Experimental study of post-fire mechanical properties of a light prefabricated composite slabs

Shen Qi¹, Meng Zhiheng¹, Wang Xintang²

¹ School of Civil and Environmental Engineering, Ningbo University, Ningbo, China
² College of Science & Technology Ningbo University, Ningbo, China
wxt196322@126.com

Abstract. The post-fire mechanical performance of a prefabricated composite slabs consisting of thin-walled steel beams with opening in web and lightweight aggregate concrete was experimentally studied, and the displacements of the composite floor specimens was discussed. The experimental results showed that the composite floors after fire had better plastic deformation capacity and greater residual bearing capacity. Type of the shearing keys, pull pieces between the precast concrete panels and the connection way of shearing keys to pull pieces had greater effect on the post-fire mechanical property of the composite slabs.

1. Introduction

To reduce the floor quality, it can be replaced by ceramsite concrete instead of the commonly used concrete with gravel as coarse aggregate to form the profiled steel plate-lightweight aggregate concrete composite slabs [1]. The thin-walled steel member-lightweight concrete composite floor was presented and the mechanical performance of it had been experimentally studied, and the combined action of the thin-walled steel beams and the ceramsite concrete had been studied [2]. Wang [3] emphatically studied the fire response and post-fire bearing capacity of a group of profiled steel sheet-ceramsite concrete composite slabs with different structural characteristics through experiments, and the results show that the lightweight composite slabs have good fire behavior and bearing capacity. Wellman[4] carried out an experimental study on the structural response of thin composite slab system (composed of a group of steel beams, ribbed steel plates and light concrete) under load-bearing and fire, and the results showed that thinner lightweight concrete plays an important role in load transfer between steel beams. Nguyen [5] and Wang [6] carried out study on post-fire performance of flat decking composite slabs and analytical model for predicting the load–deflection curve of post-fire reinforced-concrete slab, respectively. However, the lightweight concrete is not used and prefabricated concrete sheet is also not involved. Therefore, the post-fire bearing capacity test of a group of new composite slab specimens after suffering hydrocarbon fire was carried out, and the residual bearing capacity of it was presented and studied based on the test results.

2. Geometrical dimensions of specimens

The geometrical dimensions and construction of the composite floor specimens was shown in Fig. 1. It is noted that there are two thin-walled steel components with openings (named as main member) and two channel side beams longitudinally for each slab specimen; nine short thin-walled steel channels (named as sub-members) are connected horizontally. The construction and dimensions of the main member noted as MB is shown in Fig.2 (symmetrical to the left part). It is noted that all the main
components are welded by two crimped channels to form the section shown in Fig. 2, and have the section dimension of 72mm×40mm×20mm×1.0mm.

Fig. 1 Geometrical dimensions of the slab specimens and construction

The transverse sub-components SB1-A/B is made of the thin-walled steel channels, and the cross-section specifications is 80mm×20mm×0.6mm and placement direction is shown in Fig. 1, which have the length shown in Fig. 3.

All side members as shown in Fig.1 are made of thin-walled steel plates with thickness of 1.5mm, and the cross-sectional specifications are 120mm×20mm×1.5mm. Distribution of the shearing keys (SI and SII) on the upper surface of main components MB1 and sub-components SB1 are shown in Fig. 3. Layout of U-shaped tie pieces is shown in Fig.4a for specimens AS1~AS4, and construction and geometrical dimension of U-shaped tie piece is shown in Fig. 4b.
The mechanical properties of the materials used here are taken as: the Young’s modulus of steel and the yield strength is $2.04 \times 10^5$ MPa and 160 MPa, respectively, and the cube strength standard value and elastic modulus of the lightweight concrete are $\sigma_c = 32.5$ MPa and $E_c = 2.17 \times 10^4$ MPa, respectively.

3. Test result and discussion

The post-fire static load tests for four composite slab specimens as shown in Table 1 are finished here. The loading point (denoted as LP) distribution is shown in Fig. 1, in which 5 measuring points of vertical displacements is set, and denoted as number D1~D5. It is noted that the static loading test of post-fire mechanical performance of a group of specimens is finished in situ after fire test. The furnace temperature used the heating curve of hydrocarbon fire, which has the maximum temperature of 700$^\circ$C and duration of 90min.
### 3.1. Test phenomena

#### Table 1 Main parameters of the composite floor

| No  | Main members | Sub members | Post-poured layer | Type of Shearing keys | Connection ways |
|-----|--------------|-------------|-------------------|-----------------------|-----------------|
| AS1 | MB1          | SB1-A (B)  | C-m              | SI                    | N-GJ            |
| AS2 | MB1          | SB1-A (B)  | C-c              | SI                    | N-GJ            |
| AS3 | MB1          | SB1-A (B)  | C-m              | SII                   | N-GT            |
| AS4 | MB1          | SB2-A (B)  | C-m              | SII                   | N-GT            |

Note: N-GJ is U-shaped tie piece made of steel rod and not connected to the shear keys denoted as SI; N-GT is shown in Figure 4b; The shear keys SI is traditional studs with height of 40mm and diameter of 10mm, the shear keys SII is made of thin-walled steel with thickness of 2mm; C-m means that post-poured layer is cement mortar and C-c ceramsite concrete with thickness of 20mm.

In the static load test after fire, the specimens show different characteristics and phenomena, and the common phenomena and characteristics are mainly as follows: (1) The cracking sound of concrete and the pulling sound of metal materials are always accompanied by the loading process, and there is obvious unloading phenomenon after the end of the sound; (2) The first new crack in concrete slab appears just below the loading point and develops rapidly (Fig. 5a); (3) After yielding, two main cracks extend to the end of the specimen (Fig. 5b). (4) After loading and unloading, there are two-way cracks on the upper surface of each group of specimens, and the longitudinal cracks are more obvious (Fig. 6).

![first crack](image1)

![development of main cracks](image2)

**Fig. 5 Cracks on bottom of concrete panel**

![cracks on top surface](image3)

![cracks on lower surface](image4)

**Fig. 6 Distribution of cracks after unloading**

### 3.2. Displacements of specimens

The load-displacement curves of the composite floor specimen AS1 for all measuring points are shown in Fig. 6, in which $q$ is equivalent uniform load and $\Delta$ vertical displacement.
Fig. 7 Load-vertical displacement curves of AS1

Fig.7 showed that the displacement of measuring point D2 is largest, and all the other specimens have the same results. Therefore, variation of the vertical displacement denoted as $\Delta$ of measuring point D2 (mid-span displacement) with load $q$ for all composite slab specimens are drawn in Fig. 8.

Fig.8 Comparison of $\Delta$-P curves of specimens

It can be seen from Fig. 8 and Table 2 that although the composite slab specimens have undergone large deformation after fire, they still have higher post-fire bearing capacity and deformation capacity. It can be seen from the above results that the obvious deformation characteristics of the composite floor are as follows: the global stiffness of composite slabs after fire is still large. The mid-span deflection corresponding to the uniformly distributed load of 2kN/m$^2$ is only $L/770$ for the specimen AS2 with the stiffness presented here, which is much smaller than $L/400$ specified in the Code for Design of Steel Structures (GB50017-2017).

Table 2 Bearing characteristics value of specimens after fire

| SP   | $\Delta_y$/mm | $q_y$/kN/m$^2$ | $q_u$/kN/m$^2$ | $\Delta_y$/mm | $\Delta_u$/mm | $K_e$/kN/mm |
|------|---------------|----------------|----------------|---------------|--------------|-------------|
| AS1  | 10.2          | 4.32           | 5.33           | 6.3           | 12.96        | 3.2         |
| AS2  | 25.5          | 3.67           | 4.29           | 7.5           | 13.71        | 2.0         |
| AS3  | 18.9          | 2.82           | 4.01           | 6.2           | 17.15        | 2.1         |

In terms of nominal yield load and ultimate load, the bearing capacity and global stiffness of specimen AS1 are higher than those of specimen AS2 (ultimate load is 27.8% higher and linear stiffness 60% higher), which indicates that the overall bearing capacity of the composite slabs with cement mortar in post poured layer is better than that of composite slabs with ceramsite concrete in post poured layer. The main reason is that the coarse aggregate of ceramsite concrete is larger and its own strength is lower than that of cement mortar, so the bonding effect of ceramsite concrete is not as good as that of cement mortar. However, since the weight of composite slabs with using cement mortar in post poured layer increases, ceramsite concrete should be first chosen as the post-poured layer as under the condition of meeting the requirements of basic bearing capacity and stiffness. It is seen from the test results in Table 5 that, although the linear stiffness of specimen AS2 is the smallest, the mid-span deflection corresponding to uniformly distributed load 2kN/m$^2$ is far less than $L/400$ specified in the current code.
Comparing the test results of specimen AS4 and specimen AS3, it can be seen that the bearing capacity and global stiffness of AS4 are 26.5% and 52% higher than that of AS3, respectively, which shows that increasing the wall thickness of sub members of the composite floor can significantly improve the mechanical properties of the composite floor after fire. It can be also seen that the residual deformation of specimen AS4 after fire is also significantly smaller than that of specimen AS3. Therefore, the thickness of sub members of the composite floor can be increased appropriately if economic conditions are allowable. The reason why increase of the steel plate thickness of secondary beams can improve the global stiffness and bearing capacity of the composite slabs was that the overall mechanical performance of composite slabs is improved by enhancing the flexural stiffness and bearing capacity of secondary beams themselves, and it does especially for the composite floor specimens with obvious characteristics of two-way slabs.

4. Conclusions
It is concluded that the post-fire composite slab consisting of thin-walled steel beams and lightweight concrete panels has higher residual bearing capacity and larger stiffness. The results show that the maximum value of deflections of the specimens after fire presented here is much less than L/400 for the slab specimen with the lest stiffness, and increasing the wall thickness of sub members of the composite floor can significantly improve the mechanical properties of the composite floor after fire. It is concluded that the post-fire bearing capacity of the composite slabs with cement mortar in post-poured layer after fire is better than that of the composite slabs with ceramsite concrete in post-poured layer.

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