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Influence of the sheet profile design on the composite action of slabs made of lightweight woodchip concrete

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HIGHLIGHTS

- Analysis of the load-bearing capacity of composite slabs using lightweight woodchip concrete.
- Lightweight woodchip concrete ensured a dead load reduction of 50% compared to normal concrete.
- The shape of the profiled steel sheeting has a significant impact on the load-bearing capacity.
- All specimens presented a ductile bond behaviour over the whole bond length.
- Lightweight woodchip concrete is applicable in steel-composite slab systems.

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ABSTRACT

The trend for using renewable materials in construction to create sustainable and robust buildings is currently gaining in popularity. Therefore, in this work, the applicability of dense lightweight woodchip concrete in constructive engineering is investigated. Here, the material is used as a top concrete layer on composite floors with profiled sheets and is analysed with regard to its load-bearing behaviour and composite action. One specific concrete mixture which fulfils the requirement for minimum strength of LC 20/22 is used for the test series. The scale of the study comprises 22 plate elements in total. The varied parameters are the shear spans, profiled sheet types and sheet thicknesses. Each examined sheet has an undercut profile with additional embossment. On the basis of experimental results, the influences of the varied parameters and profile forms on the load-bearing and composite behaviour are discussed. This study provides important key findings which show that dense lightweight woodchip concrete can transfer sufficient longitudinal shear forces to the composite joint.

1. Introduction

Today's owners show greater interest in data on energy, ecology and health of new constructions or renovations. In contrast to what have been hitherto predominantly investment-oriented considerations, emphasis is now increasingly laid on the complete life cycle of buildings. Building materials made out of renewable resources can make a significant contribution to saving limited fossil energy resources and reducing additional CO_2 emissions. While porous lightweight woodchip concrete is already applied as sound-absorbing materials and insulation materials, the questions that arise now are whether dense lightweight woodchip concrete is applicable as a load-bearing building material and whether existing steel-concrete composite systems are suitable for this kind of concrete.

In particular, the use of steel-concrete composite systems is highly praised in modern construction concepts for buildings and bridges since the coupled structural system takes advantage of the compressive strength of concrete and the high tensile strength of steel in a mixed structure; using steel-concrete composite structures, it is possible to develop highly efficient and high-strength design elements [1–5].

Several experimental tests have been carried out by researchers to investigate the interactions between normal concrete/lightweight concrete and steel sheeting in composite floors [6–17]. Chen [6] reported that for different spans of steel profiled sheeting composite slabs, a longitudinal shear-bond slip was detected and that the slabs with end anchorage bore higher shear-bond strength than those without end anchorage. He concluded that composite slabs were unable to develop full plastic

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moment in the spans due to shear-bond failure in the steel-concrete contact areas.

In order to study the shear-bond action in embossed composite deck slabs, Marimuthu et al. [7] and Gholamhoseini et al. [11] tested specimens made out of normal concrete and profiled sheets. Their results showed that the failure mode of composite slabs depends on the shear span, as a shear bond failure was found for shorter shear spans whereas a flexural failure was found for larger shear spans. A comparison of the longitudinal shear strength calculated by the m-k method and the partial shear connection (PSC) method showed an average difference of about 26% [7]. Similar results were reported by Hedaoo et al. [8], who carried out bending tests on 18 composite specimens with steel profiled sheeting to investigate the shear bond strength in accordance with Eurocode 4 – Part 1.1 [9]. Mäkeläinen et al. [10] reported that compared to all the different characteristics of embossment, the depth of the embossment has the most effect on shear resistance behaviour. Brunet et al. [12] reported that in contrast to specimens without embossment, specimens with embossments required further slip after the failure of the chemical bond until the maximum shear capacity was achieved. Furthermore, they reported that the bond strength between concrete interface and steel sheets can be considered as a function of the rib geometry rather than an adhesive property because it is predominantly a mechanical property related to the debonding of the interface.

Most of the steel-concrete composite slabs use normal concrete as the concrete top layer; however, more recent studies show great interest in investigating the mechanical behaviour and failure mode of concrete-steel composite decks made of lightweight concrete. Kan et al. [13] performed four-point bending tests on deck specimens made from normal and lightweight concrete and reported that, whether made of normal or lightweight concrete, both steel decks showed similar structural behaviour. Similarly, Luu et al. [14] conducted an experimental investigation on lightweight composite deck slabs made out of lightweight concrete with profiled steel sheeting. The lightweight concrete used for concreting was classified as LC 16/18 and LC 35/38 in accordance with EN 206-1 [15]. Luu et al. reported that the use of lightweight concrete allowed a reduction of the dead load of the composite slab by 40% compared to normal concrete without any loss in structural performance. Penza [16] conducted an experimental study on the longitudinal shear strength of lightweight concrete slabs with trapezoidal steel sheeting. Unlike other investigations [13], she found that the benefit of using lightweight concrete was a 20% reduction in the self-weight, but it caused a loss of load-bearing capacity of 25% for short span slabs and 45% for long span slabs. Furthermore, the specimens with shorter shear span showed better vertical shear capacity and for all the tested slabs, an end slip in the direction of the profiled sheet embossments was found. The results also indicated that the longitudinal shear strength is reduced in comparison to normal concrete.

The application of lightweight wood concrete has increased in recent years and has become the focus of research projects such as [17], where the load-bearing behaviour of slabs made of lightweight woodchip concrete was investigated. The impetus for the work was to use alternative slabs for restructuring older buildings. Lightweight woodchip concrete with a dry bulk density of 1000 kg/m^3 was used. The resulting compressive strengths were of about 5 N/mm^2.

Mostly undercut and trapezoidal profiled sheets with or without mechanical dowelled interface have previously been investigated. For undercut profiled sheets, mechanical interlock develops between the concrete and the profiled steel sheets due to deformation under loading: the bond between both materials is ensured by a mechanical clamping effect when the profiled steel sheets deform. Nevertheless, slippage between both actors will appear due to longitudinal shear stress. Additional embossment of the profiled sheets to prevent slippage is meant to further improve this composite action [18–20,7,21–23,10,24,6,25].

The clamping effect is activated as soon as there is deformation of the undercut sheet under loading and its magnitude is influenced by the loading, the thickness of the profiled sheet and the geometry of the sheets (Fig. 1).

According to [26], for lightweight concrete composite floors, a load drop can be perceived once the ultimate load is reached; in contrast to normal concrete where the ultimate load is retained while bending deformation is increasing. Additionally, crack behaviour is observed which is different to that exhibited by normal concrete composite floors: a main gaping crack failure was established, whereas, for lightweight concrete composite floors, branching crack propagation or even longitudinal cracks were observed.

The main objective of the research was to investigate the usability of a dense lightweight woodchip concrete (Fig. 2**, left**) in structural engineering. Whereas porous lightweight woodchip concrete (Fig. 2**, right**) is already covered by existing standards in terms of its definition, production and assessment of conformity and is used in different engineering applications, investigations on dense lightweight woodchip concrete go no further than determining characteristic material parameters. Therefore, investigations have been performed to determine whether a dense lightweight woodchip concrete fulfils the minimum requirement in terms of strength in the composite with steel profiled sheets with undercut profiles. Furthermore, the load-deflection behaviour, slippage and cracking of two different profiled steel sheeting types are reported showing the impact of embossments as well as their interaction with a less rigid lightweight concrete. It is thereby shown that a dense lightweight woodchip concrete generally fulfils the requirements for bonding mechanisms in a composite floor system.

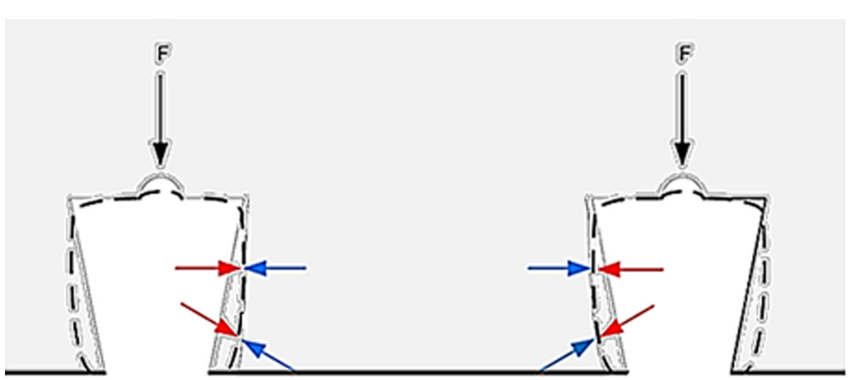

Fig. 1. Clamping effect on the profiled sheet.