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# An experimental investigation of a new perfect bond technology for composite slabs

Miquel Ferrer *, Frederic Marimon, Miquel Casafont

*Dept. of Strength of Materials and Structural Engineering, Universitat Politècnica de Catalunya BarcelonaTech (UPC), Spain*

## HIGHLIGHTS

- A new technology for bonding profiled steel sheeting and concrete is presented.
- Full-connection is achieved between steel and concrete until both materials yield.
- The longitudinal shear failure mode is extinguished in practice.
- The strength with the new system is much greater than with the embossments system.
- The new system provides high ductility to slabs through materials yielding.

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## ABSTRACT

Steel-concrete composite slabs generally fail due to the debonding with separation of sections caused by longitudinal shear forces, regardless of the shape of the sheeting profile or the design of the embossments. This article presents an innovative full-connection bonding technology, consisting of producing bands of many small crown-shaped cuttings in the profile webs as a replacement for the embossments. The new technology has been tested on three commercial sheeting profiles. The results of the investigation show that full connection is achieved with the new system, i.e., yielding of both materials occurs without any slip, in contrast to the partial connection of traditional embossments. The longitudinal shear strengths are 1.4–7 times higher. The specimens tested include the use of conventional galvanized steel and concrete, as well as ferritic stainless steel and lightweight aggregate concrete.


## 1. Introduction

Steel-concrete slabs were first used in 1938 in the United States, although cold-formed steel sheeting was only used as permanent formwork [1]. During the 1960s, steel decks with embossments were introduced and widely developed, the sheeting becoming the actual tensile reinforcement of the slab. Extensive research into longitudinal shear response of composite slabs was pioneered by Porter and Ekberg [2]. Since then, countless shapes and forms of such embossments have been designed in order to obtain the best shear connection degree between steel and concrete. However, among the three typical failure modes in composite slabs: bending, vertical shear and longitudinal shear, the latter is widely the most restrictive. The classical four-point bending test is used to provoke longitudinal shear failure, detected by measuring the longitudinal relative slip at the ends of the slab (Fig. 1), and then to determine the empirical parameters used by two calculation methods: the m-k and the Partial Shear Connection methods [3,4]. These two common methods are included in most standard codes [5–7]; however, they can lead to significantly different results [8,9].

The function of embossments is similar to that of the corrugations on reinforcing bars for concrete; however, their shear resistance efficiencies are considerably different. In reinforced concrete, radial compression components are generated on the steel rebar by the wedge effect of corrugations, whose extremely high radial stiffness completely prevents any longitudinal slip until steel yielding. Consequently, *full connection* is achieved. By contrast, in composite slabs, once the steel-concrete chemical bond is broken, the wedge effect forces acting on the embossments cause local bending of the steel sheet due to its low stiffness, and the relative slipping between the steel profile and the concrete develops easily (*partial connection*) (Fig. 1). It must be noted that, in favour of the shear failure ductility, the maximum resistance to longitudinal shear should be achieved after large slip has been developed. Therefore, relative slipping is an expected and desirable

* Corresponding author.
*E-mail address:* miquel.ferrer@upc.edu (M. Ferrer).

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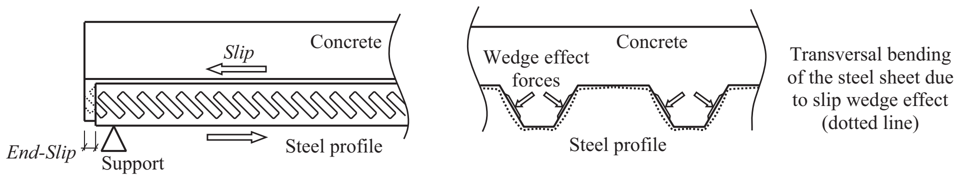



**Fig. 1.** Slip behaviour scheme of composite slabs with common embossment.

phenomenon when using embossments, in order to avoid brittleness in longitudinal shear failure

In open-rib profiles, when slip is high enough to free vertically the concrete from the sheeting, the load drops to *null connection* (Fig. 2). This fact often leads to an inefficient and premature failure of the slab, since the actual stresses of both materials when concrete is vertically freed are usually much lower than their ultimate capacities, as will be shown later in Section 6, where strain gauge measurements are presented.

Several researchers have studied the influence of different materials on the connection degree of embossed sheets, such as stainless steel [10] and high-performance or lightweight concretes [11,12]. The coating influence has also been investigated [13,14]. Pull-out and push-out test arrangements are commonly used to test and compare the efficiency of embossment designs [14,16], as well as bending load configurations [17,18]. Finite-element approaches to composite slab behaviour have been developed to better understand the slipping mechanics and to improve the current designs [15,18–22]. In these studies, the interaction between the embossments and the concrete is numerically treated as a contact problem considering adhesion and friction.

In summary, the structural efficiency of composite slabs greatly depends on their ability to transfer shear forces between steel profile and concrete. The main difficulty of steel deck designing lies in assuring the effective composite performance; i.e., to conceive systems which are highly resistant to relative slip and debonding. To date, the conventional embossment system has shown to be unable to overcome the longitudinal shear failure mode, despite all attempts to improve embossment efficiency.

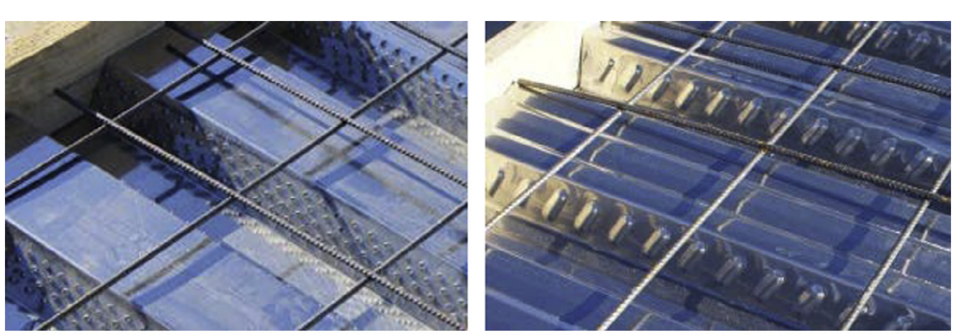
This article presents an innovative full-connection bonding technology (Fig. 3a) [23], consisting of producing bands of many small crown-shaped cuttings in the profile webs, as a replacement for the common embossments' system (Fig. 3b). The performance of the two connection systems is compared by means of experimental tests which have been carried out following the classical four-point bending test procedure.

The experimental campaign includes slabs produced using three commercial open-rib trapezoidal profiles, from 60 to 80 mm in height, named A80, C60 and W60 in this article. A set of slabs is provided with the new system (detailed in Section 4), and a second set with conventional embossments. Three punching densities have been investigated: low (LD), medium (MD) and high density (HD); and two steel thicknesses.

In most cases, the sheeting profiles have been manufactured with conventional galvanized steel and concrete. Additionally, ferritic stainless steel sheets and lightweight aggregate concrete


(a) (b)

**Fig. 2.** a) Standard bending test set-up; b) Longitudinal slip failure and vertical detachment.



(a) (b)

**Fig. 3.** a) Innovative UPC bonding technology; b) Conventional profiled sheeting with embossments.