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ECOLOGICAL PERFORMANCE OF TIMBER / WOOD-CEMENT COMPOUND COMPOSITE SLABS

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Abstract
Wood-cement compounds (WCCs) have been being used in construction since the beginning of the 20th century, mostly as a secondary structure or finishing layers such as sound or thermal insulation elements. However, WCCs' stiffness and strength are rather low, therefore WCCs should be combined with timber or a similar light-weight structural material used as a load-bearing element. The use of WCC for composite elements allows to take advantage of both materials, particularly of the strength of timber and the insulation properties of WCC. Furthermore, WCC slab elements do only require a minimal secondary structure due to their beneficial sound and thermal insulation properties. This paper reports on a life-cycle assessment (LCA) where those new and promising composite slab elements have been compared to traditional concrete, wood and timber-concrete composite (TCC) slabs regarding greenhouse gas emissions (EGG), non-renewable primary energy (NRPE) and environmental impact points (UBP).

Keywords:
Wood-cement compounds; sound and thermal insulation; life-cycle assessment

1 INTRODUCTION

Concrete is one of the most widely used construction material. Unfortunately, the use of non-renewable resources has an important impact on concrete's life-cycle assessment (LCA). Whereas wood-cement compounds (WCCs) are a mixture of hydraulic binder with wood waste (e.g. sawdust) and thus have a lesser influence on eco-balance. WCCs have been being used in construction since the beginning of the 20th century mostly as secondary-structure, but are also known for their good sound and thermal insulation properties. To use WCC in a load-bearing structure, several investigations were made to develop and test pourable WCC recipes [1]. Their performance, when used in a load-bearing composite system, has been analysed in another study [2].

Another study [3] has also investigated the sound and thermal insulation properties of wood-cement compounds and timber-WCC composite (TWCCC) elements. Based on a life cycle assessment (LCA) [2], the used cross-sections needed to be modified with regard to verifying the Serviceability Limit State (SLS), Ultimate Limit State (ULS) and accidental situation of fire exposure.

A detailed LCA has been established for two TWCCC slabs in order to compare the results with a case study [4] on concrete, timber and TCC slabs.

2 CONSIDERED SLAB TYPES

The present LCA compares five different 9.0 m single span slabs. Concrete, wood and TCC slabs originate from case study [4]. The cross-sections of these three conventional slabs have not been modified for this LCA. The TWCCC slabs are similar to slab types 2 and 5 from [2]. The other slab types (type 1, type 3 and type 4) are not considered in this LCA, because type 2 and type 5 are the most promising configurations to use as load-bearing flexural element.

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Type 2 is characterized by timber beams embedded in WCC and type 5 by a '+/-' shear-connection provided by a glulam slab. The analysed TWCCC slabs are shown in Figure 1.

Test results [2] have shown that ULS performances are insufficient for these two TWCCC slabs. Considering SLS, the results show a satisfying performance if deflection due to deadload is compensated by camber. For that reason, the two TWCCC slabs had to be modified such that all limit state performances are sufficient. In addition to the study from Eymard and Zwicky [2], fire exposure has also been taken into account. For the dimensioning of these new slabs, the latest results from an analytical study on 6-point bending tests were used (results not published yet).

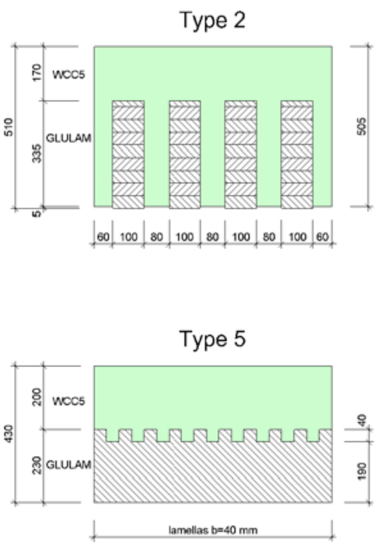

Fig. 1: New WCC slabs: cross sections.

Fire resistance class was stipulated as R60. The combustion rate for solid wood is about 0.8 mm/min [5].

The new cross section of type 2 requires timber beams h=340 mm to verify ULS. This section is unusual for solid wood which is why this slab requires glulam beams instead of solid wood.

Furthermore, both TWCCC slabs are used with only one WCC recipe (WCC5 [1]). The study from Eymard and Zwicky [2] considered a different recipe for each slab.

Note that these cross-sections have never been tested experimentally. They are only indicative and serve as basis to compare this LCA with the case study [4].

2.1 Materials properties

Compared to the previous analyses, new material properties are used here. The WCC5 recipe [1] has not been changed, only its mixing process was optimized. The following WCC properties were used for preliminary design of the new slabs:

- f_{cm} = 10 MPa
- E_m = 1000 MPa
- ρ = 11.1 kN/m^3

2.2 Building code requirements

For preliminary design, all limit states have been considered. Test results showed [2] that SLS is not governing for the considered TWCCC slabs. This is why, first of all, these two slab types were designed to offer the required verification for ULS. Afterwards, the SLS and accidental situation of fire exposure were considered. All verifications were made in accordance with [6].

As already mentioned the fire resistance class is R60 and for both WCC slab types, the combustion rate is about 0.8 mm/min, even though both TWCCC slabs are made of glulam.

For SLS verification, deflection can be compensated by a camber and variable actions should not cause a deflection higher than L/350 = 26 mm. To remain comparable with earlier results [4], the same variable action of 5 kPa is considered (category C3 according to SIA 261 [6]).

The following table shows which load has to be considered for each type and limit state, respectively.

Type	Limit State	q_{Ed} [kN/m']
Both	SLS	2.66
Type 2	ULS	11.90
Type 5	ULS	10.70
Type 2	Fire exposure	4.80
Type 5	Fire exposure	4.65

Table 1: Considered loads.

3 ECO-BALANCE

The mentioned case study [4], which investigated the environmental footprint of different slab types, serves as a basis for the present LCA. For both studies, the span (L = 9.0 m) forms the common reference so that the data can be compared.

The major differences between the earlier study [2] and this report are the modified cross sections from the two WCC slabs as well as the use of only WCC5 [1] for both slab types.

All environmental influences have been calculated with the CFSC 2014 [7] life cycle assessment data. Furthermore, the earlier results [4] have been updated because they were based on CFSC 2012 LCA data.

The LCA considers a service life of 90 years, further considering that all secondary structures are taken into account 3 times (1x new construction, 2x replacement).

3.1 Considered parameters

For all slab types, the necessary secondary structure, which is needed to meet the building

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requirements (e.g. sound insulation) is considered. The analysed parameters are separated in two subsections, load-bearing structure and secondary structure. The designs for the concrete, wood and TCC slabs are to be found in [4]. The TWCCC slabs only require a constructional screed layer (50 mm) to respect the requirement concerning impact noise level. The internal and external airborne sound levels do not cause any difficulties and no additional materials are needed as secondary structure [2].

3.2 Results

The sequence of calculation of the different environmental impacts is separated in 2 steps. First of all, the load bearing structure has been analysed and subsequently, the secondary structure and the transport of all materials have been added to the previous results. Figure 2 shows that transport has a minimal influence on the final result of all considered slab types. Therefore, this parameter is no longer considered to determine the environmental impact.

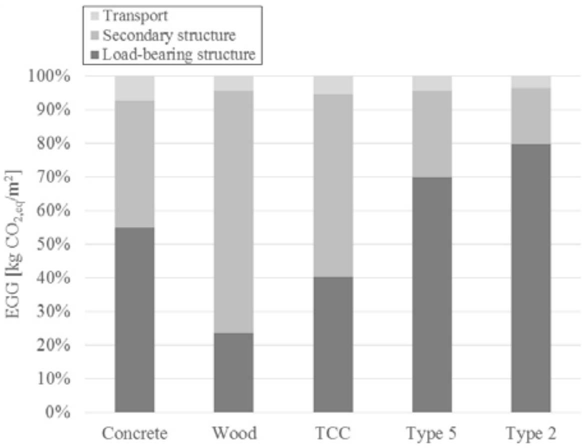

Fig. 2: relative EGG.

As shown in Figure 2, the secondary structure of both TWCCC slabs has the smallest influence of all analysed slab types on the relative amount of EGG. This is, as already mentioned, due to the high sound insulation capacity and thus a constructional screed is enough. On the other hand, the absolute EGG values, regarding only the secondary structure, are comparable to a conventional concrete slab. Figure 3 illustrates the comparison of all considered slabs.

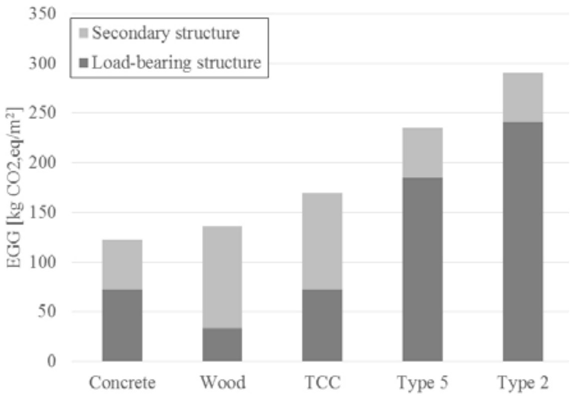

Fig. 3: EGG for different slab types.

As shown in the above Figure 3, type 2 represents the biggest total amount of EGG per square meter. Its value is more than twice the value of a concrete or wood slab and also significantly higher than EGG of a TCC or type 5 slab. This is due to the WCC recipe [1], which has a considerably higher cement content than a conventional cement recipe. Furthermore, glulam has a bigger environmental impact than solid wood. Another reason for the big difference between the TWCCC slabs and all other slabs, is the high volume of WCC.

In contrast to the study from Eymard and Zwicky [2], type 5 shows a better performance than type 2. This is due to the fact that type 2 now requires a glulam beam instead of solid wood. However, a comparison of non-renewable primary energy values shows that the difference is less obvious. Although the concrete slab needs the least amount of non-renewable primary energy, the type 2 can close the gap on the other four considered slabs.

Figure 4 shows the total amount of non-renewable primary energy required per square meter.

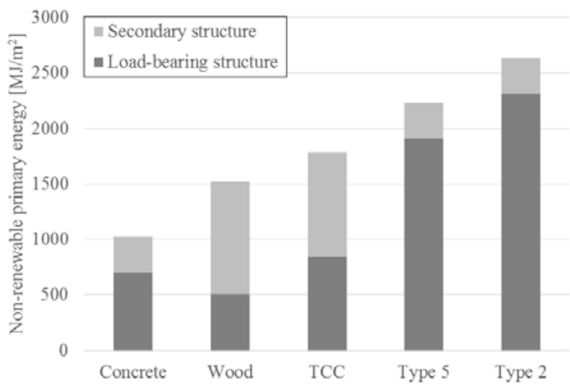

Fig. 4: non-renewable primary energy.

As already mentioned, the need of glulam has a strong influence on the results of type 5 and type 2 as well as the used WCC volume. A recent study [8] demonstrates that WCC can be combusted and thus allows to recover energy. This LCA is based on the values from [8] which

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means that WCC5 releases 3 MJ/kg and timber 9 MJ/kg during combustion. This means that a part of non-renewable primary energy can be reused and that has a positive effect on the balance of non-renewable primary energy. Figure 5 illustrates the total amount of non-renewable primary energy if combustion is taken into account.

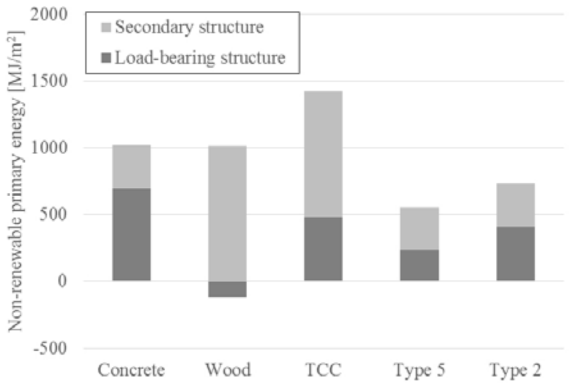

Fig. 5: total amount non-renewable primary energy.

It is obvious that both TWCCC slabs require less non-renewable primary energy for their life cycle than the other conventional slabs.

Another comparison can be made by means of environmental impact points (UBP). The UBP's 2013 quantify the environmental footprint caused on the use of energy- and material resources, of land and fresh water, by emissions into air, water and soil, by tipping of waste and by traffic noise.

Figure 6 shows this comparison with relative UBP values where the concrete slab serves as reference.

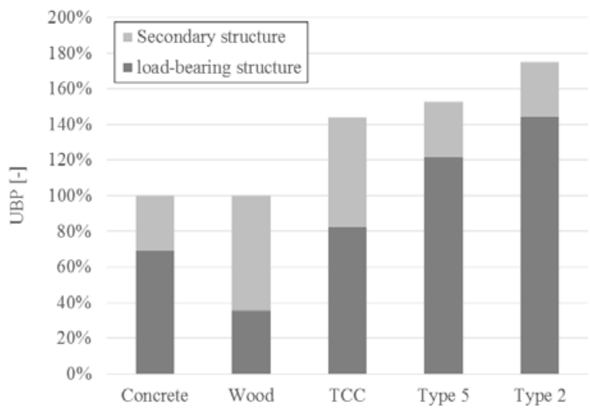

Fig. 6: relative UBP.

The environmental impact of all slabs can be roughly divided into two groups: concrete and wood as well as TCC, type 5 and type 2, respectively. The secondary structure of both TWCCC slab types has little impact on the life cycle assessment (Figure 2). Nevertheless, type 2 shows a bad performance compared to all other slab types, particularly concrete and wood slab.

This is due to the fact that the used WCC5 recipe has a high cement content and to the use of glulam beams. Note that the advantage of energy recovery is not included in UBP calculation.

4 CONCLUSION AND PERSPECTIVES

Generally speaking, the TWCCC slab type 2 is not competitive against the other construction methods if we consult the different LCA parameters. There is a great deal of unexploited potential regarding EGG and UBP values of type 2. The cement content plays a central role. However, if the non-renewable primary energy values are compared, one realizes that both TWCCC slabs are much more energy-efficient than the other conventional slabs. Particularly, type 5 shows a great performance with a very little proportion of non-renewable primary energy left at the end of life cycle. These results also show that ecological performance evaluation also depends on the referred index.

This advantage is due to the WCC containing sawdust which gives the possibility to combust the used WCC at the end of service life and this process allows an energy recovery. This effect would be even more pronounced if another WCC recipe would be used [2].

The aim must be that both TWCCC slabs can close the gap on the others, in particular regarding EGG and UBP. There are two ways of doing this:

On the one hand, the cement content plays a crucial role. A positive effect on LCA data for TWCCC slabs is produced by reducing the mass of cement used for construction. This, though, is not that simple because this parameter also directly influences all other material properties (strength, stiffness etc.).

On the other hand, the global amount of materials influences the LCA results. As the cross-sections of both TWCCC slabs had to be increased (compared to their original cross section), there is a need for optimizing the shear connector in order to reduce the mass of WCC needed. That way, it is possible again to use solid wood for type 2. This would have another positive effect on LCA data.

In conclusion, both TWCCC slab types show an interesting life cycle assessment performance and provide an alternative solution to conventional slabs, which are already nowadays far ahead regarding non-renewable primary energy. Moreover, TWCCC slabs meet all building code requirements, particularly airborne sound level, with a minimum of effort. The great thermal insulation capacity is an additional benefit.

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