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Fire resistance prediction of load bearing cold-formed steel walls lined with gypsum composite panels

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Abstract

An innovative load-bearing cold-formed steel (CFS) wall lined with gypsum composite panels was developed with the goal of improving the construction efficiency and fire performance of these walls for applications in mid/high-rise buildings. The gypsum composite panel was formed by sandwiching insulation and plasterboard strips between two layers of gypsum plasterboards. Subsequently, the predicted fire resistance of these CFS walls was predicted based on our previously developed and experimentally validated modeling method. The degenerated material properties of the cold-formed steel and thermal physical property of the gypsum plasterboard and aluminum silicate wool were obtained from our pervious experimental investigations and used as the basic input parameters in the present fire resistance modeling. The results showed that the fire performance of the CFS walls lined with gypsum composite panels improved greatly. The configuration details and corresponding design load levels were also determined for the CFS walls with a fire resistant rating of 120 and 150 min.

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Key words: cold-formed steel load-bearing wall; gypsum composite panel; fire performance simulation; thermal response model; thermo-mechanical response model; easy construction

Introduction

In recent years, cold-formed steel (CFS) walls consisting of a CFS frame and one or two layers of sheathing are increasingly utilized in the construction of load-bearing components in mid-rise buildings. The fire performance of such walls becomes an important concern in fire safety engineering. A few experimental fire investigations have been performed to determine the effects of different configurations on the fire performance of load-bearing CFS walls (Gerlich et al. 1996; Kwon et al. 1998; Sultan and Kodur 2000; Alfawakhiri 2001; Feng et al. 2003; Sakumoto et al. 2003; Feng and Wang 2005; Kodur and Sultan 2006; Kolarkar 2010; Chen and Ye 2012; Chen et al. 2012, 2013a) and some important conclusions were formulated. For instance, a load-bearing CFS wall without cavity insulation provided higher fire resistance compared to a cavity-insulated assembly (Kodur and Sultan 2006). In addition, our prior experiments demonstrated great improvement in the fire resistance rating of CFS walls by using aluminum silicate wool as external insulation, which was located externally and sandwiched between two layers of gypsum plasterboard instead of cavity insulation (Chen et al. 2013a). However, there are still some construction problems for a CFS wall with external insulation that cannot be neglected, which would limit its application in engineering. Therefore, this paper developed an innovative load-bearing CFS wall lined with gypsum composite panels to improve the construction efficiency and fire performance of such walls for applications in mid/high-rise buildings. Subsequently, the fire resistance performance of such CFS walls was simulated using our previously developed and experimentally validated modeling method.

Configuration details of CFS walls lined with composite panels

Fig. 1 shows the configuration details of one of our previous experimental specimens that showed the fire resistance time of 137 min when the specimen was subjected to a load ratio of 65% (i.e., 65% of the ultimate capacity at room temperature) and fire exposure to the ISO 834 standard time-temperature curve from one side (Chen et al. 2013a). The fire resistance testing time was reduced to 71 min after removing the external insulation (see Fig. 1) on the fire side (Chen et al. 2012). Therefore, the fire resistance performance of CFS walls was greatly improved by using the external insulation. However, the following construction problems cannot be neglected for CFS walls with external insulation:

(1) The construction process is rather complicated, including fixing the base layer gypsum plasterboards, aluminum silicate wool (external insulation) and face layer gypsum plasterboards successively on either side of the CFS frame. Additionally, it is not easy to install the aluminum silicate wool vertically on the base layer surface of CFS walls.

(2) During the installation of the face layer of the gypsum plasterboard, the surface planeness of CFS walls is hard to control due to the compressive deflection of the external insulation.

(3) Detachment and opening of the plasterboard joints was observed in the previous externally insulated CFS wall specimens after severe fire exposure (Chen et al. 2013a). This behavior would accelerate the temperature rise of the steel studs and is unfavorable for the fire performance of CFS walls.

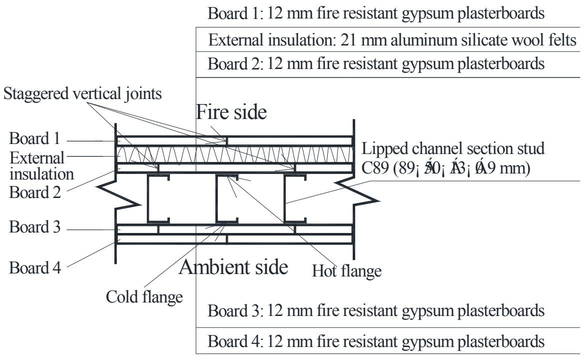
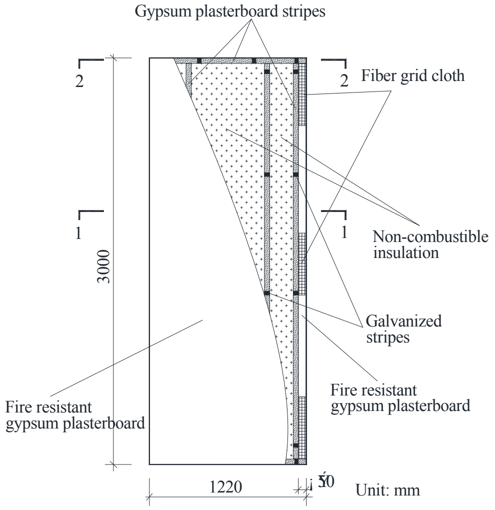


Fig. 1 Details of specimen configuration in Chen et al. 2013a

To address these concerns, an innovative gypsum composite panel was developed to be used in CFS walls instead of the traditional wall boards, as shown in Fig. 2. The gypsum composite panel was formed by sandwiching the insulation and plasterboard strips between two layers of fire resistant gypsum plasterboard. The plasterboard strips were applied along the periphery as well as in the field of the gypsum plasterboard. The insulation was laid in the cavity formed by the gypsum plasterboard and plasterboard strips. The desired depth of the cavity for the insulation was obtained by selecting the appropriate thickness and number of plasterboard strips that were fixed by several galvanized steel stripes (Fig. 2) equally distributed along the stripes length. The non-combustible fiber grid cloth (Fig. 2) was bonded to the inner surface of the gypsum plasterboards to prevent the insulation from falling off when the gypsum composite panel was in a fire. In addition, there were two notches along two long edges of composite panel as shown in Fig. 2. The gypsum composite panel was built by screwing each layer of gypsum plasterboard with the plasterboard stripes into the galvanized stripes (Fig. 2), which provides the pull-out resistance for the self-taping screws. At the same time, the loose fill insulation could be compacted during the assembly process of the composite panel.



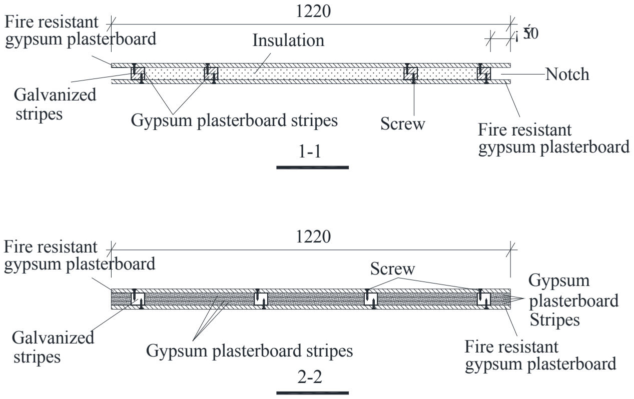


Fig. 2 Details of the gypsum composite panel

Fig. 3 shows the structural details of the cold-formed steel wall lined with gypsum composite panels on either side. The load-bearing steel frame was built by assembling CFS lipped channel section studs with the top and bottom tracks made of CFS unlipped channel sections using self-taping wafer head screws. Each gypsum composite panel was applied vertically and screwed to the steel studs only along the plasterboard stripes in the field of panel and screwed to the steel tracks along the plasterboard stripes on the top and bottom edges of the panel. Adjacent composite panels were jointed together by inserting the plasterboard stripes into the notches (see Fig. 2) of the composite panels and screwing them to the non-load-bearing resilient channels along the left and right edges of composite panel. The resilient channels were insulated by rock wool, applied vertically and attached directly to the steel tracks by using self-taping wafer head screws. The spacing of the resilient channels was equal to the width of the composite panels. In Fig. 3, there was only a single row of screws on either side of the stud flanges and all the vertical joints of composite panels were located over the center line of the resilient channel webs. Therefore, the influence of opening up of the vertical joints of the composite panels on the temperature history of the steel studs became insignificant for CFS walls in a fire due to the fire protection provided by insulating the resilient channels.

Besides, the construction of the CFS walls lined with composite panels is quite simple because the composite panels can be prefabricated in bulk. At the same time, the surface planeness of CFS walls is easy to control because the presence of the plasterboard stripes. Hence, the three construction problems can be solved simultaneously by using CFS walls sheathed with composite panels.

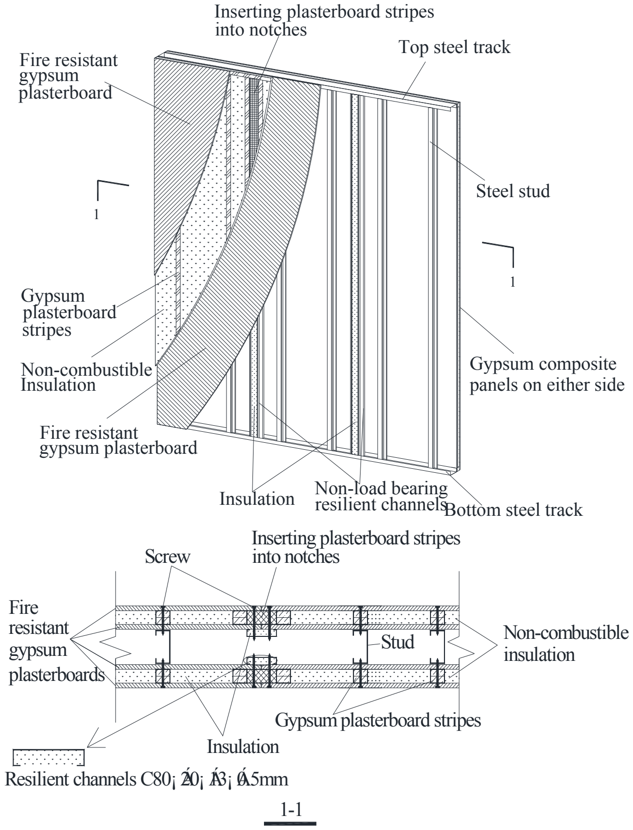


Fig. 3 CFS wall lined with gypsum composite panels on both sides

Fire resistance predictions of CFS walls

Two CFS wall samples (W1 and W2) lined with gypsum composite panels were developed, as shown in Fig. 4. The steel studs and tracks were fabricated from a

0.9 mm Q345 galvanized steel sheet with the design yield strength of 300 MPa and elastic modulus of 206 GPa. The steel studs had a height of 3000 mm and were spaced at 610 mm. The gypsum composite panels were attached to the steel studs, tracks and resilient channels by 70 mm long self-taping bugle head screws, spaced 300, 150 and 150 mm, respectively. The fire resistance performance of these two samples (W1 and W2) was predicted by our previously developed modeling method (Chen et al. 2013b). In the thermal response modeling, the emissivity, ε_γ, was assumed to be 0.8. The temperature on the fire side was specified by the standard ISO 834 time-temperature curve. The temperature on the ambient side was 20°C. Fig. 5 showed the thermal physical properties of the fire resistant gypsum plasterboard and aluminum silicate wool which was obtained from previous experimental investigations (Chen et al. 2013b). In addition, the critical temperature for the collapse of the gypsum plasterboard was 800°C (Sultan 2010; Chen et al 2012, 2013a).

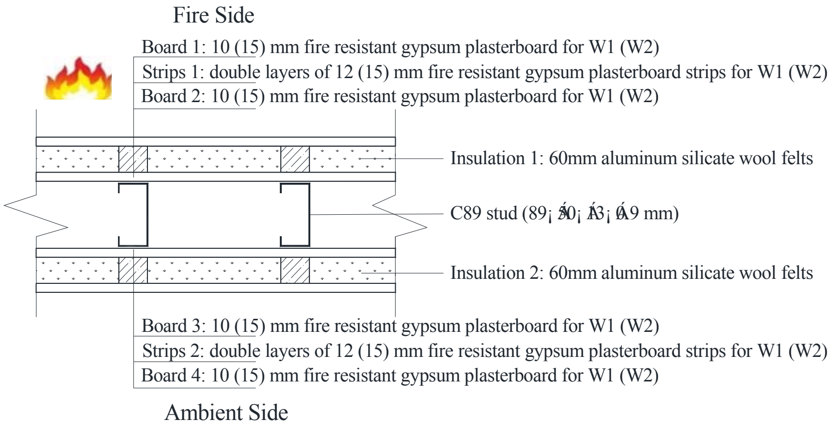
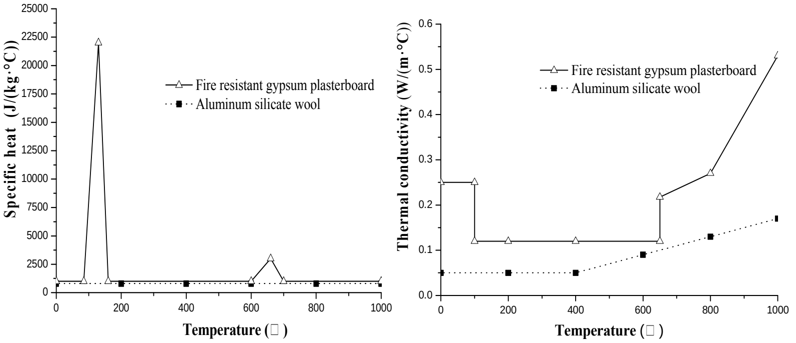
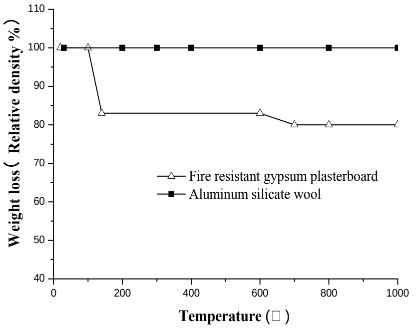


Fig. 4 Two samples of CFS walls lined with gypsum composite panels



(a) Specific heat (b) Thermal conductivity



(c) Weight loss

Fig. 5 Thermal physical property of fire resistant gypsum plasterboard and aluminum silicate wool (Chen et al. 2013b)

Fig. 6 showed the predicted time-temperature profile of wall sample W1. The time-temperature curves at point “3” and “4” were obtained from the thermal response model of a CFS wall lined with double layers of fire resistant gypsum plasterboards and one external layer of aluminum silicate wool insulation on both sides; the time-temperature curves of point “5” and “6” were obtained from the thermal response model of a CFS wall lined with double layers of fire resistant gypsum plasterboards and double layers of plasterboard stripes on either side. Fig. 6 indicated that the gypsum plasterboard collapsed at the fire side face layer after fire exposure of approximately 40 min. In addition, the temperature on the ambient surface of W1 (point “7” in Fig. 6) increased gradually while remaining below 75°C. The integrity and insulation were maintained throughout the fire exposure simulation. Because the inner surface of the wall cavity was closest to hot and cold sources for the steel studs, the temperature responses of the hot and cold flanges was similar to the wall cavity (Chen et al. 2012). Hence, it would be conservative if the maximum temperatures between points "3" and "5" and the maximum temperatures between points "4" and "6" were used as the temperature profiles of the hot and cold flanges of the steel stud, respectively, as shown in Fig. 7.

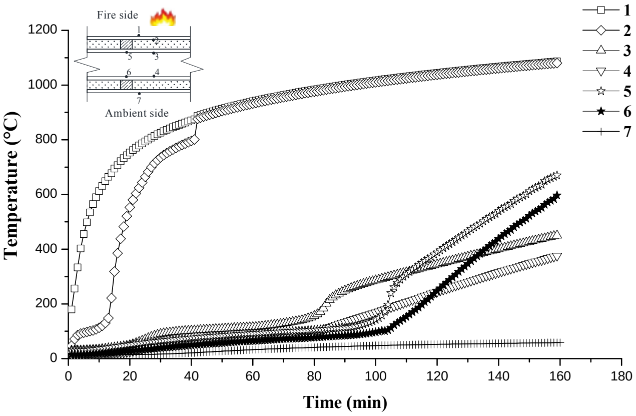


Fig. 6 Predicted time-temperature profiles of the CFS walls (W1)

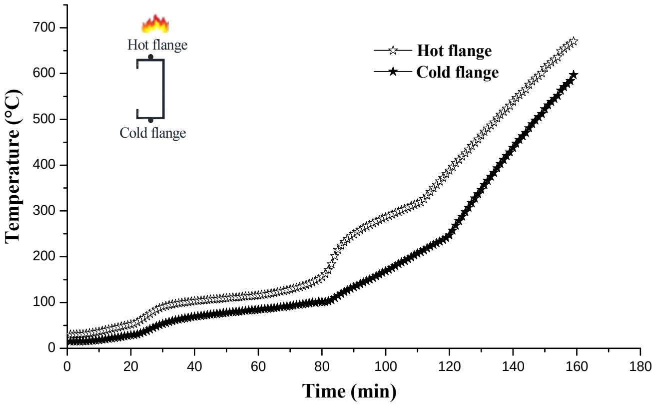
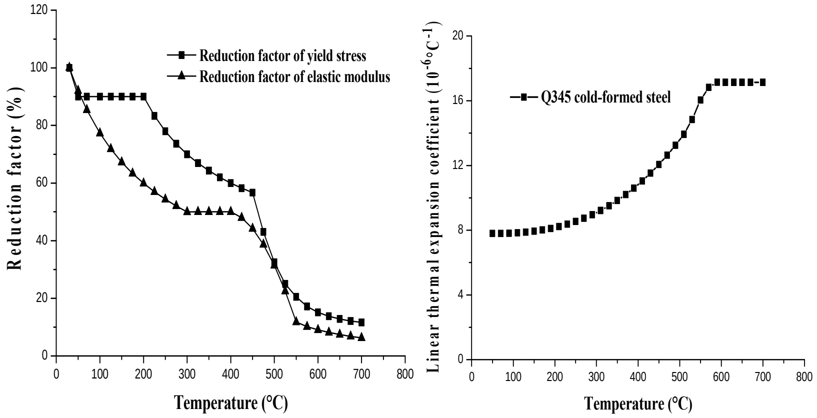


Fig. 7 Approximate time-temperature curves of the hot and cold flanges of the steel stud for W1

In the thermo-mechanical modeling, the reduced material properties and the coefficient of linear thermal expansion for the Q345 cold formed steel at elevated temperatures were obtained from our transient state experimental investigations (Fig. 8, Ye and Chen 2013). The testing axial compressive strength for each wall stud of W1 was 29.8KN at ambient temperature (Chen et al 2013a). According to the current design rules of AISI S100-2007 (2007), the nominal axial strength for each wall stud of W1 was 29.1 KN at ambient temperature, which compared well with the testing result. The design axial strength for each wall stud was determined by multiplying the nominal axial strength by the resistant factor; it was 24.7 KN at ambient temperature. Fig. 9 showed the fire resistance prediction for W1 obtained from the present thermo-mechanical response model. In Fig. 9, the design load ratio was defined as the percentage of the design axial strength of the wall stud at ambient temperature. The predicted fire resistance time of W1 became greater than 120 min when the design load ratio was no more than 74%. Fig. 10 showed the predicted time-dependent lateral deflection for W1 under the design load ratio of 74%. The positive values of the later deflection indicated deformation toward the fire side.



(a) Reduced material properties (b) Linear thermal expansion coefficient

Fig. 8 Reduced material properties and linear thermal expansion coefficient for the Q345 cold formed steel at elevated temperatures (Ye and Chen 2013)

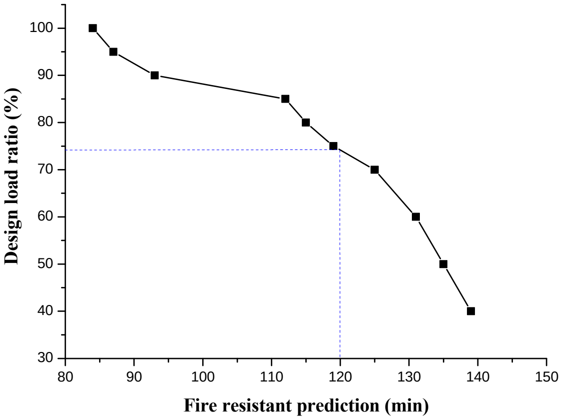


Fig. 9 Fire resistance prediction of W1 obtained from the thermo-mechanical response model

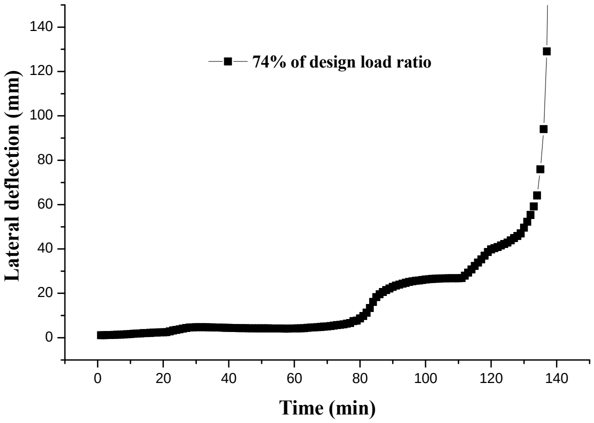


Fig. 10 Predicted time-dependent lateral deflection for W1 under the design load ratio of 74%

Based on the same modeling method, the fire performance prediction of wall sample W2 was conducted, as shown in Fig. 11 to Fig. 13. The predicted fire resistant time of W2 was greater than 150 min when the design load ratio was no more than 92%. Moreover, according to previous experimental investigations, the testing fire resistance time of non-cavity insulated CFS walls lined with a double layer of 12 mm fire resistant gypsum plasterboards on both sides was only 71 min when the design load ratio was 80% (Chen et al. 2012). Hence, the fire performance of load-bearing CFS walls is greatly improved by using gypsum composite panels on either side of steel frame.

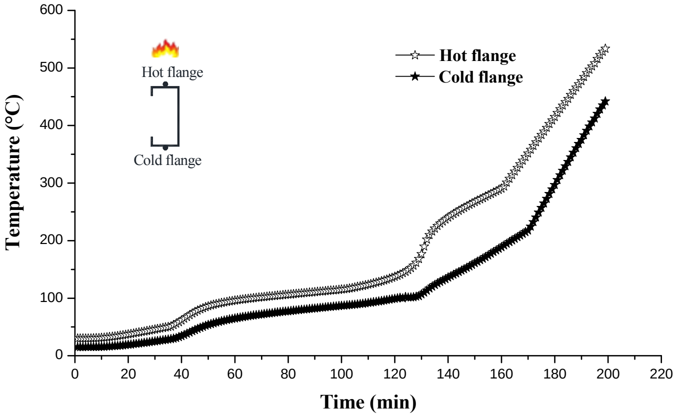


Fig. 11 Approximate time-temperature curves of the hot and cold flanges of the steel stud for W2

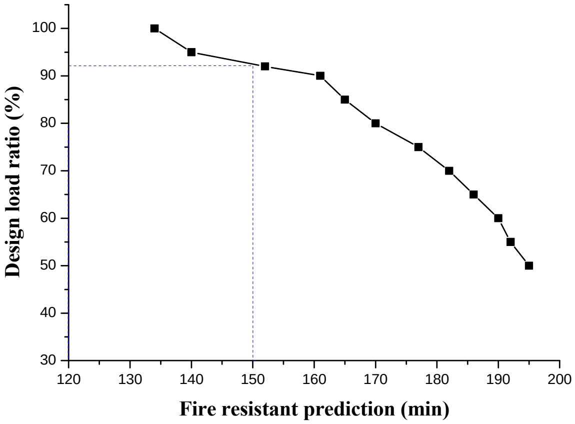


Fig. 12 Fire resistance prediction of W2 obtained from the thermo-mechanical response model

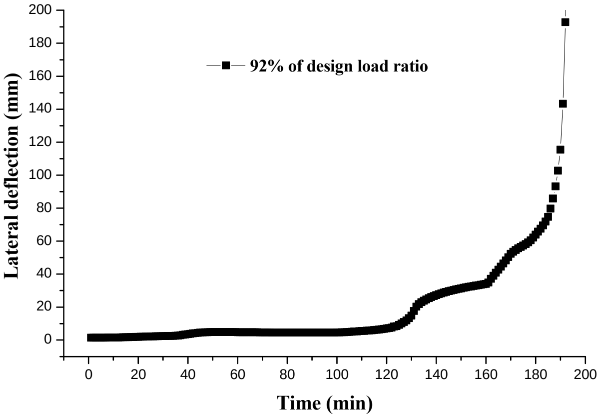


Fig. 13 Predicted time-dependent lateral deflection for W2 under the design load ratio of 92%

Conclusions

This paper presented an innovative CFS wall lined with gypsum composite panels, with the advantages of easy construction and elimination of the opening of the board joints, which has an unfavorable influence on the fire performance of CFS walls. The fire resistance performance of CFS walls lined with gypsum composite panels was predicted based on our previously developed and experimentally validated modeling method. The degenerated material property of the cold-formed steel and thermal physical property of the gypsum plasterboard and aluminum silicate wool were obtained from our pervious experimental investigations and used as the basic input parameters in the fire performance modeling. The results showed great improvement of the fire performance for CFS walls lined with gypsum composite panels. The configuration details and corresponding design load levels were also given for the CFS walls with fire resistant ratings of 120 and 150 min. A series of fire experiments on CFS walls lined with composite panels is scheduled and will be presented later.

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