The effect of filling materials on the behaviour of filled steel tube composite beam

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Abstract. This study is concerned with investigating the performance of filled steel tube composite beams, the composite beam consisting of a filled steel tube and reinforced concrete slab connected by perfobond connector. Six composite beams were tested; the main parameter in this investigation was the type of filling materials used to fill the steel tube. All specimens were simply supported, the specimens tested using a four-point load. The deflection at mid-span and slips were recorded with loads. All specimens failed by the flexural and the specimens show similar behaviour during the test, the first crack of the concrete slab appears in the final stages of loading. It is found that the highest ultimate strength of the composite beam obtained when using normal concrete as a filling material. The other filling material (wood, aggregate, and lightweight concrete) were less density and ultimate load. Wood is the best filling material as an alternative to normal concrete. All these filling material gives higher ultimate strength of the composite beam compared with a hollow steel tube composite beam. The test demonstrated that the gypsum is useless as a filling material.

Keywords: Filled steel tube, Composite beam, perfobond shear connector, lightweight concrete, aggregate, gypsum, wood section, deflection, slip, and crack.

1. Introduction
The composite beam has higher load capacity, ductility, stiffness, and more economical than the non-composite or steel equivalent beam because it utilizes the advantage and properties of both combined materials, steel section as good in tension stress and concrete as good in compression stress[1–3]. The concrete-filled steel tube (CFST) member is one of the types of composite member common use in recent decades [4]. Figure 1 shows the typical sections CFST section [5].The steel tube in CFST member works as a formwork also the steel tube provided confinement to the inner concrete and prevents spalling and bulging of concrete under load, this confinement leads to an increase in the strength of the concrete. The concrete which filled steel tube prevents or delays the buckling in the steel tube [6], therefore the performance of the CFST member under loading is better than hollow steel tubes [5].

The CFST is commonly used recently in bridges, and there are few studies on this topic [7–10]. Figure 2 shows the CFST composite girder. Using the CFST composite girder in bridges reduces the cost of construction and the noise and vibration induced by cars and trains therefore CFST is an environment friendly [11]. The concrete compressive strength has a slight effect on the behavior of the CFST beam, so to reducing the self-weight of CFST member, the lightweight concrete is used as a filling material to fill the steel tube [12]. Shear connectors links between steel beams and concrete slab are important to the construction of a composite structure, Figure 3 shows the commonly used types.
Figure 1. Typical section of concrete filled steel tube.

Figure 2. The CFST composite girders [13].

Figure 3. Types of shear connectors [14,15].
Most previous studies were done on columns used in high-rise buildings and in areas that exert earthquakes because of the advantages of using CFST columns. Some studies focused on the behavior of CFST under flexure without a concrete slab, but a few previous studies study the CFST composite beam, this member consists of CFST and concrete slab connected by a shear connector [9,10,13]. Kang et al. [13] studied experimentally the flexural behavior of concrete-filled steel tube beams. The experimental program included many parameters such as the type of filling material (normal concrete, air mortar), and the internal mechanical friction. In addition, the authors test three specimens of continuous CFST composite girder. The test results show that filling the steel tube with concrete or air-motor lead to an increase in the flexural strength and stiffness of the member and good ductility was achieved. Mossahebi et al. [1] studied experimentally the behavior of CFST girder composite with reinforced concrete slab; the authors test one specimen of CFST composite girder, the CFST has a longitudinal hole made by putting PVC pipe inside the concrete in the core to reduce the weight of the specimen. The major conclusion was that using the CFST composite girder as a bridge girder is possible and useful. Cho et al. [16] investigated the flexural strength of the concrete filling steel tube (CFST) that composite with the concrete slab. The study consists of three parts included experimental, numerical, and the proposition of simple equations to evaluate the flexural strength of bending moment. The authors conclude that the proposed equations give a good estimation of the CFST composite girder and the CFST composite girder can be used as a bridge girder. Fu et al. [12] studied the behavior of lightweight CFST beam composite with reinforced concrete slab experimentally and theoretically. The authors test testing only one specimen, the concrete used in the concrete slab was normal concrete, while the infilled concrete inside the tube was lightweight to reduce the specimen weight. The theoretical study included many parameters such as a change in the dimensions of the specimen (thickness of steel tube and thickness of concrete slab). The authors concluded that the CFST composite with slab shows a good ductility and higher load capacity. In addition, the internal slip between the steel tube and the lightweight concrete inside the steel tube can be ignored. Farhan and Shallal [17] studied the performance of lightweight concrete filled steel tube beam (circular and square) composite with a reinforced concrete deck slab, the shear connector used in this study is perfobond shear connector. The major conclusions were the hollow steel tube beam has an ultimate load capacity and stiffness lower than the CSFT beam, and the ultimate load decreased with decreasing the compression strength of the concrete slab. Malaga and Danawade [18] study the behavior of steel tube that filled with wood section. The authors determined the interfacial shear stress in wood-filled steel tubes. The mechanical bonding between the steel tube and the wood section is achieved by structural epoxy adhesive. The experimental results indicate that the flexural behavior of wood filled steel tubes is largely dependent on interfacial shear strength. Danawade et al. [19] studied the behavior of steel tube filled with the wood section. The authors focus on the effect of tolerance between the steel tube and the wood section on the flexural performance of wood-steel composites. They concluded that there is no effect of tolerance on the performance of wood-steel composites.

The filling materials have little effect on the behavior of concrete-filled steel tubes; therefore, this study focuses on the effect of filling material on the behavior of filled steel tubes. This study includes testing six specimens of steel tube composite beam that filled with different materials under a two-point load. The materials that filled the steel tube are normal concrete, lightweight concrete, gypsum, wood, and aggregate, while the last specimen is a hollow steel tube.

2. Experimental program
The experimental program includes a test of six specimens. The specimen consisted of two main parts, the filled steel tube, and the concrete slab. The summery of specimens are listed in Table 1. The nomenclature of the specimen contains two parts the first is S, which refers to the section of the steel tube which means square, the second part refers to the name of the infill material inside the steel tube. Five materials were used to fill the steel tube (normal concrete NC, lightweight concrete LC, Gypsum GY, wood section WO, and Aggregate AG). The last specimen is constructed without filling material (hollow section HO). The dimensions of the steel tube were 100*100*3 mm. figure 4 shows the details
of the specimens. The dimensions of the concrete slab were 450*75*1660 mm (the effective length of the span was 1500 mm). The steel tube and the deck slab were connected by perfobond shear connector with dimensions 50*5 *1600 mm. The bottom layer of transverse steel reinforcement passed through the perfobond plate. The concrete slab was constructed from normal concrete.

Table 1. Summery of specimens

| Specimen | Filling material        |
|----------|-------------------------|
| S-NC     | Normal Concrete         |
| S-LC     | Lightweight Concrete    |
| S-HO     | Hollow Section          |
| S-GY     | Gypsum                  |
| S-WO     | Wood -section           |
| S-AG     | Aggregates              |

Figure 4. Details of specimen.

3. Material Properties
The cement that was used in all mixture was ordinary Portland cement (type I) and the maximum size of aggregate used in the concrete mix is 10 mm, while the size of coarse aggregate that was used as filling material in the specimen S-AG was a range from 4.75 to 9.5 mm. The fine aggregate used in the concrete mix conforms to [20] specification requirements. An expanded clay aggregate (LECA) with a maximum size of 10 mm was used as a coarse aggregate in lightweight concrete in the specimen S-LW. The gypsum used in specimen S-GY is conforming to ASTM C 472 [21] and the compressive strength of the gypsum is 4.8 MPa. The compressive strength and tensile strength of the wood section are 35.2
MPa and 45.4 MPa respectively, the test methods of the wood section are conformed to the requirement of [22]. Tables 2 list the details of the concrete mixture with the compressive strengths. The mix M3 used to construct the concrete slab while the other two mixes (M1 and M2) used to fill the steel tube. The density of the materials used to fill the steel tube and concrete slab was listed in Table 3. The steel properties of the section used in the present work are shown in Table 4.

### Table 2. Concrete mixing details

| Mix                  | Mixing ratio | W/C | SP % | fcu (MPa) |
|----------------------|---------------|-----|------|-----------|
| Lightweight concrete M1 | 1:1.75:0.5    | 0.32| -    | 17.38     |
| Normal concrete M2    | 1:1.5:3       | 0.35| -    | 38.27     |
| Normal concrete M3    | 1:1:2         | 0.30| -    | 53.22     |

### Table 1. Density of filling material.

| Material               | Density (kg/m³) |
|------------------------|-----------------|
| Lightweight concrete M1 | 1669.2          |
| Normal concrete M2      | 2432.7          |
| Normal concrete M3      | 2438.2          |
| Aggregates              | 1497.8          |
| Wood                   | 500.0           |
| Gypsum                 | 1482.7          |

### Table 2. The steel properties

| Component                     | fy (MPa) | fu (MPa) |
|-------------------------------|----------|----------|
| Steel tube                    | 365      | 397.5    |
| Reinforcement bars            | 520.5    | 661.6    |
| Perforobond plate connector   | 422.4    | 568      |

### 4. Test Arrangement

A hydraulic testing machine with 1000 kN capacity was used in the test. All the specimens of the CFST composite beams were tested under a four-point load (simply supported beam exposed to a two-point load). Figure 5 shows the test machine and the locations of the digital dial gauges, where dial gauges No. 1 was used to measure the deflection at mid-span while the other two were used to measure the slip at the end of the span and one sixth of the span.

### 5. Results and Discussions

The results obtained from the test of specimens are load, cracks load, deflection during the loading stage, and the slip at the one-sixth and the end of the specimen. The experimental results showed that the failure of all the specimens due to the flexural effect. Table 5 display the test results of the filled steel tube (FST) composite beam. Dead loads are one of the major loads to which a structure is exposed, so designers strive to reduce this type of load. This study aims to find suitable materials to fill the steel tube, so one of the important things to compare these materials is to study the density of each of them. The density of wood was the lowest among the materials, as it was equal to 500 kg/m³, then it was followed by gypsum, gravel, lightweight concrete, and finally normal concrete.

#### 5.1. Cracks

During the test, the visible cracks to the eye are the cracks in the concrete slab only. Table 5 shows the crack load (the load corresponding to the occurrence of the first cracks in the concrete slab), also the ratio of crack load to ultimate load for the specimens. The reason for the appearance of cracks in the
concrete slab of composite FST is due to the natural axis located at the steel tube zone but during loading, the natural axis moves upwards so it is within the concrete slab. Generally, in all specimens, the appearance of the first crack was with a percentage higher than 90% of the ultimate load where the lower percentage was 90.61% of the ultimate load for the specimen S-WO. The minimum value of cracked load was 66.1 kN for specimen S-GY followed by the specimens S-HO, S-LC, S-WO, S-AG, and S-NC at 73.5, 75, 82, 84.5, and 95.5 kN respectively. All cracks were flexural cracks, these cracks distributed between the two-point load and some time under the applied loads. Figure 6 shows the cracks in the concrete slab of some specimens.

![Figure 6. Cracks in the concrete slab of some specimens.](image)

**Table 3.** Test results of loads and deflections.

| Specimen | $P_{cr}$ (kN) | $Pu$ (kN) | Percent of ($P_{cr}/Pu$) | Deflection (mm) |
|----------|---------------|-----------|--------------------------|-----------------|
| S-NC     | 95            | 95.5      | 99.48                    | 23.7            |
| S-WO     | 82            | 90.5      | 90.61                    | 25.93           |
| S-AG     | 84.5          | 87.5      | 96.57                    | 19.26           |
| S-LC     | 75            | 82.5      | 90.91                    | 20.93           |
| S-HO     | 73.5          | 75.5      | 97.35                    | 22.63           |
| S-GY     | 66.1          | 72.9      | 90.67                    | 21.61           |
Figure 6. cracks in concrete slab of specimens.

5.2. Ultimate load and Load-Deflection Curve

Table 5 shows the ultimate load and corresponding mid-span deflection of tested specimens, the ultimate load was 95.5 kN of the specimen S-NC, the other specimens show decreasing in the ultimate load when compared with the reference specimen (S-NC). The best filling material used as an alternative to normal concrete was wood, as its ultimate load was 90.5 kN, with a decrease of 94.7%, followed by gravel, lightweight concrete, hollow steel tube, and then gypsum, at a reducing percent of 91.6%, 86.6%, 79% and, 76.3% respectively. In general, the filling materials used in this study increase the strength of the FST composite beam compared with the hollow steel tube (HST) composite beam with the exception of the specimen (S-GY) that was filled with gypsum. Where the ultimate load decreased by 3.44% compared to the hollow steel tube specimen, this percentage is considered low and it can be concluded that the use of gypsum material as filling material is considered unhelpful. Figure 7 shows the load-mid deflection curves of investigated specimens. All the specimens have the same behaviour during the test.

5.3. Slip

The slip means the horizontal movement differentiation between two different materials such as the difference in horizontal movement between the filled steel tube and the concrete slab. Two types of slip were demonstrated in this study. The first type between the steel tube and the filling material, but this type demonstrated in one specimen only (S-WO). Figure 8 shows the slip between the steel tube and wood section, from this figure, the failure occurs in the zone of the interface layer but in some time in the layers of the wood section. The second types of slip occur between the concrete slab and steel tube, two dial gauge used to measure the slip the first one was put at the end of specimens while the second was put at one-six of the span. Figure 9 shows the slip through the span at different stages of the load. Slip values were more evident in the final stages of loading when reaching 90% of the final load. The specimens that recorded the largest slip were S-WO, and S-HO these specimens were considered as less
moment of inertia in the final stages of loading, the moment of inertia of the specimen S-WO was reduced because of loss of the bond between the steel tube and wood section.

**Figure 7.** Load-deflection curves of the test specimens.

**Figure 8.** Internal slip inside the tube of S-WO
Figure 9. Slip-span curves during loading stages.
6. Conclusions
This work is an experimental study of the effect of filling steel tube composite beam using different materials, the experimental investigations include test six specimens. The following comments can be drawn as the most important concluding remarks from the experimental work conducted in this research as reported above.
1. The filling materials used in this study increased the strength of the FST composite beam except for the specimen that filled gypsum shows a decrease in the strength of the specimen.
2. The best material for filling the steel tube instead of normal concrete is wood, as it showed the highest strength between the specimens after the specimen that was filled with normal concrete. In addition, the density of wood is the lowest among the materials used, which leads to a reduction of dead loads.
3. The strength of the specimen that filling by the wood was influenced by the bond between the wood section and the inner surface of the steel tube therefore slip between them occurs at the final stage of loading.
4. The behaviour of the specimens during the loading stages was similar in deflections and slips.

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