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Experimental investigation on ferritic stainless steel composite slabs

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ABSTRACT

Steel-concrete composite structures are well established in the construction of floors and roofing, being interesting solutions as steel decks act as formwork for relatively large spans and support the weight of the concrete and construction loads. However, the use of stainless steel decks in such structures has been very limited, although their mechanical properties, corrosion resistance, aesthetics and emissivity make them excellent for visually exposed composite floor slabs where the thermal capacity of the slab is mobilized as part of an energy saving strategy. This paper presents a comprehensive investigation on composite slabs with trapezoidal ferritic stainless steel decks in order to assess the performance of such structural members. Composite slabs made from EN1.4003 ferritic stainless steel and common C25/30 concrete were tested in two series of span lengths in order to determine the different parameters defining their ultimate longitudinal shear response. Reference tests on slabs with galvanized steel were also conducted with identical geometries and configurations. The m and k parameters used in the m-k Method and the design longitudinal shear strength $\tau_{u,Rd}$ corresponding to the Partial Connection Method have been determined according to EN 1994-1-1:2004. Finally, the behaviour of these composite slabs was compared with the performance shown by the conducted reference slabs with galvanized steel deck in terms of Ultimate and Serviceability Limit States.

1. Introduction

The use of deck profiles as steel-concrete composite floor systems and roofing is common in construction, since the steel deck acts as formwork for relatively large spans and supports the weight of the concrete, as well as construction loads. Given that decking profiles usually present unusual shapes and are fabricated from cold-forming procedures, they are characterized by high strength-to-weight ratios, but also by a high susceptibility to buckling. Trapezoidal decks have been employed in building construction since last decades, and the design of such structures is well established in EN 1994-1-1:2004 [1], although the use of stainless steel decks has been very limited since it is a relatively new construction material. The low thermal expansion coefficient and emissivity of ferritic stainless steels allow the mobilization of their thermal capacity in visually exposed composite floor slabs as part of an energy saving strategy, reducing the requirement for heat/cooling in buildings.

Stainless steel is a material with high initial investment requirements, although the consideration of lifecycle costs demonstrates its competitiveness [2]. The absence of nickel in the composition of ferritic stainless steels helps reducing and stabilizing their price, making them especially attractive for construction applications, as established in [3]. As other stainless steel families, they are characterized by a nonlinear stress-strain behaviour, with a combination of good mechanical and impact properties, excellent corrosion resistance, better response at high temperatures and aesthetics. In recent decades, the use of stainless steel for architectural and construction applications has increased thanks to the research developed on the structural behaviour of stainless steel members and the publication of specific design guidance. The cost of the stainless steel, in relation to that of competing materials, has become much lower, while many new grades and product forms are now widely available all over the world. Nowadays, the stainless steel is not viewed purely as a decorative option for facades and panels and is part of building structures such the roof of the Delhi Parliament Library, the UAE Pavilion at the Shanghaï Expo or the roof in New Doha airport (Qatar) as the largest stainless steel roof in the world. There are also some examples for bridges and pedestrian bridges as the Girder Bridge in Stockholm (Sweden), the Cala Galdana Bridge in Menorca (Spain) and the Helix pedestrian bridge in Marina Bay (Singapore) [4].

The research has been focussed in the cross-sectional behavior of I-shaped, circular (CHS), rectangular (RHS) and square hollow sections (SHS) for different types of stainless steels alloys such as austenitic, ferritic and duplex [5–8] in the last years. In addition, studies on stainless steel members have been carried out [9–11]. Currently, a new

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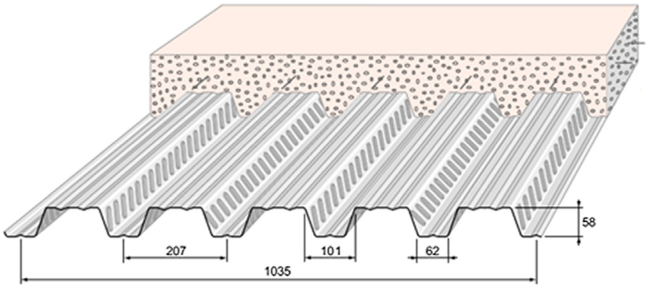

Fig. 1. Trapezoidal steel deck in composite floor slab [19].

generation of research projects aimed at studying stainless steel structures and the effects of the material non-linearity on the global behavior of frames is active [12–14]. However, the use of ferritic stainless steel decks is not generalized, so the structural performance of such profiles in construction stage and as part of composite slabs needs to be carefully assessed.

This was addressed in the European Research Project entitled Structural Applications of Ferritic Stainless Steel (SAFSS), which provided all the necessary information for the assessment of ferritic stainless steel structural elements. As part of this Research Project, the behaviour of trapezoidal ferritic stainless steel decks as composite floor slabs was investigated (see Fig. 1), as reported in Ferrer et al. [15]. First, the structural performance of ferritic stainless steel decks in construction stage was investigated through an extensive experimental programme, where the expressions codified in EN 1993-1-3:2006 [16] and EN 1993-1-4:2006 [17] were assessed. This research was reported by the authors in Arrayago et al. [18], and it was concluded that in general expressions in [16,17] are applicable to ferritic stainless steel decks, although some modified expressions can be used if higher accuracy is required in the design.

The behaviour of composite floor slab systems has been systematically investigated during the last decades through different experimental and numerical studies [20–27], and the fire performance of such structures has also been carefully characterized [28–30]. In addition to the punching shear failure, the failure of composite slabs is governed by three major failure modes, as shown in Fig. 2, which are bending (for considerably high shear spans L_s), vertical shear (for low shear spans) and longitudinal shear (for intermediate values of L_s). These failure modes are related to the relative slip between the steel deck and the concrete at supports, and the shear span L_s is the distance from the point of application of concentrated force to its respective reaction force. This paper is focused on this last failure mode, which is the most common for composite slabs, with the purpose of studying the longitudinal shear performance of ferritic stainless steel decks in composite slabs and to determine the values of the different parameters required for the practical use of such decks.

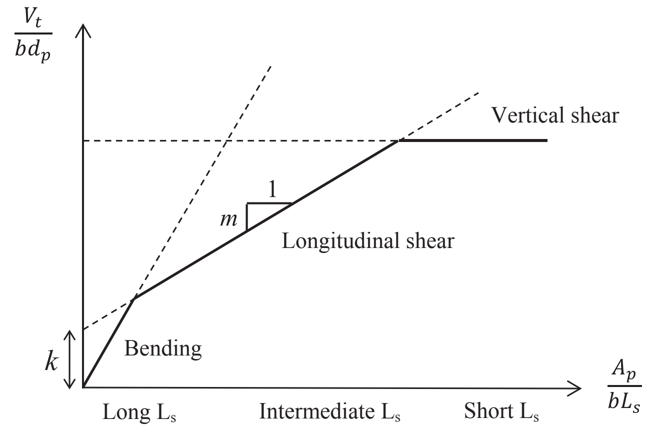

Fig. 2. Failures modes for composite slabs, boundaries of the longitudinal shear failure mode.

EN 1994-1-1:2004 [1] provides two alternative methods for the design of concrete-steel composite slabs with embossments and without end anchorage: the *m-k* Method and the Partial Connection Method (PCM). While the former is applicable to both ductile and brittle slabs, the PCM can only be used for ductile longitudinal shear connections. The longitudinal shear behaviour of composite slabs may be considered as ductile if the failure load exceeds the load causing a recorded end slip of 0.1 mm by more than 10%, according to EN 1994-1-1:2004 § 9.7.3(3) [1]. Both methods require the determination of different parameters which relies on full scale tests, since the complexity of the failure mode and the parameters affecting the shear bond resistance favoured empirical design methods. Consequently, the obtained parameters are limited to the variables considered in the tests. In order to calculate the *m-k* parameters, slabs with two different shear span lengths L_s need to be tested, provided that all specimens fail showing longitudinal shear failure modes. Thus, two series of three slabs with intermediate shear spans need to be tested in order to determine the two empirical parameters, *m* and *k*. Regarding the PCM, the longitudinal shear strength τ_u (degree of interaction between the deck and the concrete) can be directly derived from the ultimate bending moment resistance of four slab tests showing ductile failure.

This paper presents the experimental programme on composite slabs with ferritic stainless steel decks in order to assess the design provisions for this corrosion resisting material, as well as to obtain the values of the different parameters used in the design of such structures (*m-k* parameters and the ultimate shear strengths τ_u). Provided that two equivalent specimens with galvanized steel were available, additional tests were carried out on these reference slabs for comparison purposes. In addition, obtained results have been compared with similar ferritic stainless steel-concrete composite slabs reported in [31]. These alternative tests consisted on four slabs with different span lengths to those adopted in the present experimental study, which did not allowed for the estimation of the *m* and *k* parameters (requiring at least two series of three specimens). Moreover, since the parameters derived from experimental results are limited to the variables considered in the tests, specimens with additional span lengths are of interest.

2. Experimental programme

This section describes the conducted experimental programme on composite slabs with ferritic stainless steel trapezoidal decks. The geometry of the slab is first reported, followed by the material properties and pouring procedure. Finally, a comprehensive description of the conducted tests is provided.

2.1. Description of the slabs

The composite concrete-stainless steel slabs considered in this experimental study comprised a trapezoidal ferritic stainless steel Cofraplus 60 deck and common C25/30 concrete.

2.1.1. Properties of the stainless steel deck

The studied Cofraplus 60 profile is 0.8 mm thick, 58 mm high and presents a total width of 1035 mm, involving 5 waves, according to the requirements in EN 1994-1-1:2004 § B.3.3 (5) [1], which states that the total slab width needs to be wider than three times the overall depth, 600 mm and the cover width of the profiled sheet. The upper part of the waves is reinforced with two stiffeners, while the lower wave shows a single stiffener. Webs are inclined with a 72° angle and present several embossments to guarantee a good connection between the deck and the concrete. These embossments show an inclination of 60° and different direction in both webs for each wave, as shown in Fig. 1. A detailed geometrical definition of the representative wave is shown in Fig. 3.

In previous investigations by Arrayago et al. [18] the strength of the