Thin-Walled Structures 73 (2013) 145–157

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Improved fire resistant performance of load bearing cold-formed steel interior and exterior wall systems

Wei Chen [a], Jihong Ye [a,*], Yu Bai [b], Xiao-Ling Zhao [b]

[a] Key Laboratory of Concrete and Prestressed Concrete Structures of the Ministry of Education, Southeast University, Nanjing, China
[b] Department of Civil Engineering, Monash University, Melbourne, Australia

ARTICLE INFO

Article history:
Received 27 July 2012
Received in revised form
28 June 2013
Accepted 29 July 2013
Available online 6 September 2013

Keywords:
Cold-formed steel load-bearing wall
Full scale fire experiment
External insulation
Aluminum silicate wool
ALC board
Bolivian magnesium board

ABSTRACT

In order to improve the fire performance of load-bearing CFS wall systems for applications in mid-rise buildings, different panels and external insulation were examined in this paper. Experiments on six full-scale CFS wall specimens were performed in which the insulation material of aluminum silicate wool was located outside the CFS frame and sandwiched between two layers of boards on the fire side instead of being placed in the cavity. Five types of panels were involved in the experiments, including gypsum plasterboard, bolivian magnesium board, oriented standard boards (OSB), autoclaved lightweight concrete (ALC) boards and rock wool boards. The results showed a noticeable reduction of heat transfer to the surface of steel stud and a considerable improvement of fire performance of CFS walls by using aluminum silicate wool as external insulation. For CFS walls with aluminum silicate wool as external insulation on fire side, gypsum plasterboard as face layer and bolivian magnesium board as base layer on both sides, different load ratios may result in different failure modes, and the fire resistant time can be more than 150 min when the load ratio was less than 0.65. It was also demonstrated that the fire performance of CFS wall systems lined with bolivian magnesium board or ALC boards were superior to those lined with gypsum plasterboard and OSB. Therefore, bolivian magnesium board may be recommended to replace gypsum plasterboards as the base layer and ALC board may be used to replace OSB as exterior wall panels of CFS wall systems for applications in mid-rise buildings.

1. Introduction

Cold-formed steel (CFS) wall systems using C-sections and one or two layers of sheathing are commonly utilized in the construction of both the load-bearing and the non-load bearing walls in residential, commercial and industrial buildings [1–3]. In these applications, fire performance of such wall systems becomes an important concern in fire safety design. Due to the cold-forming process and high section factor [1], the material degradation of cold-formed steel became faster than that of hot rolled steel at elevated temperatures [4–7]. Thus, the fire resistant performance of CFS wall systems mainly depended on the protection of wall panels. In addition, in order to meet the building acoustical requirements, the cavity in CFS wall systems was usually filled with insulation materials to reduce the sound transmission between compartments. Such insulation also affects the fire performance of CFS walls.

A few studies [3,8–17] were carried out to determine the effect of different configurations on the fire performance of CFS load-bearing wall systems. Among these researches, Kodur et al. [8] reported that load-bearing CFS walls without cavity insulation provided higher fire resistance in comparison to a cavity insulated assembly. The fire ratings were 83 min for CFS walls lined with two layers of gypsum plasterboards without insulation and 59 min for those with rock fiber cavity insulation. It was explained that the cavity insulation reduced the ability of the gypsum board facing the fire side to remain in place, causing the fire exposed gypsum plasterboard to crack and fail more quickly than when the cavity was empty. Another insulation configuration was proposed as a result. A concept of external insulation was introduced by Kolarkar [3] in which insulation was located externally and sandwiched between two boards instead of the cavity insulation. In this study, nine full-scale load-bearing CFS walls lined with gypsum plasterboards (with a thickness of 16 mm) were examined in cellulosic fire curve, and glass fiber, rock fiber and cellulose fiber were used as external insulation materials. All the wall specimens were subjected to a load ratio of 0.2 (i.e. 20% of the ultimate capacity at room temperature). The experimental results [3] showed that the failure time of wall specimens with no external insulation was 110 min while those with rock wool and cellulose fiber external insulation showed a failure time of 136 and 124 min, respectively. Thus, the external insulation demonstrated certain improvement of the fire rating of load-bearing walls. It appeared that the previous researches [3,8–17] were mainly focused on CFS wall systems assembled with gypsum plasterboards. However, for the CFS walls lined with commonly used 12-mm thick gypsum plasterboards,

* Corresponding author. School of Civil Engineering, Southeast University, Nanjing 210096, China. Tel.: +86 2583795023; fax: +86 2583794253.
E-mail address: yejihong@seu.edu.cn (J. Ye).

0263-8231/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.tws.2013.07.017

it was difficult to achieve a fire rating of more than 120 min under service load. However, such a fire rating is often required for load-bearing walls of mid-rise buildings [18].

Recently, the authors conducted a detailed experimental study [19] on five full-scale load-bearing walls with different panels, aiming to investigate the fire performance of load-bearing CFS wall systems lined with fire resistant panels made by materials (bolivian magnesium board and calcium silicate board) other than gypsum plasterboards. The specimens were subjected to load ratios of 0.32 or 0.65 and no insulation was involved. The results showed that the fire performance of bolivian magnesium board was considerably better than that of the fire resistant gypsum plasterboard. Although the calcium silicate board presented a good performance of rigidity, it was not suitable for using in the CFS wall systems due to a noticeable disadvantage of explosive spalling at high temperatures. The investigated specimens [19] exhibited fire endurance times ranging from 71 to 98 min and were still not satisfactory enough for the fire resistant requirement of 120 min. Another challenge is to extend the fire resistant time of traditional exterior wall systems lined with oriented standard boards (OSB). Such systems were currently used in low-rise CFS structures while may be not suitable for applications in mid-rise CFS structures due to the combustibility of OSB and a higher requirement of fire resistant rate of mid-rise buildings than low rise structures.

Accordingly, this paper presents a step forward to improve the fire resistant rate of load-bearing CFS wall systems and explore their potential applications in exterior wall systems for mid-rise CFS structures. Six full-scale CFS wall specimens were examined under simultaneous fire loading and mechanical loading in compression at different load levels. Aluminum silicate wool was used as external insulation on the fire side. Five types of boards were used as wall panels in preparation of these specimens (see details in Section 2). The effects of external insulation, load ratios, type of boards were therefore investigated.

2. Experimental set-up

2.1. Specimens

Six full-scale CFS wall specimens (Sp1 to Sp6) were prepared. Among these specimens, specimens Sp1–Sp3 presented the same configuration and load ratio, respectively, as the Specimens 1–3 (namely, Sp1-pre to Sp3-pre) examined previously in Chen et al. [19], while with protection of additional external insulation. Five types of panels were used in this study, including 3000 × 1200 × 12 mm fire resistant gypsum plasterboard manufactured by Lafarge, 2400 × 1200 × 12 mm fire resistant bolivian magnesium board manufactured by YiHe Green Board Co., 2400 × 1200 × 18 mm OSB manufactured by Tolko Industries LTD., 2400 × 1200 × 50 mm autoclaved lightweight concrete (ALC) board manufactured by Ashai New Building Materials Co., and 1200 × 600 × 35 mm rock wool board with a density of 170 kg/m^3 manufactured by CSR Building Materials Co. Considering a good decoration effect and a wide acceptance of gypsum plasterboards, the fire resistant gypsum plasterboard was still installed as the face layer boards for specimens Sp1–Sp4 on both sides and as the face layer boards on the fire side of specimens Sp5 and Sp6. Fig. 1 shows the detailed configurations of all the specimens. Different from Kolarkar's experiments [3], aluminum silicate wool (with a density of 120 kg/m^3 manufactured by Jiyongli Refractory Materials Co.) was used as external insulation on the fire side and sandwiched by the boards B1 and B2 (see Fig. 1). No external insulation was included between B3 and B4 on the ambient side of specimens. The aluminum silicate wool had excellent performance of thermal insulation and low thermal conductivity and was commonly used on various hot and cold faces of furnaces. In Fig. 1, Sp1–Sp4 represented CFS interior wall

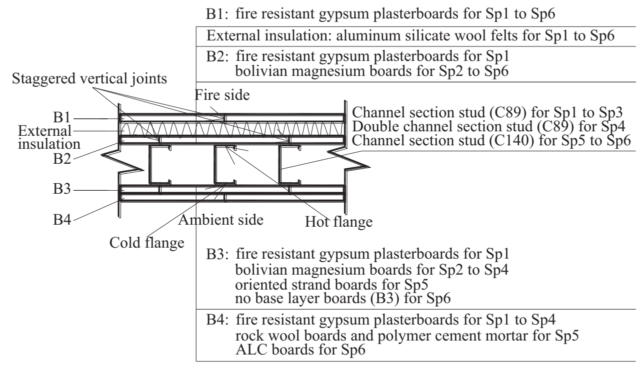

Fig. 1. Details of specimen configuration.

systems. Sp5 lined with OSB and rock wool board on the ambient side represented common types of exterior wall systems of low-rise CFS structures in cold region. Sp6 sheathing with only ALC boards on the ambient side represented a new CFS exterior wall systems proposed in this study.

Fig. 2 shows the construction details of Sp5 and Sp6. Sp1 presented similar details as those of Sp1-pre and Sp2–Sp4 had similar details as those of Sp2-pre [19]. The steel frames consisted of five commonly used CFS lipped channel section studs (C89 89 × 50 × 13 × 0.9 mm for Sp1 to Sp3 or C140 140 × 50 × 13 × 1.2mm for Sp5 to Sp6) or five back-to-back double lipped channel section studs (double C89 89 × 50 × 13 × 0.9 mm for Sp4 and to consider higher load capacity of CFS walls) spaced at 600 mm and were built by attach the studs to the top and bottom tracks made of CFS unlipped channel sections (U91 91 × 50 × 0.9 mm or U142 142 × 50 × 1.2 mm) using 16 mm long self-drilling wafer head screws. The studs and tracks were fabricated from galvanized steel sheet (Q345) with a nominal wall thickness of 0.9 mm (C89 and U91) or 1.2 mm (C140 and U142) and minimum yield strength of 345 MPa.

The vertical joints of all specimens were always located over the center line of stud flanges as shown in Fig. 1. For the horizontal joints (see Fig. 2b and c) between panels, channel section blocks (see Fig. 2a) were mounted inside with the frame at the corresponding locations by self-drilling screws. This is to prevent heat flow directly going into the specimen cavity when the horizontal joints are opened in fire. The screw-to-panel edge distance, i.e. the minimum distance from the edge of the panels to the screws, was 25 mm for Sp4 due to the configuration of back-to-back double channel section studs, and was 15 mm for the other specimens. In addition, a gap of 10 mm was left between the CFS frame and boards to avoid loading on the boards. The fire resistant silica gel was used to fill this gap to reduce the transfer of heat towards tracks directly.

2.2. Instrumentation and experimental procedure

A self-balance loading frame was specially designed and manufactured as shown in Fig. 3a. The internal space of vertical furnace was in 3 m width and 3 m height. Five jacks with a 200 kN capacity for each were mounted at the bottom supporting beam of the loading frame at a spacing of 600 mm. The loads were transferred to a specimen through the moving steel beam (see Fig. 3a). A detail introduction of loading frame and vertical furnace was presented in Chen et al. [19]. The specimen was mounted into the loading frame by bolting the top and bottom tracks with the top supporting beam and bottom moving beam, respectively. Six linear variable displacement transducers (LVDT) were used to measure the axial shortening and out-of-plane movements of the studs as shown in Fig. 3a. Thirty three k-type thermocouples (see Fig. 3b) were installed to measure the temperature responses across the wall and along the stud lengths, as shown in Fig. 3b.