature reviewed, the experimental series described in the present work was initially based on these results and procedures.

Our specimen (dimensions according to EN 196-1, [10]) were made using cement (CEM I 42,5 R), sand (sieved and remixed in proportions similar to standard sand according to EN 196-1) and a variation of aggregate types (untreated wood chips vs. cement coated wood chips), water-binder-ratio and admixture of superplasticizer. Untreated softwood chips (UW) were received from a sawmill; cement coated wood chips (CW) used are a commercial product of the brand CEMWOOD, originally marketed as leveling fill. Although these chips are not produced as aggregate for concrete, this use case has been described in [4]. Details for selected mixtures are given in Table 1:

Table 1: details for selected concrete mixtures (WLC1: maximum strength, WLC2: minimal GWP)

values in [kg/m³]	**water**	**CEM I 42.5 R**	**UW**	**CW**	**sand**	**superplasticizer**
WLC1 (CW, max. f_{cm})	150	551	-	300	931	3
WLC2 (UW, min. c_i)	200	386	193	-	661	3

3 INTERMEDIATE EVALUATION

3.1 RESULTS

First results from our experiments show a maximum compression strength value for WLC of 25.3 MPa. This is within the same range compared to the values given in [2] (cf. Table 2). However, due to differences in various parameters like cement type, wood chip selection, and concrete consistency, not all our mixtures are directly comparable to those given in [2].

Workability of the resulting concrete varies from very stiff and hardly compactable in mixtures with low w/b-ratio and no superplasticizer to rather fluid consistencies in mixtures with high w/b-ratio and/or superplasticizer (cf. Figure 1, a & b). During compaction on a vibration table, the ingredients of mixtures with fluid consistency tended to separate, which was compensated by reduced vibration times in following test series (cf. Figure 1, c & d).

(a) stiff consistency *(b) fluid consistency* *(c) separation of ingredients due to vibration* *(d) homogenous cross section (reduced vibration time)*

Figure 1: examples of fresh concrete consistencies (a, b) and hardened specimen cross sections (c, d)

Complementing our experimental measurements, we compared CO_2-intensity values (as proposed in [11], p. 150) from our results with selected values from the literature. GWP values were estimated based on following assumptions: considering the atomic masses of carbon and oxygen, there is a ratio of 3.67 (kg CO_2)/(kg C). Carbon content of dry wood is estimated to 50%, wood moisture is 12% (measured in spot samples). The maximum potential of CO_2 sequestration in UW is therefore -1.64 kg CO_2/kg (neglecting emissions for processing & transport). For CW, GWP information was taken from the manufacturer's data sheet (-94.8 kg CO_2/m^3 or -0.0948 kg CO_2/kg, estimating the material's bulk density to 1 g/cm³). Exact values for the cement used could not be determined from the manufacturer. A rather conservative assumption of 0.8 kg CO_2/kg was made based on values given for various CEM II types in the German database ÖKOBAUDAT [12]. For superplasticizer, a value of 0.944 kg CO_2/kg was taken from [6]. GWP and c_i values for WLC from [2] have been accordingly recalculated, all values in italics come from the original sources (cf. Table 2).

Table 2: comparison of CO_2 intensity, GWP, and compression strength values

	WLC1 (CW, max. f_{cm})	WLC2 (UW, min. c_i)	WLC CW [2] (max. f_{cm})	WLC UW [2] (min. c_i)	standard concrete [11]	eco-concrete [11]
c_i [(kg CO_2)/(m³ MPa)]	16.4	-0.7	11.1	-14.7	*11.5*	*7.5*
GWP [(kg CO_2)/m³]	415	-4.6	332	-73.5	*370*	*251*
f_{cm} [MPa]	25.3	6.2	*29.8*	*5.0*	*32.2*	*33.5*

3.2 DISCUSSION

Some mixtures of the experimental series so far and from [2] can be rated CO_2-neutral or even CO_2-negative (cf. Table 2). The corresponding compression strength values, however, are comparatively low. Increasing strength values for mixtures with GWP values equal to or below zero will be a focus in ongoing experiments.

Advantages concerning strength properties are generally expected when using minerally coated wood chips in WLC. In contrast to improvements on wood-cement compatibility and strength properties of the resulting concrete, using cement coated wood chips as aggregate results in a lower CO_2 sequestration impact due to the additional cement content that comes with this kind of material. Regarding the estimations made for GWP and c_i values, there is no advantage compared to standard concrete. A second approach to reduce the carbon footprint of WLC will therefore be to find other treatments of wood chips enabling similar improvements on strength while having less impact on GWP compared to cement coated chips. Further investigations will include the application of limestone-based coatings and heat treatment of wood chips.

4 CONCLUSION

Further examinations towards carbon-neutral WLC recipes in future test series include methods to improve wood-cement compatibility, the usage of different cement types and additives, as well as increasing wood content. Preliminary results presented in this work as well as those from the literature show that carbon negative WLC mixtures can be achieved. Appropriate application areas will be proposed depending on the resulting strength values. Long-term research goals comprise the evaluation of durability and recyclability of WLC.

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