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Composite Constructions of Timber and High-Performance Concrete

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Abstract Currently Timber-Concrete Composite (TCC) Constructions are often applied for strengthening existing timber beam slabs. The load bearing capacity of the composite construction is primarily affected by the material properties of the timber beam and the concrete slab. But the type of bond between both parts is also of high importance. The concrete slab has to perform several tasks, not only in load carrying direction of the ceiling but also perpendicular to the direction of span or for stiffening the whole building. These tasks will be pointed out in this paper. Furthermore the working process (easy workable mixture and exchange of conventional reinforcement) and the dead load of the construction are of particular interest in the field of redevelopment. Several innovative concretes have been verified for the use in TCC constructions. Regarding their fresh and hardened concrete properties, they all can be described as High Performance Concretes (HPC). In this paper Self Compacting Concrete (SCC), Fiber Reinforced Concrete (FRC), Structural Lightweight Concrete (SLWC), High Strength Concrete (HSC) or combinations of them will be focused. Especially the advantages but also the disadvantages of innovative concretes for the use in TCC will be presented as well as the results of some experimental investigations.

Keywords: Timber-concrete composite construction, timber beam ceilings, retrofitting, high-performance concrete, fiber concrete, self compacting concrete, structural lightweight concrete, high strength concrete

Introduction

Timber-Concrete Composite (TCC) Constructions have been used in the retrofitting of existing timber beam ceilings for the last few decades. Using special metallic fasteners, a concrete slab is connected with the timber beams. They differ in effectiveness, price and input of labor. The level of connection ranges between 0 (no connection) and 1 (rigid connection) and influences the load bearing behavior of the composite construction.

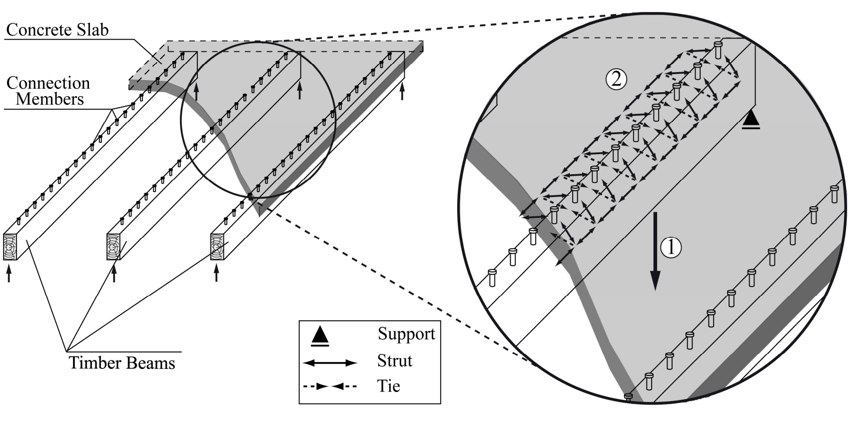


Figure 1: Principle structure of a TCC ceiling with loading of the concrete slab

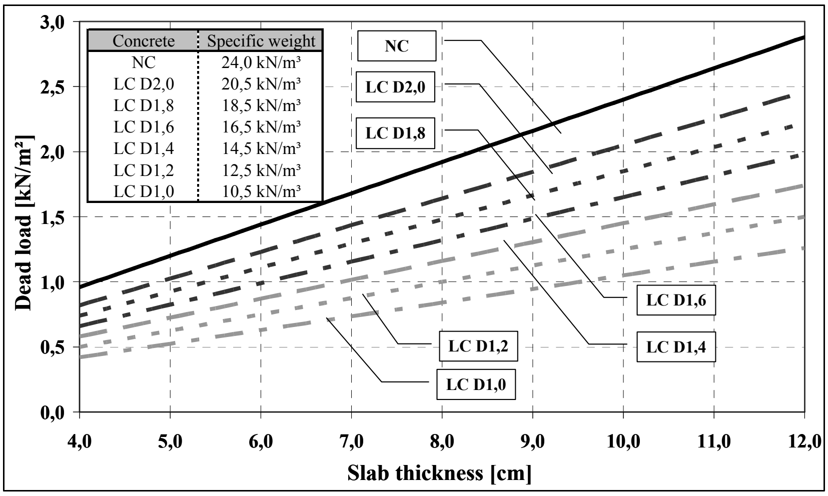
Fig. 1 shows the principle structure of a TCC ceiling. The concrete slab on top is connected to the timber beams. The picture furthermore shows some special loadings of the concrete slab in the TCC construction. Main requirements for the concrete slab are assembled in (Holschemacher and Dehn 2004). It is reasonable to make a trisection in structural, static and structural-physical requirements. These aspects will be described in the following. The thickness of the slab has to be small not only

regarding the dead weight of the construction and the load on subordinated components but also with regard to door sizes and parapet heights. Furthermore a plan and horizontal surface is needed. The concrete slab proportionally takes bending moments and lateral forces in the load carrying direction of the ceiling, depending on the level of connection between the members of the composite constructions. Secondary loadings are lateral tensile forces caused by the combing agents (Fig. 1 framework model (2)) but also bending moments and lateral forces perpendicular to the direction of span (Fig. 1 force between two beams (1)). Additionally, the concrete slab effects a load distribution in lateral direction and is of particular importance in order to stabilize the building. The structural-physical requirements especially concerning the airborne- and the impact-sound insulation as well as the fire behavior of the construction are important too. These aspects can be achieved using TCC floors. In this case it is necessary to think about the optimal components of the composite construction.

The design of concrete has changed during the last years. The common way of combining cement with water and aggregates has been modified into a combination of cement, water, aggregates, admixtures and additives. So the variety of concretes that can be used for TCC constructions has grown considerably. Most of the innovative concretes can be described as high performance concretes. These building materials are called high performance concerning their fresh concrete properties as well as their hardened concrete properties. The following types of concrete will be presented in this paper: Structural Lightweight Concrete (SLWC), Self Compacting Concrete (SCC), High Strength Concrete (HSC) and Fiber Reinforced Concrete (FRC).

Concrete with Innovative Hardened Concrete Properties

The hardened concrete properties which are of particular interest are the compressive strength, the post-cracking behavior and the dry density. Regarding the aspect of reducing the dead weight of the construction the use of structural lightweight concrete is sensible. This kind of concrete is dense and of low dead weight resulting form the use of porous lightweight aggregates. The main disadvantage of them is the characteristic to suck of a part of the water for making concrete which has to be considered by calculating the mixing ratio. Fig. 2 shows the dead weight of a concrete slab for common slab thicknesses for TCC constructions, a picture of lightweight aggregates and the savings of weight by using SLWC (right). The values and nomenclature is taken from the German regulation.



Concrete	Savings in weight
NC	-
LC D2,0	14,6 %
LC D1,8	22,9 %
LC D1,6	31,3 %
LC D1,4	39,6 %
LC D1,2	47,9 %
LC D1,0	56,3 %

Figure 2: Structural Lightweight Concrete according to German regulation (DIN 1045-1 2008)

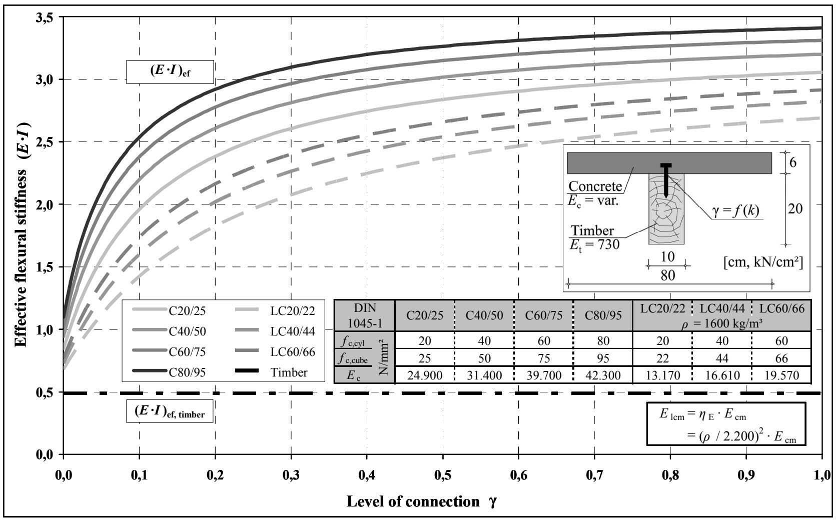


Figure 3: Influence of the modulus of elasticity on the stiffness of a TCC construction

Fig. 3 represents the influence of the modulus of elasticity of the concrete slab on the effective stiffness (*E·I*) of the TCC construction depending on the level of connection (*γ*). With the same slab thickness it is possible to increase the effective stiffness by using concrete with a higher modulus of elasticity. In this graphic the values for the coefficient of elasticity (E_c) were chosen according to the German standard (DIN 1045-1 2008) pictured in the table inside the graphic. These are only proposals. The real value strongly depends on the type of the aggregates especially their own modulus of elasticity. Lightweight concretes have a lower E-modulus with a comparable compressive strength. Nevertheless, by using different concretes, the effective stiffness of the TCC construction can be increased significantly.

Fiber concrete is an alternative for the slab on top of TCC constructions. In certain cases conventional reinforcement can be economized. This is especially expedient in buildings with little space to work in. To analyze the post-cracking behavior of the FRC in serviceability as well, ultimate-limit state four-point bending tests are realized. By the help of the LVTD placed on both sides of the beams load-deflection-curves are monitored. The experimental set-up is shown in Fig. 4. The tests are carried out on beams with a cross section of 150x150mm and a length of 700mm. The casting and storing of the specimen as well as the test set-up are chosen according to the German regulations (Stahlfaserbeton-Richtlinie 2010) which are similar to those of RILEM.

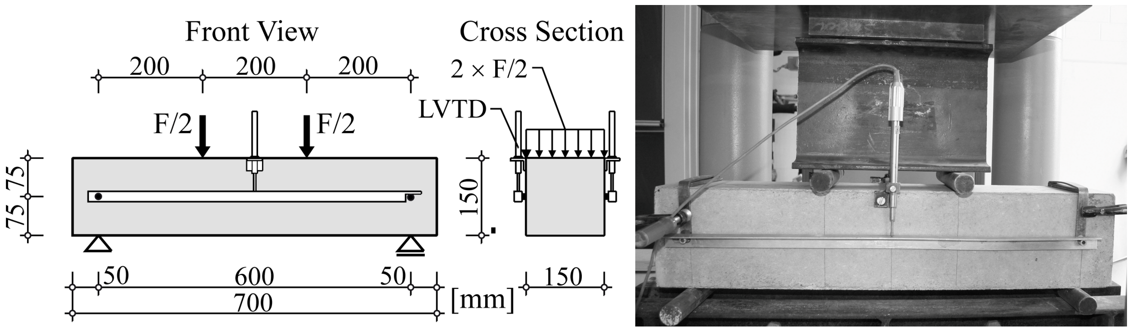


Figure 4: Test set-up of the (4)four-point bending test

Concrete with Innovative Fresh Concrete Properties

For the building construction the fresh concrete properties are also of particular interests. Two main factors are important in this case. At first the concrete has to be asily workable and compactable, furthermore it should be pumpable because in most cases of retrofitting the location for placing the concrete cannot be reached by crane.

In this case SCC can be a potential possibility. It is characterized by a good workability and flow-ability as well as the property of venting without external influence. It is often chosen for complex formworks, high reinforcement ratios and little space for compacting measures. To achieve the self-venting properties as well as adequate resistance against segregation and bleeding it is very complex to develop these kind of concrete. In Germany quite extensive experimental investigations are required by using SCC. They are described in their own regulation (SVB-Richtlinie 2003). This guideline has to be attended from a diameter in the flow table test of more then 700 mm. SCC is sensitive to the variability of the source materials and has higher amounts of finest grain (cement, fly ash, limestone flour) often effecting higher shrinkage, hydration heat and a not needed compressive strength (higher minimum reinforcement).

Due to these facts it is often better to use concrete which is easily workable but not self-compacting. Easily workable concrete requires a small amount of energy for compacting which can be realized by stocking the concrete. The ability of pumping the concrete should not be forgotten. For normal concrete it is often not the problem. But special investigations like pumping tests become necessary using special kinds of concretes like FRC, SLWC and SCC.

Combination

The TCC construction is a special composite construction. It often requires several different properties of the used concrete. So it may be sensible to use fiber reinforcement in LWC, for example. LWC exhibits a higher brittleness because the cement matrix has a higher compressive strength compared with the lightweight aggregates. In opposite to normal concrete, here the cement matrix shows a lower compressive strength compared to the aggregates. For fiber reinforcement not only steel fibers can be used. It is also possible to apply polymer fibers if they are capable for the use as reinforcements in concrete. Therefore they should have a higher modulus of elasticity than the concrete and they should be big enough to bridge the cracks and transfer loads from one crack boarder to the other.

At the University of Applied Science Leipzig a research project was started in 2009 to investigate the effectiveness of Polyvenylalcohol-Fibers (PVA-Fibers) for their use in TCC constructions. Therefore they are mixed into Dry Lightweight Concrete (DLWC). Dry concrete is regulated in a guideline in Germany (Trockenbeton-Richtlinie 2005). The used PVA-Fibers are shown in Table 1 and the geometrical and mechanical properties are pointed out.

Table 1: Properties of the used PVA-Fibers

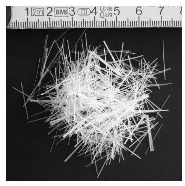
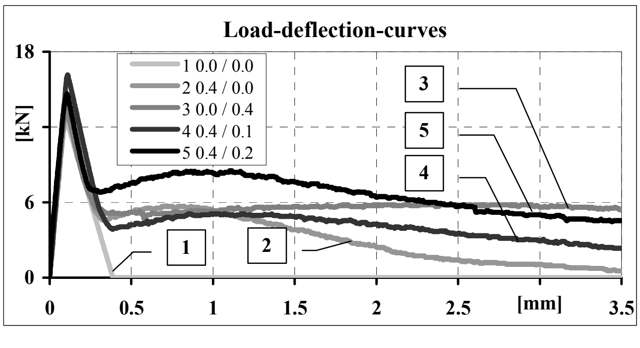
PVA-Fiber	*Geometrical properties*		*Mechanical Properties*	*Picture*
F1	Length: Diameter: Thickness ratio: Wight:	18 mm 0,2 mm 90 1,3 g/cm³	Tensile strength: 1.600 N/mm² Modulus of elasticity: 37.000 N/mm² Elongation at fracture: 6 %	
F2	Length: Diameter: Thickness ratio: Wight:	30 mm 0,66 mm 45 1,3 g/cm³	Tensile strength: 800 N/mm² Modulus of elasticity: 30.000 N/mm² Elongation at fracture: 7 %	

Fig. 5 shows the used dry concrete on the left, the flow fable test in the middle and pumping test on the right which was carried out with the easy flowable mixture. The aim of the project is to create a PVA-Fiber reinforced dry lightweight concrete (PVA-FRDLC). It is transported to the building site in a silo or bag and is processed and placed just by adding a certain amount of water. Several topics come together with this. The concrete has to be easily workable and compactable; it should also be

pumpable, which might be problematic if porous lightweight aggregates are used. The corresponding amount of PVA-Fibers should be distributed equally without agglomerations. Nevertheless special hardened concrete properties like compressive strength, splitting tensile strength or certain loads in post-cracking range should be achieved. Another big problem is to guarantee the industrial production of dry concrete by the help of the existing facility. PVA-Fibers were chosen instead of steel fibers, which are mostly more effective, because the steel fibers wear out the concrete pump and pump-line. Investigations have just started but some results could already be reached and will be presented in the following.

Figure 5: Dry concrete (left), flow table test (middle), Pumping test (right)

Fig. 6 shows some results of the first investigations. Concretes with different fibers and fiber contents were tested. Five mixtures were realized and the used fiber contents are given in the table on the right in percentage by volume (Vol.-%). The first value always represents the content of fiber F1, the second of fiber F2 (compare Table 1). The dry density of all concretes was about 1.6 kg/m³. The flexural bending and post-cracking behavior was tested in a four-point-bending test as mentioned before. Furthermore, the compressive strength ($f_{cm,cube}$) and splitting tensile strength (f_{tm}) after 28 days was measured on cubes with an edge length of 150mm in each instance. All of the cubes were stored in water until the test date. The results are given in the table on the right of Fig. 6. On the left side average load-deflection-curves representing the fiber contents of 0.4 Vol.-% F1 (curve 2), 0.4 Vol.-% F2 (curve 3), 0.4 Vol.-% F1 in combination with 0.1 Vol.-% F2 (curve 4) and 0.4 Vol.-% F1 in combination with 0.2 Vol.-% F2 (curve 5) compared to the reference concrete without fibers (curve 1) are documented. The table pictured on the right side additionally shows the load values initial crack load F_u, load corresponding to 0.5mm and 3.5mm deflection $F_{0.5}$, $F_{3.5}$. The load values represent the serviceability limit ($F_{0.5}$) and ultimate limit state ($F_{3.5}$). As expected the load bearing capacity was improved with increasing fiber content. Compared with fiber F2 (curve 3), fiber F1 (curve 2) shows a more inductile behavior. With fiber cocktails synergetic effects can be used especially in the serviceability limit state.



Fiber content [Vol.-%]	$f_{cm,cube}$ [N/mm²]	f_{tm} [N/mm²]	F_u [kN]	$F_{0.5}$ [kN]	$F_{3.5}$ [kN]
0.0 / 0.0	26.15	2.17	13.27	-	-
0.4 / 0.0	21.97	1.96	14.13	5.20	0.53
0.0 / 0.4	23.75	1.92	13.48	5.20	5.40
0.4 / 0.1	22.72	2.02	16.17	4.20	2.33
0.4 / 0.2	24.43	2.13	14.64	7.53	4.53

Figure 6: Load deflections curves and harden concrete properties of PVA-FRC

Obviously these synergetic effects are especially strong in the range of a deflection between 0.3 and 2.5mm. Curve 5 (representing the fiber cocktail 0.4 Vol.-% F1 and 0,2 Vol.-% F2) shows the highest bearing capacity until a deflection of approximately 2.4 mm. The load value $F_{3.5}$ seems to be mainly influenced by fiber type F2 because of their geometrical properties. The compressive and

splitting tensile strength is not observably influenced by the fiber content. It is possible that higher fiber contents will affect increasing strength values. Fiber agglomerations were not observed at any of the investigations. The consistence was hardly reduced by the application of fibers.

Summary

The TCC construction is an effective opportunity to toughen up timber beam ceilings. But there are some special problems concerning this reconstruction method. These are for example the dead weight of the construction, the often cramped space inside the existing buildings or the reducing of the height of rooms or doors and parapet heights. During the last years the investigations have increasingly concentrated on the combination with high performance kinds of concretes. By the help of them it is possible to orientate the TCC ceiling on the special requirements of nearly every situation in the field of retrofitting. The effectiveness in the construction process can be increased by the use of fiber concrete because in some reasons conventional reinforcement can even be economized (effecting smaller slab thicknesses) or by the help of easily respectively self-compacting concrete because the effort to compact the concrete can be minimized. SLWC helps to reduce the dead load of the whole construction. The combination of several innovative concrete properties can be sensible as shown in the paper. By the use of the concretes listed above it is possible to adapt existing buildings on today's requirements in a cost-optimized and resource-gentle way. The field of possible research is not yet exhausted.

Acknowledgement

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