Experimental Study on the Feasibility of Disassembling and Reusing Lightweight Façade Wall Systems

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Abstract. This paper presents experimental investigations into the feasibility of disassembling and reusing exterior lightweight infill walls. The work stems as necessary steps towards the advancement of circular economy principles in future constructions. The experiment employed the single-shear test method commonly used to assess the shear strength of steel connections. The test samples consisted of cold-formed steel plates attached to hot-rolled steel plates, connected by screws. The cold-formed steel plate represents the track, a component of exterior lightweight infill walls, while the hot-rolled steel plate represents the beams of the primary structural frame. In total, twenty-one specimens were made: nine were tested after screwing, nine were tested after unscrewing and re-screwing, and three were tested after unscrewing, re-screwing, unscrewing, and re-screwing. The unscrewing step demonstrates the disassembly of the infill walls, while the re-screwing demonstrates their reuse. The experimental results revealed that the average peak strengths of the samples with different connections exhibited negligible differences. This can be attributed to the interaction between the screws and the connected cold-formed steel and hot-rolled steel plates, a mechanism further discussed in this paper. The test outcomes imply that exterior lightweight infill walls can be disassembled from the primary structural frame's beams after the infill walls' service life, and subsequently reused in the construction of other exterior lightweight infill walls. The study also demonstrated that more specimens should be tested to confirm the observation.

Keywords: Building science · Lightweight Structures · Reuse · Design for Disassembly · Cold-Formed Steel · Experiment

1 Introduction

The construction of building façades in the UK has increasingly used exterior lightweight infill walls (see Fig. 1), due to their lightness which enables quick construction, and thanks to their capacity to be easily integrated with a large range of insulations and finishing to achieve the required thermal performance and aesthetic look. The walls are often replaced every 30 years during building refurbishment for space adaptation,

V. Ungureanu et al. (Eds.): CESARE 2024, LNCE 489, pp. 253–261, 2024.
https://doi.org/10.1007/978-3-031-57800-7_23

energy efficiency compliance, or humidity control [1, 2], despite their potential for longer use. The removed wall components are often sent to landfills or energy-intensive recycling processes, which contribute to some detrimental environmental impacts, such as carbon emissions and resource depletion. In fact, the frequent replacement of walls leads to a significant contribution to carbon emissions from these walls (more than 20% of the building's total embodied carbon). Although past efforts targeted recycling to improve the material use of these components, significant improvements remain difficult to achieve. Presently, circular practices of reuse for these components are lacking [3]. To address this issue, the authors have studied the disassembly potential for future reuse of components of exterior lightweight infill walls, focusing on lightweight cold-formed steel (CFS) members in previous research [4]. This study further explores the overlooked potential of disassembling and reusing the exterior lightweight infill wall itself by focusing on the screwed connections between the wall and the beam. Screwed connections in CFS systems has been largely studied to understand their shear behavior [5–7], but no work has been previously done to understand whether they could be safely removed and then reused again. This is what this paper starts to address. Connections' behavior is, indeed, critical for the possibility of disassembling and reusing any construction system, as also reviewed in Kitayama & Iuorio, 2023 [8]. The work presented in this paper is based on a set of experiments conducted in the George Earle testing laboratory at the University of Leeds. The experiment was conducted during March-April 2023. Readers may also refer to the relevant recent study [9] by the authors that investigated the potential of disassembly and reuse of gypsum plaster boards, another key component of the exterior lightweight infill walls, based on the literature survey.

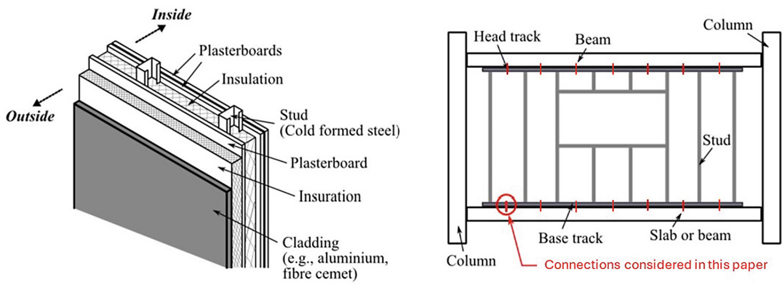

Fig. 1. Exterior infill wall: (left) notations of infill wall components; (right) notations of lightweight cold-formed steel members and surrounding primary structure.

2 Experiment

2.1 Preparation

CFS tracks of Grade S390 galvanized with Z275 zinc coating and hot-rolled steel (HRS) plates of Grade S355 (uncoated) were used for the experiment. The CFS tracks were cut to a length of 235 mm and the HRS plates were cut to a length of 250 mm. The CFS and

HRS plates were connected using Hex Head self-drill screws with 5.5 mm diameter and 40 mm length. Figure 2 shows the geometry of the specimen. Table 1 shows the cases of specimens and how they were tested.

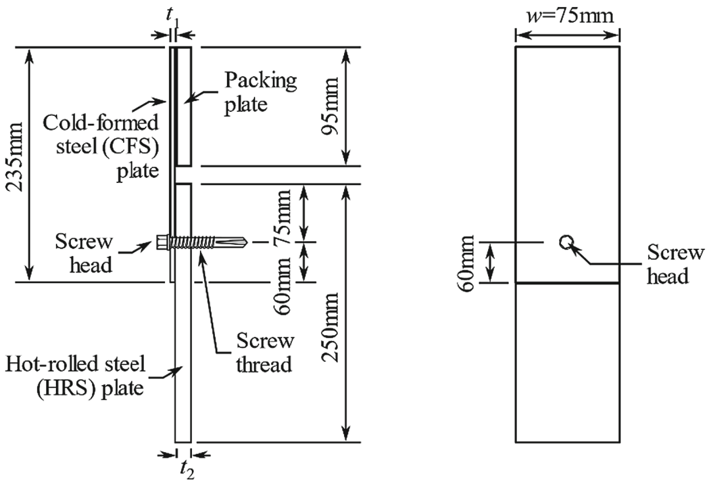

Fig. 2. Geometries of the tested specimens.

Table 1. Table captions should be placed above the tables.

Thickness CFS t_1 (mm)	Thickness HRS t_2 (mm)	Connection	Number of test
1.6	15	Screw → Test	3
1.6	15	Screw → Unscrew → Screw → Test	3
1.6	15	Screw → Unscrew → Screw → Unscrew → Screw → Test	3
1.6	10	Screw → Test	3
1.6	10	Screw → Unscrew → Screw → Test	3
2.0	15	Screw → Test	3
2.0	15	Screw → Unscrew → Screw → Test	3

As shown in Table 1, different thicknesses of CFS and HRS plates were used (1.6 mm or 2.0 mm for CFS plates; 10 mm or 15 mm for HRS plates). Seven different cases were considered. The case "Screw → Test" demonstrates the installation of walls and use. The case "Screw → Unscrew → Screw → Test" demonstrates the installation of walls, disassembly of the wall, subsequently re-install the wall and use. The case "Screw → Unscrew → Screw → Unscrew → Screw → Test" demonstrates the installation of walls, disassembly of the wall, re-installation the wall, disassembly of the wall, re-installation of the wall and use. Each case was tested three times with three different specimens with the same geometry to study the average behaviour of the connections.

Figure 3 shows the method of opening holes on the CFS and HRS plates. Note that the colour of the edge of the CFS plate (dark brown) is different from other part (silver). This is because the zinc coating of the edge of the CFS plate (about 10 cm in length) was removed using acid to measure the thickness of the CFS plates without zinc coating. The thickness of the zinc coating on the 1.6 mm CFS plates was 0.033 mm and that on the 2.0 mm CFS plates was 0.256 mm.

Fig. 3. Tested specimen preparation.

Figure 4 shows the photo of experiment of one of the cases listed in Table 1. A 600 kN Instron 5989 testing machine was used to perform the tests for the specimens to be pulled in tension and the screw is subjected to shear force. The test was conducted in displacement control (1 mm/min) and the data were collected every 0.5 s.

Fig. 4. Experiment of screwed connection (single-shear test method).

2.2 Results

The results of the tests are shown in Figs. 5, 6 and 7 for the specimens with 1.6 mm CFS and 15 mm HRS, 1.6 mm CFS and 10 mm HRS, and 2.0 mm CFS and 20 mm HRS, respectively. Figures 5 and 6 indicate that the unscrew and re-screw may cause slight reductions in the strength of the connection while Fig. 7 indicates that the same process may cause a slight increase in connection strength. Regardless of the reduction or increase in strength, the difference before and after the unscrew and re-screw processes did not cause notable differences in the observed strength values.

Figure 8 shows the photos of a failed specimen after the test. As seen in the photos, the failure occurred in shear in the screw at the intersection between the CFS and HRS plates. All the tested specimens showed the same failure mode.

Figure 9 presents the relationship between imposed displacement and the resultant force (strength) of the connection for specimen with 1.6 mm CFS and 15 mm HRS plates and for the case "Screw → Unscrew → Screw → Unscrew → Screw → Test". It shows that there is notable variability between the results of the three curves and indicates that the number of tests should be increased to obtain reliable observations.

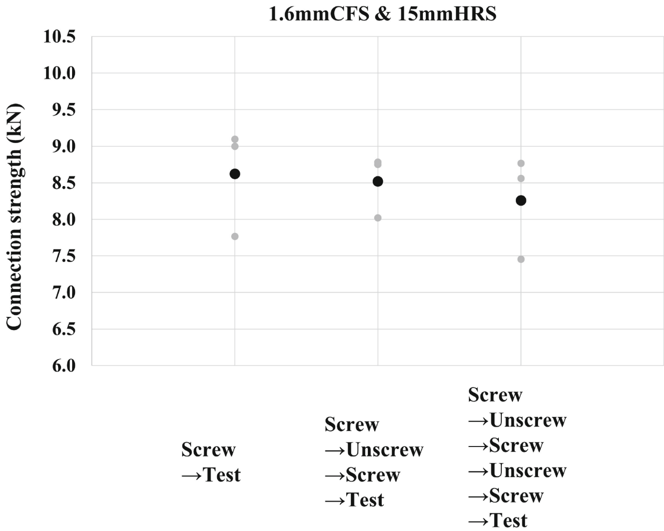

Fig. 5. Connection strength for specimen with 1.6 mm CFS plate and 15 mm HRS plate. The average of the three tests was indicated by large black dots. Individual test results were indicated by small grey dots.

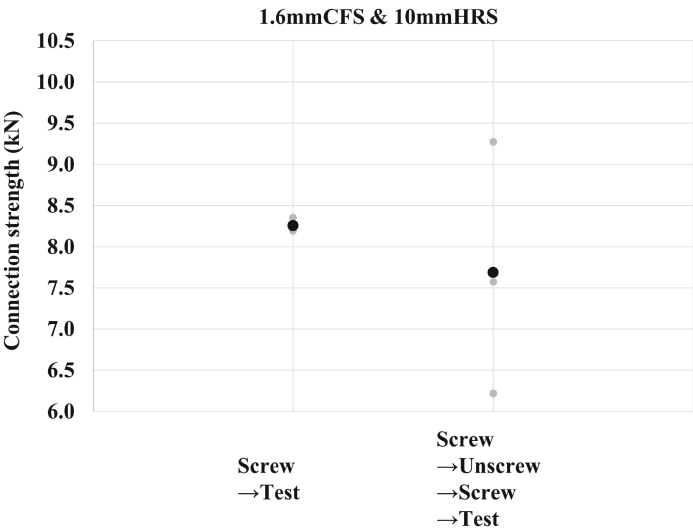

Fig. 6. Connection strength for specimen with 1.6 mm CFS plate and 10 mm HRS plate. The average of the three tests was indicated by large black dots. Individual test results were indicated by small grey dots.

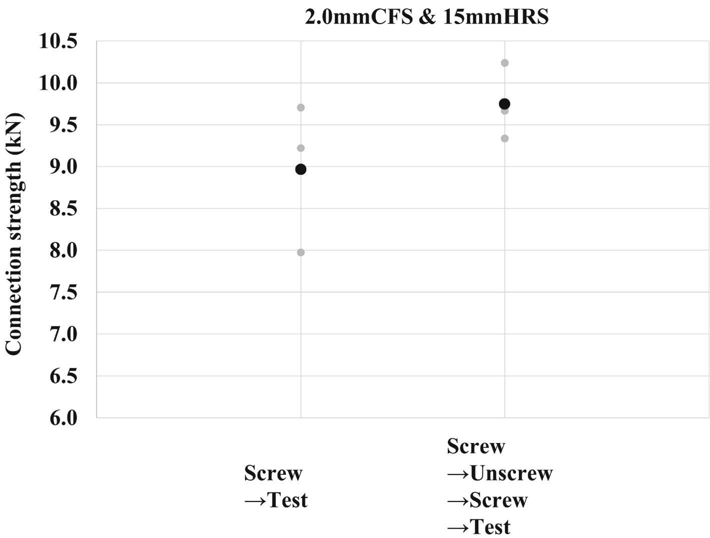

Fig. 7. Connection strength for specimen with 2.0 mm CFS plate and 20 mm HRS plate. The average of the three tests was indicated by large black dots. Individual test results were indicated by small grey dots.

Fig. 8. Failed connection after test.

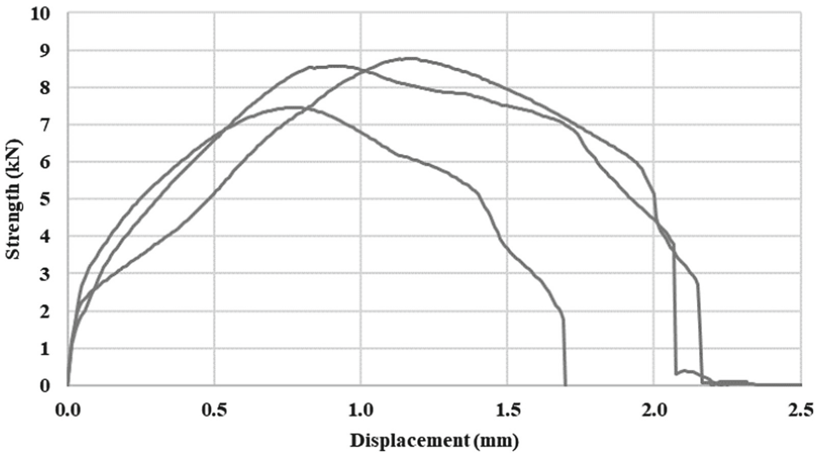

Fig. 9. Three test results from “Screw → Unscrew → Screw → Unscrew → Screw → Test” with 1.6 mm CFS and 15 mm HRS plates.

3 Conclusion

This paper presented an experimental study that investigated the feasibility of disassembling and reusing the exterior lightweight infill walls. The experiment focused on the connection between a typical steel member and a cold-formed steel plate representing the track of an infill wall and a hot-rolled plate representing a typical steel beam. To consider disassembly and reuse, the installed screws were unscrewed and re-screwed to the connection. It was observed that the process “Screw → Unscrew → …” tended to change the strength of connection negligibly. This indicated that there is a high potential for disassembly and reuse of the exterior lightweight infill walls. To confirm the observations from this study, further experimental work with more specimens would be necessary.

Acknowledgements. This research was funded by the UK Research and Innovation (UKRI) Engineering and Physical Sciences Research Council (EPSRC) through the Interdisciplinary Circular Economy Centre for Mineral-Based Construction Materials (ICEC-MCM) (EPSRC Reference: EP/V011820/1). The authors are grateful to Etex employees, particularly Dr. Jean-Philippe Boisvert (Research Programs & Partnerships) and Mr. Andy Mudie (Head of Marketing UK & Ireland), for inspiring discussions during the project.

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