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Fire performance of cold-formed steel wall panels and prediction of their fire resistance rating

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ABSTRACT

Recent research at the Queensland University of Technology has investigated the structural and thermal behaviour of load bearing Light gauge Steel Frame (LSF) wall systems made of 1.15 mm G500 steel studs and varying plasterboard and insulation configurations (cavity and external insulation) using full scale fire tests. Suitable finite element models of LSF walls were then developed and validated by comparing with test results. In this study, the validated finite element models of LSF wall panels subject to standard fire conditions were used in a detailed parametric study to investigate the effects of important parameters such as steel grade and thickness, plasterboard screw spacing, plasterboard lateral restraint, insulation materials and load ratio on their performance under standard fire conditions. Suitable equations were proposed to predict the time–temperature profiles of LSF wall studs with eight different plasterboard-insulation configurations, and used in the finite element analyses. Finite element parametric studies produced extensive fire performance data for the LSF wall panels in the form of load ratio versus time and critical hot flange (failure) temperature curves for eight wall configurations. This data demonstrated the superior fire performance of externally insulated LSF wall panels made of different steel grades and thicknesses. It also led to the development of a set of equations to predict the important relationship between the load ratio and the critical hot flange temperature of LSF wall studs. Finally this paper proposes a simplified method to predict the fire resistance rating of LSF walls based on the two proposed set of equations for the load ratio–hot flange temperature and the time–temperature relationships.

1. Introduction

Cold-formed steel sections are commonly used in various combinations to provide load-bearing Light gauge Steel Framed (LSF) wall systems in buildings (Fig. 1). Under fire conditions, cold-formed steel stud sections heat up quickly as they are thin-walled, resulting in fast reduction to their strength and stiffness. Therefore these stud sections are commonly used in planer structural wall systems with plasterboard on both sides as fire protection. Plasterboards protect the steel studs by delaying the temperature rise in the studs during building fires. Since the LSF walls are often subjected to fire on one side, non-uniform temperature distributions will develop across the depth of LSF wall studs. This will induce additional bending moments on the studs due to thermal bowing, neutral axis shift and magnification effects. Hence the thin-walled steel studs will be subjected to combined actions of axial compression and bending moment during a fire event. This fire behaviour of LSF wall panels has been investigated by many researchers in the past [1–10] and several fire design rules have been proposed [1–3,5,6,9,10]. Klippstein [1] and Gerlich et al. [2] developed their fire design rules based on AISI design provisions [11] while Alfawakhiri's [5] study was based on Canadian cold-formed steel design rules. Ranby [3], Kaitila [6], Feng and Wang [9] and Zhao et al. [10] developed their fire design rules based on Eurocode 3 Part 1.3 [12]. These design rules are complex and time consuming and hence do not suit routine design purposes.

In order to overcome this problem related to the need for simplified design rules and to address the lack of research data on Australian LSF wall systems, a detailed investigation based on full scale fire tests and finite element analyses was conducted on both conventional Australian LSF walls with and without the use of cavity insulation and the new composite panel system developed recently at the Queensland University of Technology. Details of 10 full scale fire tests and their results including the temperature and deflection profiles measured during the tests are presented in [13] along with the failure times and modes. A suitable finite element model of LSF wall studs subject to fire conditions was then developed using ABAQUS, and validated using the results of fire tests [14].

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In this paper idealised time–temperature profiles were first proposed for LSF wall studs based on the results from the full scale fire tests. These idealised time–temperature profiles were then used in a detailed finite element analysis based parametric study of LSF wall studs under fire conditions. The validated finite element models were used in this parametric study to investigate the behaviour of LSF walls. This study included the effects of various parameters such as steel grade, steel thickness, screw spacing, plasterboard restraint, various insulation materials and load ratios. Finally, a simple design method was proposed based on the parametric study results to predict the fire resistance rating of LSF wall panels with varying wall configurations (single and double layers of plasterboards, cavity and externally insulated) and structural parameters (steel grade and thickness) under varying load ratios.

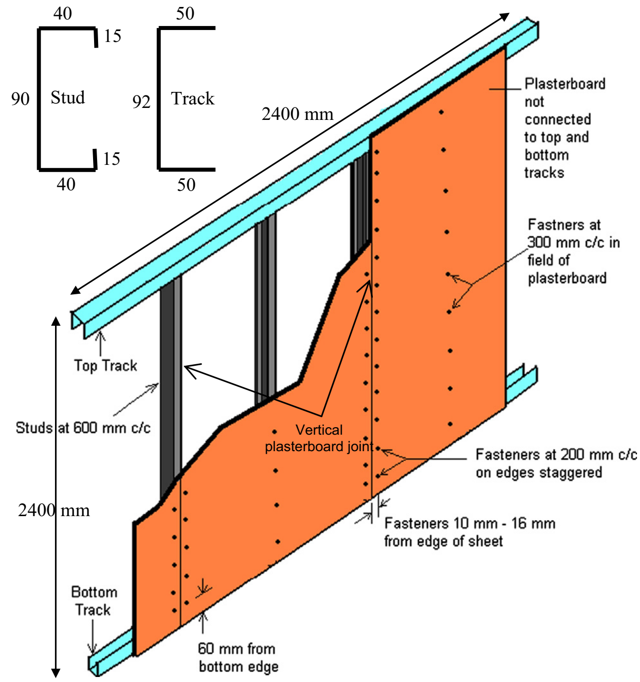


Fig. 1. LSF wall panel.

2. Experimental study

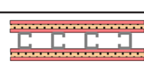
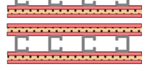
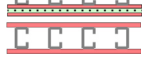
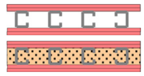
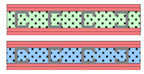
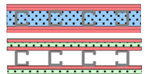
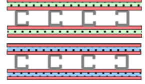
This section provides brief details of the series of full scale fire tests of LSF walls conducted first to evaluate the fire resistance rating (FRR) of load bearing LSF wall assemblies. One wall specimen was tested to failure under an axial compression load at room temperature while ten wall specimens subjected to a constant axial compression load were exposed to standard fire conditions on one side to evaluate their fire performance (Table 1). Conventional Australian LSF wall panels lined with single or double layers of plasterboard with or without cavity insulation were considered. A new LSF wall system based on a composite panel was also included in which a 25 mm external insulation was sandwiched between the two plasterboards [13]. The plasterboards used in the study were 1200 mm in width by 2400 mm in length with a thickness of 16 mm and density of 13 kg/m^2. The densities of glass, rockwool and cellulose fibre insulations used in this study were 13.88 kg/m^3, 100 kg/m^3 and 100–110 kg/m^3, respectively. Their thermal conductivity, specific heat and relative density at ambient and elevated temperatures are given in [15].

All the steel frames used in the load bearing LSF wall panels were built to a height of 2400 mm and a width of 2400 mm as shown in Fig. 1. The studs and tracks used in the test frames were fabricated from G500 galvanised steel sheets with a nominal base metal thickness of 1.15 mm, a yield strength of 569 MPa and an elastic modulus of 213,520 MPa at ambient temperature. Their dimensions are shown in Fig. 1. Test frames were lined on both sides by single or double layers of 16 mm gypsum plasterboards manufactured by Boral Plasterboard. Table 1 shows the details of the 10 LSF wall specimens used in this study with two load ratios.

The furnace was designed to deliver heat based on the standard fire curve given in [16]. The loading frame was designed to load the individual studs of LSF wall specimens in compression from the bottom side (Fig. 2) using hydraulic jacks. The axial shortenings of the studs and the out-of-plane movements of the wall specimen were measured using Linear variable displacement transducers. K type thermocouples were used to measure the temperature development across the wall specimens. The stud (hot flange, web and cold flange) temperatures were measured at three levels for interior studs, namely, at 0.25, 0.50 and 0.75 H, and at mid-height for exterior studs.

In each fire test an axial compression load of 15 kN (for a load ratio of about 0.2) or 30 kN (for a load ratio of about 0.4) was

Table 1
LSF wall systems considered in fire tests.

Test	Index	Configuration	Insulation		Load ratio	Failure time (min)	
			Material	Location		Test	FEA
1	CP-GF		Glass fibre	External	0.2	118	115
2	CP-GF		Glass fibre	External	0.4	108	110
3	CP-RF		Rock fibre	External	0.4	134	131
1*	1 × 1		None	-	0.2	53	53
2*	2 × 2		None	-	0.2	111	115
3*	CI-GF		Glass fibre	Cavity	0.2	101	100
4*	CI-RF		Rock fibre	Cavity	0.2	107	105
5*	CI-CF		Cellulose fibre	Cavity	0.2	110	109
6*	CP-RF		Rock fibre	External	0.2	136#	154
7*	CP-CF		Cellulose fibre	External	0.2	124	129

(1–3) – Tests conducted by the first author of [13]; (1*–7*) – Tests conducted by the second author of [13]; (#) – Earlier failure time due to lack of space for thermal expansion; Cavity – Insulation is placed within the LSF frame; External – Insulation is placed outside the LSF frame.