Study of post-fire mechanical properties of the light composite slabs after suffering hydrocarbon fire

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Abstract. The post-fire mechanical behaviours of the composite floors consisting of lightweight aggregate concrete and thin-walled steel members were experimentally studied, and the test result of the composite floor specimens was discussed. The experimental results showed that the residual load-bearing capacity of the composite slabs after suffering hydrocarbon fire can be effectively improved by increasing the wall thickness of transverse sub-members appropriately. The ultimate load of the composite slab specimens after fire with using the commonly used stud shearing connectors was larger than that with using the shear keys made with thin-walled steel plate.

1. Introduction
To reduce the floor quality, it can be replaced by lightweight aggregate 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 fire response and post-fire bearing capacity of a group of profiled steel sheet-ceramsite concrete composite slabs with different structural characteristics were emphatically studied rough experiments [2], and the results showed that the light composite slabs had better fire behavior and bearing capacity. The thin-walled steel member-light concrete composite floor was presented and the mechanical properties of it had been studied [3], and the combined action of the thin-walled steel beams and the ceramsite concrete had been analyzed. An experimental study on the structural response of thin composite slab system under load-bearing and fire was carried out by Wellman[4], and the results showed that thinner lightweight concrete plays an important role in load transfer between steel beams. 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 were carried out, respectively by Nguyen [5]. However, the lightweight concrete was not used and prefabricated concrete sheet was also not involved. Therefore, the post-fire bearing capacity test of a group of new composite floor 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 and mechanical parameters 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 members with openings (noted as MB2) and two channel side beams longitudinally for each slab specimen; 12 short thin-walled steel channels (named as sub-members) are connected horizontally. The construction and dimensions of the main member noted as MB2 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 112mm×40mm×20mm×0.8mm (Fig. 2c).

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. All side members as shown in Figure 1 are made of thin-walled steel plates with thickness of 1.5mm, and the cross-sectional specifications are 120mm×20mm×1.5mm. The mechanical properties of the materials used here are taken as: the Young’s modulus of steel and the yield strength is 2.04×10^5MPa and 160MPa, respectively, and the cube strength standard value and elastic modulus of the lightweight concrete are σ_c = 32.5MPa and Ec=2.17×10^4MPa, respectively.

3. Test results 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. It is noted that the static load 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°C and duration of 90min.

3.1. Test phenomena

| No | Main members | Sub members | Post-poured layer | Type of Shearing keys | Connection ways |
|----|--------------|-------------|-------------------|-----------------------|-----------------|
| BS1 | MB2          | SB1-A (B)   | C-m               | SI                    | N-GT            |
| BS2 | MB2          | SB1-A (B)   | C-m               | SI                    | N-GT            |
| BS3 | MB2          | SB1-A (B)   | C-m               | SI                    | N-GJ            |

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 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) There was clear cracking of concrete at loading point; (2)There are obvious cracks at the end of specimens ; (3)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.

3.2. Distribution of vertical displacement of specimens

The post-fire distribution of deflection along the longitudinal direction of the slab specimens after fire are shown in Fig. 3, respectively for ultimate load and final failure, which indicted the deformation of the composite slab under static load.

It is seen that the deformation forms of two states are quite different for all specimens. For the specimens presented in Table 1, deformation form of three specimens became quite different with approaching the final failure, and the value of deflection of BS1 is largest instead of BS2. It can be seen that the deformation form of specimen BS2 is not varied although there is large amount of increase in deflection. It is also seen that there is apparent asymmetry in deflection for specimen BS1 and BS3.

3.3. Vertical displacement-load relations

Relation of vertical displacement at measuring point D2 and the equivalent uniform load $q$ is shown in Fig.4, and the bearing capacity values of the specimens are listed in Table 2. The results show that use of SI shear keys (ordinary bolts) can help to improve the yield load, ultimate load and global stiffness of composite slabs after fire when other conditions are the same, and the yield load and global stiffness of specimen BS1 are 1.69 and 2 times of that of specimen BS2, respectively; From the test results of specimen BS2 and BS3, it can be seen that the overall mechanical performance of composite slabs after fire with C-type steel bar as tie pieces between prefabricated slabs is better than that of composite
slabs with thin-walled steel as tie pieces. It is shown that the yield load, ultimate load and stiffness of BS3 are higher than those of BS2, and the global stiffness of BS3 is 2.95 times of that of BS2.

![Graph showing load-vertical displacement of measuring point D2](image)

**Fig.4** Curves of load-vertical displacement of measuring point D2

| SP   | \( \Delta_0 / \text{mm} \) | \( q_y / \text{kN/m}^2 \) | \( q_u / \text{kN/m}^2 \) | \( \Delta_y / \text{mm} \) | \( \Delta_u / \text{mm} \) | \( K_e / \text{kN/mm} \) |
|------|-----------------|----------------|----------------|----------------|----------------|----------------|
| BS1  | 30.7            | 4.51           | 4.84           | 5.6            | 13.75          | 4.2            |
| BS2  | 36.1            | 2.76           | 4.27           | 3.7            | 11.48          | 2.1            |
| BS3  | 20.5            | 5.21           | 5.73           | 6.1            | 10.58          | 6.2            |

**Table 2** Bearing characteristics value of specimens after fire

3.4. Strains of specimens

The distribution of strains along the height of the cross-section at mid span of the main steel member of all specimens is shown in Fig.5, respectively for two load level (that is \( q=3\text{kN/m}^2 \), \( q=4\text{kN/m}^2 \)), and the corresponding measuring points of strains can be seen in Fig.2c.

![Graph showing variation of strains along height of cross section of steel beam](image)

**Fig.5** Variation of strains along height of cross section of steel beam

It can be seen that the normal strain distribution along the section height of the thin-walled main members of the specimens presented in Table 1 basically conforms to the assumption of plane section. The result also presents the concave distribution which is larger at both ends of cross section.

The results show that the tensile strain of the lower flange of the thin-walled steel member is much larger than the compressive strain of the upper flange. In order to compare the strain characteristics of the specimens, the ratio \( \varepsilon_c/\varepsilon_t \) of compressive strain of flange \( \varepsilon_c \) to tensile strain of lower flange \( \varepsilon_t \) in the mid-span section of the main steel member of each specimens for the equivalent uniform load of 3kN/m² are obtained as 0.42, 0.53 and 0.20, respectively for specimens BS1, BS2 and BS3. The ratio \( h_c/h_t \) (herein after referred to as \( \rho \)) of the height of compression zone \( h_c \) to the height of tension zone \( h_t \) at the same load level are obtained as 0.81, 0.87 and 0.70 for three slab specimens. The results comprehensively reflect the combined effect between the lower thin-walled steel members and the
upper concrete of the composite slab specimens after fire. Generally speaking, the smaller the ratio of $\varepsilon_2/\varepsilon_1$ and $h_2/h_1$, the better the combined effect of the two parts of the composite slabs presented above, which leads to that the integrity of the composite slab specimens is better and the bearing capacity greater.

![Graphs and diagrams showing load-strain curves for typical points on the specimen.](image)

Fig. 6 Curves of load-strain of typical points of the specimen

In order to understand the stress condition of the specimens more comprehensively, the variation curves of the strains of measuring points C1 (span direction), C2 and C3 (transverse direction) on the lower surface of concrete slabs with load are shown in Fig. 6.

It can be seen from Figure 6 that: (1) The transverse strain at the bottom of concrete slab is completely different, the strain of specimen BS1 is compressive strain and that of BS2 is tensile strain; (2) The absolute strain of BS2 specimen is larger than that of BS1 specimen, which shows that different shear keys have certain influence on the stress state of concrete after fire, and the stress state of concrete of the composite slab specimen with SI-type shear keys is better than that with SII-type shear keys. It is seen from the results of specimens BS2 and BS3 that the maximum strain of the former is obviously larger than that of the latter. Typically, the strains of test point C2 of two specimens are $9.76 \times 10^{-4}$ and $-1.32 \times 10^{-4}$ respectively for equivalent uniform load of 3kN/m², and the strain of this measuring point of BS2 specimen increases sharply for the load larger than 3kN/m². The results show that the fire resistance of the composite slabs with using U-shaped steel bar as tie piece is better than that with using U-shaped thin-walled steel as tie pieces, which is consistent with the above conclusions.

4. Conclusions

It is concluded that deformation form of three specimens became quite different with approaching the final failure, and the value of deflection of BS1 is largest instead of BS2. The tensile strain of the lower flange of the thin-walled steel member is much larger than the compressive strain of the upper flange. The results showed that the smaller is the ratio of $\varepsilon_2/\varepsilon_1$ and $h_2/h_1$, the better is the combined effect of the two parts of the composite slabs presented above, which leads to that the integrity of the composite slab specimens is better and the bearing capacity greater. Different shear keys have certain
influence on the stress state of concrete after fire, and the stress state of concrete of the composite slab specimen with SI-type shear keys is better than that with SII-type shear keys.

Acknowledgments
This work was financially supported by the national natural science foundation of China (No.51678312).

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