Fire Safety Journal 98 (2018) 109–119

Contents lists available at ScienceDirect

Fire Safety Journal

journal homepage: www.elsevier.com/locate/firesaf

Temperature profile and resistance of flat decking composite slabs in- and post-fire

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ARTICLE INFO

Keywords:
Flat-decking profile
Composite slabs
Heat transfer
Standard fire tests
Post-fire residual strength
Simplified assessment approach

ABSTRACT

This paper presents the experimental and numerical results on fire resistance of the composite slabs using flat profiled decking with vertical webs and top flanges embedded in concrete based on a series of tests including heat transfer, ISO834 standard fire, and post-fire residual strength tests. The study aims to provide temperature profiles across the slab thickness for different standard fire durations, to demonstrate the effectiveness of embedded components and to determine post-fire residual strength of the composite slabs. Test results showed that when exposed to fire, the embedded vertical webs and top flanges of the flat decking sustained much lower temperature compared to that at the soffit. Therefore, the webs and the top flanges help to reduce the amount of fire reinforcement required at the bottom part of the composite slabs. The integrity of steel decking and concrete can be maintained even after four hours of standard fire, which eliminate concrete spalling and minimise post-fire damage. A simplified assessment approach to evaluate the post-fire residual strength of flat decking composite slabs was also proposed. The heat transfer and structural finite element models were developed and validated with the test results to study fire resistance of the slabs, and to compare its performance with the traditional trapezoidal and re-entrant composite slabs.

1. Introduction

During the last few decades, structural fire resistance of composite slabs has been the subject of extensive research [1–5]. They provided the background for many fire design codes in which the essential assessment is to determine fire resistance of structural elements for a specified duration. Currently, Singapore adopts EN 1994-1-2 [6] (EC4.P1-2) for design of composite slabs in fire, in which the fire resistance is determined through a semi-empirical method. However, only the design provisions for trapezoidal and re-entrant steel decking profiles are available in EC4.P1-2 [6]. In practice, these decking profiles are not considered in the slab fire resistance because they will reduce strength significantly at an early stage in the fire and debond from the concrete. (see Figs. 21 and 22)

This research investigates a new type of thin-gauged steel decking profile, in which part of the web and the top flange is embedded in the concrete slab. This flat profiled decking has similar benefits compared to traditional ribbed profiled decking (i.e., trapezoidal and re-entrant) at ambient temperature. The advantage of this type of decking is under fire situation. When exposed to the standard fire, the embedded decking components could sustain much lower temperature compared to the soffit, thus could be taken into account when calculating the slab fire resistance. It is expected that the amount of fire reinforcement required at the bottom part could be reduced for this type of composite slabs. Comparing to solids reinforced concrete slabs, theoretically the thermal and structural responses of the flat decking composite slabs are similar to the former. However, practically the flat decking could diminish concrete spalling, and the embedded webs and top flange may contribute to structural fire resistance of the flat profiled decking slabs. Therefore, an experimental study is required to address the above issues between using the flat profiled decking and traditional ribbed profiled decking as well as solid reinforced concrete slabs.

When a composite slab is subjected to a fire, depending on severity, it may develop significant structural damages and require partial or total retrofitting. Recent work [7] showed that post-fire structural strength of beams and columns could be evaluated to assess structural stability and repair strategy after a fire event. Currently, there are no data or simplified methods to evaluate the residual strength of composite slabs after a fire. The reason may be due to early de-bonding of conventional steel decks from the concrete in the fire, and thus they are not considered in the fire

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https://doi.org/10.1016/j.firesaf.2018.04.001
Received 28 June 2017; Received in revised form 11 March 2018; Accepted 7 April 2018

0379-7112/© 2018 Published by Elsevier Ltd.

Table 1
Test programme.

No.	Specimens	Deck thickness (mm)	Slab thickness (mm)	Dimension *b* x *L* (m)	ISO fire duration (min)	Type of test
1	S105.1H	0.75	105	0.9 × 2.2	60	Heat transfer
2	S120.2H	0.75	120	0.9 × 2.2	120	Heat transfer
3	S150.3H	0.75	150	0.9 × 2.2	180	Heat transfer
4	S170.4H	1.00	170	0.9 × 2.2	240	Heat transfer
5	S120.2H-2	0.75	120	0.9 × 3.2	120	Structural test
6	S170.4H-2	1.00	170	0.9 × 3.2	240	Structural test
7	S120.0H	0.75	120	0.9 × 2.2	–	Structural test
8	S105.1H	0.75	105	0.9 × 2.2	–	Residual test
9	S120.2H	0.75	120	0.9 × 2.2	–	Residual test
10	S150.3H	0.75	150	0.9 × 2.2	–	Residual test

resistance of composite slabs. However, the integrity of flat decking composite slabs would enhance post-fire structural resistance by minimising concrete spalling and maintaining compatibility of concrete and steel decking during fire exposure. Therefore, this study focuses on the resistance of flat decking composite slabs in- and post-fire condition. A series of seven composite slabs were tested in standard fire condition stipulated by EN 1991-1-2 [8]. After the standard fire tests, the slabs were allowed to cool down naturally and then tested to failure at ambient temperature to assess their post-fire residual strength.

This research is to study thermal and structural behaviour of the flat decking composite slabs. The objectives were to provide the slab cross-sectional temperature profiles for different durations of the standard fire curve. The thermal experimental results were used to establish the empirical equations to predict temperature distribution so as to predict fire resistance of the composite slabs. Data from experimental investigations were used to calibrate heat transfer and structural finite element (FE) models. Comparisons among the three decking profiles were carried out to show the effectiveness of flat decking in fire. A simplified post-fire resistance assessment approach was also proposed for this type of composite slabs.

2. Experimental programmes

2.1. Test programme

A total of seven composite slabs with identical flat steel decking, normal weight concrete and anti-crack steel mesh were tested. The slab thickness complied with the requirements for structural adequacy and integrity in EC4.P1-2 [6]. For all the slabs, there was no fire reinforcement except the provision of an anti-crack mesh of diameter 6 mm at 200 mm spacing in both directions, placed 20 mm beneath the top surface of the slab. The hot-rolled steel mesh was continuous across the whole slab with a yield strength of 500 MPa and an ultimate strength of 620 MPa. Ultimate strain of the mesh was 15.8%, and the elastic modulus was 203.4 GPa. Table 1 shows the specimen nomenclature and dimensions, the standard ISO fire duration from 1 to 4 h and the type of test conducted. For example, specimen S170.4H refers to a slab thickness of 170 mm, four hours duration of ISO fire.

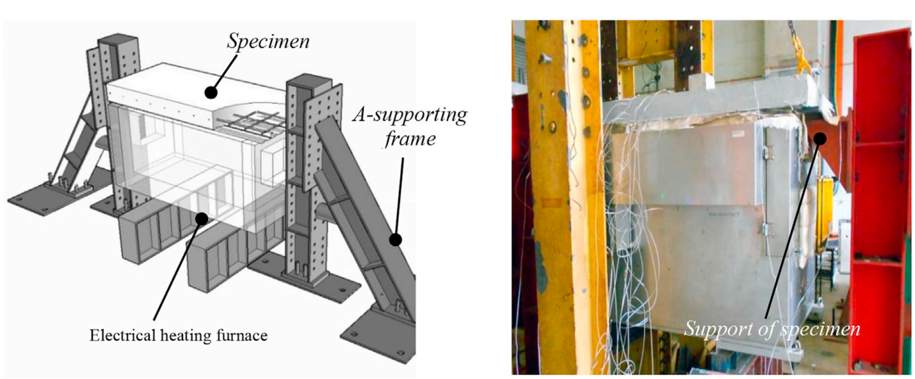
The specimens were cast using ready-mixed concrete with the aggregate size ranging from 10 to 20 mm and water/cement ratio of 0.38. Six cylinders (150 mm in diameter and 300 mm long) were tested at 28 days after casting at ambient temperature, giving a mean compressive cylinder strength of 30 MPa. The flat profiled deck was fabricated by LCP Building Products Pte. Ltd. (Singapore) with a yield strength of 550 MPa. The embedded rib is 55 mm high and the top flange is 30 mm long. The total area of 0.75 mm thick deck is 1211 mm^2/m.

To determine the temperature profile across the composite slab, four heat transfer tests (no. 1 to 4) were carried out to determine temperature distributions across the slab thickness and four fire durations. Therefore, mechanical load was not applied on the four specimens. The slab thickness in the heat transfer tests are determined so that the integrity and insulation criteria as recommended in EC4.P1-2 [6] are met.

Three structural tests were conducted (no. 5 to 7), viz. one at 2 h, another at 4 h, and the third at ambient as the control specimen. After the heat transfer tests, the first three specimens (no. 1 to 3) were cooled down naturally. Then they were loaded to failure at ambient temperature to determine the residual strength (no. 8 to 10). For specimen S170.4H, since the flat decking was already damaged in the heat transfer test, it was excluded in the residual strength tests.

2.2. Standard heat transfer fire tests

All the temperature curves followed the standard ISO834 fire, where electrical heating was applied automatically for different fire durations, i.e. 1, 2, 3 and 4 h. Fig. 1 shows the test setup for the heat transfer tests. The specimens were put freely on top of the bracket of A-supporting frames at both sides (Fig. 1(b)) with each support length of 100 mm, thus the slabs were considered as the simply supported slabs with a clear span of 2 m. The gap between the furnace and the specimen was filled by insulation materials to avoid heat loss.



a) Design view b) Actual setup

Fig. 1. Setup for heat transfer fire tests.

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