

Experimental study on behavior of friction-grip bolted shear connectors in composite beams with cold-formed steel section

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Abstract

Nowadays, composite beams consisting of steel beams and concrete slabs are widely used in the construction industry. In this research, an experimental study was carried out to investigate the performance of friction-grip bolted shear connectors in composite beams with cold-formed steel sections. For this purpose, 17 full-scale push-out tests were tested according to EC4 in order to investigate the performance of this connection. Of particular interests were load-slip curves, the maximum shear capacity, ultimate slip (ductility) and failure modes. Experimental results show that the behavior of this connection is different from that of headed-stud shear connector. The diameter and strength of bolt and thickness of cold-formed steel section have the most critical effects on the shear capacity and ductility of these connections with a maximum increase of 67.8, 32.87 and 263.6%, respectively. The results also highlight that the predominant failure mode in all specimens is bearing. The ultimate slip obtained from the experimental results with an average of 11.36 mm in all specimens also shows that these connections have the desired slip characteristic of the EC4 code ($=6$ mm), therefore they are considered ductile connections. The results showed that the behavior of these connections is different from the behavior of headed-stud shear connectors, and the loading of the connection is done in three stages. Abstract

Keywords

Cold-formed steel section, Deconstructable shear connectors, Composite floor joists, Friction-grip bolts, Push-out test.

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1. Introduction

Composite beams, consisting of steel sections and concrete slabs, are commonly used in construction due to their high strength and stiffness [1–4]. In conventional composite systems, welded headed stud connectors are usually employed to transfer longitudinal shear forces between the steel beam and concrete slab [5–8]. However, in cold-formed steel sections, because of the limited thickness of the steel plate, welding shear connectors is difficult and may reduce the efficiency of the connection. Cold-formed steel sections have become increasingly popular in the construction industry because of their low weight, cost efficiency, corrosion resistance, and high fabrication speed [9–12]. Compared with hot-rolled steel sections, CFS sections can reduce the structural self-weight significantly, resulting in lower transportation and installation costs.

One of the important challenges in composite beams with CFS sections is the development of suitable shear connectors. To overcome this problem, friction-grip bolted shear connectors have been introduced as an effective alternative. These connectors can be demounted after the service life of the structure and reused, which makes them compatible with sustainable construction systems [13]. Several experimental and numerical studies have been conducted on bolted shear connectors in hot-rolled composite beams [14–17]. However, limited research is available regarding their behavior in composite beams with CFS sections. Therefore, this study aims to experimentally investigate the behavior of friction-grip bolted shear connectors in such systems.

2. Methodology

In this study, seventeen full-scale push-out specimens were fabricated and tested based on the EC4 push-out test method. The specimens consisted of two precast concrete slabs connected to cold-formed steel sections using friction-grip bolted shear connectors (Table1). The investigated variables were:

- CFS thickness: 1 mm and 2 mm
- Bolt diameter: 6 mm, 8 mm, 10 and 12mm
- Bolt strength: 5.6 and 8.8
- Clearance between bolt and concrete hole: 4 mm and 8mm

The main objective was to investigate the effect of these parameters on the ultimate shear resistance (P_m), ultimate slip (δ_u), ductility, and failure modes.

According to the loading regime specified by EC4, the test was performed in three stages. In the first stage, the specimen was loaded up to 40% of the estimated failure load. In the second stage, 25 loading cycles between 5% and 40% of the failure load were applied. Finally, the specimen was loaded monotonically until failure.

The relative slip between the concrete slabs and the CFS section was measured using two LVDTs installed symmetrically on both sides of the specimen.

Table1 The characteristics of specimens.

No	t (mm)	Bolt grade	d_b (mm)	D (mm)	f'_c (MPa)
1	1	5.6	6	10	30
2	1	5.6	8	12	30
3	1	5.6	10	14	30
4	1	5.6	12	16	30
5	1	8.8	6	10	30
6	1	8.8	8	12	30
7	1	8.8	10	14	30
8	1	5.6	6	14	30
9	1	5.6	8	16	30
10	1	5.6	12	20	30
11	2	8.8	8	12	30
12	2	8.8	10	14	30
13	2	8.8	12	16	30
14	2	8.8	8	12	30
15	2	8.8	10	14	30
16	2	8.8	12	16	30
17	2	8.8	12	20	30

3. Results and Discussion

The experimental results showed that the load-slip behavior of FGB connectors in CFS composite beams consists of three distinct stages. In the first stage, called full shear interaction, the pretension force in the bolts creates friction between the CFS section and the concrete slab, resulting in very high stiffness and negligible slip. In the second stage, when the applied load exceeds the frictional resistance, slip occurs rapidly. In the third stage, after the bolt contacts the surrounding concrete hole, bearing action starts and load transfer continues.

The experimental results showed that increasing the CFS thickness from 1 mm to 2 mm significantly improved the ultimate shear capacity. The maximum increase in shear resistance due to thickness was 263.6%. Bolt diameter was also an effective parameter, increasing the shear resistance by up to 67.8%. In addition, increasing the bolt strength from grade 5.6 to 8.8 improved the ultimate shear capacity by 32.87%.

The ductility of the specimens was evaluated based on the EC4 criterion. The results showed that all

specimens, except specimen PT1-5-12-8, had characteristic slip values greater than 6 mm, which confirms that the proposed connection can be classified as ductile.

The observed failure modes included bearing failure in the CFS section, distortional buckling of the CFS section, and bolt shear failure. Among these, bearing failure was the dominant failure mode in all specimens. Bolt shear failure was observed only in specimens with bolt grade 5.6. In specimens with bolt grade 8.8, no bolt shear failure occurred.

4. Conclusion

Based on the experimental investigation conducted in this study, the following conclusions can be drawn:

- The structural behavior of friction-grip bolted shear connectors in CFS composite beams differs from conventional fixed shear connectors.
- The load-slip behavior consists of three distinct stages: full interaction, almost zero interaction, and partial interaction.
- The thickness of CFS sections, bolt diameter and bolt strength significantly affect the mechanical performance of the connection.
- Bearing failure is the dominant failure mode in all specimens.
- Bolt shear failure occurred only in specimens with lower bolt strength.
- The majority of specimens satisfied the EC4 ductility requirement.
- The EC4 equations result in conservative predictions for the shear capacity of FGB connectors in CFS composite beams because the bearing failure mode of CFS sections is not considered.

5. References

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