STEEL FIBRE REINFORCED LIGHTWEIGHT CONCRETE USED FOR TIMBER-CONCRETE COMPOSITE FLOORS

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Abstract:

Regarding the redevelopment of existing residential buildings the timber-concrete-composite construction is an innovative possibility to toughen up 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. In this case timber is mainly loaded in tension and concrete is generally loaded in compression. This results in specific material properties of the composite beams influencing the bearing capacity in a positive way. Conventional reinforcement is required to take the lateral tensile forces caused by the shear connectors but also as principal reinforcement orthogonal to the direction of span. Alternative to this kind of reinforcement steel fibres can be used to improve the construction progress, material properties as well as the load transfer. This paper shows the advantages and limits of utilization of steel fibre reinforced concrete relating to timber-concrete-composite constructions.

Keywords: timber-concrete-composite, timber beam ceiling, steel fibre, shear connector, redevelopment

1 Introduction

The idea of combining the construction materials timber and concrete in the way that they both can take and carry on loads is not new. Already in 1939 a patent for a timber-concrete-composite ceiling was submitted in Germany by Schaub. The examples for appliction reach from ceiling systems for existing residential buildings and new buildings up to timber-concrete-composite bridges for road construction [1]. The cityscape of Central Europe towns is mainly characterised by buildings constructed before the 50th of the last century. The protection of historical main structure of these buildings is getting more important today. Floors built up till that time were primarily made of timber. Often today's requirements concerning bearing capacity, serviceability (deformation, vibration behaviour and sound insulation) but also fire protection cannot be achieved. Reasons can be the change of use of the building or the biological damage of supporting wooden structures. Among other forms of reconstruction the timber-concrete composite construction method can be an alternative. Thereby a concrete slab is added to the timber beams as shown in Fig. 1. Both parts of the construction are connected by using special shear connectors. In this case timber is mainly loaded in tension and concrete is generally loaded in compression. The specific material properties can be sensibly utilised.

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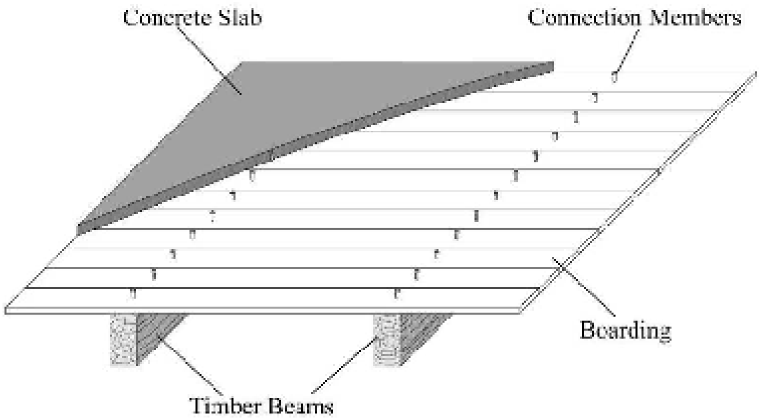


Fig. 1 Principle structure of a timber-concrete composite ceiling

Metallic combing agents such as nails or screws are used as shear connectors. Often it is only allowed to use them connecting timber or timber and steel. To use them in timber-concrete-composite constructions it is necessary to apply for an approval in individual case or a national technical approval.

2 Load-bearing characteristics of timber-concrete-composite floors

Examining the load-bearing characteristics of timber-concrete-composite floors is a complex intention. In this paper only a few aspects can be taken up. In general those matters which are of interest to this topic.

2.1 The concrete slab in timber-concrete-composite floors

Different requirements have to be achieved by the concrete slab. It is reasonable to make a trisection in structural, static and structural-physical requirements [2]. Constructional needs are a plane and horizontal surface. The slab thickness has to be small especially regarding the dead weight and the load on the subordinated components but also with regard to door sizes and parapet heights. Static aspects are primary that the concrete slab proportionally takes bending moments and lateral forces in load carrying direction of the ceiling. Secondary loadings are lateral tensile forces caused by the combing agents but also bending moments and lateral forces perpendicular to the direction of span. The concrete slab is also important in the complete system in order to stabilise the building. The structural-physical requirements especially concerning the airborne- and the impact-sound insulation as well as the fire behaviour of the construction are important, too. All these aspects can be achieved by using timber-concrete-composite floors. In this case it is necessary to think about the optimal components of the composite construction.

2.2 The “ideal” concrete for timber-concrete-composite constructions

The properties to characterise the “ideal” concrete can be derived from the requirements listed before. Therefore the concrete should have specific fresh and hardened concrete properties. In the case of existing residential buildings it is advantageous to use a lightweight concrete in order to reduce the dead load of the construction. With the use of fibres is possible to increase the ductility of the concrete slab.

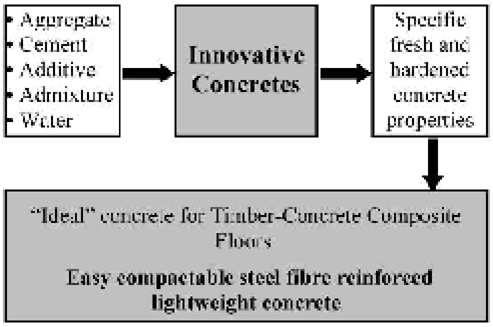


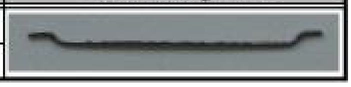
Fig. 2 Example for using innovative concretes in timber-concrete-composite floors

In certain cases conventional reinforcement can even be economised. This is especially expedient in buildings with little space to work in. The concrete should be easily workable and compactable. It should be possible to pump the concrete without any problems. Fig. 2 abstracts the main statements by using innovative concretes in timber-concrete-composite floors.

3 Experimental Investigation

The aim of the experimental program was to develop a concrete mixture for a pumpable, easy compactable steel fibre reinforced lightweight aggregate concrete (SFRLWC) especially for the use in timber-concrete-composite floors. The difficulty was to find an optimum between flowability and stability of the mixture. On the one hand flowability is necessary to pump the concrete, on the other hand the matrix has to be stabile enough to prevent sedimenting of the steel fibres as well as floating of the lightweight aggregates. In the following the most important steps which were needed to find the optimal concrete composition are presented. Many mixtures with changing quantities and types of the components were tested but some basic parameters were fixed during the test program. First of all the cement (CEM II/B-M(S-LL) 32,5 R in conformity with EN 197-1) was always the same only the amount given to the mixtures was varied.

Tab. 1 Properties of the investigated steel fibre

Description		Used steel fibre	
Geometry			Picture of the glued fibre bundles
Shape		straight	
Surface		plane	
Cross-section		circular	
Anchorage		hooked ends	
Variables			
l_f	[mm]	35	
d_f	[mm]	0,55	
λ	[mm]	64	
f_t	[N/mm²]	1.100	
n_f	[kg⁻¹]	14.500	
further information			Piture of a single fibre
coating		no coating	
form of delivery		glued in bundles	

The investigated steel fibre was also the same during the test program. Only the fibre content ranged between 0 and 60 kg/m³. The properties of the applied steel fibre are shown in Tab. 1. In all cases clayey lightweight aggregates were used in different amounts and grain sizes.

Tab. 2 shows the concrete composition of the first investigated lightweight concrete (LWC 1). The produced mixtures only differ concerning the fibre amounts (20, 40, 60 kg/m³)

Tab. 2 Concrete Compositions of the lightweight concrete 1 (LWC 1)

Components		Concrete Compositions			Unite	Picture Lightweight Aggregates 2/10
		LWC 1 20	LWC 1 40	LWC 1 60		
Cement	c	350,0	350,0	350,0	kg/m³	
Total Water	w	231,0	231,0	231,0	kg/m³	
	w/c ratio	0,660	0,660	0,660	kg/m³	
Additives	Steel Fibres	20	40	60	kg/m³	
	Fly Ash	140,0	140,0	140,0	kg/m³	
	w/(c+FA) ratio	0,471	0,471	0,471	kg/m³	
Admixtures	Superplasticizer	1,75	1,75	1,75	kg/m³	
Aggregates	0/2 Sand	57,0	57,0	57,0	%	
	2/10 Lightweight Aggregates	43,0	43,0	43,0	%	

28 days after placing the hardened properties were tested. The concrete compressive strength was measured on cubes with an edge length of 150 mm in each instance. Beyond four-point bending tests were realised to analyse the post cracking behaviour of the steel fibre reinforced lightweight concrete. This can be presented in load-deflection-curves where the influence of fibres on the carrying capacity of the concrete in serviceability as well ultimate-limit state can be shown. The experimental set-up is shown in Fig. 3. The test was 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 specimens as well as the test set-up were chosen according to the German regulations [3] (similar to those of RILEM).

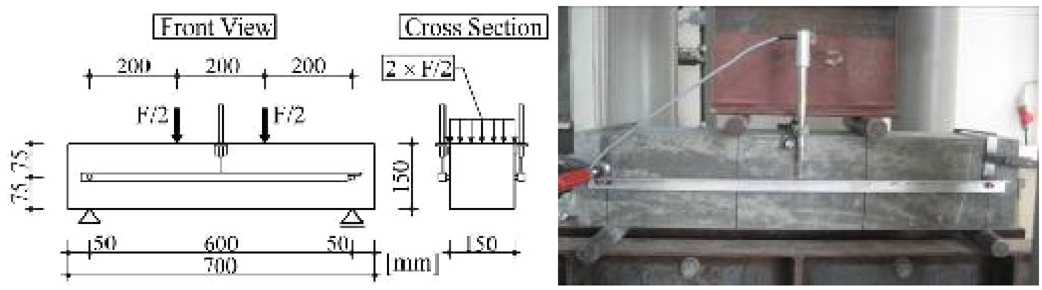
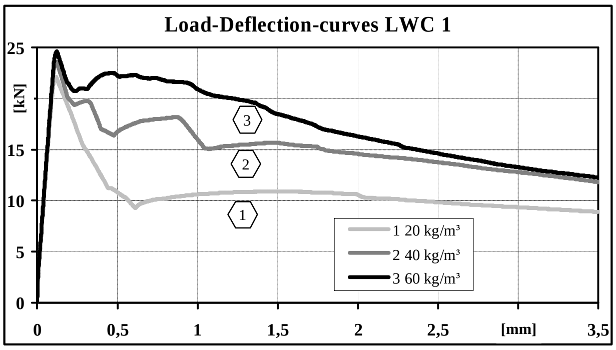


Fig. 3 Experimental set-up of the four-point bending test

In Fig. 4 the experimental results of LWC 1 are summarised. On the left side average load-deflection-curves representing the fibre contents of 20 kg/m³ (curve 1), 40 kg/m³ (curve 2) and 60 kg/m³ (curve 3) are documented. The table on the right side shows the strength values (cube compressive strength $f^{28}_{cm,cube}$), the load values (initial crack load F_{ic}, load corresponding to 0.5 mm and 3.5 mm deflection $F_{0.5}$, $F_{3.5}$) and the density of the light weight concrete ($\rho_{c,f}$ - fresh concrete, $\rho_{c,h}$ - hardened concrete) tested in these series. As expected the load bearing capacity was improved by increasing fibre content.



Fibre content		20 kg/m³	40 kg/m³	60 kg/m³
$f^{28}_{cm,cube}$		40,75	37,50	39,00
$\rho_{c,f}$	[kg/dm³]	1,740	1,680	1,690
$\rho_{c,h}$	[kg/dm³]	1,725	1,665	1,675
F_{ic}	[kN]	22,13	23,54	24,60
$F_{0.5}$	[kN]	10,81	16,76	22,19
$F_{3.5}$	[kN]	8,91	11,81	12,24

Fig. 4 Average load-deflection curves for LWC 1

In view of the necessary tensile strength of the concrete as part of the composite beam a fibre content of 50 kg/m³ was chosen. However a pumping test was carried out to investigate the pumpability of the easy flowable mixture. As it can be seen in Fig. 5 the concrete mixture segregates, the lightweight aggregates floated upwards and the fibres sedimented. The result was that the pump lead was blocked by an agglomeration of fibres and aggregates.

Fig. 5 Results of the pumping test

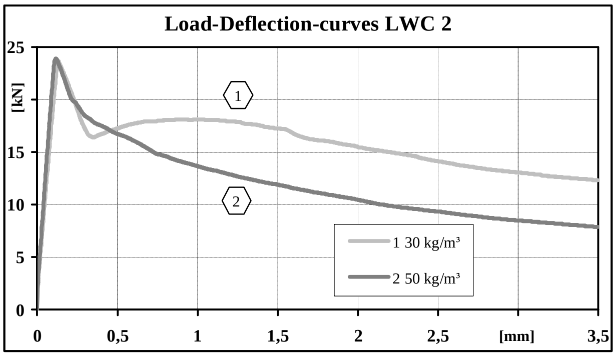
Therefore the amount of cement and fly ash was increased from 350 kg/m³ to 400 kg/m³ respectively from 140 kg/m³ to 200 kg/m³ and the grain size of the lightweight aggregates was reduced (Tab 3).

Tab. 3 Concrete Compositions of the light-weight-concrete 2 (LWC 2)

Components		Concrete Compositions			Unite	Picture Lightweight Aggregates 1/4
		LWC 2 0	LWC 2 30	LWC 2 50		
Cement	c	400,0	400,0	400,0	kg/m³	
Total Water	w	221,0	221,0	221,0	kg/m³	
	w/c ratio	0,553	0,553	0,553	kg/m³	
Additives	Steel Fibres	0	30	50	kg/m³	
	Fly Ash	200,0	200,0	200,0	kg/m³	
	w/(c+FA) ratio	0,368	0,368	0,368	kg/m³	
Admixtures	Stabiliser	0,27	0,27	-	kg/m³	
	Superplasticizer	6,88	6,88	6,88	kg/m³	
Aggregates	0/2 Sand	41,0	41,0	41,0	%	
	1/4 Lightweight Aggregates	59,0	59,0	59,0	%	

Fig. 6 Fracture surfaces 50 kg/m³ (left) 30 kg/m³ (right)

In Fig. 6 exemplary specimen's fracture surfaces for the fibre dosage 50 kg/m³ (left picture) and 30 kg/m³ (right picture) are shown. With LWC2 50 the fibres segregates and were unsteady distributed. Therefore stabiliser was added. This effected a stabile mixture and a regular fibre distribution with LWC2 0 and LWC2 30. The influence of the distribution of the fibres is documented in Fig. 7. The average load-deflection curves show that higher fibre content does not stringently effects a higher load bearing capacity.



Fibre content		0 kg/m³	30 kg/m³	50 kg/m³
$f^{2}_{cm,cube}$	[N/mm²]	16,00	17,00	-
$f^{7}_{cm,cube}$	[N/mm²]	21,50	20	-
$f^{28}_{cm,cube}$	[N/mm²]	23,33	27,35	38,75
$f^{56}_{cm,cube}$	[N/mm²]	29,00	31	-
$\rho_{c,f}$	[kg/dm³]	1,526	1,569	1,765
$\rho_{c,h}$	[kg/dm³]	1,523	1,571	1,758
F_{ic}	[kN]	21,68	23,63	23,90
$F_{0.5}$	[kN]	-	17,25	16,73
$F_{3.5}$	[kN]	-	12,31	7,87

Fig. 7 Average load-deflection curves for LWC 2

Tab. 4 presents the final concrete mixture. The amount of cement has been increased from 400 kg/m³ up to 420 kg/m³ and the amount of fly ash has been reduced from 200 kg/m³ to 180 kg/m³. This resulted in a more stabile mixture because cement has a higher demand on water.

Tab. 4 Concrete Composition of the light-weight-concrete 3 (LWC 3)

Components		LWC 3 30	Unite	Picture Lightweight Aggregates 1/4
Cement	c	420,0	kg/m³	
Total Water	w	243,0	kg/m³	
	w/c ratio	0,579	kg/m³	
Additives	Steel Fibres	30	kg/m³	
	Fly Ash	180,0	kg/m³	
	w/(c+FA) ratio	0,405	kg/m³	
Admixtures	Stabiliser	0,27	kg/m³	
	Superplasticizer	6,93	kg/m³	
Aggregates	0/2 Sand	61,0	%	
	1/4 Lightweight Aggregates	39,0	%	

Several characteristic parameters like the maximum load and the sliding modulus (k_S) are needed to assess a timber-concrete-composite construction. These values depend on the type of connection and the material properties of the concrete slab and the timber. Fig. 8 shows the experimental set-up of the push-out test and the loading regime according to DIN EN 26891 [4] to determine these dates.

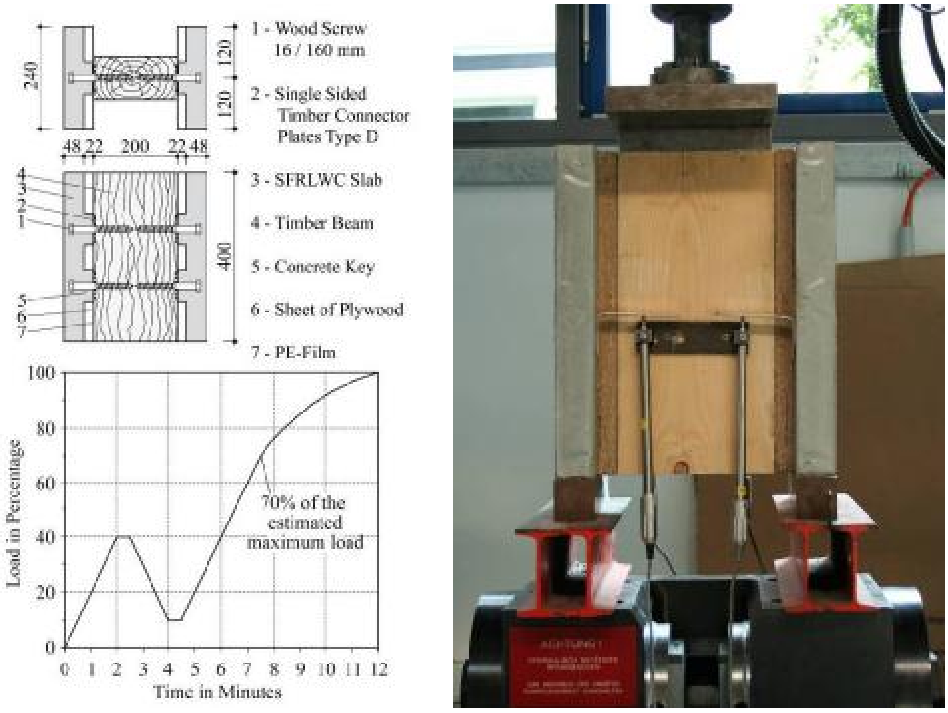
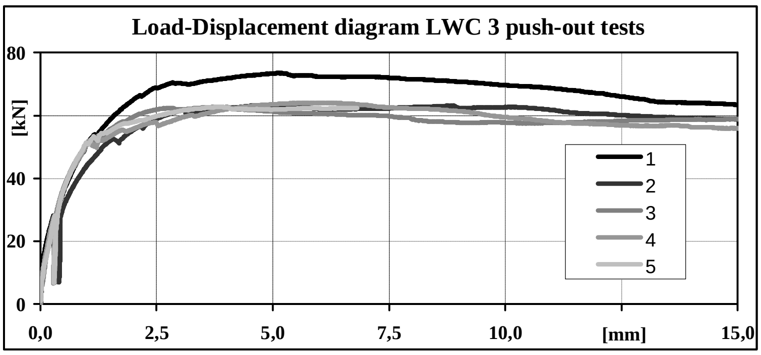


Fig. 8 Experimental set-up and loading regime for the push-out test

In Fig. 9 the experimental results of the tested LWC 3 are given. On the left the load-displacement diagrams of the push-out test are pictured up to a displacement of 15 mm. On the right the strength values (cube compressive strength $f^{28}_{cm,cube}$, splitting tensile strength $f^{28}_{ct,sp}$ and the modulus of elasticity E_{cm}), the fresh and hardened concrete density ($\rho_{c,f}$ respectively $\rho_{c,h}$) and results of the push-out tests (ultimate load F_{max} and the sliding modulus k_S) are stated.



Fibre content		30 kg/m³
$f^{28}_{cm,cube}$	[N/mm²]	30,20
$f^{28}_{cm,cyl}$		17,20
$f^{28}_{ct,sp}$		2,30
E_{cm}		18.094
$\rho_{c,f}$	[kg/dm³]	1,717
$\rho_{c,h}$		1,676
$F_{max,m}$	[kN]	65,27
$k_{S,m}$	[kN/mm]	734

Fig. 9 Load-displacement diagram and experimental results

Fig. 10 Arranged ceiling before casting (left), casting of SFRLWC (middle), finished timber-concrete-composite ceiling

Fig. 10 pictures the practical application of the developed SFRLWC in a residential building in Altenburg/Thuringia (Germany) which was partly redeveloped in 2008.

4 Conclusion

It was difficult to create a mixture of an easy compactable and pumpable SFRLWC. The stability of the mixture strongly depends on the type and specifications of the concrete mixer as well as the kind of placing the concrete. But with the right admixtures (superplastisizer, stabiliser) and an optimised composition it became realistic. With the application of SFRLW in Altenburg it was stated that without conventional reinforcement the working process could be enhanced and the death weight of the ceiling could be minimised. The timber-concrete composite construction with fibre reinforcement shows a ductile load bearing behaviour and can resist the existing tensile forces. Furthermore the enormous influence of the fibre distribution in the failed cross section of steel fibre reinforced concrete on the load bearing capacity was proved with the experimental results. In the main the application of SFRLW for timber-concrete composite floors is conceivable in the field of reconstruction.

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