RECENT DEVELOPMENTS IN TIMBER-CONCRETE COMPOSITE

AVANCES RECIENTES EN COMPUESTOS DE HORMIGÓN Y MADERA

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Abstract

Timber-concrete composite (TCC) is increasingly applied for strengthening of existing timber beam ceilings in construction practice. Also, for construction of new buildings some interesting TCC systems have been developed in the last years.

The paper is focused on recent research results on TCC gained at HTWK Leipzig / Germany. Especially, the structural performance of shear connectors and the application of high performance concrete layers in TCC systems are presented in detail. By the application of fibre reinforced light-weight concrete with self-compacting fresh concrete properties the load bearing behavior of TCC slabs could be improved essentially. Furthermore, it is possible to decrease the depth of the concrete slab in the TCC system. This fact leads to a considerable reduction of the dead load of TCC slabs and is of essential importance for strengthening of existing structures.

Finally, some practical applications of TCC are reported.

Keywords: timber-concrete composite; shear connector; structural behavior; high performance concrete; strengthening and repair; practical applications

Resumen

Los compuestos de hormigón y madera están siendo utilizados cada vez más para el refuerzo de forjados de madera existentes. Además, en los últimos años se han desarrollado interesantes sistemas mixtos de madera y hormigón para proyectos de nueva costrucción.

El artículo se centra en resultados recientes de la investigación sobre las estructuras mixtas de hormigón y madera obtenidos en la HTWK de Leipzig (Alemania). De manera especialmente detallada se presenta el comportamiento estructural de las conexiones y la utilización de hormigón de alto rendimiento en los sistemas mixtos de hormigón y madera. Con la utililzación de hormigón reforzado con fibras de acero con propiedades autocompactantes, el comportamiento estructural de los compuestos de hormigón y madera ha podido ser mejorado considerablemente. De este modo es posible reducir el espesor de la losa de hormigón en los compuestos de hormigón y madera, lo que conlleva una clara reducción del peso propio del forjado de hormigón y madera y es de gran importancia para el refuerzo de sistemas estructurales existentes.

Por ultimo, se presentan algunas aplicaciones prácticas de los compuestos de hormigón y madera.

***Palabras clave**: compuestos de hormigón y madera, medios de conexión, capacidad resistente, hormigón de alto rendimiento, reforzamiento et restauración, aplicacionés prácticas*

1. INTRODUCTION

Timber-concrete composite (TCC) is a well-established technique for strengthening of existing timber beam ceilings and for construction of floors in new buildings. Basically, TCC consists of timber beams that are connected with a concrete slab by shear connectors, Fig. 1. Other possible applications of TCC are wall constructions that are not the topic of this paper.

The shear connectors ensure the interaction of timber beams and concrete slab in the composite member. Usually, sheer connectors cause a flexible, but not a rigid bond between the timber and the concrete part of the composite section. Therefore, besides the depth of concrete slab and concrete strength class the stiffness and the ultimate load of shear connectors are of essential importance for the load-bearing behavior of TCC constructions, Fig. 2.

First applications of TCC trace back to the lack of resources in the early 20th century. It has been recognized that concrete is a valuable construction material for bearing compressive forces. Other advantages of concrete in comparison to other often-applied construction materials are the good fire resistance and durability. However, in flexural concrete members the tensile zone of the cross section has to be strengthened by materials with high tensile strength. Besides steel – leading to reinforced concrete – timber is a good material for this purpose. So, application of TCC leads to structural systems with advantageous load bearing capacity and low dead load at reasonable costs.

Beside the mentioned advantages TCC owns also some disadvantages. One of those is the fact that there are no normative rules for the design of TCC. Of course, TCC members can be designed according to codes for timber structures, e.g. Eurocode 5 [1]. But there is no information about characteristic or design values of stiffness and ultimate load of shear connectors available in the codes. This circumstance is the main obstacle for application of TCC in practice. Hence, in Germany TCC is mainly limited to strengthening of existing timber beam ceilings. For this purpose it is a very economic technology because the boarding can stay in place whereas for other strengthening techniques the boarding has to be removed [2], [3]. Application of TCC in new construction is limited to few special new buildings.

Nowadays, the main research in TCC is focused on the development of high-effective shear connectors, the load-bearing behavior of TCC members and some special structural-physical topics. In the following some results of the TCC research projects performed at HTWK Leipzig are presented.

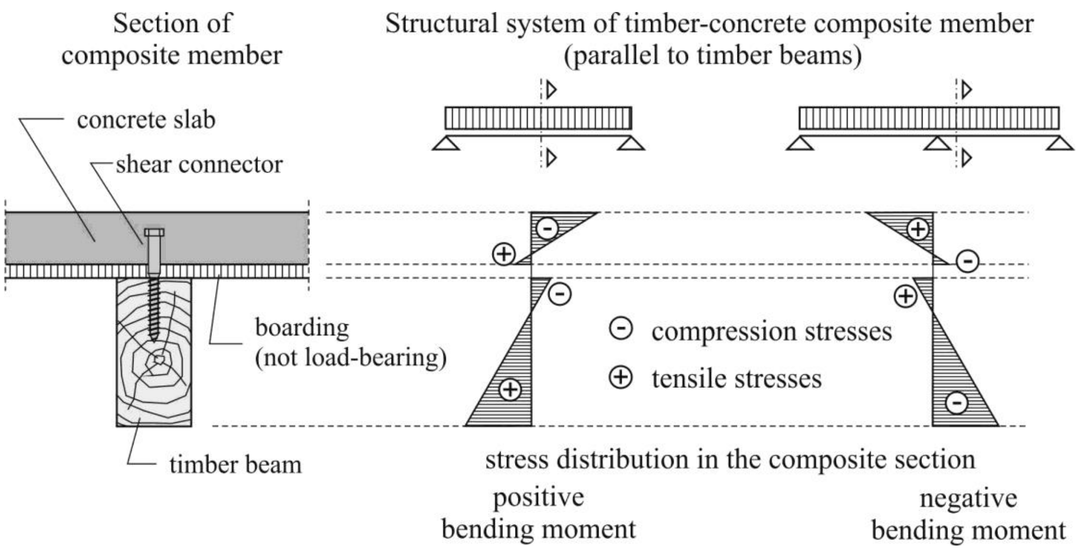


Figure 1: Timber-concrete composite members in case of strengthening of existing timber beam ceilings

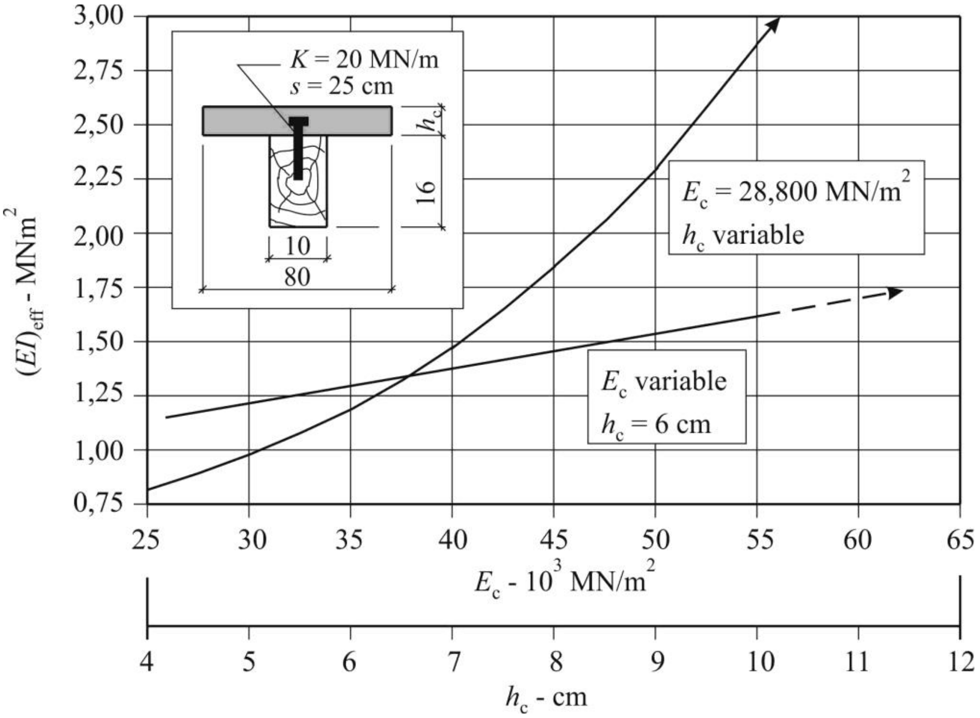


Figure 2: Influence of concrete slab depth and modulus of elasticity on stiffness of TCC systems, calculation according to Eurocode 5 [1]

2. APPLICATION OF STEEL FIBRE REINFORCED CONCRETE IN TCC

Basically, the concrete slab in TCC has to bear stresses caused by shear forces and bending moments in parallel direction to the timber beams, Fig. 1. Besides this, there are secondary stresses in the slab caused by the following facts [5]:

- There is a spreading of load in the concrete slab starting from shear connectors.
- Loads acting between the timber beams cause shear forces and bending moments in the concrete slab in rectangular direction to the timber beams. In case of larger single loads there is a significant lateral load distribution bearing more than only one timber beam.
- There are restraints caused by shrinkage of timber and concrete.
- The concrete slab is part of the embracing system.

So, it is not useful to apply plain concrete in TCC. There is a need for reinforcing the concrete slab. If an ordinary mesh reinforcement is used the resulting minimum depth of the concrete slab is 8 cm at least because of the fact that a concrete cover for reinforcement is needed at top and buttom side of the section. An alternative is the application of fibre reinforced concrete using steel or polymeric fibres. Then, there is no need for a concrete cover and the depth of the concrete slab can be reduced to the statically appropriate value of few centimeters, Fig. 3. Another effect is the better load-bearing behavior of shear connectors when steel fibre reinforced concrete is applied; see Chapter 3, Fig. 6.

A further improvement can be achieved if steel fibre reinforced lightweight concrete (SFRLWC) is used in TCC, especially when strengthening existing timber beam ceilings [6]. Caused by the lower material density the increase of the dead load of construction by adding the concrete slab at the top of the timber beams is reduced. This is also a valuable effect for other members that are loaded by TCC slabs, e.g. walls and foundations. However, if SFRLWC has to pump at site some special considerations are necessary [7].

The application of SFRLWC with self-compacting properties makes the casting process much easier. However, there is only little experience with this material in construction practice.

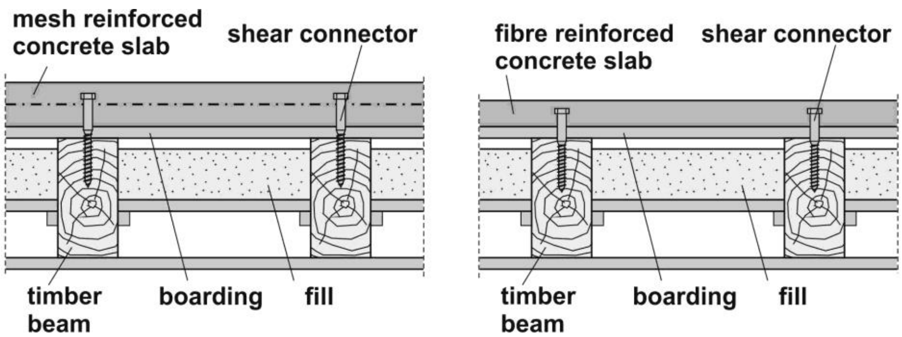


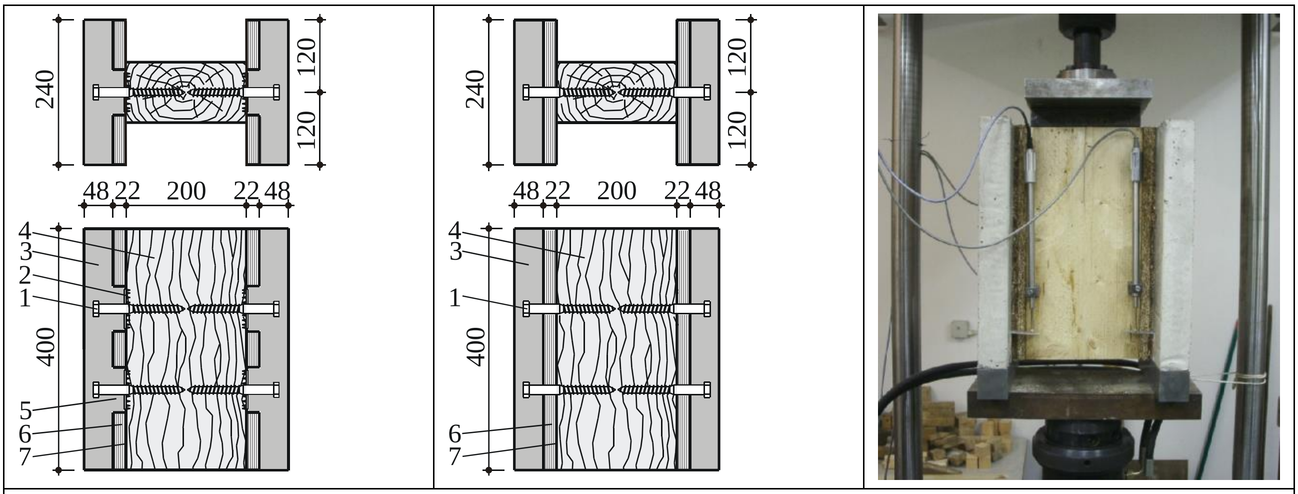
Figure 3: Strengthening of existing timber beam ceilings with TCC; left: application of a mesh reinforced concrete slab, right: application of steel fibre reinforced concrete

3. DEVELOPMENT OF SHEAR CONNECTORS FOR TCC

Ultimate load and stiffness of shear connectors influence essentially the load-bearing behavior of the complete TCC system. Besides, shear connectors should be easy to assemble and must not be too expansive to give them a chance in construction practice. Therefore, many investigations have addressed the development of suitable shear connectors.

For this reason numerous push-out tests were carried out at HTWK Leipzig. The geometry of used push-out specimens is presented in Fig. 4. The concrete used for the specimen was classified in the concrete class C20/25 according EC2; the timber beams exhibit an average compressive strength in grain direction of 51 MPa, an average bending strength of 62 MPa and a Youngs-Modulus of 12300 MPa. All specimens were loaded in a servo-hydraulic testing machine, whereby the loading regime was implemented according to DIN EN 26891 [4]. At first the load was increased force-controlled with a loading rate of 20 % of the estimated maximum load per minute until 70 % of the maximum value, Fig. 5. Within this loading regime the force was kept constant for 30 seconds at 40 % of the estimated maximum load. After that the further loading was applied path-controlled until failure of the specimen or a displacement of 15 mm.

The experiments showed that a combination of notch with screw is an economic and technical advantageous solution. When applying steel-fibre reinforced concrete a further improvement of the load-bearing behavior of the connectors is achievable, Fig. 6.



1 - Wood Screw 16/160 mm
2 - Single Sided Timber Connector Plates Type D
3 - SFRC Slab
4 - Timber Beam
5 - Concrete Key
6 - Sheet of Plywood
7 - PE-Film

Figure 4: Push-out specimen for investigation of the structural behavior of shear connectors

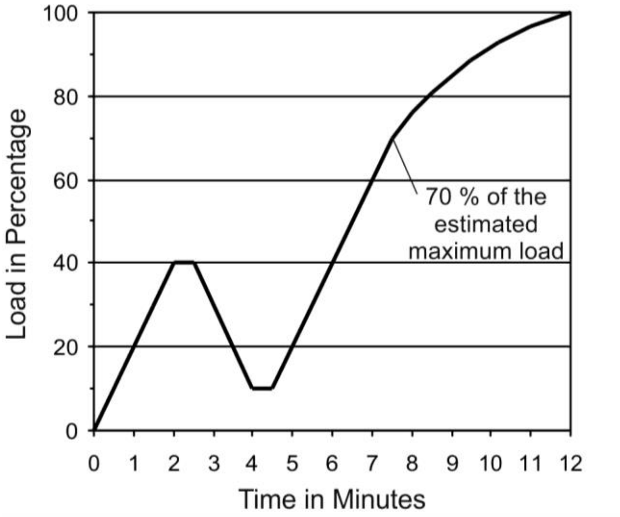


Figure 5: Push-out specimen for experimental investigation of structural behavior of shear connectors

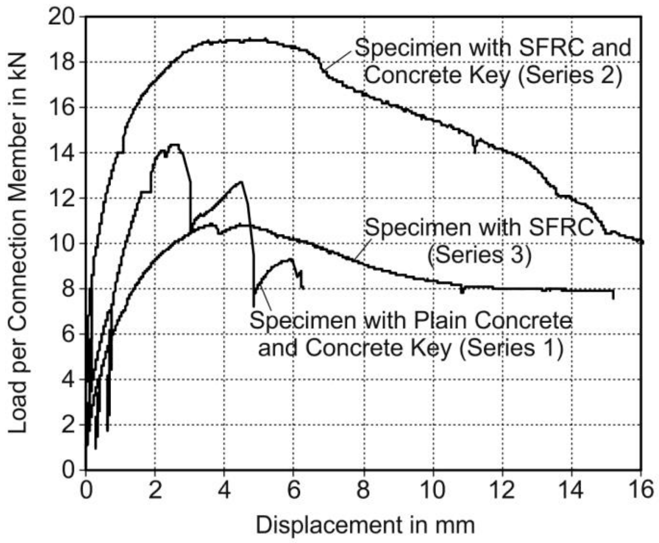


Figure 6: Push-out specimen for experimental investigation of structural behavior of shear connectors

4. LATERAL LOAD SHARING IN TCC-FLOORS

TCC slabs are able to distribute loads along and perpendicular to the axis of the timber beams. A concentrated load applied to one of the composite beams will deflect it due to bending. Because of the stiffness of the concrete slab adjacent beams also deflect although no load is applied to them directly. These beams contribute to the load bearing of the whole system and relieve the loaded beam partly, Fig. 7 [8], [9]. The described behavior of distributing loads perpendicular to the span is called lateral or transversal load bearing behavior and investigated at HTWK Leipzig for some years.

For investigation of lateral load bearing behavior some experiments have been carried out accompanied by numerical analysis based on FE-method [10]. Basically, the specimens were single-spanned slabs, spanned in direction of the timber beams, Fig. 8. The slabs consisted of three beams (10/20 cm) aligned in one direction and had a distance between each other of 60, 75 or

90 cm. The span of the system was 3.90 m. The load was applied with a constant velocity of 0.1 mm/s in the mid span of the central bar.

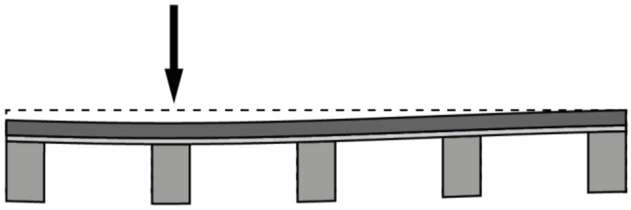
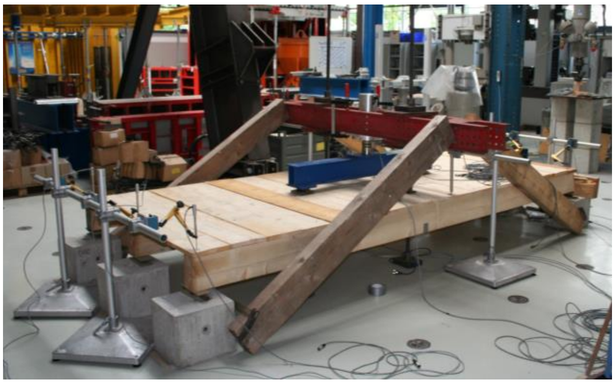


Figure 7: Principle of lateral load sharing in TCC structures



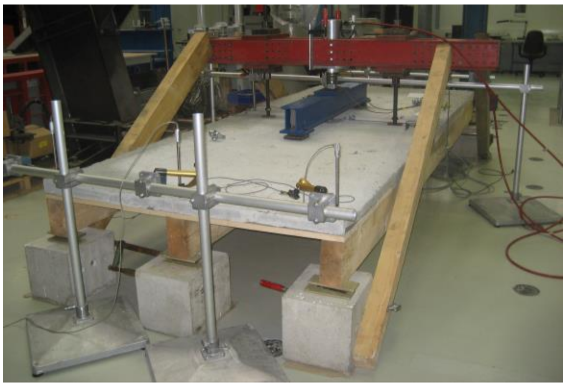


Figure 8: Experimental set-up of tested TCC ceilings

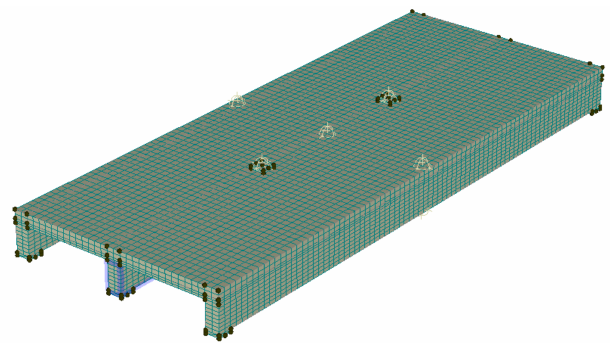


Figure 9: FE-model with timber beams and concrete topping

The experimentally determined load-deflections curves of the TCC ceilings were the basis for development and calibration of a FE-model as shown in Fig. 9. Details of the FE-model are reported in [11]. The FE-program ATENA was used for the numerical investigations. For all elements the 3D Solid Brick Elements were chosen. The bond between wood and concrete part of the model was realized by a smeared 3D-interface material. The comparison between the load-displacement curves of the central beam (loaded) at mid span (Figure 10 green curve) and the response of the FE-model (Figure 10 red curve) shows a very good accordance.

A parametric study showed that in TCC ceilings with dimensions usually in practice there is an essential load transfer in lateral direction. Even in case of unfavorable boundary conditions the deflection of the loaded beam is only 60 % in comparison to a beam without consideration of load transfer. This fact should be considered in the design of TCC ceilings to achieve economical results.

5. APPLICATION IN PRACTICE

TCC is a well-proven technique for strengthening of existing timber beam ceilings. In this way a lot of square meters of timber beam ceilings with to low stiffness already have been successfully revaluated, Fig. 11. Especially the application of steel fibre reinforced concrete in TCC has led to a simplification of the construction progress as the otherwise needed mesh reinforcement can be cancelled. This saves a lot of time because the transport of mesh reinforcement, usually 6,00 m in length, to the required place is quite complicated. Very often tight staircases have to be used as way for transport causing many problems.

For the construction of new buildings just few TCC systems were applied. Main reason is the advantage of competing reinforced concrete slabs in lower member height, better sound insulation and fire resistance [12].

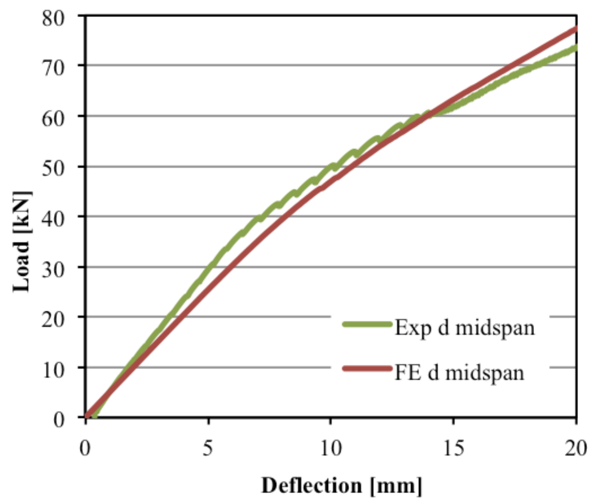


Figure 10: Mid span deflection of the TCC ceiling – comparison of test (green line) and simulation (red line)

Figure 11: Strengthening of existing timber beam ceilings with TCC; left: typical building with timber beam ceilings, right: arranged ceiling before casting

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