Pilot tests with lightweight woodchip concrete in composite slab constructions

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Abstract

Lightweight concrete based on woodchips is a material with several characteristics which can be used on one site for load carrying structures when dense lightweight concrete matrixes are required and on the other side porous lightweight concrete matrixes can be realized for mechanical requests. Lightweight woodchip concrete for bearing constructions can make a contribution to reduce the construction´s weight. Sufficient compression strength but a reduced elasticity modulus of this concrete requires an application in composite constructions. Therefore an interesting aspect could be an application in composite slabs. In the context of a research project at the University of Luxembourg composite slabs with lightweight woodchip concrete are investigated. The results of the first static tests on small elements with various element heights and sheet thicknesses are presented.

Introduction

Lightweight concrete based on renewable products in constructive elements is able to reduce the self-weight of the construction. Although adequate compression strength of the woodchip concrete can be realized, the elastic modulus is, compared to other lightweight concrete with similar density class, lower, due to the renewable aggregates themselves. According to this, the renewable aggregates must be considered as imperfections in the concrete matrix. Thus, for designing constructive elements a composite partner becomes necessary. A relative young researcher's field in the last years is the use of lightweight concrete in composite slabs [1]. New in this context is the application of a lightweight woodchip concrete. For this purpose, small composite slabs are made by using composite sheets with a re-entrant profile and additional embossments to increase the composite actions. These small elements are tested to obtain first information about the composite behaviour, the composite actions, the slippage, the deflections and the load bearing behaviour. These first results are used for the planning of representative composite slabs related to EC4 [2].

1 Present research project

A given lightweight woodchip concrete should be implemented in constructive elements, and finally a parameter study will be applied via the finite element method. A number of pilot tests with different mixtures are realized to determine an adequate slab system. The present used composite sheet is a re-entrant profile with additional embossments. In this paper an interpretation of the results of small pilot tests will be presented.

1.1 Dimensions of the elements and varied parameters

The chosen composite sheet is kept constant for all elements while the sheet thickness and the height of the slabs are varied. The width and the lengths of the elements are constant as well as the span, see hereunto table 1. Additionally a required reinforcement related to EC 4 and EC 2 [3] is embedded. The variations of the parameters can be identified in the elements name. For example the slab name "4-120-1.25" describes: "4" the slab´s number, "120" the height in mm and "1.25" the sheet thickness in mm. In the following sections the presented names are used and in the context of a better identification in the following figures, the different sheet thicknesses are coloured in black (1.25 mm) and grey (1.0 mm).

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Table 1 Dimensions of the small slabs and sheet thickness

height [mm]	length [mm]	width [mm]	span [mm]	composite sheet	sheet thickness [mm]
120	1100	450	900	 SHR 51/150/ © Montana AG 2011	1.0/ 1.25
160	1100	450	900		1.0/ 1.25
200	1100	450	900		1.0/ 1.25

1.2 Experimental set-up and measuring equipment.

The small composite elements are tested by a three point bending test via displacement control. In figure 1 the equipment is shown in a lateral view (left) and a top view (right). The deflections are measured via displacement transducers at three points. At the third points of the span, onto the concrete side, two measuring points are installed, and finally at the steel sheet side in the middle point of length. The strains are measured by strain gauges on the concrete and sheet surfaces. The relative displacements between the concrete and the sheet are measured above the sheet profile at the lateral surface of the slab.

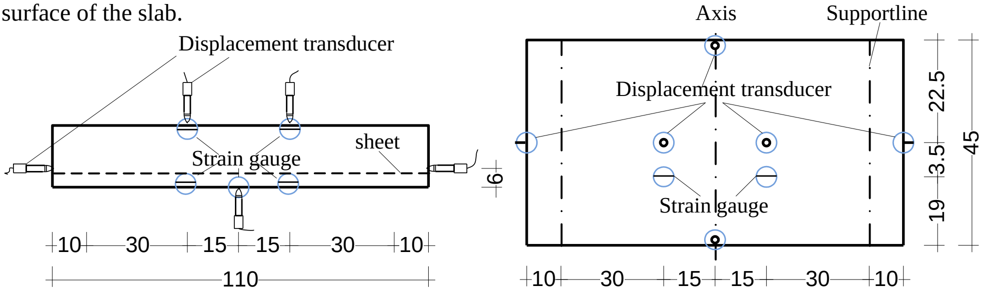


Fig. 1 (left) Lateral view (right) Top view of the measuring equipment

1.3 Material characteristics

The material characteristics are defined according to DIN 12390 [4] and DIN 1048 [5], thereby the mixture should be conform to the requirements related to EC 4. In table 2 the material parameters of the here used concrete are listed, therein the minimum compression strength is not achieved. EC 4 as well as the accreditation requires minimal compression strength of LC20/22. Additional cubes are produced for every slab to obtain the compression strength at the day of testing the elements, as well as controlling for the constancy of the mixture. Minor changes related to the compression strength of the cubes and the densities of the mixture are detected and explain the less value of the averaged result of all tested cubes in table 2. The compacting of a lightweight concrete must be done in a careful manner [6]. At the one hand the freshly mixed concrete needs due to a low density more compacting energy or compacting time, but on the other hand local demixing occurs faster due to more compacting energy respectively compacting time. The compacting of the elements and the specimen in the concrete forms are different. Thus, to compare the compression strength of the default samples with the present strength of the elements, some core samples according to DIN 12504 [7] are tested.

Table 2 Material characteristics

Compression strength, cylinder, 28d	13.1 [N/mm²]	Compression strength, core sample, d> 90d	13.3[N/mm²]
Compression strength, cube, 28d	16.9 [N/mm²]	Compression strength, cube, d> 90d averaged over all slabs	16.5 [N/mm²]
Splitting tensile strength, 28d	1.55 [N/mm²]	bending tensile strength, 28d	2.8 [N/mm²]
Elastic Modulus, 28d	5200 [N/mm²]	Density class, oven-dry	1,2

2 Present test results

A representative load-displacement diagram and the corresponding load-slippage diagram of two different tests are shown in figure 2. The elements were realized with a height of 200 mm. The black line represents a sheet thickness of 1.25 mm, while the grey line shows the behaviour for a sheet thickness of 1.0 mm. In both diagrams the y-axis describes the forces and the x-axis the deflection in the middle of the slab for the load displacement diagram as well as the relative displacement between the concrete and the steel sheet. For the bond behaviour diagram the influence of the height of the slab as well as the influence of the sheet thickness can be discussed. The ultimate load is higher when using a sheet with a thickness of 1.25 mm, but the beginning of slippage occurs earlier than for a sheet thickness of 1.0 mm, and this is representative for all conducted tests. All in all a ductile material behaviour can be observed by using a composite sheet with a re-entrant profile and additional embossments [8], see also section 2.2. By regarding the bearing load and the slippage load, the bending behaviour is nearly the same for these presented slabs. Furthermore, in figure 2 (left) the influence of the neoprene support can be detected. Therein, the origin of the disturbance of the linear curvature (dashed line) can be explained with the application of an elastic neoprene stripe.

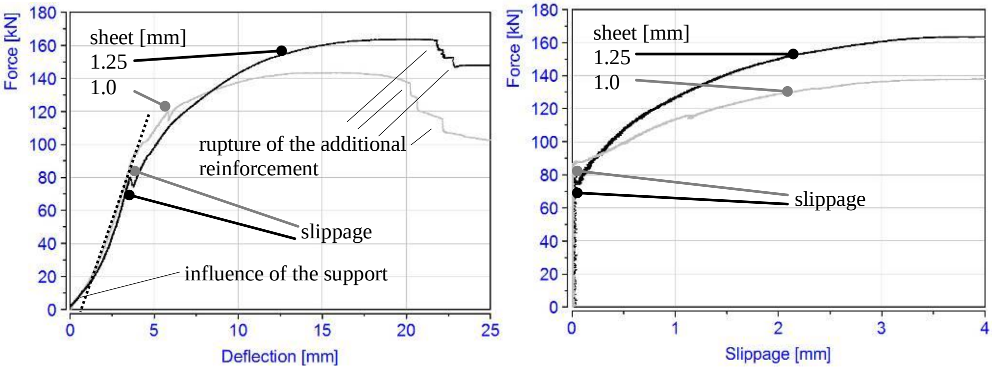


Fig.2 (left) Load displacement-diagram (right) Bond behaviour

2.1 Analysis of the results

The results of the load bearing behaviour of all conducted tests are resumed in figure 3 (right), and therein the y-axis of the bar diagram represents the loading and the x-axis represents the different heights of the slabs. Furthermore, the different coloured bars represent the results for different sheet thicknesses. In this diagram it can be observed, that independent of the heights of the slabs, the bearing load is increasing with the sheet thickness. In figure 3 (right), the y-axis represents the load at the beginning of slippage while the x-axis also describes the height of the slabs. In this illustration it can be seen that the slippage forces, for all varied element heights, are higher by using the thinner steel sheet of 1.0 mm.

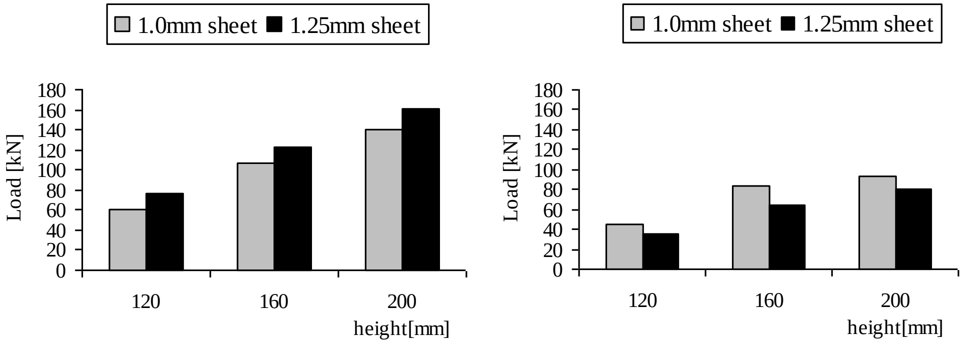


Fig. 3 (left) Load-bearing behaviour (right) Load by beginning of slippage

2.2 Ductility criterion

The ductility criterion related to EC 4 is fulfilled, when the loading after slippage, until the limit load $F_{,max}$, can be increased about 10 percent: $F_{max} \geq 1.1 * F_s$. Thereby the slippage is defined with a relative displacement about 0.1mm. Although the dimensions of the elements are not comparable with slabs and the weak material characteristics are not conform to the standards, the ductility criterion is fulfilled. In figure 4 the loading increment, from start of slippage till ultimate load, is shown. The ductility criterion is fulfilled with an adequate reserve. The increase of the ultimate load due to an increase of the steel thickness as well as the decrease of the slippage load due to an increased sheet thickness can be observed in figure 3.

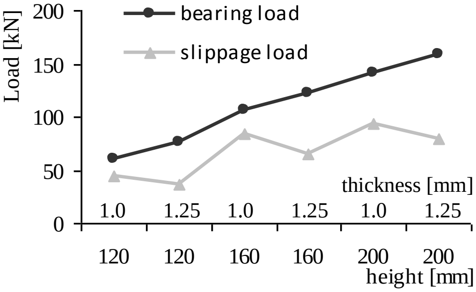


Fig. 4 Limit load compared with the slippage load

2.3 Interpretation of the results.

To interpret the results, the composite action will be split into the mechanical and the frictional bond. First only the mechanical bond will be discussed. By reaching the slippage force, relative displacements between the concrete and the sheet occur. The embossments can be regarded as barrier for the concrete which must be first overcome. In the contact zone of the embossment and the concrete, additional forces are developed, see figure 6 (left). Relative displacements leads to two possible reactions: The concrete resists and the embossments get deformed, or the concrete get deformed while the embossments remain intact. The last case can occur when the compression strength is lower than a concrete C12/15 [9]. Although a LC12/13 is present, in these tests the concrete get deformed what can be explained by the low elasticity module. In figure 5 the relative displacement between the concrete and the steel sheet is shown. The left figure shows the intact embossments while the right figure pictured the deformed concrete surface at the contact zone.

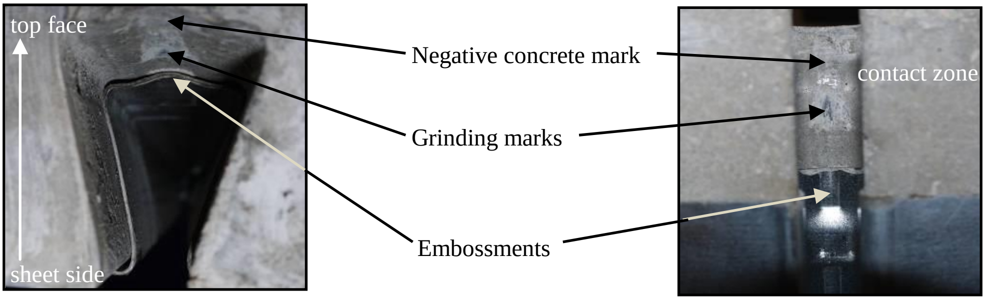


Fig. 5 (left) Intact sheet embossments due to reduced elasticity module of the lightweight concrete formulation, (right) Grinding marks at the contact zone on the concrete site.

The results in section 2.1 show that the forces, when slippage is activated, are higher for a sheet thickness of 1.0 mm as for a sheet thickness of 1.25 mm, see figure 3 (right). Therefore, with the present results it can be interpreted, that an increase of the sheet thickness does not lead necessarily to an increase of the mechanical bond due to the embossments. Consequently, the origin lies in the frictional bond. The frictional bond occurs when the transverse strain of the steel sheet is activated during the loading. Then, the re-entrant form get deformed and the concrete between the steel is clamped, see hereunto figure 6 (left). An adequate frictional bond due to frictional forces can only be obtained, when the sheet stiffness is elastic enough and when the stiffness of the concrete is high enough [10]. The elastic module of the applied concrete is very low and in combination with a sheet thickness of 1.25 mm, the stiffness of the steel sheet will be increased. Consequential, adequate frictional forces due to transverse strains between the sheet walls are not able to be developed in an adequate manner. Therewith the frictional bond became the crucial point to increase the slippage load.

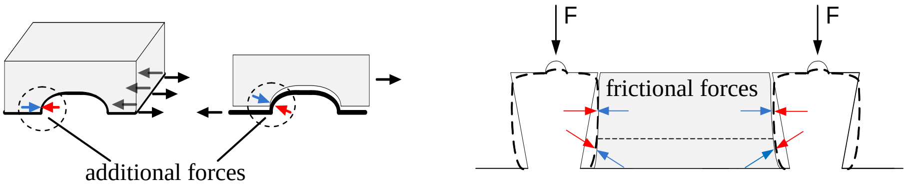


Fig. 6 (left) Additional forces in the contact zone, (right) Frictional forces due to transverse strains resulting of the deformation of the sheet

3 Crack pattern due to shrinking effects and loading

Before the elements are tested crack pattern due to shrinking could be observed at nearly all elements. The corresponding height of these cracks had a maximal length of two third of the element height. Only these cracks opened while loading, hence the shrinking cracks have determined the crack pattern in this pilot tests. In figure 7 a representative load displacement diagram with the corresponding crack pattern is shown. While the cracks width increased the crack length also increased. In accordance with [1] only one crack pattern occurred after reaching the ultimate load and it is related to the longitudinal cracks at the elements with a height of 120 mm. These cracks also started at the top of the reentrant steel sheet and continued up to the top of the element, see figure 8. No longitudinal cracks are developed at the elements with a height of 160 mm or 200 mm.

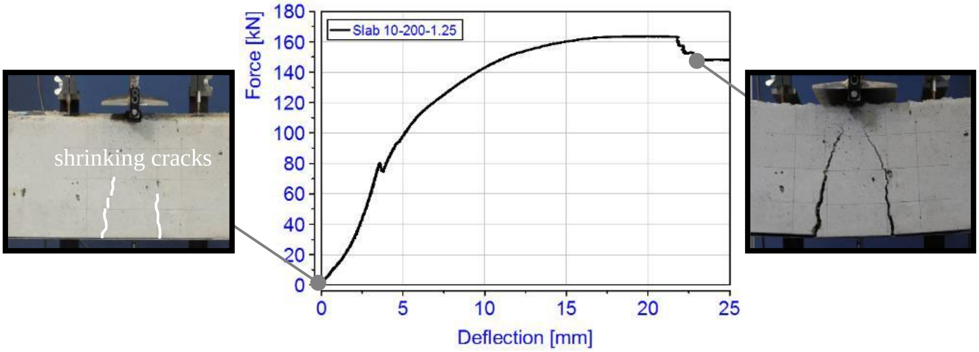
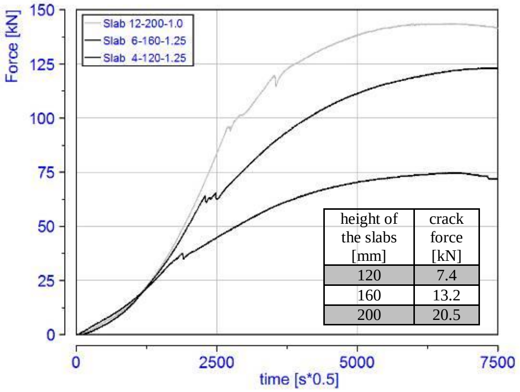


Fig. 7 Crack pattern due to shrinking and crack evaluation due to loading

Fig. 8 (left) Beginning of the longitudinal cracks at the top of the steel sheet, (right) To the top continued longitudinal cracks

The pilot tests are done via displacement control and after reaching the tensile strength of the concrete, the steel sheet is directly activated. However, no influence of the concrete´s crack forces can be obtained in the curvature of the load-time diagram. In figure 9 the corresponding load-time diagrams of the slabs with a height of 120, 160 and 200 mm are shown and a continuous curvature until the beginning of slippage can be seen.



height of the slabs [mm]	crack force [kN]
120	7.4
160	13.2
200	20.5

Fig. 9 Load-time diagram of the slabs with all present heights and the corresponding crack forces

Conclusion

By regarding the load bearing behavior and the composite action in these pilot tests, an application of lightweight woodchip concrete in composite slabs is first of all not excluded. The influence of the height of the elements as well as the influence of the sheet thickness could be demonstrated in these test series. Recapitulatory, an increase of the ultimate load is caused with an increase of the sheet thickness as well as the height of the elements. Furthermore, due to an increase of the elements height, the beginning of slippage can be delayed. Though, the beginning of slippage has occurred earlier by using a thicker steel sheet due to the low elastic module of the lightweight woodchip concrete. This research results should be taken into account when designing a woodchip lightweight concrete in composite slabs, so the requirements related to the serviceability state due to slippage and deflection, can be a crucial point. A test series related to EN 1994-1, Annex B will start at the University of Luxembourg soon. With the standardised test set-up the design value of the longitudinal shear resistance will be determined [11].

References

[1] Kurz, W., Mechterine V., Brüdern, A., Hartmeyer, S., Kessler, C.: Leicht Bauen mit Verbunddecken im Wohnungs- und Gewerbebau. In: Fraunhofer IRB Verlag (2009)

[2] DIN EN 1994-1, Eurocode 4: Bemessung und Konstruktion von Verbundtragwerken aus Stahl und Beton - Teil 1-1: Allgemeine Bemessungsregeln und Anwendungsregeln für den Hochbau. In: Beuth-Verlag (2004)

[3] DIN EN 1992-1, Eurocode 2: Bemessung und Konstruktion von Stahlbeton- und Spannbetontragwerken - Teil 1-1: Allgemeine Bemessungsregeln und Regeln für den Hochbau. In: Beuth-Verlag (2011)

[4] DIN EN 12390-1-7, Prüfung von Festbeton. In: Beuth-Verlag (2001)

[5] DIN 1048-5, Prüfverfahren für Beton: Festbeton, gesondert hergestellte Probekörper. In: Beuth-Verlag (1991)

[6] Faust, T.: Leichtbeton im Konstruktiven Ingenieurbau. In: Ernst & Sohn (2002)

[7] DIN EN 12504-1, Prüfung von Beton in Bauwerken, Teil 1: Bohrkernproben- Herstellung, Untersuchung und Prüfung unter Druck. In: Beuth-Verlag (2000)

[8] Bode H. ‚Sauerborn, I.: Zur Bemessung von Verbunddecken nach der Teilverbundtheorie. In: Stahlbau 61, Heft 8, pp 241-250 (1992)

[9] Kuhlmann, U.: Stahlbau Kalender- Verbundbau. In: Ernst & Sohn (2010)

[10] König, G. ‚Faust, T.: Konstruktiver Leichtbeton im Verbundbau. In: Stahlbau 69, Heft 7, pp 528-533 (2000)

[11] Minnert ‚J.‚Wagenknecht, G.:Verbundbau-Praxis, Berechnung und Konstruktion”, In: Bauwerk (2008)