ASSESSING THE BUSHFIRE PERFORMANCE OF LOW-RISE STEEL STRUCTURES USING FULL SCALE BUSHFIRE FLAME FRONT SIMULATION

KB Watson [1], JE Leonard[2], I Bennetts[3], MH Kelly[4], L Macindoe[5], and TG Clayton[6]

[1] Executive Director, National Association of Steel-framed Housing Inc, Australia
kwatson@nash.asn.au
[2] Research Scientist, CSIRO, Sustainable Ecosystems, Melbourne, Australia
Justin.Leonard@csiro.au
[3] Principal Risk Engineer, Noel Arnold and Associates, Melbourne, Australia
ian.bennetts@noel-arnold.com.au
[4] Consultant, National Association of Steel-framed Housing Inc, Australia
mkelly@nash.asn.au
[5]Research Engineer, CSIRO, Materials, Science and Engineering, Melbourne, Australia
Lyndon.Macindoe@csiro.au
[6]Senior Research Engineer, BlueScope Steel Research, Port Kembla, Australia
trevor.clayton@bluescopesteel.com

ABSTRACT

Bushfire attack on buildings involves burning embers, radiant heat and/or direct flame impingement. Resistance to these attack mechanisms involves consideration of materials, design, installation and maintenance. Few solutions are currently available for construction in the most severe bushfire attack conditions, referred to in regulations as “flame zone”.

An experimental building incorporating steel sheet roofing and cladding together with steel roof, wall and floor framing was devised to withstand flame zone conditions. The test building was finished with a range of materials and features typical of low-rise construction, and built to six-star energy rating.

Testing was carried out using a bushfire flame front simulator designed to recreate actual bushfire flame temperatures and radiant heat flux profiles. The simulator uses a liquid propane burner grid originally devised to assess the resistance of bushfire fighting vehicles caught directly in the path of a high-intensity bushfire. The test was conducted outdoors under prevailing wind conditions (within set criteria) allowing for the effects of oxygen supply and convective heat loss on test elements.

Instrumentation measured air and building element surface temperatures throughout the building, radiation levels at the exposed building face and behind windows, and air quality inside the building. Post-test evaluation of the building was carried out to assess structural and building envelope weaknesses and repair needs.

INTRODUCTION

Following the devastating Victorian Black Saturday bushfires, the National Association of Steel-framed Housing (NASH) investigated different methods of providing a non-combustible, robust and durable bushfire building solution for severe bushfire exposure conditions.

It was considered that a steel roof together with steel trusses, steel wall studs with steel external cladding and exposed steel sub floor should be able to survive in the flame zone of a real bushfire and provide an inherently robust system that did not have the potential for external or cavity ignition, assuming that windows or other external openings had not been breached. The concept is that the entire non-combustible roof, wall and floor structure acts together to protect the habitable space.

NASH engaged the CSIRO to conduct a full scale fire test using the Bushfire Flame Front Simulator (BFFS) at the NSW Rural Fire Service (RFS) Eurobodalla Training Centre near Mogo, NSW. This facility was originally designed to assess the resistance of bushfire fighting vehicles that may be caught directly in the path of a high-intensity bushfire. It has been progressively modified to enable a wider range of test subjects and parameters. It is the only facility in the world that can model the immersion of a full scale vehicle or structure in a high-intensity bushfire flame front.

The projects aims were to:

- design a low-rise predominantly non-combustible steel test building with the widest possible use of common building materials and methods,
- assess the performance of such a building system using full-scale testing; and
- provide supporting evidence for Building Authority approval as a Alternative Solution under the BCA Performance Requirement.

REGULATORY REQUIREMENTS

The performance requirement in the Building Code of Australia (BCA) 2010 for bushfire areas states that for a Class 1 building, or a Class 10a building associated with it the “building that is constructed in a designated bushfire prone area must be designed and constructed to reduce the risk of ignition from a bushfire while the fire front passes.” (BCA, 2010: 66) The associated Functional Statement states that the “building constructed in a designated bushfire prone area is to provide a resistance to bushfires in order to reduce the danger to life and minimise the risk of the loss of the building.” (BCA, 2010: 64)

For BCA 2010, compliance with AS 3959-2009 (SA 2009) is a Deemed-to-Satisfy Provision for each of the above building classes in all jurisdictions except for Class 1 and 10a in South Australia. Slight variations to class applicability apply in New South Wales.

Alternative performance solutions to the Deemed-to-Satisfy Provisions are possible, provided it can be demonstrated to the relevant Building Authority that they satisfy the same Performance Requirements as the Deemed-to-Satisfy Provisions or that they are at least equivalent.

AS 3959-2009 specifies that for houses designated as being in the Flame Zone, systems should either meet deemed-to-satisfy provisions or pass a test to AS 1530.8.2 (SA 2007). The AS 1530.8.2 test is conducted in a modified compartment fire test furnace that has accepted limitations in its ability to model actual fire conditions. Specifically, the time-temperature profile and availability of oxygen during the test exposure in the AS 1530.8.2 furnace test differs from the conditions associated with bushfire fire front behaviour. In addition a furnace test can only provide a piecewise solution as only parts of the building system can be tested at any one time. In bushfire design the integrity of the whole building is critical as a single weakness can compromise the entire system. Offsetting some of these limitations is the long (30 minute) duration of high temperature exposure associated with the AS 1530.8.2 test.

FLAME ZONE EXPOSURE

A flame zone exposure profile has been proposed by Leonard (2010) and consists of three phases:

- pre-radiation
- flame immersion and
- post radiation

The profile is based on a worst case scenario and exceeds the profile recently adopted as the basis for testing of private bushfire shelters.

The pre-radiation profile was derived from modelling a range of fire scenarios using the detailed method given in Appendix B of AS 3959-2009. In some cases more conservative assumptions were used. These included:

- The flame body was assumed to have an emissive temperature of 1200^{o}K rather than 1090^{o}K
- A vegetation setback from the house was zero rather than 10m

The flame immersion time was derived from modelling a range of fire scenarios using the detailed method in AS 3959-2009 as well as experimental data from bushfires. A 110 s flame immersion time was chosen as being the worst case scenario.

The post radiation radiant heat profile was based the time decay from heavy fuels.

TEST BUILDING

The test building was nominally 8m x 4m x 5m high (see Fig. 2), constructed with steel framing (floor, wall and trussed roof) and suspended on steel stumps such that it was about 0.5 m off the ground. The design incorporated a number of typical building characteristics including a gable and hip roof. Steel sheeting was used for the external cladding including the underside of the floor and the majority of the eaves lining except for two sections which were lined with calcium silicate board for comparison. Two windows (one involving a protective curtain and AS 1530.8.2 rated for flame zone) and a solid core timber door protected by a steel security door were located on the front wall and a sliding glass door (met AS3959 BAL 40 requirements except a screen wasn't installed) on the back wall. The floor, wall and ceiling were insulated with fibreglass batts while foil backed fibreglass insulation blanket was installed under the roof sheeting. 10mm plasterboard was used for the internal wall and ceiling lining. Cement sheeting was used for the floor. Timber skirting and architraves were used around the walls, windows and doors. Various other common components such as a flue, down lights, ceiling access panels, and power switches were included.

BUSHFIRE FLAME FRONT SIMULATOR

The simulator uses grids of liquid propane fuelled burners to simulate the radiant heat and flame exposure profile of an actual bushfire front. The simulator allows the flexibility for the grids to be placed on both sides as well as under the test object as is required for testing fire tankers. The wind velocity during the test is critical and testing is often delayed until a constant wind is available to ensure the heat from the grid impacts correctly onto the test object. However some variation in the radiant heat and flame exposure due to the wind is inevitable.

The grid layout for testing the building is shown in Fig. 3. It consists of a row of 3 burner clusters about 5m from the front of the house which are used for the pre-radiation (see foreground in Fig. 3) and post-radiation phases of the test. The jet size of each burner in the cluster is different and can be activated singularly or in combination to provide a stepwise flame intensity and hence radiation profile on the building. The large 6 x 3 grid of burners adjacent to the front wall of the building (see centre in Fig. 3) can provide a 16 MW/m fire line intensity for the flame immersion phase (see Fig. 4).

The gas delivery system (pipe diameters, supply pressure, dump value, etc) is designed to ensure a rapid and repeatable response. The grid is controlled from an adjacent building using feed back from radiometers mounted on the front wall of the test building to permit the desired intensity to be achieved.

INSTRUMENTATION

Approximately 100 Mineral Insulated Metal Sheath thermocouples were installed in the building to monitor the exterior temperature against the outside skin of the building, the internal air temperature in the building cavities and room, the temperature of the steel framing and the inside surface temperature of the plasterboard and windows. Four water cooled Schmidt-Boelter radiometers were mounted inside enclosures bracketed to the outside of the front wall (see Fig. 3) to measure the radiant heat applied to the building while similar radiometers were placed behind each window to measure the radiant heat passing through the window. Tubing to the building was installed to allow air sampling during the test.

The data were collected by data loggers located in the centre of the floor and communicated back to laptops in the control room. Cameras were also placed both inside and outside the building to record the test.

OUTCOMES

Testing took place on 16 April 2010. The test was a success with the simulator performing exceptionally well, providing a very realistic flame front simulation closely matching the target exposure profile. In effect the test was more severe than intended with the pre-radiation peaking 10 kW/m^2 above the profile and the flame immersion phase lasting 40 s longer than scheduled. This is reasonable given the first time nature of the test, scheduling preventing a full calibration of the burners and the unexpected extent of the flame immersion which almost enveloped the whole building including flame contact on the back wall. The building after the test is shown in Fig. 5.

The following are the major outcomes:

- The air temperatures on the outside of the building reached a peak of 1100°C. A plot of the average air temperature across the front wall of the building is shown in Fig. 6.
- The variation in the air temperature on the outside of the building is shown in Fig. 7.
- The stumps were protected (see Fig 2) from the heat. The data indicate they would have been exposed to excessive temperatures without this protection.
- The floor system was still serviceable after the test. The bottom of the insulation was blackened.
- The wall system lost its insulation during the test and the steel studs suffered localised buckling due to thermal stresses.
- The roof system was still serviceable after the test. Most of the damage occurred at the eaves. The top of the ceiling insulation was blackened but otherwise unaffected. The roof insulation blanket was intact except near the eaves.
- The front timber solid core door was noted to be well alight before the flame immersion phase. Large gaps around the perimeter of the door were evident after the test. Timber solid core doors are only specified for BAL 40 and below in AS 3959-2009 and not BAL FZ flame zone situations.
- Smoke had started filling the room from near the door early into the flame immersion phase.
- The window at the gable (RHS) end of the front wall shattered during the first half of flame immersion phase.
- One of the two panes in the back door shattered during the second half the flame immersion phase. This was unexpected but was a result of flames flowing under the building and rolling back on to the rear wall.
- The glass in the window at the hip (LHS) end of the front wall (protected by a curtain) softened and slumped at the end of the flame immersion phase providing a gap for hot air to enter the building. The window system has passed the AS1530.8.2 test for flame zone although AS 1530.8.2 uses a lower peak temperature (~850^{o}C) than that applied by the bushfire simulation.
- The room air conditions were compromised by the failure of the windows and doors even though the front windows and door had been boxed out to isolate them from the room.
- The interior room surfaces adjacent to the openings were blackened but elsewhere the plasterboard, and timber skirtings and architraves were unaffected or had light discoloration.

The following actions are needed to improve the building performance:

- Improved design of the wall system - additional protection/insulation is needed on the outside of the wall frame and around the eaves; use of rock wool rather than fibreglass to improve the heat resistance of the insulation
- Improved window and door systems required, including shutters capable of protecting low-specification products. Solution are needed for sealing gaps around openings to resist both smoke and heat.

CONCLUSION

A full scale test of the performance of a complete building system exposed to flame zone conditions was undertaken. It provides a new alternative method for the assessment of the performance of buildings in bushfire-prone areas.

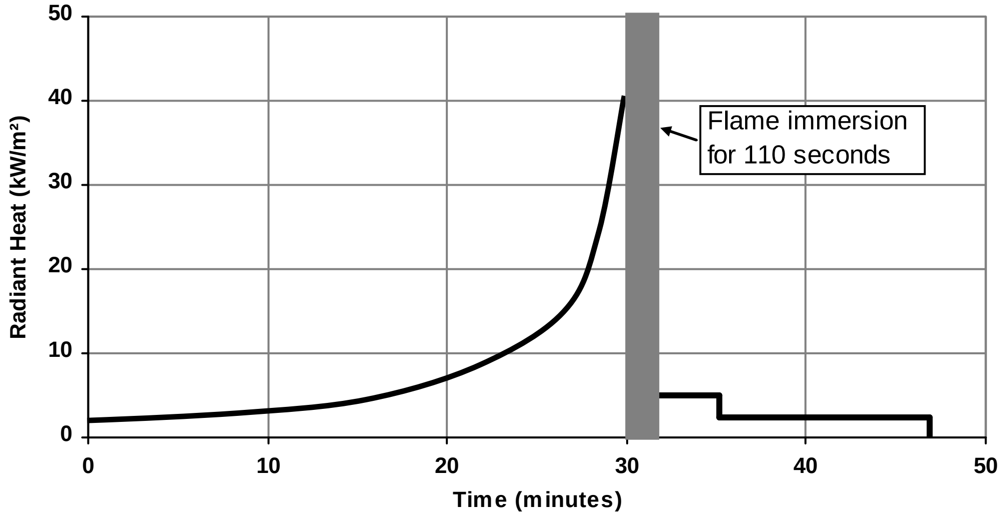

Fig. 1 Flame zone exposure

Fig. 2 Pre radiation phase of the testing.

Fig. 3 Liquid propane burners

Fig. 4 Flame immersion phase

Fig. 5 The building after the test

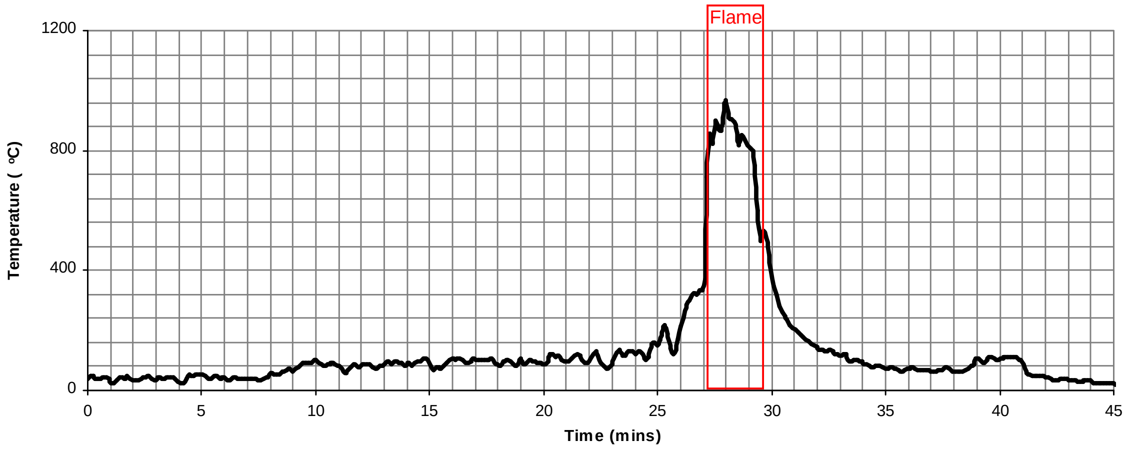

Fig. 6 Average air temperature across the front wall of the building

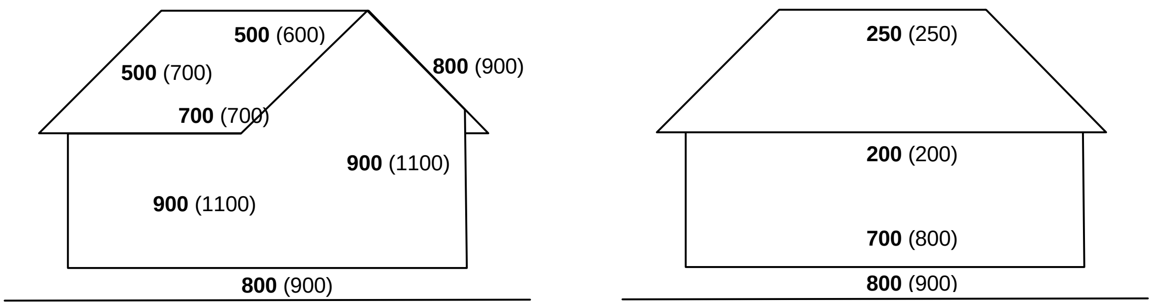

Fig. 7 Typical air temperatures on the outside of the building during flame exposure

(RHS: Front; LHS: Back; Peak values shown in brackets)

REFERENCES

BCA (2010) "Building Code of Australia", Australian Building Codes Board

Leonard, J. (2010) "Proposed Testing Methodology for a Whole of House Assessment for Flame Zone (BAL FZ) Equivalent Performance in AS3959-2009", CSIRO Sustainable Ecosystems

SA (2007) "Methods for fire tests on building materials, components and structures Part.8.1Tests on elements of construction for buildings exposed to simulated bushfire attack-Radiant heat and small flaming sources AS 1530.8.1" Standards Australia

SA (2009), "Construction of buildings in bushfire-prone area AS 3959", Standards Australia

BRIEF BIOGRAPHY OF PRESENTER

Ken Watson

Ken is the Executive Director of the National Association of Steel-Framed Housing (NASH)

Prior to joining NASH:

- Ken managed a large engineering fabrication business which fabricated galvanizing kettles and stainless steel tanks as well as undertaking a wide range of general fabrication work.
- Worked with the Structural Steel Development Group of BHP Steel in a number of roles including Manager, Research and Development Manager and Market Development Engineer
- Worked as a structural engineer in both the building and engineering construction markets.

Ken has a BE(Civil) from the University of Melbourne and a MEngSc from the University of Sydney and is a fellow of the Institution of Engineers.