Considerations regarding the concrete in TCC-Constructions

Klaus Holschemacher[1], Hubertus Kieslich[1], Torsten Mueller[1]

[1] University of Applied Sciences, Leipzig, Germany

ABSTRACT: Timber-concrete composite (TCC) constructions are often applied for strengthening existing timber beam ceilings. Thereby a concrete slab is added to the timber beams. Both parts of the construction are connected by using special shear connectors. The material properties of the timer beams and the concrete slab influence the bearing capacity of the composite construction as well as the type of bond between both parts. The concrete slab has to perform several tasks concerning structural and structural-physical requirements. These tasks will be pointed out in this paper. Furthermore the working process, the dead load of the construction and economic aspects are of particular interest in the field of redevelopment. Several innovative concretes have been verified for the use in TCC constructions. They all can be described as high performance concretes (HPC). The properties which create a high performance concrete can be the fresh and the hardened concrete properties or a combination of them. In this paper several innovative concretes will be focused on. Especially the advantages but also disadvantages of these concretes for the use in TCC construction will be presented. Additionally some experimental experiences especially concerning fiber reinforced concrete (FRC) with different fiber types and fiber contents will be presented.

1 INTRODUCTION

Timber-concrete composite (TCC) constructions are currently often applied in the retrofitting of existing timber beam ceilings but also in new constructions. Figure 1 shows the principle structure of a TCC ceiling. The concrete slab on top is connected to the timber beams.

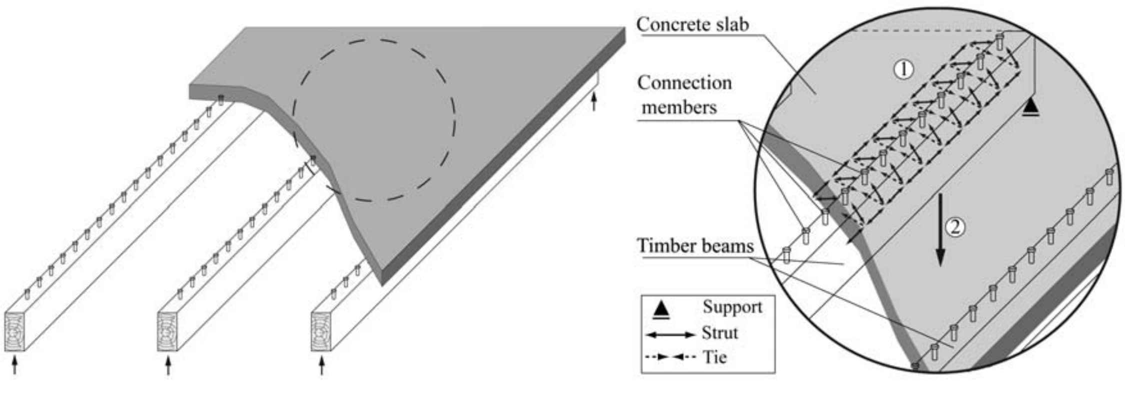


Figure 1. Principle structure of a TCC ceiling (left), loading of the concrete slab (right)

The connection members differ in effectiveness, price and input of labor. The level of connection ranges between zero (no connection) and one (rigid connection). The efficiency of the composite construction is generally affected by the properties of the used construction materials as well as by the level of connection. In detail figure 1 shows some special loadings of the concrete slab in the TCC construction. Regarding the requirements for the concrete slab 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 (figure 1 framework model (1)) but also bending moments and lateral forces perpendicular to the direction of span (figure 1 force between two beams (2)). 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. It is necessary to think about the optimal components of the composite construction. No simple solution can be given; every project makes different demands on the construction.

2 INNOVATIVE CONCRETES FOR TCC-CONSTRUCTIONS

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. Due to that the variety of concretes useable for TCC constructions has grown considerably.

Table 1. Advantages and disadvantages of different concretes

Type of concrete	Advantages	Disadvantages
Self-compacting concrete (SCC)	no labor input for compacting the concrete	higher costs, surveillance required, higher amount of fine ingredients (higher temperature, higher shrinkage)
Structural lightweight concrete (SLWC)	savings of weight	higher costs, workability limited (aggregates sucking up the mixing water)
High strength concrete (HSC)	higher strength and higher modulus of elasticity (thin slabs, higher stiffness)	higher costs, higher amount of fine ingredients (higher temperature, higher shrinkage)
Fiber reinforced concrete (FRC)	higher ductility, savings of reinforcement	with high fiber contents the workability is limited (especially for pumping the concrete)
Self-compacting fiber reinforced concrete (SCFRC)	no labor input for compacting the concrete, higher ductility, savings of reinforcement	workability is limited (possibility of blocking of aggregates and fibers)
Self-compacting structural lightweight concrete (SCSLWC)	no labor input for compacting the concrete, higher ductility, savings of reinforcement, savings of weight	workability is limited (especially for pumping the concrete)

Most of the innovative concretes can be described as high performance concretes (HPC). They are called high performance not only concerning their fresh concrete properties but also their hardened concrete properties. Innovative concretes with special fresh concrete properties are for example easy workable or self-compacting concrete (SCC). Structural lightweight concrete (SLWC), high strength concrete (HSC) and fiber reinforced concrete (FRC) are examples for innovative concretes with specific hardened concrete properties. Often it is expedient to use a combination of different fresh and hardened concrete properties. Examples are self-compacting fiber reinforced concrete (SCFRC) and self-compacting structural lightweight concrete (SCSLWC).

Table 1 summarizes the advantages and disadvantages of different types of innovative concretes. The table cannot be complete, other kinds of concretes or other advantages and disadvantages can be added. The special situation of the reconstruction (buildings with little space to work in, small slab thickness, low additional loads needed) requires special solutions. Certain innovative concrete properties will cause problems in other fields, the applicability is limited. At the University of Applied Science Leipzig a research project is carried out (since 2009) to develop a PVA-(Polyvinylalcohol) fiber reinforced dry lightweight concrete (PVA-FRDLC) especially for the use in TCC constructions.

3 EXPERIMENTAL INVESTIGATIONS

In the following FRC will be focused on. Different concretes and fiber types will be compared especially regarding their effectiveness. Therefore a normal strength lightweight concrete (LC20/22), a normal strength concrete (C30/37) and a high strength concrete (C70/85) were chosen. The lightweight concrete is reinforced with PVA-(Polyvinylalcohol) fibers (lightweight PVA-fiber reinforced concrete – LWPVAFRC). The normal weight concretes are reinforced with steel fibers (steel fiber reinforced concrete – SFRC and high strength steel fiber reinforced concrete – HSSFRC)

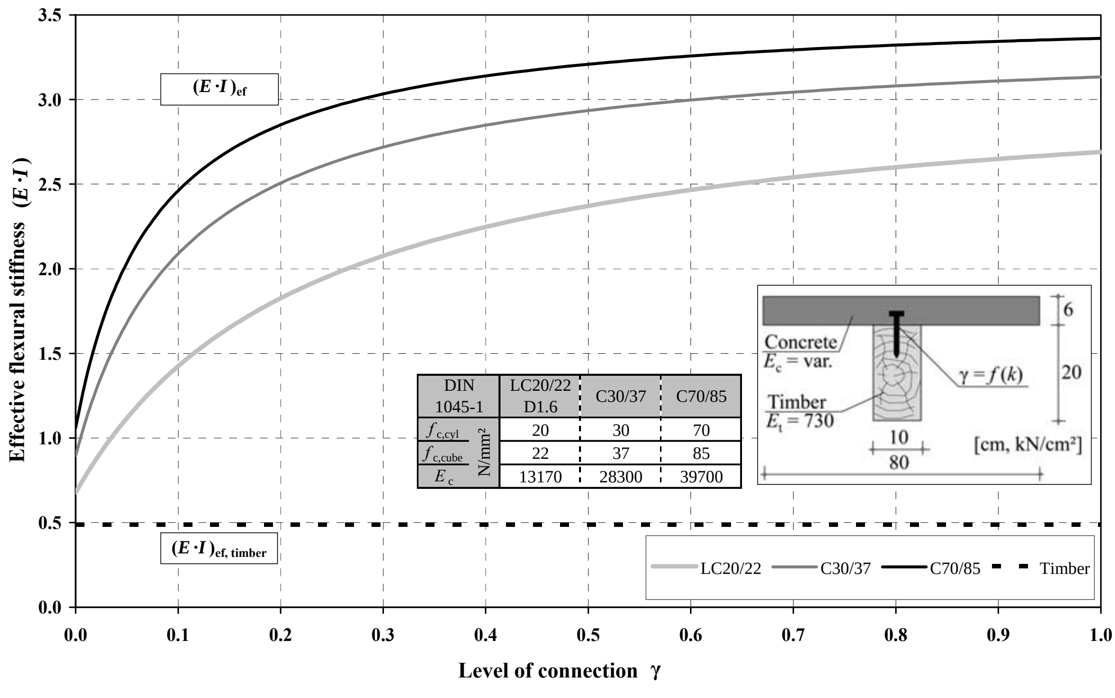


Figure 2. Influence of the modulus of elasticity on the stiffness of a TCC construction

Figure 2 represents the influence of the modulus of elasticity of the concrete slab on the effective stiffness ($E \cdot I$) of the TCC construction depending on the level of connection (γ). For calculating the effective stiffness the γ-procedure deduced by Möhler for flexibly connected bending or compression members (Möhler 1956) was chosen. It is used in the German model code too (DIN 1052 2008). Thereby the Steiner's dues of the plane-area moment are reduced because of the flexibility of the connection members. The level of connection is mainly influenced by the type and distance of the chosen connection members. At higher γ-values than 0.5 the effective stiffness of the construction cannot be increased significantly. This is especially interesting regarding the economic design of TCC constructions. 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.

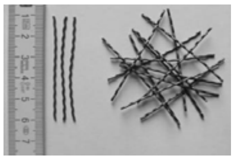
The table above (Table 2) summarizes the concrete mixtures which were chosen to be presented in this paper. The authors are not allowed to give further information concerning the LWPVAFRC. The high strength concrete demands a higher amount of cement and an other type of cement.

In every experimental series two fibers with a fiber content of 0, 0.25 and 0.5 vol.-% were chosen. In the following table (Table 3) the geometrical and mechanical properties of the used PVA and steel fibers are summarized. Two steel and two PVA fibers were chosen. S-F1 is hooked end steel fiber and the Fiber S-F2 a corrugated steel fiber. The PVA fibers differ in length and diameter but not in shape.

Table 2. Components of the concrete mixtures

Components		LWPVAFRC	SFRC	HSSFRC
		[%] of mass of the dry mixture	Content in [kg/m³]	
cement		n/a	276.0	400.0
total water		18.5	175.0	132.0
w/c-ratio		n/a	0.634	0.330
additives	fibers	0 / 0.248 / 0.498	0 / 20 / 40	0 / 20 / 40
	fly ash	n/a	121.0	100.0
w/(c+FA) ratio		n/a	0.441	0.264
admixtures	PCE	-	1.38 – 1.93	10.0 – 11.6
	Retarder	-	-	0.8 – 2.0
aggregates		0/2 sand (n/a.)	0/2 sand (685.0)	0/2 sand (696.9)
		2/8 gravel (n/a.)	2/8 gravel (435.8)	2/8 gravel (443.4)
		1/4 lightweight aggregate (n/a.)	8/16 gravel (627.5)	8/16 gravel(638.4)

Table 3. Properties of the used fibers

Properties	PVA-F1	PVA-F2	S-F1	S-F2
				
l_f [mm]	18	30	50	50
d_f [mm]	0.2	0.66	1	1
λ [-]	90	45	50	50
ρ [g/cm³]	1.3	1.3	7.85	7.85
f_t [N/mm²]	1 600	800	1 100	1 100
E [N/mm²]	37 000	30 000	200 000	200 000
n_f [kg^{-1}]	1 375 500	78 500	3 150	2 850

28 days after placing the hardened concrete properties were tested. The concrete compressive strength ($f_{c,m,cube}$), splitting tensile strength ($f_{t,m}$) and density (ρ_m) were measured on cubes with an edge length of 150 mm in each instance. The modulus of elasticity (E_m) was measured on cylinders with a diameter of 150 mm and a height of 300 mm. The results are given in Table 4.

Table 4. Hardened concrete proteries

Properties		$f_{c,m,cube}$ [N/mm²]	$f_{t,m}$ [N/mm²]	E_m [N/mm²]	ρ_m [kg/dm³]
LWPVAFRC	Reference	30.09	2.75	17 165	1.626
	PVA-F1-0.25	29.92	2.64	12 493	1.623
	PVA-F1-0.5	29.53	2.10	13 918	1.626
	PVA-F2-0.25	33.56	2.83	14 171	1.696
	PVA-F2-0.5	28.65	2.42	12 762	1.601
SFRC	Reference	42.44	3.23	30 420	2.344
	S-F1-0.25	39.02	2.99	27 223	2.342
	S-F1-0.5	43.66	3.04	29 329	2.371
	S-F2-0.25	41.58	3.23	28 689	2.338
	S-F2-0.5	41.03	3.02	27 873	2.369
HSSFRC	Reference	86.15	4.18	38 438	2.433
	S-F1-0.25	86.82	5.12	43 106	2.431
	S-F1-0.5	91.06	5.63	41 238	2.443
	S-F2-0.25	86.16	4.84	40 327	2.437
	S-F2-0.5	95.43	4.96	41 686	2.446

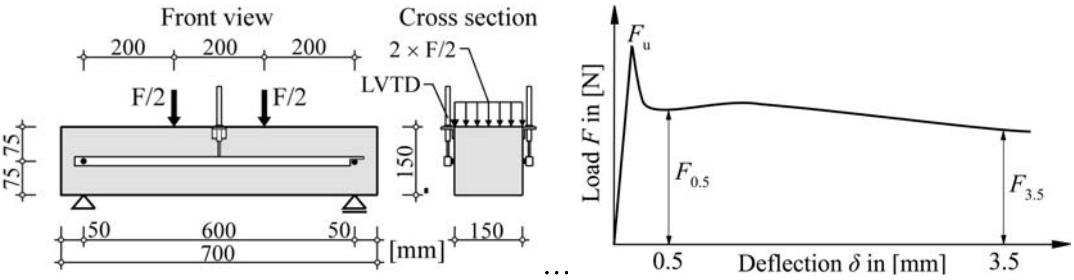


Figure 3. Test set-up and analysis of the four-point bending test

To analyze the post-cracking behavior of the FRC in serviceability as well as ultimate-limit state four-point bending tests are realized. Using LVTD's placed on both sides of the beams load-deflection-curves were monitored. The experimental set-up is shown in figure 3. The tests were carried out on beams with a cross section of 150 x 150 mm and a length of 700 mm. The casting and storing of the specimen as well as the test set-up were chosen according to the German regulations (Stahlfaserbeton-Richtlinie 2010) which are related to those of RILEM (RILEM 2002). With the load value at a deflection *i* of 0.5 and 3.5 mm residual flexural strength can be derived (equation 1). These values represent the tensile strength of the FRC in the serviceability limit state ($F_{0.5}$) and ultimate limit state ($F_{3.5}$). Analyzing pre- and post-cracking behavior is important for design of FRC members, subjected to bending. According to the modern standards (Stahlfaserbeton-Richtlinie 2010), residual flexural tensile strength is of particular importance.

$$f^{\mathrm{f}}_{\mathrm{cfl,Li}} = \frac{F_{\mathrm{i}} \cdot l}{b \cdot h^2} \quad (1)$$

The influence of fiber content and fiber type on pre- and post-cracking behavior of LWPVAFRC, SFRC and HSSFRC beams are shown in figure 4. The diagrams show the load (ordinate) in relation to the deflection (abscissa). Every graph represents the average load deflection curve of 6 single beams. They differ strongly in the maximum load and post cracking behavior depending on the type of concrete, the fiber type and fiber amount. Generally it can be noticed that the load bearing capacity was improved with increasing fiber content. In every case only one crack occurred in the bending zone of the beams and the load was never increased over the initial crack load, so called under critical load bearing behavior. These load increases corresponding to the increase of compressive strength regarding the different types of concrete. A high initial crack load requires higher energy absorption by the fibers.

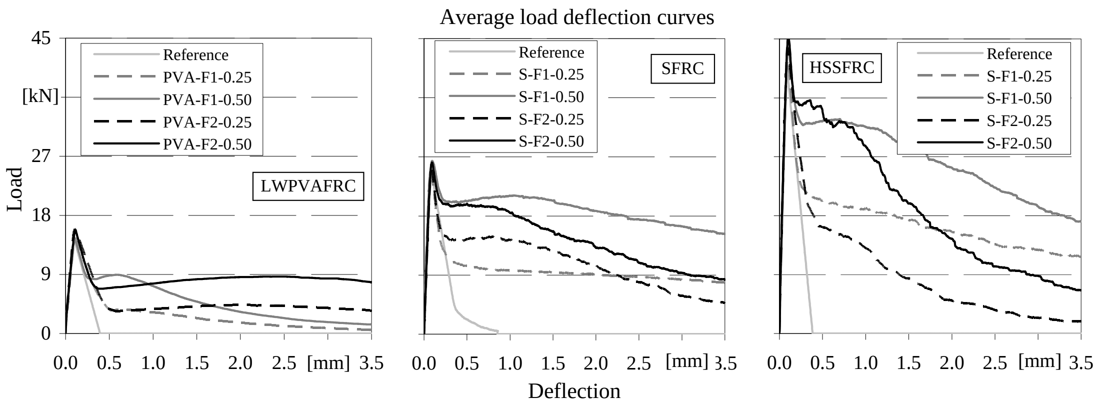


Figure 4. Average load deflection curves of different fiber concretes

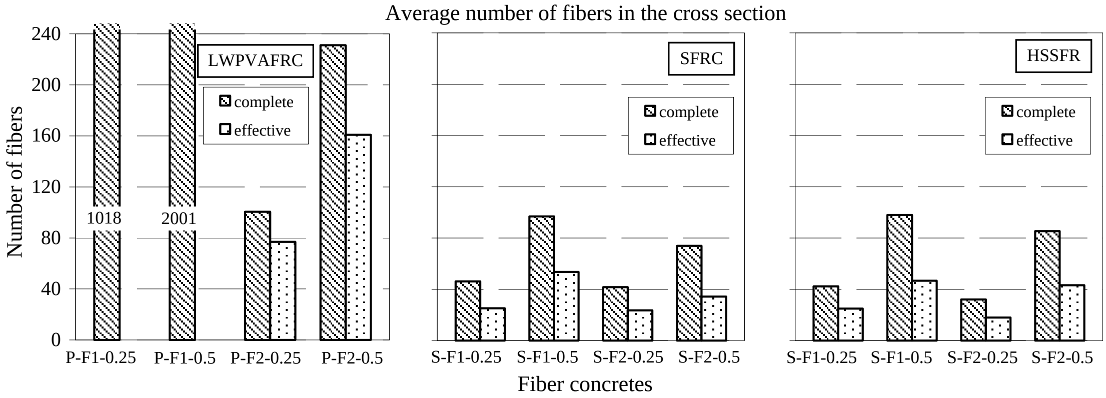


Figure 5. Average number of fibers in the cross section of the tested beams

The short PVA fiber (PVA-F1) represents a high load bearing capacity compared to the long PVA fiber (PVA-F1). This can be explained by the faster pull-out of the short fibers out of the concrete matrix. With increasing deflection a clearly higher load decrease was observed. Independent of the concrete compressive strength the load drop with increasing deflection was distinctly higher for the corrugate fiber (S-F2) in comparison to the end hooked steel fiber (S-F1). In respect of the fiber type S-F2 it was noticed that more fibers were broken during the test. Comparing the high strength and normal strength concrete a higher number of steel fibers (independent of fiber type) cracked during the bending test. The number of fibers crossing the crack was determined for each specimen. In figure 5 the average number of fibers in the cross section of the tested beams is pictured. Effective fibers are defined as those sticking out more than 5 mm out of the fracture surface, lying not parallel to the crack border and not near to the specimens' edges.

In figure 6 the efficiency of the fibers depending on the residual loads in the four-point bending test, the fiber type and fiber content is shown. As reference value of efficiency the steel fiber F2 for a fiber content of 0.25 vol.-% was chosen with 100 %. For the calculation of the efficiency the number of fibers, the area of the fibers and the residual tensile strength were related to each other. With increasing deflection in the test the efficiency of the fibers decreases except of the PVA-fiber F2 at a fiber content of 0.25 vol.-%. For low deformations the fibers PVA-F1 and PVA-F2 have nearly the same efficiency. But with higher deflections long fiber type (PVA-F1) was clearly more effective.

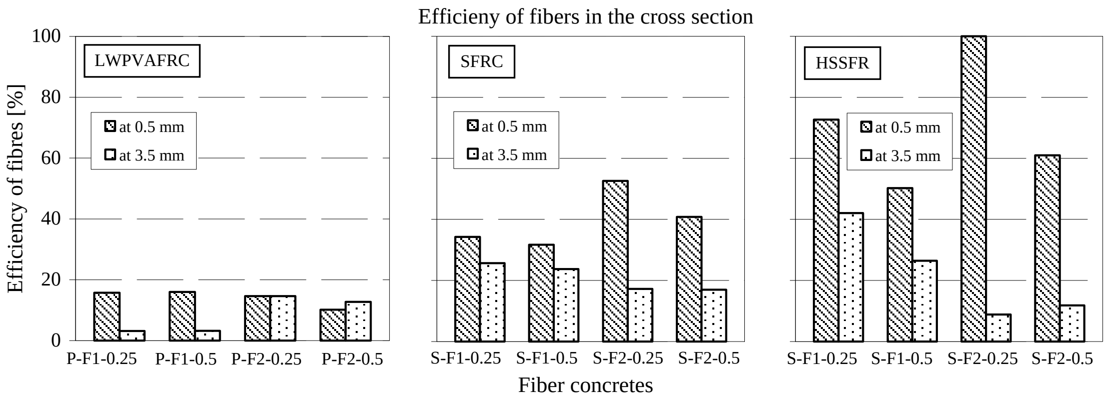


Figure 6. Efficiency of the fibers in the cross section

The loss of efficiency is the highest for the steel fiber F2 at a fiber content of 0.25 vol.% used in the high strength concrete. The PVA fibers independent of fiber type illustrate the lowest efficiency at a deflection of 0.5 mm compared to the steel fibers. It can be seen that with increasing compressive strength the loss of efficiency was increasing for the steel fibers (independent of fiber type). From these facts it can be deduced that it is sensible to use high strength steel fibers (2 000 N/mm²) for high strength concrete.

4 CONCLUSION

The TCC construction is an effective opportunity to toughen up timber beam ceilings. The effectiveness of this reconstruction method is mainly influenced by the type of concrete added to the timber beams. 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 short PVA fiber type F1 are not proper for using in a TCC construction as single reinforcement. All tested fiber concretes require an additional bar or mesh reinforcement. 0.5 vol.-% are not sufficient to generate a critical or over critical load bearing behavior.

5 ACKNOWLEDGEMENT

The study which is the base for parts of the presented paper was part of the research projects: "PVA-faserbewehrter Trocken-Fertigleichtbeton" (support code 1763X09) and "Betonstahlbewehrter Stahlfaserbeton" (1775B08). They are supported by the Federal Ministry of Education and Research of the Federal Republic of Germany. We thank the Federal Ministry of Education and Research for the financial advancement as well as the project executing organization "Arbeitsgemeinschaft industrieller Forschungsvereinigungen (AiF)" for the cooperative collaboration and assistance. At the end of this paper the authors want to thank our colleagues Yvette Klug, Stefan Käseberg and Christiane Rabe for supporting our work at the Institute of Concrete Construction at the University of Applied Science Leipzig.

6 REFERENCES

Möhler, K. 1956. "*Über das Tragverhalten von Biegeträgern und Druckstäben mit zusammengesetzten Querschnitten und nachgiebigen Verbindungsmitteln*" University lecturing qualification, TH Karlsruhe, Germany (in German).

DIN 1052 2008. "*Entwurf, Berechnung und Bemessung von Holzbauwerken – Allgemeine Bemessungsregeln und Bemessungsregeln für den Hochbau (Design of timber structures – General rules and rules for buildings)*" Berlin, Germany, Beuth Verlag (in German).

DIN 1045 2008. "*Tragwerke aus Beton, Stahlbeton und Spannbeton (Concrete, reinforced and prestressed concrete structures)*" Berlin, Germany, Beuth Verlag (in German).

Deutscher Ausschuss für Stahlbeton 2010. "*DAfStb-Richtlinie Stahlfaserbeton (Stahlfaserbeton-Richtlinie)"* Berlin, Germany Beuth Verlag (in German).

RILEM TC 162-TDF 2002. Test and design methods for steel fibre reinforced concrete *Materials and Structures*, 35: 579-582.

Holschemacher, K., Klotz, S., Klug, Y., Weiße, D. 2003. Application of steel fibre reinforced concrete for the revaluation of timber floors. In Bontempi, F. (ed) *System-based Vision for Strategic and Creative Design*, 1393-1398.

Kieslich, H., Klug, Y., Mueller, T., Kaeseberg, S., Holschemacher, K. (2009) Steel fibre reinforced lightweight concrete used for timber-concrete composite floors. In Kohoutková, A. (ed) *Proceedings of 5th International Conference Fibre Concrete 2009; Technology, Design, Application*, 139-147.