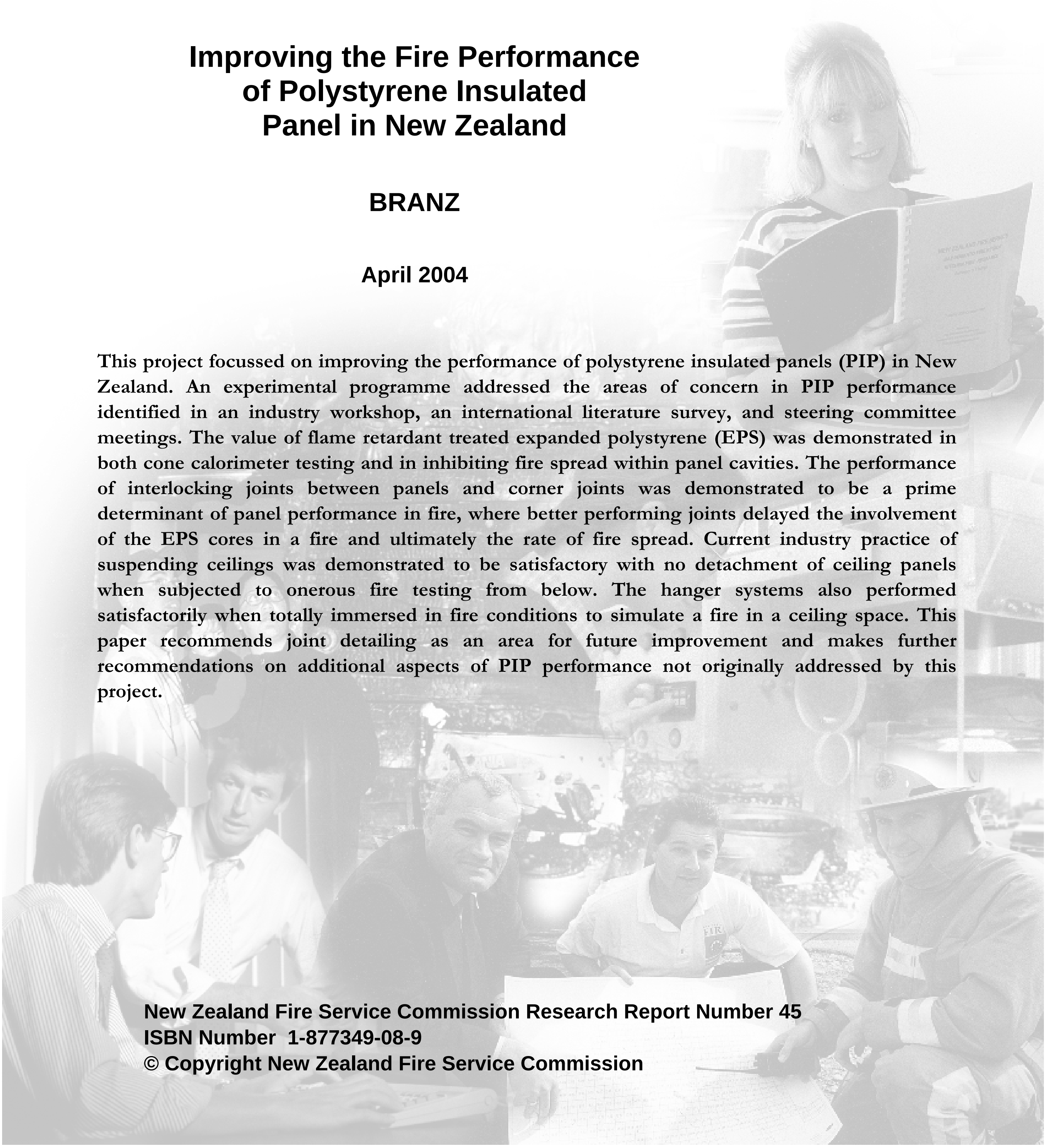
Fire Research
Report



Improving the Fire Performance of Polystyrene Insulated Panel in New Zealand

BRANZ

April 2004

This project focussed on improving the performance of polystyrene insulated panels (PIP) in New Zealand. An experimental programme addressed the areas of concern in PIP performance identified in an industry workshop, an international literature survey, and steering committee meetings. The value of flame retardant treated expanded polystyrene (EPS) was demonstrated in both cone calorimeter testing and in inhibiting fire spread within panel cavities. The performance of interlocking joints between panels and corner joints was demonstrated to be a prime determinant of panel performance in fire, where better performing joints delayed the involvement of the EPS cores in a fire and ultimately the rate of fire spread. Current industry practice of suspending ceilings was demonstrated to be satisfactory with no detachment of ceiling panels when subjected to onerous fire testing from below. The hanger systems also performed satisfactorily when totally immersed in fire conditions to simulate a fire in a ceiling space. This paper recommends joint detailing as an area for future improvement and makes further recommendations on additional aspects of PIP performance not originally addressed by this project.

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IMPROVING THE FIRE PERFORMANCE OF POLYSTYRENE INSULATED PANEL IN NEW ZEALAND

P C R Collier and G B Baker

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Preface

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P C R Collier and G B Baker

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ABSTRACT

This project focussed on improving the performance of polystyrene insulated panels (PIP) in New Zealand. An experimental programme addressed the areas of concern in PIP performance identified in an industry workshop, an international literature survey, and steering committee meetings. The value of flame retardant treated expanded polystyrene (EPS) was demonstrated in both cone calorimeter testing and in inhibiting fire spread within panel cavities. The performance of interlocking joints between panels and corner joints was demonstrated to be a prime determinant of panel performance in fire, where better performing joints delayed the involvement of the EPS cores in a fire and ultimately the rate of fire spread. Current industry practice of suspending ceilings was demonstrated to be satisfactory with no detachment of ceiling panels when subjected to onerous fire testing from below. The hanger systems also performed satisfactorily when totally immersed in fire conditions to simulate a fire in a ceiling space. This paper recommends joint detailing as an area for future improvement and makes further recommendations on additional aspects of PIP performance not originally addressed by this project.

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1. INTRODUCTION

Polystyrene Insulated Panel (PIP) has been used as a building material in New Zealand for over thirty years. The product consists of a core of expanded polystyrene foam (EPS) with light-gauge metal skins laminated to opposite faces creating a sandwich panel. PIP has many features, which make it ideally suited to applications in the New Zealand building industry such as coolstores, freezing works, lightweight cladding, food processing factories, the hospitality industry, etc. There is growing concern, however, about the fire performance of the material within New Zealand and overseas. The primary purpose of this research project was to thoroughly investigate the fire performance of PIP and identify changes to the way that the product is designed and/or constructed in New Zealand that will lead to an improvement in the current level of fire performance. The project included industry consultation, theoretical and experimental research and involved all the key industry stakeholders such as manufacturers, users, designers, fire engineers, the Fire Service, insurers, and regulators.

1.1 Background

The use of PIP as a building material in New Zealand is surprisingly widespread. The product has been manufactured in New Zealand for over 30 years and the current national production is estimated at approximately 750,000 m^2 per annum. The largest single project, for example a large cold storage facility, would require approximately 20,000 m^2 of the material, while at the other end of the scale, a freezer room in a fast-food outlet would require approximately 20 m^2. The types of buildings that PIP is used in are many and varied. The traditional applications are the primary export sector facilities such as freezing works and dairy factories. The product is also used, however, in applications that are not so immediately obvious. Every modern supermarket would have between 5 and 15 freezer and chiller rooms using PIP, while some even have PIP as the external cladding and roofing. A large proportion of the bars and restaurants in the hospitality industry have freezer and chiller rooms. The material is used extensively in the food industry where all manner of products are processed. PIP is even used in the construction of residential dwellings.

Although PIP has a number of performance features that make it the only practical choice in many situations, and hence an important and significant building material, the product does have one significant limitation – it does not perform well in some fire situations. A number of aspects of the fire performance of the product are not well understood. Research in the UK (Shipp et al., 1997; Harwood and Hume, 1997) has shown that there is no risk to building occupants, but rather to fire fighting personnel.

One aspect in particular that presents a danger to fire fighting personnel is the stability of suspended ceilings, a very common construction method in food processing factories. In the well-publicised Sun Valley fire, two fire fighters were killed by a collapsing PIP ceiling and rapid combustion of the large amount of foamed polystyrene and polyurethane core material (Cooke, 1997). Another example of the threat posed to fire fighters was the Ernest Adams fire incident (NZFS, 2000). One important aim of this project is to make recommendations on construction details, which provide greater levels of structural stability for PIP during fires. Solutions that result in smaller PIP fires will generally provide a greater level of safety for fire fighting personnel, thus achieving a reduction in social impact.

Examples of the perceived areas of concern in the market, when the product is involved in a fire are:

- effectiveness of suppression strategies
- fire growth and rapid spread

- the danger to fire fighters caused by structural instability as a result of support systems that are susceptible to fire damage and rapid loss of integrity when exposed to elevated temperatures
- greater chance of unseen fire spread in concealed spaces due to extensive use of suspended ceilings
- combustibility of the EPS core
- the density of the smoke produced
- environmental damage resulting from contaminated fire fighting water runoff.

Because of the widespread usage of the product, the issue of the fire performance of PIP is potentially a significant problem. Not only is a large quantity of the product manufactured each year in New Zealand, but there is a sizeable stock of existing buildings constructed from PIP.

Because the product is so widely used in the New Zealand building industry, and because it is important for both the local and export markets, PIP will continue to be used in significant quantities. In many situations, PIP is the only financially viable choice that exists in New Zealand currently.

Recent New Zealand research (Baker, 2002), while only dealing with very specific aspects of PIP fire performance, has nonetheless thoroughly surveyed the state-of-play internationally. Work has been done in Europe on product testing (Cooke, 1987; Parlor, 2000), but this focused primarily on reaction-to-fire testing which classifies the performance of different products, involving the insurance industry, regulators and testing agencies. A lot of attention is focussed on changing to non-combustible core materials. Such options are not yet economically viable in the New Zealand context, or do they deliver the full benefits that some claim. None of this research addresses ways of improving the performance of PIP by design and/or construction. The work that most closely aligns itself with this research project is contained in a European publication (IACSC, 1999) by the International Association of Cold Storage Contractors. The main deficiency of this particular document is that it contains a number of “good ideas” that have not actually been thoroughly validated by experimental research. New Zealand construction methods also differ significantly from those used in Europe.

This research project covers ground in a manner more relevant and comprehensive than has been attempted previously.

In summary, the primary reasons for conducting this research project are:

- the product is used in a wide variety of building applications in New Zealand.
- there are compelling reasons to continue using the product extensively in this country.
- a fire performance problem does exist but is not well understood.
- there are no practical solutions currently available to the New Zealand building industry.

1.2 Methodology

A fundamental cornerstone of this project was the industry-wide approach to achieving successful outcomes by involving all the stakeholders in the process.

A steering committee was established at the outset of the project to oversee the research. Representation on the committee was from the three organisations funding the project, namely Plastics New Zealand, the New Zealand Fire Service, and BRANZ Limited (representing the Building Research Association of New Zealand) and an additional representative from the insurance industry was co-opted onto the committee after the initial meeting.

The project was divided into six distinct phases.

1.2.1 Phase one – industry workshop

A workshop was held to bring together all the relevant stakeholders, with representation from manufacturers, designers, product end-users, the Fire Service, regulators, insurers, fire engineers, and contractors etc. The purpose of the workshop was to clearly establish the key fire performance issues that affect the stakeholders, and hence the general direction that the research program would take.

1.2.2 Phase two – international literature survey and NZBC requirements

The second stage of the overall project involved a detailed survey of research that exists internationally. The purpose was to establish what is relevant and can be used in the New Zealand context, and to ensure that the proposed New Zealand research does not repeat what has already been done overseas. The current fire safety requirements for PIP in the NZBC were evaluated. A paper was prepared summarising the results of this desktop research, and this information was then circulated to the steering committee.

1.2.3 Phase three – develop New Zealand strategy

Based on the steering committee recommendations a coherent strategy that addressed the key fire safety issues that applied in the New Zealand context was developed. This phase of the project identified construction methods that were likely to have the greatest chance of successfully achieving the aims of the project. A strategy paper was prepared and circulated to the participants of the industry workshop and other stakeholders in general for comment and feedback.

1.2.4 Phase four – stakeholder signoff

Refinements were made to the content of the strategy document based on the responses from the stakeholders. The steering committee then identified which of the solutions proposed were worthy of further investigation in the laboratory.

1.2.5 Phase five – experimental research

An experimental research programme was developed to subject a number of PIP configurations to various forms of reaction-to-fire and fire resistance testing. The purpose of such testing was to identify effective ways of improving the fire performance of the product as it is used to construct PIP buildings.

1.2.6 Phase six – final recommendations

The final stage of the project was to prepare a New Zealand Fire Service Commission (NZFSC) Research Report detailing the findings of the research and giving recommendations that can be adopted by the industry. This report also makes recommendations on further areas of research.

2. INDUSTRY WORKSHOP

Prior to the literature survey the industry workshop was held to get a wide cross-section of industry input into identifying the key issues relating to the fire performance of PIP. The information gathered at the workshop was subsequently used to define the direction of the project.

The workshop consisted of presentations from six guest speakers and two group breakout sessions for workshop participants to discuss issues raised by the presenters, each followed by a formal question session for the presenters.

2.1 Issues identified

The following list summarises the major issues identified at the workshop:

- Testing Methods

  A need to establish a realistic test appropriate to PIP. The 10 min FRR test based on AS1530.4 needs to be seriously reviewed.

- Design Methods
  - need to advance towards an industry standard and design methods/code of practice to make PIP more acceptable
  - need harmonised solutions
  - take a close look at UK code of practice
  - are dependent on research and tests applicable to materials.

- Delamination of skins

  Delamination happens at 150-200ºC when adhesive fails and is independent of core material.

- Fire fighting
  - reluctance of Fire Service to enter (PIP) burning buildings, except for rescues
  - way-finding difficult due to dense smoke
  - delamination and falling panel skins a hazard

  New Zealand Fire Service is pleased with evacuations, only one death recorded, Gear meats' fire in 1970's.

- Causes of fire
  - hot work
  - hot process, such as cooking etc
  - electrical faults
  - fabric of building is seldom the first item ignited.

- Sprinklers
  - are very effective, even in high buildings with rack storage
  - with dry systems in low temperature buildings there is a slight time delay
  - sprinklers protect contents and control the incident.

- Insurance
  - building use and potential causes of fire are less influential factors than the level of fire protection in determining risk
  - concern that all PIP buildings are lumped into one category
  - a variety of factors are considered, all PIP buildings are lumped into one category, and each case is taken on its merits
  - classification of building material is becoming important in determining risk/rates
  - New Zealand is in an advantageous position to influence the (world) insurance market, by developing improvements in EPS systems etc.

- Fire behaviour
  - PIP constructed buildings are unique in providing a 'highly insulating', 'low thermal inertia' envelope for specific use buildings characterised by an absence of venting
  - the nature of the building envelope is responsible for rapid temperature rises and heat containment in the event of fire, which to a certain extent negates the flame retardant properties of the EPS
  - the containment of heat and smoke density make fire fighting difficult, generally resulting in a total loss of the building
  - there is no credible evidence of fire growth within the EPS itself; it is the heat containment and high temperatures that cause the EPS to burn, releasing large quantities of smoke.

- Environmental
  - smoke production is the main pollutant where the EPS core, the laminating adhesive, and paint coatings are the major sources, with an infinitesimal contribution from the flame retardant in the EPS
  - contaminated water run off is of less significance and the volume is of as much concern as the pollutants it contains.

These topic areas identified at the workshop were subsequently consolidated down into five general areas that were relevant to the scope of the project, as follows:

Adequacy of current NZBC requirements for PIP
Design/construction methods to improve fire performance
Fire fighting issues
Fire behaviour of PIP
Environmental issues.

These five areas were then used as the basis for the second stage of the project, the literature review phase.

3. LITERATURE SURVEY

3.1 International literature survey

The international literature review primarily focused on material sourced from fire journal articles, research reports, industry associations and other literature reviews. The internet was searched to gain an appreciation of the more current developments that may not have yet reached the print media.

The objective of the literature review was to define a platform from which to begin developing a strategy for addressing the problem as defined in New Zealand and designing an experimental programme specifically for advancing solutions in the New Zealand context.

3.1.1 Design and construction, fire fighting and fire behaviour issues

The International Association of Cold Storage Contractors (IACSC, 1999) makes a variety of recommendations in their publication Guidelines for the design, specification, construction, maintenance and fire management of insulated envelopes for temperature controlled environments. The IACSC document covers a number of areas relevant to this project.

In understanding the causes of fire, 50% of fires are caused by arson external to the building, with the majority of the remainder caused by electrical faults, hotwork, cooking, and the build-up of combustible residues in ducting.

The addition of non-combustible material in and around PIP joints is considered a positive step towards preventing fire spread. It is also recommended that damage caused to PIP that exposes the combustible core be repaired as soon as possible.

Typically, PIP buildings do not have windows and are under ventilated. Major fires are therefore usually ventilation-controlled, making fire fighting difficult. This restricts normal routes by which water would usually be directed at fires and, because of the smoke contained, visibility is restricted. If a partial collapse then occurs by falling panels, and ventilation is increased, volatile gases can burn and return the fire to a fuel-controlled condition thus increasing the temperature, which then makes the fire harder to extinguish. Often fire in these types of buildings will burn until the combustible contents are almost completely consumed.

Various improvements in design and/or construction are suggested:

- more secure joint design and security of internal linings of the ceiling panels
- fire stops/breaks in panels to inhibit fire spread in panels
- positive fixing of lower facings is considered a primary solution
- knock out panels to assist ventilation and entry for fire fighting, but this raises security issues.

In another report commissioned by the UK Mineral Wool Association (Eurisol), Dr Gordon Cooke (2000) considers fire safety issues and implications for the risk assessment process. Cooke’s report considers recommendations in the IACSC (1999) Guidelines and other publications, which are highlighted as follows:

- iIn recommending fire stops/non-combustible fire breaks in panels to inhibit fire spread, there is no clear test data evidence that these behave satisfactorily in fire

- it is possible that a plastic foam insulation can achieve a good fire test result but still be an extreme hazard
- the fire behaviour of combustible cored sandwich panels depends on the behaviour of the facings, joints, and core material. The ISO 9705 (ISO, 1993) room corner test is a realistic fire scenario to assist in evaluating panel behaviour
- if it were possible to hermetically seal the core material between steel faces, and it remained so during fire, the combustible material would decompose by pyrolysis and if contained would add little hazard to the fire. In reality the fire is likely to cause distortion of the steel panels and allow the molten material to become involved in the fire
- vertical transport of the pyrolysis gases within panels to exit some distance away from the fire in an upper storey or another part of a building is another hazard. Methods of testing this mode of smoke transport are proposed. Fire stopping seals could provide protection against transport of the pyrolysis gases and be the subject of a proposed test method.

Cooke also describes the factors that affect fire severity:

- the insulation effect of steel skinned sandwich panels only result in slightly higher temperatures, compared with drywall systems, and may not significantly affect flashover
- delamination of the panel facings is considered a more significant factor in the fire severity as the panel core is then exposed and contributes to the fire load, temperatures, and hazard
- heat balances show that the heat losses to the enclosure by radiation and conduction are minimal (30% or less) compared with losses due to escaping gases (50-60%)
- ISO 9705 room corner tests demonstrate flashover; other test methods seem to be biased against flashover, being open-sided rigs that do not contain the heat to the same extent.

A significant conclusion made by Cooke is that combustible wall and ceiling linings can lead to flashover. It therefore follows that if the metal faces of PIP become detached, the potential for severe flashover exists, similarly with the opening of joints. This is in addition to the simultaneous hazard of the falling panel skins.

3.1.2 Health and environmental issues

The health and environmental issues associated with PIP can be divided into two areas of consideration, namely the direct effect on human health of smoke from burning the combustible expanded polystyrene (EPS) core of PIP, and the general pollution risk from smoke and water runoff that result from fire fighting operations involving PIP building fires.

'The Internet Journal of Rescue and Disaster Medicine' (Heikki Savdainen, 1999) examines the effects of smoke from burning polystyrene and polyurethane on humans as follows-: The fire and smoke toxicity from polystyrene is mainly due to the carbon monoxide (CO) given out from the material, while the health effects of smoke particles from polystyrene are assessed to be less harmful than smoke from wood, cork, leather, or rubber. The toxicity of polyurethane adhesive is more severe releasing CO and cyanide (HCN) and is limited by the thinner layer of the glue line on each face, but it still has the potential to cause longer term respiratory problems. This necessitates special treatment facilities and strategies, as long-lasting bronchial hyper-reactivity may result from exposure to fire smoke.

Technical information from the company that originally developed EPS, BASF (1995), states that the products of combustion of EPS formed in the event of fire do not differ very much from the fumes given off by other organic materials. They consist predominantly of CO_2 and H_2O. They also contain CO and soot depending to an extent on the conditions of burning. In addition, traces of hydrogen bromide (HBr) occur in the fumes given off by flame-retarded EPS.

The BASF literature also states that in the event of fire, no risk, or hazard to the environment by toxic fumes or risk of contaminating water may be expected. The gaseous products of combustion are comparable to those that are given off by wood-based materials. Slight traces of hydrogen bromide, which is precipitated by water used for extinguishment, may find its way into natural water courses can be regarded as harmless. Brominated dioxins were not detected either in the gas phase or in the fire residues in various experiments. All that was detected were small amounts of brominated furans, which do not fall under prohibited chemical ordinances.

3.2 New Zealand experience

Historically in New Zealand, insulated panel with a non-EPS core has only rarely been used. Periodically, major fires occur in PIP buildings and a pattern similar to the UK experience is evident. A comprehensive New Zealand Fire Service (NZFS, 2000) report on the Ernest and Adams Ltd fire in February 2000 confirms the areas of international concern. The initial conclusions from the Ernest and Adams Ltd fire report are as follows:

- early involvement of the steel-clad polystyrene building panels which represented the bulk of the available fuel
- extensive fire involvement and spread through a concealed space between the ceiling and the roof
- absence of fire resistant separations or automatic fire extinguishing equipment to slow or restrict the fire spread
- specific training for fire fighters in the risks and hazards of fire fighting in PIP buildings is required
- a high degree of compartmentalisation with many internal partitions and a large uncompartmented ceiling space were factors in the difficulty in fighting the fire
- the ceiling panels delaminated and fell at a relatively early stage of the fire. The failure of nylon bolts, specified for insulation purposes, was a primary factor
- polystyrene contained within the sandwich panels vaporised and increased in pressure on heating and may be forced through any joints or penetrations as a highly flammable gas and contributed to fire spread within or external to the panels.

Specific recommendations from the NZFS report on the fire at Ernest and Adams Ltd (NZFS, 2000) are summarised as follows:

- A Fire Service code of practice be drawn up to assess the hazards in all buildings where PIP is one of the main construction materials
- the attachment mechanism for joining the sandwich panels together or to support the structure be re-examined, especially under fire conditions. The predominant use of nylon bolts is questioned
- dynamic fire-ground assessment of buildings of this type is required when responding to an emergency – especially the entry into concealed spaces
- good practice is required for the elimination of unprotected penetrations, which pass through the core of a sandwich panel

- adoption of mandatory analogue addressable heat and smoke detectors for providing accurate, reliable and quick detection of any fire in buildings constructed from these type of materials is necessary
- a fire resistant internal lining on PIP such as gypsum board to insulate it from the heat of fire is desirable
- a thermal imaging camera could be an invaluable tool for locating heat sources and hot spots.

3.3 Analysis of New Zealand Building Code requirements

The current requirements of the Approved Documents for the Fire Safety Clauses of the New Zealand Building Code (NZBC) (BIA, 2001) that relate to PIP have some shortcomings. The test method specified requires that the flame barrier assembly be subjected to the same conditions as the standard fire resistance furnace test (SA, 1997) for a period of 10 minutes. At the completion of the test, the exposed face of the flame barrier is inspected. The flame barrier is considered to have passed the test if no cracks, openings or other fissures have developed, that would permit vision through the flame barrier or joint. Inspection of the assembly may be made during the process of a longer duration test if an adequate assessment can be made of the heated face of the specimen after 10 minutes duration. In the case of a fire barrier protecting EPS, it is not possible to see into the furnace during a test due to the dense smoke that has evolved. At the conclusion of the test at 10 minutes, the specimen is removed and the smoke cleared by compressed air before an inspection of the fire exposed face.

The shortcomings of the test method are in relation to flame barriers protecting the combustible EPS core. The purpose of such flame barriers is to protect the EPS from ignition. The metal skin of PIP functions as the flame barrier. However, it is not the EPS burning that is the problem. It is the gases evolved and escaping from the containment of the barriers that create the hazard. These gases burn and produce dense smoke.

BRANZ experience of this test method is highlighting difficulties and deficiencies in determining a pass or fail. For example, a particular joint design may be included in two locations at opposite ends of a specimen, one is deemed to pass and the other to fail on the basis of the gaps formed. This problem may arise where the exposure conditions vary for different locations in a furnace, especially with the practical difficulties of ensuring the exposure is exactly to the prescribed fire exposure conditions in the first 10 minutes when conditions are unstable, and the combustion of the gases evolved from the pyrolysis of foamed plastic may be causing localised temperature excursions. Another practical issue is that while smoke is being cleared to permit the specimen to be examined, further movement of specimen joints occurs. It then becomes difficult to accurately assess the pass/fail criteria specified in the NZBC Acceptable Solution, C/AS1.

3.3.1 A new test method

As well as practical issues associated with determining whether a specimen has passed or failed the current flame barrier test procedure, there is general concern that the AS 1530.4 (SA, 1997) test method is not representative of realistic fire exposure for PIP. The significant features of fire involving PIP are as follows:

- delamination of metal facings of the barriers especially from ceilings creates a falling hazard and exposes additional fuel increasing severity of the fire
- dense smoke makes vision in fire spaces difficult and has an impact on fire fighting and rescue

- the very effective insulation property of the product and lack of ventilation openings are a disadvantage in fire, because the heat is contained within a building envelope, resulting in higher temperatures and a more rapid fire growth
- dense smoke and water run off from fire fighting are environmental issues.

The adoption of an effective test method that can be referenced by regulatory authorities or used as a specification for an Alternative Solution is a longer term objective. The test method will need to evaluate the performance of flame barriers for foamed plastics, where the issues of fire spread and smoke development are the principle criteria.

Delamination of the panel skins has also been identified as a major hazard, both from a falling hazard and then the exposure of additional fuel for the fire. A test method that evaluates the security of fixing the underside of long spans of panels is a priority. The advantages of the ISO 9705 (1993(E)) room corner fire test method in simulating flashover conditions, thus providing a sufficiently severe test, should also be incorporated.

3.4 Summary and conclusions of literature survey

Several key features and trends have become evident in the literature survey that are common to international and New Zealand experiences alike. Some of the findings are contradictory however, for example, the proposal that joint design including fire stops will limit fire spread within panels is questioned by some anecdotal evidence. There is disagreement among experts as to whether fire will actually spread in the cavity between the metal skins. But, there is general agreement that because of the typical layout of buildings constructed from PIP, fire can spread within concealed spaces making fire fighting difficult because the fire is unseen and can appear at unexpected locations. Proposing a test method to evaluate the internal spread from panel to panel may not actually achieve any tangible benefit. Also the assumption that the highly insulating nature of the polystyrene cored panels retains heat within a building envelop is refuted by some studies, offering the lack of ventilation as the reason for rapid heat build-up, coupled with the exposure of additional fuel to the fire as panel skins become detached.

The implementation of risk assessment techniques specifically developed for PIP buildings offers a retroactive measure for existing buildings. To develop such techniques further, more knowledge is required of the fire behaviour of the product; in particular, what are the significant high risk features as opposed to other less significant features. This also flows onto the concept of dynamic risk assessment at the fire scene where decisions can be made on the basis of the likely development scenario. Such decisions may range from the current perceived notion of letting the fire burn, to a more aggressive but safe means of containment, extinguishment and rescue operations if required. Fire fighter training specifically aimed at PIP buildings coupled with an assessment of the risks and general features of each individual building, on a region by region basis, will be a valuable resource for a dynamic risk assessment should the need arise.

The significant trends from the literature survey which are relevant to the scope of this project are summarised as follows:

- assuming that in New Zealand new construction is likely to be with PIP containing EPS and combined with the existing building stock, then investigating possible ways of managing the risk with EPS, as opposed to introducing alternative core materials for insulated panel construction, will be a worthwhile part of this project
- it is worth investigating ways of improving the fire performance of panel joints, but significance at this stage is not quantified
- secure fixing of lower panels to prevent delamination of skins exposing the panel core to fire and creating a falling hazard is considered very important

- the fire behaviour of the combustible cored sandwich panels depends on the behaviour of the facings, joints and core material. The ISO 9705 room corner test is a realistic fire scenario to assist in evaluating panel behaviour
- if it were possible to hermetically seal the core material between steel faces and it remained so during the fire, the result would be that the combustible core material would decompose by pyrolysis and, if contained, would add little hazard to the fire
- fires in typical cool stores and PIP buildings are ventilation controlled, thus making fire fighting more difficult and the fire tends to burn longer and at higher temperatures as heat loss by escaping gases is limited
- the insulating effect of PIP is of minor significance in containing the heat, especially once the EPS core has melted and the heat is able to transfer across the cavity between the steel skins
- fire fighting strategies based on a dynamic risk assessment at the fire scene offer a last line of defence and will enhance fire fighter safety
- there is concern that the current test method used to assess 10-minute flame barriers for PIP is not realistic.

4. EXPERIMENTAL

4.1 Strategy

A draft strategy paper was prepared and circulated to industry for their comment. From the strategy paper (see Appendix 1), four areas were identified for experimental investigation. The following experimental programme was developed by the steering committee to address the four areas identified.

4.1.1 Fire performance characteristics

Cone calorimeter testing of flame retardant (FR) and non-flame retardant (NFR) PIP samples with variable radiation levels and duration determined critical ignition fluxes. The ignition characteristics of EPS in a molten state, including the effectiveness of FR treatment when the EPS is molten, will be useful data in evaluating the effectiveness of other protection measures such as the importance of containing the EPS within the panel.

4.1.2 Fire spread in cavities

It was proposed that full-scale PIP specimens be subjected to a fire source where flames directly impinge upon the core of the sample. Measurements were taken to monitor how susceptible the specimens are to self-sustaining fire spread.

4.1.3 Core involvement in fire growth

It was proposed that various joint configurations be tested to ascertain the effectiveness of various methods for minimising core involvement, as well as monitoring fire growth and smoke production.

4.1.4 Structural collapse

It was proposed that PIP ceiling specimens, complete with proprietary suspension systems, be subjected to realistic fire exposure conditions in the BRANZ full-scale furnace. Variable levels of load were applied to the ceiling to test the effectiveness of the suspension systems.

4.2 Cone calorimeter testing

The objective was to evaluate the ignition characteristics, at different radiation fluxes, configurations, and durations, of EPS. Five different sample variations were prepared; FR treated and NFR, with and without the steel flame barrier skin and the inclusion of 4.5 mm cement board between the EPS and the steel skin. The steel skin used the version used on ceiling panels (CP) with polyester paint coating. The nominal dimension of the samples were 100 x 100 x 25 mm x 20-22 mm depth for the EPS with the addition of the 0.6 mm steel skin and 4.5 mm fibre-cement board where included.

The cone calorimeter measures the oxygen consumption, mass loss, smoke, and time to ignition of the samples. The mass loss rate is required to calculate the heat release rate.

Table 4.1 shows the cone calorimeter tests conducted in order to capture the critical parameters and determine where there was a significant change in the measured values. This was intended to address the issues of the ignition characteristics and demonstrate the value of FR treated EPS.

Table 4.1: Schedule of cone calorimeter testing.

Specimen type	FR-S	FR-N	NFR-S	NFR-N	FR-S-FC
Radiation, kW/m^2					
15			1	1	
20			1	1	
25	1	1	1	1	
26	1	1			
27.5	1	1			
30	1	1	1	1	1
40					1
50	1	1	1	1	1
60					1
75					1

Key to specimen types:

FR = flame retardant treated EPS
NFR = non-flame retardant treated EPS
S = covered will steel skin
N = not covered with steel skin
FC = a layer of 4.5 mm fibre-cement board between the EPS and the steel skin
1 = the number of samples tested

4.2.1 Cone calorimeter results

Typical observations of the samples followed a similar pattern. The samples without the steel skin melted and receded away from the cone forming a pool of molten EPS, which depending on the heat flux level would either ignite or just evaporate and evolve smoke without ignition. In the case of the steel skinned samples, the same melting occurred at a slower rate forming a pool of molten EPS under the skin, and if the heat flux was above the critical level, ignition would occur. For the samples with the fibre-cement board a greater heat flux was required to achieve ignition.

The results are presented in Table 4.2, Table 4.3, Table 4.4, and Table 4.5 and graphs of the results are shown in Figure 4.1, Figure 4.2, Figure 4.3, and Figure 4.4. The more significant parameters are time to ignition and total heat release, peak heat release is inconclusive. This is due to some spikes/peaks and these correspond to the critical heat flux and a difficulty in establishing the transition to burning when an initial burning self extinguishes and then re-ignites, maybe more than once. Other inconsistencies were observed and a particular example is illustrated in Table 4.3 for the peak heat release rate where the result for a heat flux 30 kW/m^2 is greater than for 50kw/m^2. In the case of the 30kW/m^2 exposure there was minimal burning around 20 kW/m^2 for about 400 seconds and then a narrow spike of short duration in the peak heat release of 217 kW/m^2 and then extinguishment. By comparison, the heat release rate in for a heat flux of 50kW/m^2 increased steadily to a peak of 97kW/m^2 and then reduced such that the total heat releases for the 30 and 50 kW/m^2 exposures are very similar. The average smoke extinction area as a measure of the smoke evolved is similarly inconclusive.

Table 4.2: Time to ignition, seconds

Specimen type	FR-S	FR-N	NFR-S	NFR-N	FR-S-FC
Heat Flux, kW/m^2					
15			1400	624	
20			1000	193	
25	1000	1000	335	109	
26	1000	177			
27.5	128	115			
30	176	120	156	78	1000
40					236
50	83	37	68	26	198
60					156
75					135

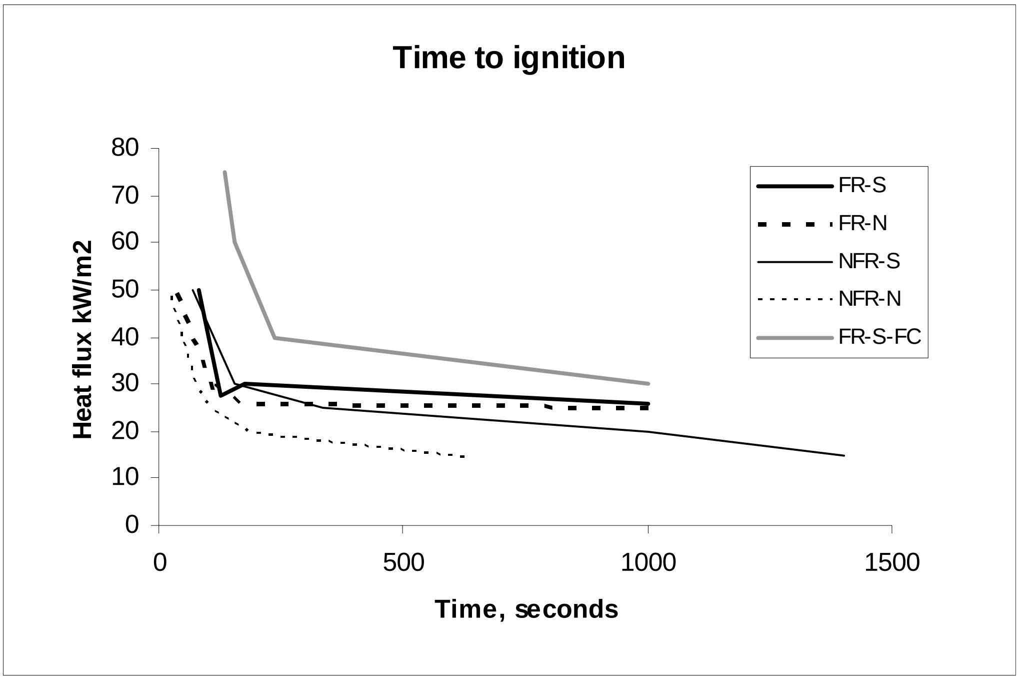

Figure 4.1: Critical heat flux, time to ignition.

Table 4.3: Peak Heat Release Rate, kW/m^2.

Specimen type	FR-S	FR-N	NFR-S	NFR-N	FR-S-FC
Heat Flux, kW/m^2					
15			2	289.5	
20			4.3	295.5	
25	4.8	3	278	334.3	
26	2.3	179			
27.5	6	197.9			
30	217	193.4	330	319.7	1.9
40					64.8
50	97	305.6	476.7	507.3	76.5
60					91.3
75					144.6

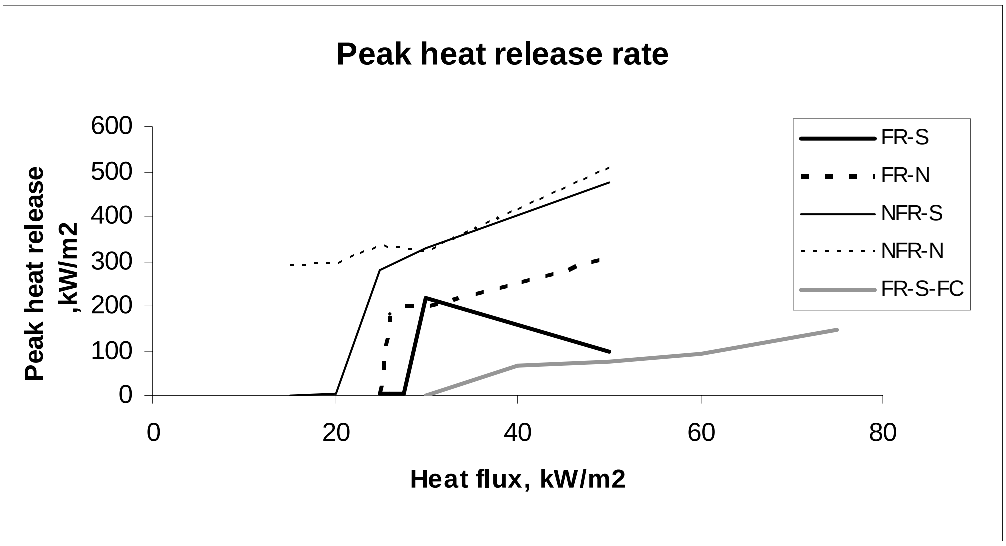

Figure 4.2: Peak heat release rate.

Table 4.4: Total Heat Release, MJ/m^2.

Specimen type	FR-S	FR-N	NFR-S	NFR-N	FR-S-FC
Heat Flux, kW/m^2					
15			0	11.3	
20			0.9	13.5	
25	0.1	0.2	15.3	17.5	
26	0.1	13.4			
27.5	0.4	15.9			
30	17.2	15.4	17.37	16.4	0
40					24.1
50	18.6	14.9	17.3	16.9	20.2
60					26.8
75					25.9

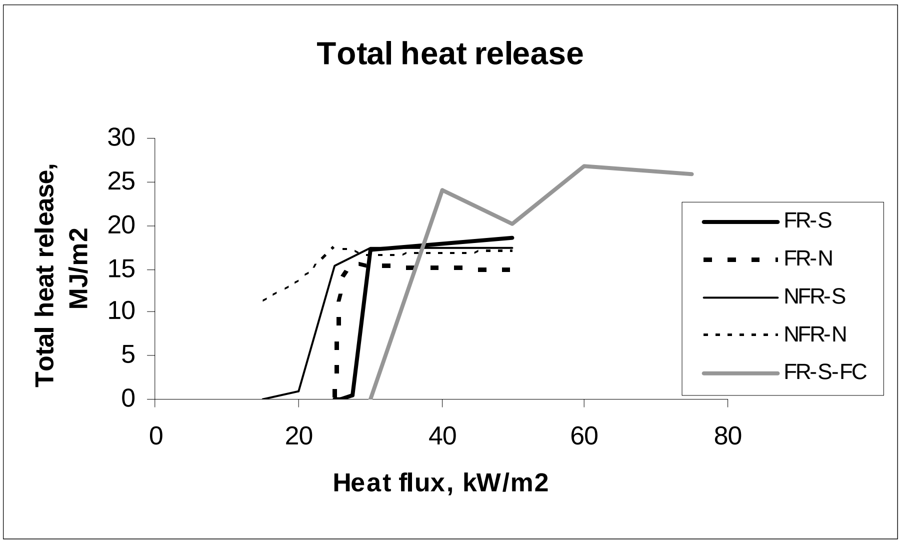

Figure 4.3: Total heat release.

Table 4.5: Average Smoke Extinction Area, m^2/kg.

Specimen type	FR-S	FR-N	NFR-S	NFR-N	FR-S-FC
Heat Flux, kW/m^2					
15			110	1139	
20			870	1255	
25	692	842	1232	1273	
26	598	1254			
27.5	1243	1424			
30	1029	1351	1009	1261	382
40					351
50	1004	1394	977	1174	609
60					469
75					559

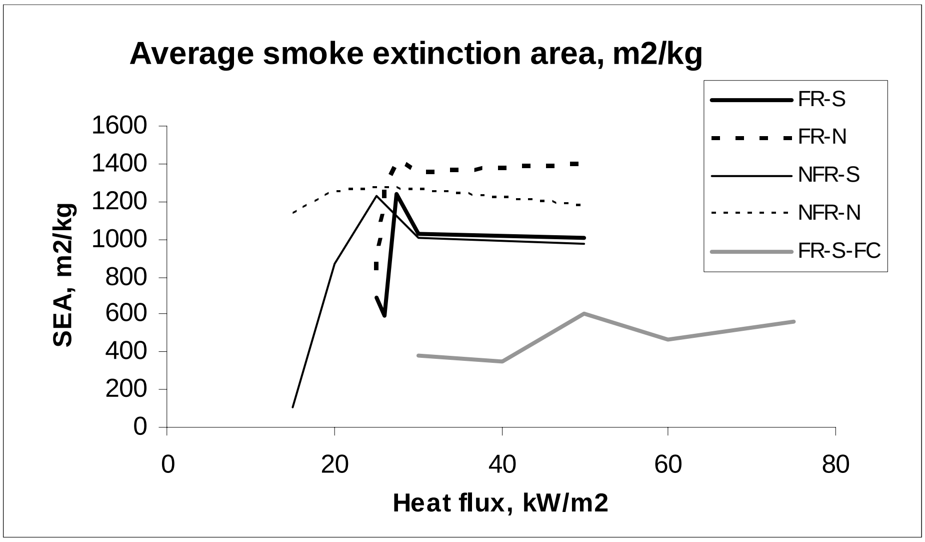

Figure 4.4: Average smoke extinction area.

4.2.2 Discussion of cone calorimeter results

Critical ignition fluxes were identified demonstrating the value of FR treatment of EPS and steel skins. Additional trials indicated that a layer of fibre-cement board between the steel skin and the EPS similarly increased the time to ignition.

The total heat release of the samples was consistent with the heat of combustion of the EPS provided the critical heat flux was exceeded. For the samples protected by a steel skin the total heat release was marginally higher, perhaps due to the contribution of the adhesive. For the samples with the additional protection of the fibre-cement board, the total heat release was highest consistent with a double layer of adhesive.

The cone calorimeter testing confirmed the superior performance of FR treated EPS compared with standard grade EPS. The attachment of steel skins also improved the performance. The addition of the fibre-cement board was shown to improve the performance markedly.

4.3 Fire spread in cavities

This phenomenon is defined as self sustaining combustion that occurs in the cavity between the metal skins of PIPs when the EPS core has melted in a fire. There is considerable disagreement within the industry and published literature as to the significance of this problem and this experimental phase was designed to demonstrate the behaviour of the panel core.

Three experiments were conducted as described in Table 4.6, the panels comprised a 100 mm thick FR treated EPS core between 0.6 mm colour steel sheets. A 200 mm x 200 mm hole was cut in the panel skin to simulate a service opening such as a light fitting or accidental damage to a panel by forklift or deliberate damage such as in an arson attempt. Two of the specimens were mounted in a vertical orientation to simulate a wall and the third one was mounted horizontally to simulate a ceiling. Each test panel contained a standard interlocking joint between the two 1200 mm wide sections making up the 2400 mm total width. The joint was not riveted. The perimeter of each panel was capped with aluminium channel 100 x 25 x 1.6 mm and secured with 4.8 mm diameter aluminium rivets at 200 mm centres. The interlocking joint and perimeter capping were sealed with a refrigerant grade silicone sealant.

In each case, a gas burner was placed against, or under (in the case of the ceiling), the hole to initiate and sustain combustion. Each panel specimen was positioned under an exhaust hood to collect the combustion products for analysis. Thermocouples were installed within the cavity at a middle depth of 50 mm in a 600 mm x 600 mm grid pattern as illustrated in Figure 4.5 to record the progression of the melting and then combustion of the EPS core. The same nominal 600 mm x 600 mm grid pattern was retained for the horizontal trial, although the panel was shortened from 4000 mm to 2900 mm.

Table 4.6: Cavity fire spread trials

Trial number	Panel dimensions, mm	Fire exposure
Trial 1, wall	4000(h) x 2400 x 100	(a)(1)
Trial 2, wall	4000(h) x 2400 x 100	(a)(2)
Trial 3, ceiling	2900 x 2400 x 100(h)	(b)(3)

Notes:

(a) A 200 x 200 hole was cut in the panel and the gas burner was placed at the bottom edge of the hole at 350 mm height. The horizontal location of the hole and burner was in the centre of the 1200 mm wide left hand panel section to avoid direct flame contact on the panel interlocking joint.

(b) For the horizontal specimen the gas burner was placed at a distance of 850 mm below the 200 x 200 mm cut out. The location of the hole and burner was in the centre of a 1200 mm wide panel section to avoid direct flame contact on the panel interlocking joint.

(1) 40 kW for 60 minutes.

(2) 100 kW for 10 minutes, 200 kW for the next 10 minutes, and 300 kW for 40 minutes up to 60 minutes.

(3) 100 kW for 10 minutes, 200 kW for the next 10 minutes, and 300 kW for 10 minutes up to 30 minutes.

The fire exposure of the wall in trial 1 was intended to simulate a minimal exposure to establish a lower bound in the first trial to see if any ignition was self-sustaining should it occur. Then on the basis of the first result, the second trial was intended to subject the panel to a stepwise increasing exposure up to a maximum of 300 kW to determine if cavity spread could be initiated. The third trial, on the ceiling, repeated the same exposure as trial 2 but was stopped after 30 minutes as the EPS had been substantially consumed.

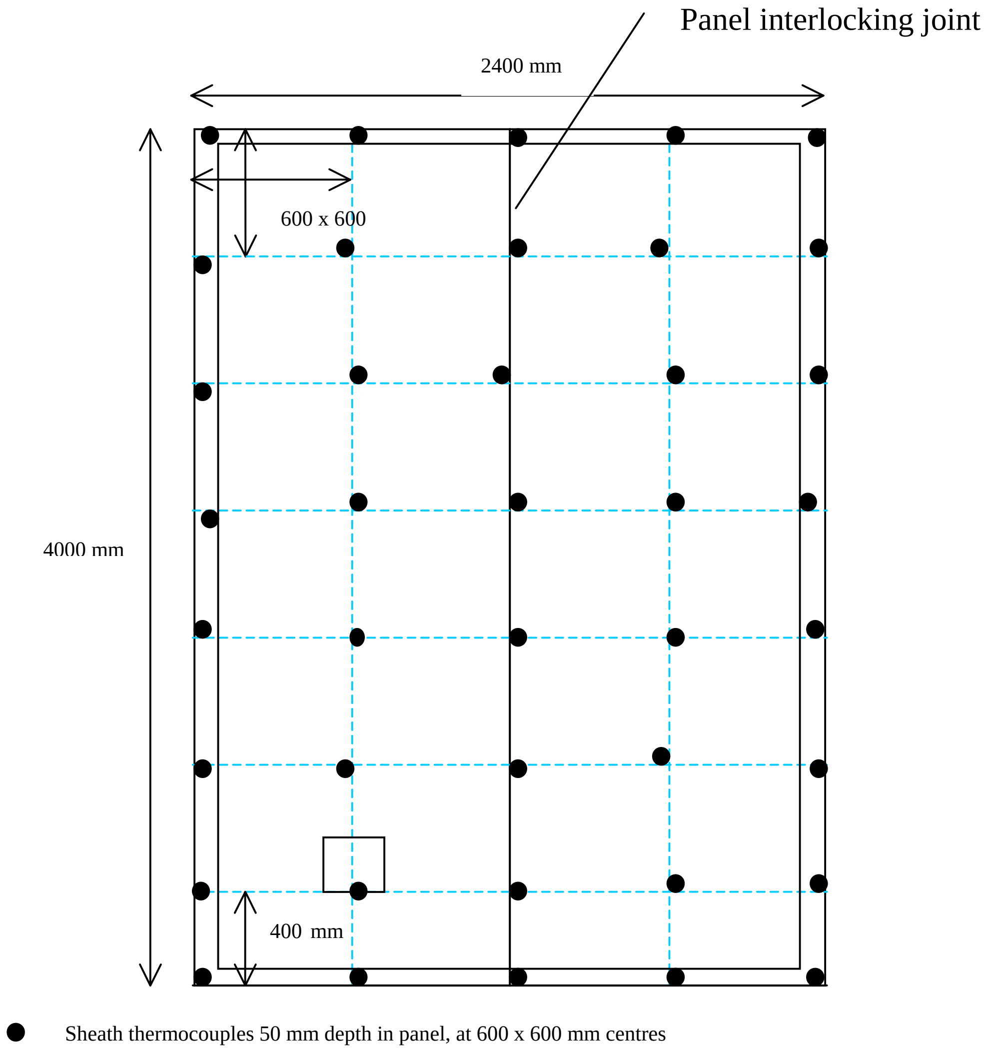

Figure 4.5: Vertical panel instrumentation.

Figure 4.6: Vertical panel for trial 1 and 2 to evaluate fire spread in cavities.

Figure 4.6 illustrates the 4000 mm high vertical panels used for trials 1 and 2, showing the 170 mm x 170 mm burner and a 200 mm x 200 mm hole in the panel skin. The horizontal tubes above the burner contain sheath thermocouples at 600 mm intervals, coinciding with the height of the thermocouples inside the panel, to record the flame temperatures that the panel is exposed to.

4.3.1 Trial 1 vertical panel – commentary and results

In trial 1 the 40 kW exposure was intended to show whether low level heating would initiate fire spread within the panel. Only minimal melting within the panel resulted in a loss of about 35% of the panel core in 60 minutes, as shown in the contour map in Figure 4.7 based on interpolated thermocouple temperatures. The light grey region shows the extent of melting of the EPS core and it is assumed that the molten/liquid flowed downward toward the flame and ignition source at the opening where some burning occurred heating the panel internally. At the conclusion of the trial, no appreciable fire spread within the panel beyond the heated zone was evident.

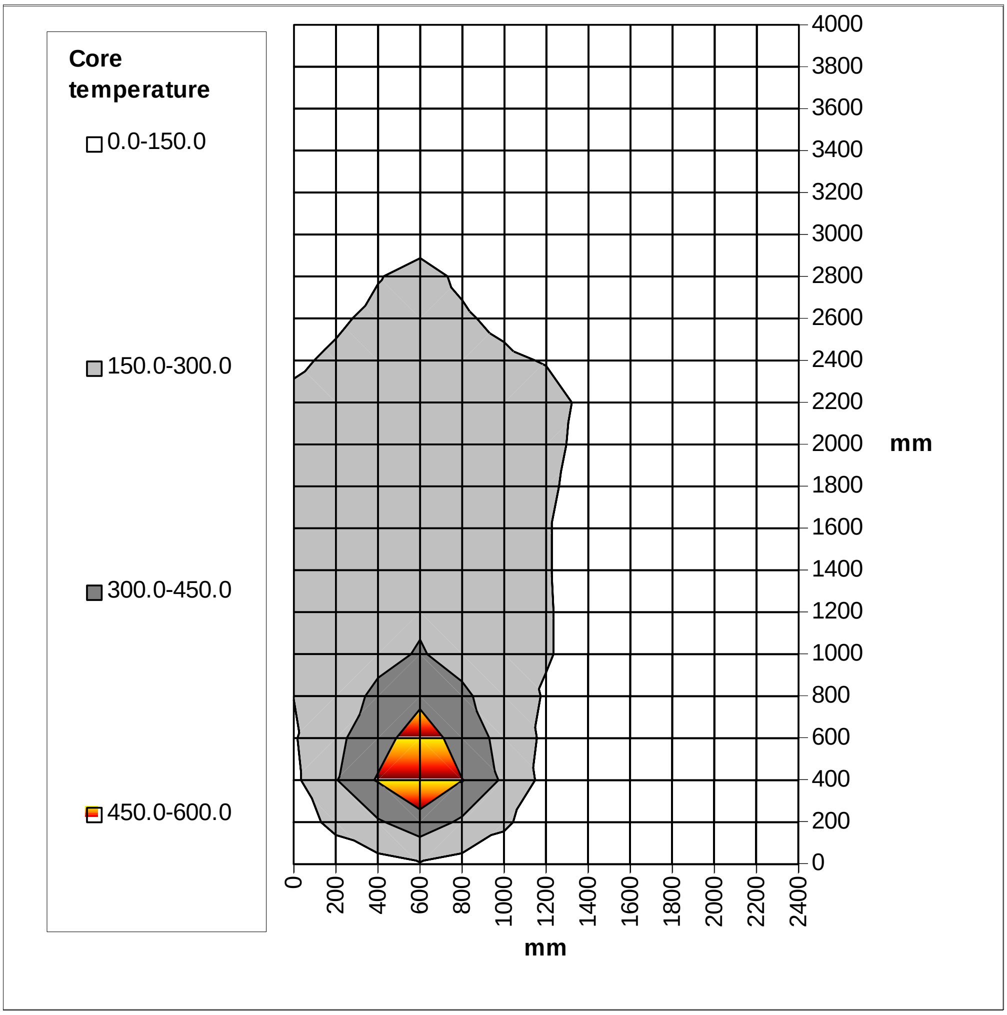

Figure 4.7: Temperature contours after 60 minutes exposure at 40 kW in trial 1, EPS core 35% melted.

4.3.2 Trial 2 vertical panel – commentary and results

In trial 2 with the same specimen configuration, the fire exposure was increased in 100 kW increments at 10-minute intervals to 300 kW and remained at that level until 60 minutes had elapsed.

After 10 minutes exposure there were no visible signs of fire spread or heating on the panel reverse side beyond the limited light grey contour shown in Figure 4.8, which matches closely with the boundary of the flame in the photograph in Figure 4.9.

Similarly, at 20 minutes and 200 kW another stable condition was reached as indicated in Figure 4.10 and confirmed by boundaries of the flame in Figure 4.11. The extent of the melting and consequently the EPS available for burning had increased to 31% this was limited by the boundary of the heat affected zone. Apart from some slight rippling and buckling of the panel surfaces on both sides no opening of the joint or edge capping was evident.

When the output of the burner was increased to 300 kW after 20 minutes and continued until 60 minutes further melting occurred reaching 48% at 30 minutes and 70 % at 60 minutes as shown in Figure 4.12, Figure 4.13 and Figure 4.14. In the process of this happening, buckling of the panel skins around some of the perimeter occurred and the skins became detached from the end capping as the rivets melted and sheared. In addition, the un-riveted central panel joint opened on each side allowing air to enter and gases to escape. This resulted in flaming on the unexposed side at 60 minutes as shown in Figure 4.15

For trials 1 and 2 the additional heat release rate over and above the burner output was minimal, indicating very minor contribution from burning of the panel core.

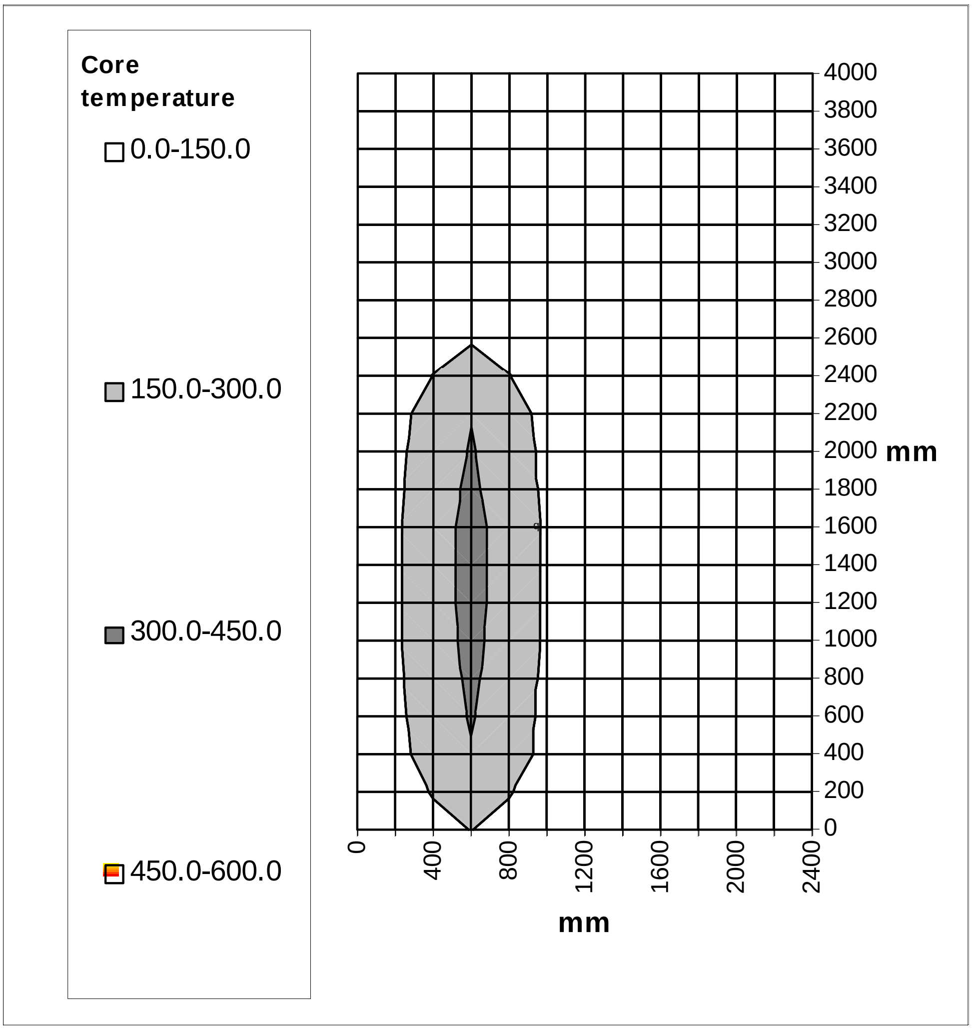

Figure 4.8: Temperature contours after 10 minutes exposure at 100 kW in trial 2, EPS core 18% melted

Figure 4.9: Trial 2 after 10 minutes at 100 kW.

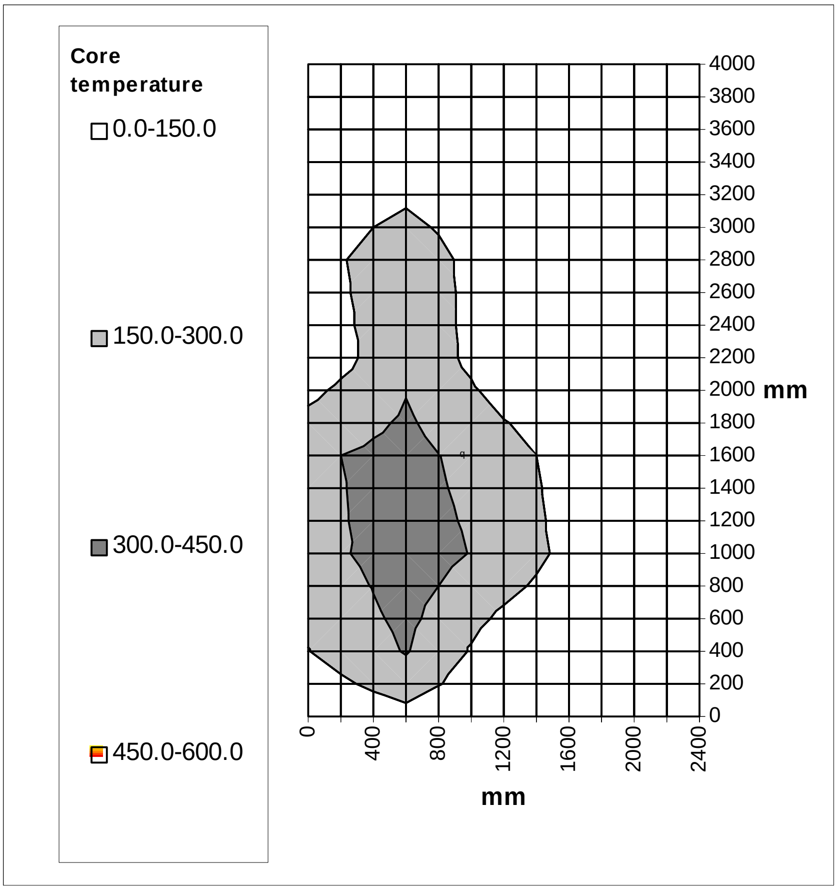

Figure 4.10: Temperature contours after 20 minutes up to 200 kW in trial 2, EPS core 31% melted.

Figure 4.11: Trial 2 at 20 minutes at 200 kW.

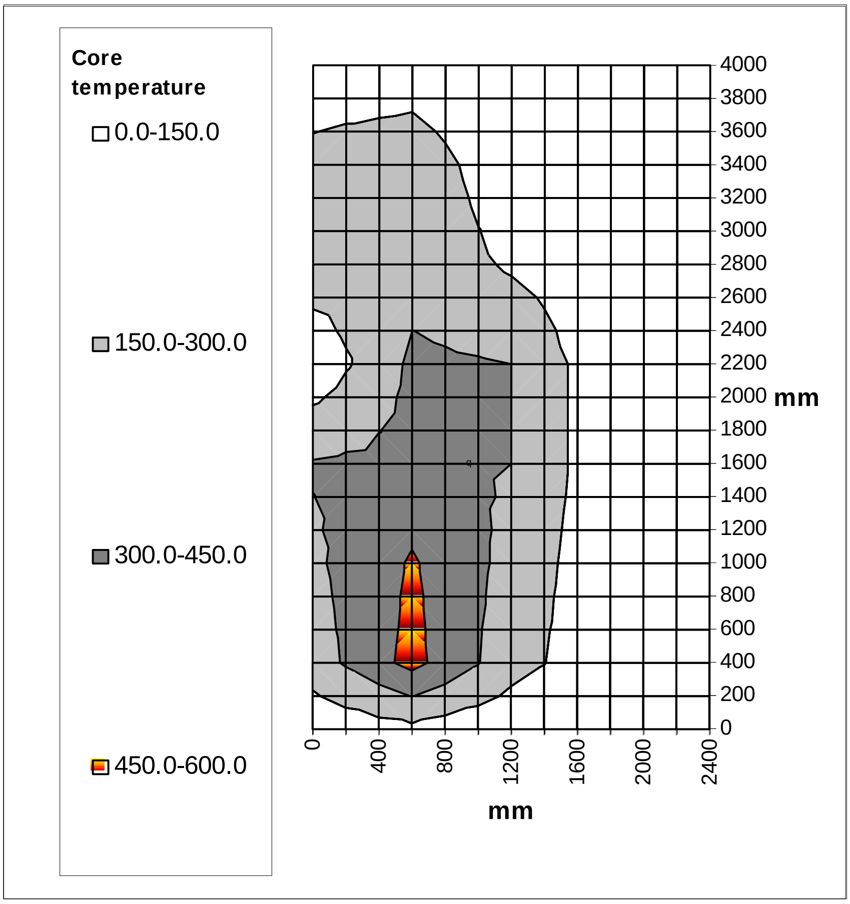

Figure 4.12: Temperature contours after 30 minutes exposure up to 300 kW in trial 2, EPS core 48% melted.

Figure 4.13: Trial 2 at 30 minutes exposure 300 kW (reverse angle) taken from RHS front side of specimen.

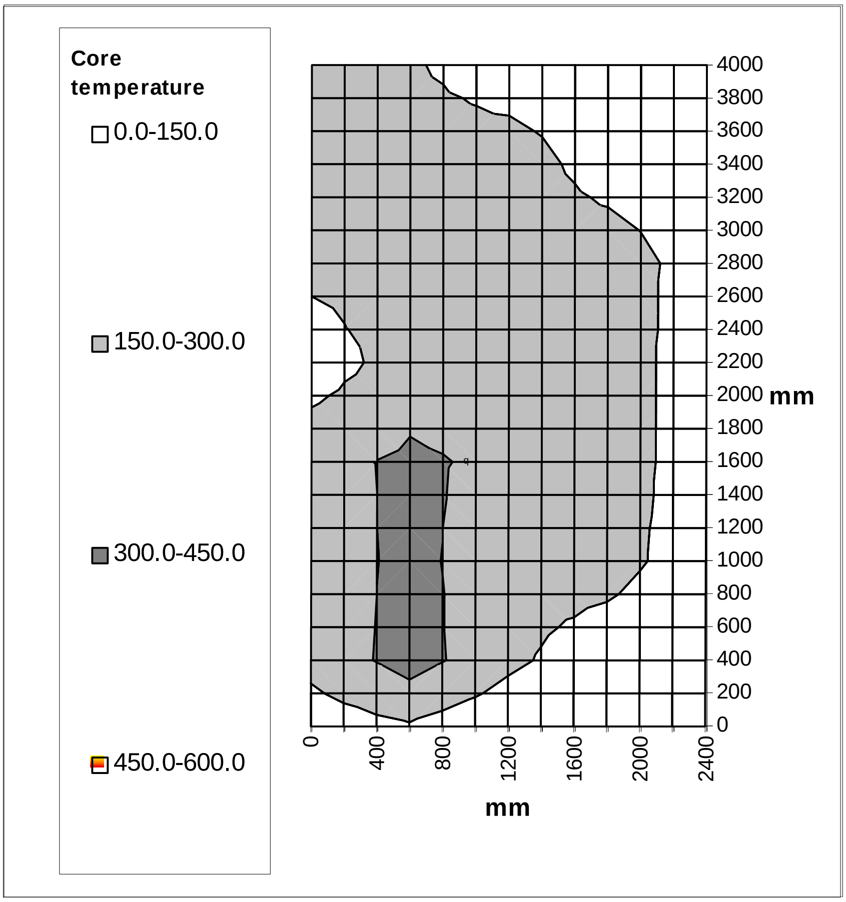

Figure 4.14: Temperature contours after 60 minutes exposure up to 300 kW trial 2, EPS core 70% melted.

Figure 4.15: Trial 2 at 60 minutes exposure, flaming on the unexposed side (left in picture) due to ignition of gases escaping from gaps in edge capping.

4.3.3 Trial 3 horizontal ceiling panel – commentary and results

In trial 3, the same 100 mm thick panel was exposed from below and the behaviour was different for a number of reasons. In order to accommodate the panel under the extraction hood the 4000 mm dimension had to be reduced to 2900 mm so that the gases could be captured and prevent the laboratory filling with smoke. Additionally, the sides were confined with fibre-cement board to similarly prevent escape of the smoke, as shown in Figure 4.16. This had the effect of containing the heat under the panel and contributed to a more severe test than trial 2.

Figure 4.16: Horizontal panel.

Figure 4.17 shows the location of the burner and cut out under the panel. Figure 4.18 and Figure 4.19 show the burner at outputs of 100 and 300 kW respectively.

Figure 4.17: Location of burner and cut out in panel.

Figure 4.18: Trial 3 at 2 minutes and 100 kW.

The fire exposure on the horizontal panel was more intense compared with the vertical orientation because of the burner being 850 mm below a 200 x 200 mm cutout in the lower skin of the ceiling. This caused the ceiling jet to flow over and heat a larger area of the ceiling compared with the vertical wall trials. The resulting molten EPS in the heated region was then able to flow across the ceiling panel, out of the cutout and into the burner flame igniting and increasing the intensity of the fire. This resulted in a spike in the heat release rate from 100 kW to in excess of 300 kW as shown in Figure 4.24 and was accompanied by a significant increase in smoke production. The legend in Figure 4.24, RHR is the total heat release calculated from oxygen consumption and BHR is the gas burner heat release.

Figure 4.19: Trial 3 at 22 minutes and 300 kW.

Similar but smaller spikes in the smoke production were noted each time the burner output was increased. This was due to the greater area covered by the ceiling jet melting additional EPS, which either flowed into the burner flame or escaped from the edge capping and which burnt as shown in Figure 4.20.

Figure 4.20: Trial 3 flaming on upper surface of specimen at 24 minutes.

Figure 4.21: Trial 3 underside of panel after 30 minutes.

Further molten EPS in minor quantities was observed to escape from a partly opened centre interlocking joint on the underside in the later stages of the trial as shown in Figure 4.21.

Figure 4.22: Trial 3 top side of panel, showing heat affected zone.

Figure 4.22 shows the upper side of the of the ceiling panel and the burnt steel skin in the region of the cutout.

The deposition of molten EPS that was not ignited in the burner below the cutout is shown in Figure 4.23.

Figure 4.23: Trial 3 molten EPS had flowed from opening above burner and either burnt in the flame or deposited and solidified on floor.

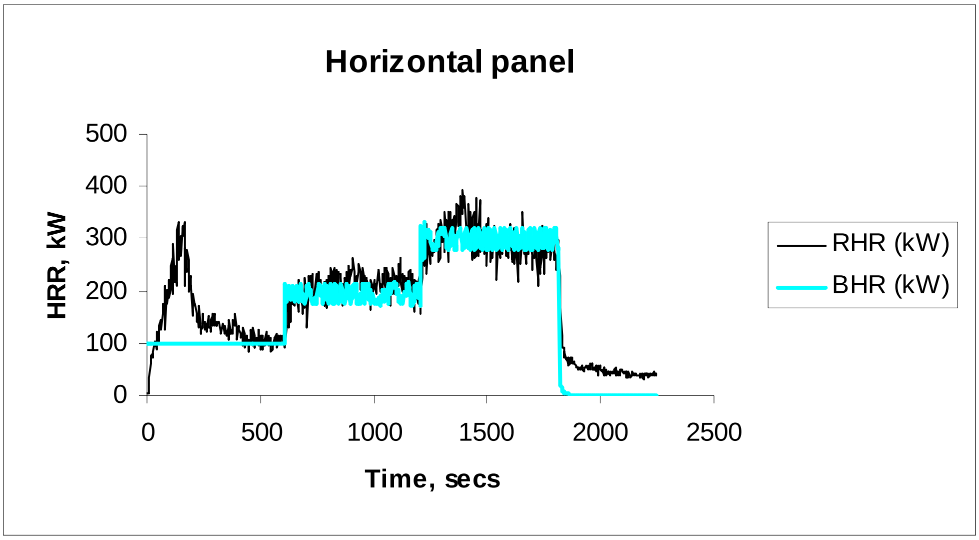

Figure 4.24: Trial 3 heat release rate and spikes due to molten EPS flowing onto fire and increasing the heat release rate.

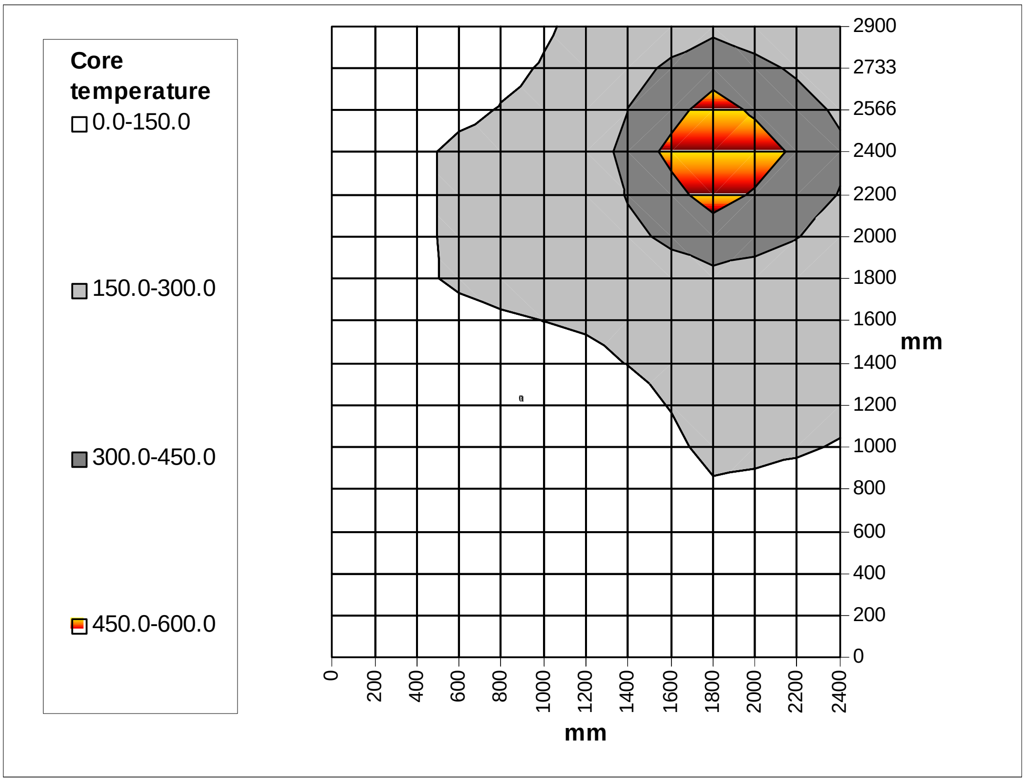

Figure 4.25: Temperature contours after 10 minutes exposure at 100 kW in trial 3 as viewed from fire exposed underside, EPS core 42 % melted.

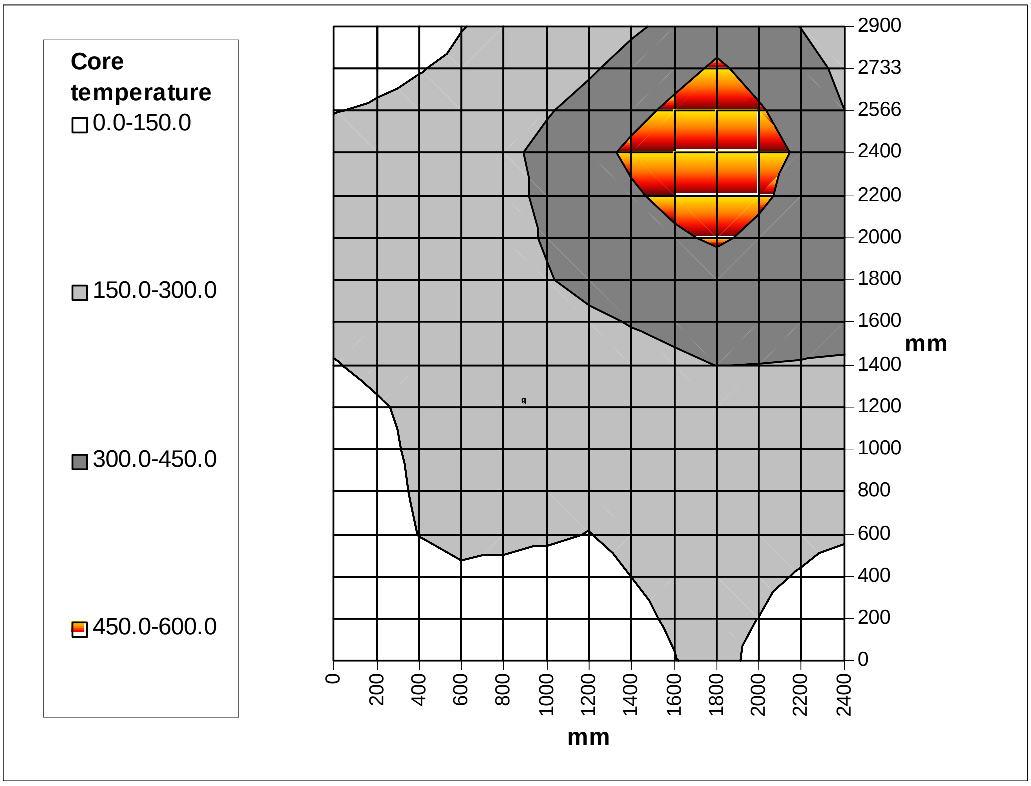

Figure 4.26: Temperature contours after 20 minutes exposure up to 200 kW trial 3, EPS core 80% melted.

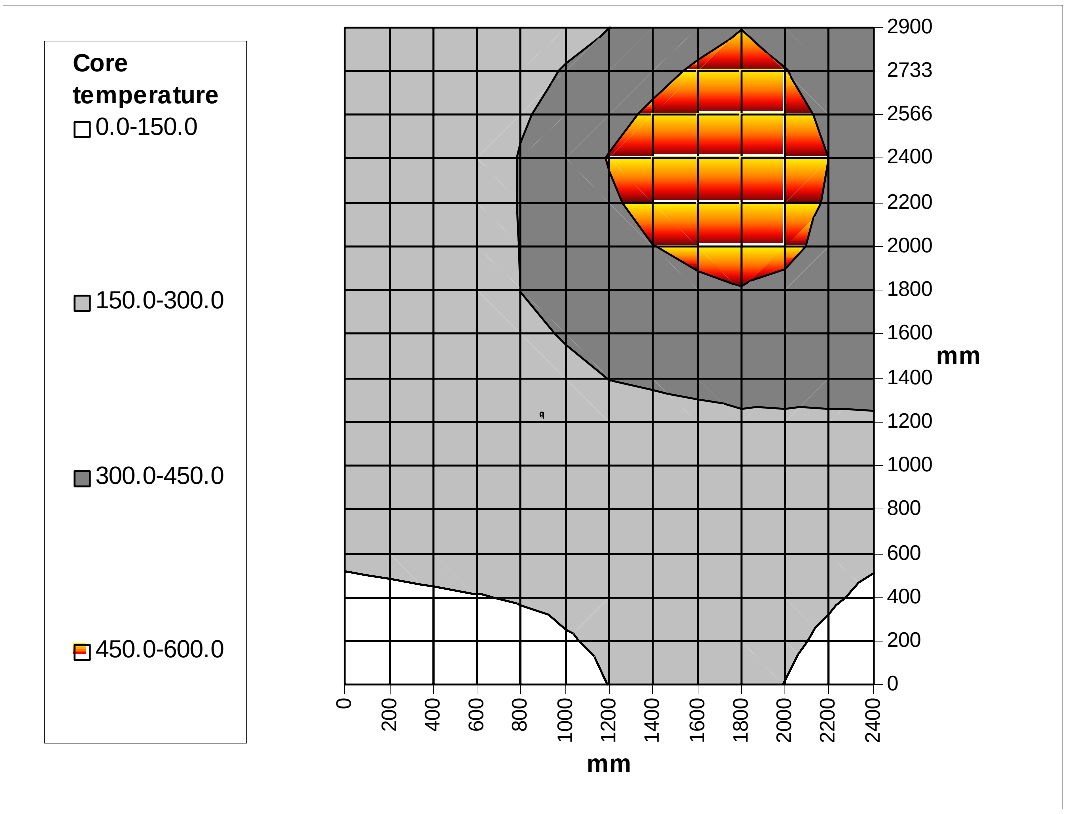

Figure 4.27: Temperature contours after 30 minutes exposure up to 300 kW trial 3, EPS core 91% melted.

The temperature contour maps in Figure 4.25, Figure 4.26, and Figure 4.27 indicate a more severe exposure due to the more intense exposure because of the horizontal orientation, the ceiling plume, and the containment around the perimeter to limit the escape of smoke. Such containment can be justified because in real building situations ceilings are generally bounded by walls. The additional plume heating resulted in 30-40 % of the EPS core melting and becoming involved in the first 10 minutes, compared with 15-20% for the vertical panel with the same 100 kW HRR from the burner in the first 10 minutes.

4.3.4 Comparison of cavity fire spread results

Figure 4.28 and Figure 4.29 show the progression of melting and burning of the EPS core in the three trials.

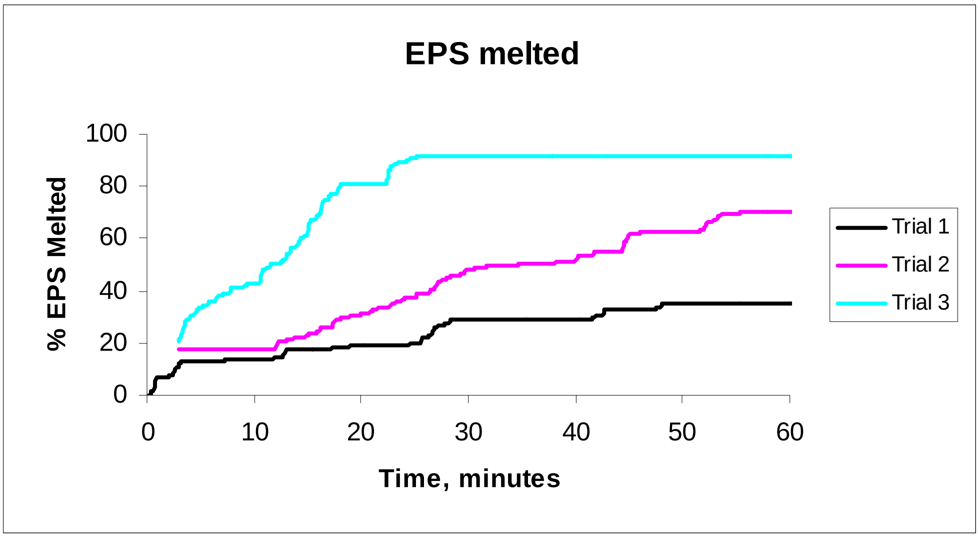

Figure 4.28: The extent of the melting of the EPS core in trials 1 to 3.

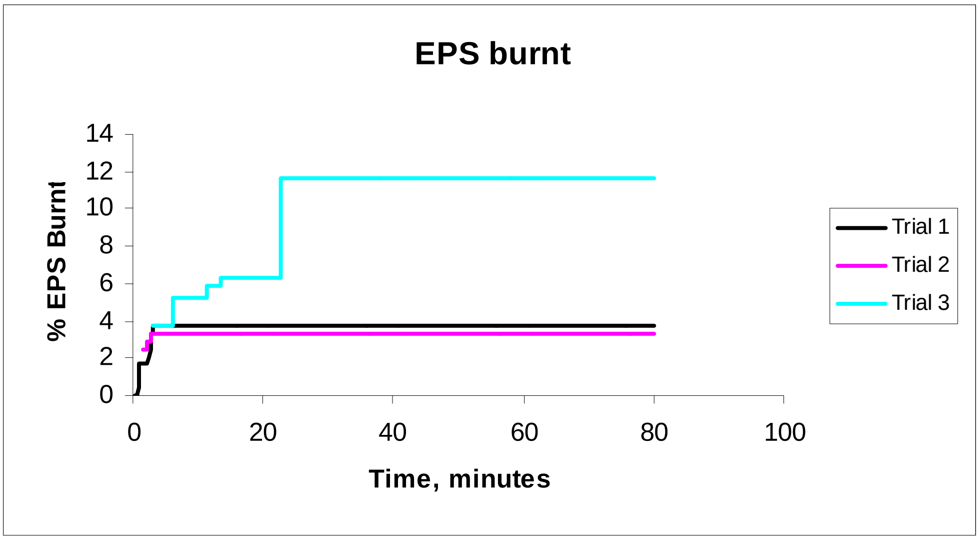

Figure 4.29: The percentage of the area where the temperature indicated burning of the EPS core within the panels.

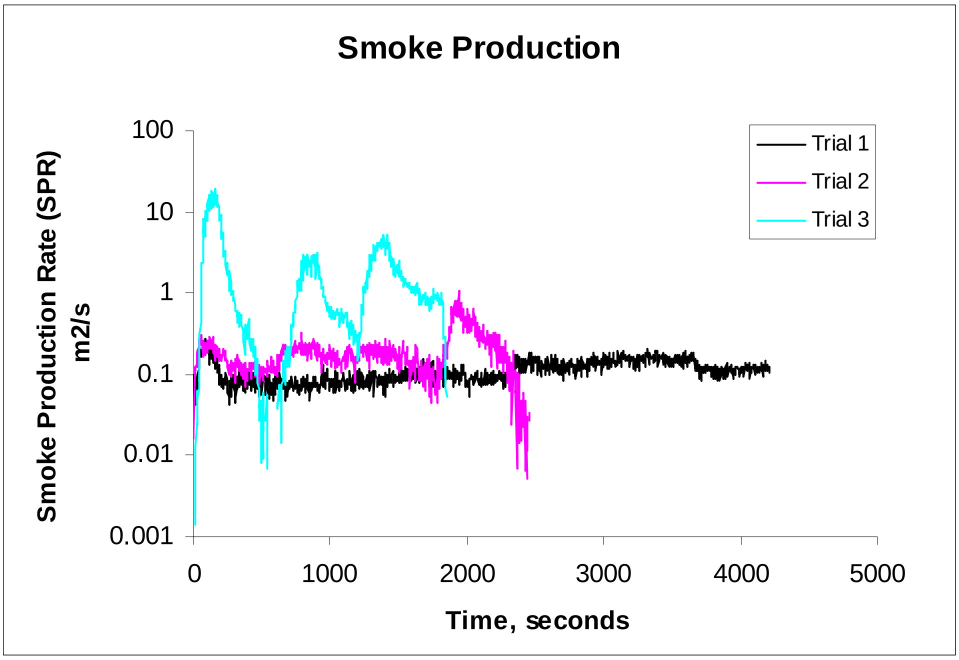

Figure 4.30: Smoke production in trials 1 to 3 on a logarithmic scale.

The spike in the graph in Figure 4.30 in excess of 10 m^2/s (trial 3) coincided with the observation of thick black smoke and soot in the ceiling panel trial (3). For the two wall panel trials 1 and 2 the maximum smoke production was 1 m^2/s and otherwise averaged 0.1 m^2/s.

4.3.5 Post-test inspection

For comparison purposes with the temperature contour maps and the percentage melted Figure 4.31, Figure 4.32, and Figure 4.33 show the remaining EPS when the panels were opened up for inspection. The remaining EPS matches that expected on the basis of the internal temperature measurements although the length of time the panel cores were exposed to the prevailing temperature could also be a factor accounting for some variation. It can clearly be concluded that fire spread within cavities is not self sustaining provided the joints remain intact.

Figure 4.31: Remaining EPS core in trial 1.

Figure 4.32: Remaining EPS core in trial 2.

Figure 4.33: Remaining EPS core in trial 3.

4.3.6 Summary of cavity fire spread trials

In the three trials conducted, it was demonstrated that self sustaining fire spread did not occur. Generally, the fire involvement of a panel’s EPS core was limited to the heated zone where it melted and flowed to a hotter zone where combustion could take place, provided there was an opening such as a hole cut in the panel skin. Flaming was also observed where gaps had opened around the perimeter and interlocking joints. Such openings were a requirement for allowing combustible gases to escape and mix with air or for air to enter the cavity, the subsequent dilution of the flame retardant halogen gas with combustion supporting air created conditions such that flaming may occur. If flaming remote from the burner occurred this further heated the surrounding EPS leading to increased localised burning, which was inhibited from spreading further for the reasons outlined above, unless more openings occurred.

The graphs showing the percentage of melted (150^{o}C) and burnt (450^{o}C) EPS in the cores in Figure 4.28 and Figure 4.29 show that in the case of the vertical wall (1 and 2) the spread is dependent on the burner heat output. In the case of trial 1 the spread of the melted EPS region had only increased marginally from 30 minutes and a stable condition had been reached with only minimal fire spread up to 60 minutes. For the horizontal ceiling, the extent of the spread is significantly greater because of the more concentrated heat exposure on the panel surface. It is also significant that the difference between 90 % of the core melting compared with only 12 % reaching a combustion level temperature demonstrates that the EPS melted initially and flowed to an opening before flaming in the presence of air. The smoke production graph in Figure 4.30 indicates that in trial 3 significant burning of the EPS occurred external to the panel.

Fire spread within cavities was not indicated, provided the panels remain relatively intact. Some flaming in isolated locations and of short duration was observed, but this could not be considered fire spread.

4.4 Panel joint performance in fire

The objective was to establish the influence of joint details on the involvement of the panel cores in fire growth. The rivet spacing on the interlocking joints was expected to be a significant determinant of the fire performance of PIPs.

Five specimens for testing in accordance with the ISO 9705 (1993E) room/corner test were prepared.

Three trials were conducted on interlocking joints (see Figure 4.34) using panels nominally 2400 mm high x 1200 mm wide and 100 mm thick, with 0.6 mm steel skins. The test panels were constructed from 1200 mm wide panel sections cut in the centre and the two 600 mm wide sections were rotated and joined at the slip joint (see

Figure 4.37). The perimeter was then capped with 100 x 25 x 1.6 mm aluminium channel and riveted at 200 mm centres.

A further two trials on mitre corner joints using panels nominally 2400 mm high x 2 sections 600 mm wide at right angles and 100 mm thick, with 0.6 mm steel skins (see Figure 4.35). The test panels were constructed by joining two panel sections with the edge cut at 45^{o} angle and capping the internal and external edges with 40 x 40 mm and 50 x 50 mm angles respectively and riveting at 200 mm centres with 4.8 mm diameter aluminium rivets. Trial 4 used 1.6 mm aluminium angle for the mitred corners and the perimeter was then capped with 100 x 25 x 1.6 mm aluminium channel and riveted at 200 mm centres. Trial 5 used 0.6 mm steel angle for the mitred corners and the perimeter was then capped with 100 x 25 x 0.6 mm steel channel and riveted at 200 mm centres.

The panel details are summarised in Table 4.7.

Table 4.7: Joint trials.

	Panel dimensions H x W x T, mm	Joint detail	Joint rivet spacing, mm fire exposed side	Joint rivet spacing, mm un-exposed side
Trial 1	2400 x 1200 x 100	Interlocking joint	2400(3)	2400(3)
Trial 2	2400 x 1200 x 100	Interlocking joint	1200	2400(3)
Trial 3	2400 x 1200 x 100	Interlocking joint	600	2400(3)
Trial 4	2400 x 600(2) x 100	Mitre joint (1)	200	200
Trial 5	2400 x 600(2) x 100	Mitre joint (2)	200	200

Notes:

(1) 1.6 mm aluminium angle, 40 x40 mm internal corner, and 50 x 50 mm external angle corner.
(2) 0.6 mm steel angle (with 10 mm safety edge), 40 x40 mm internal corner, and 50 x 50 mm external angle corner.
(3) rivets on top and bottom capping only.

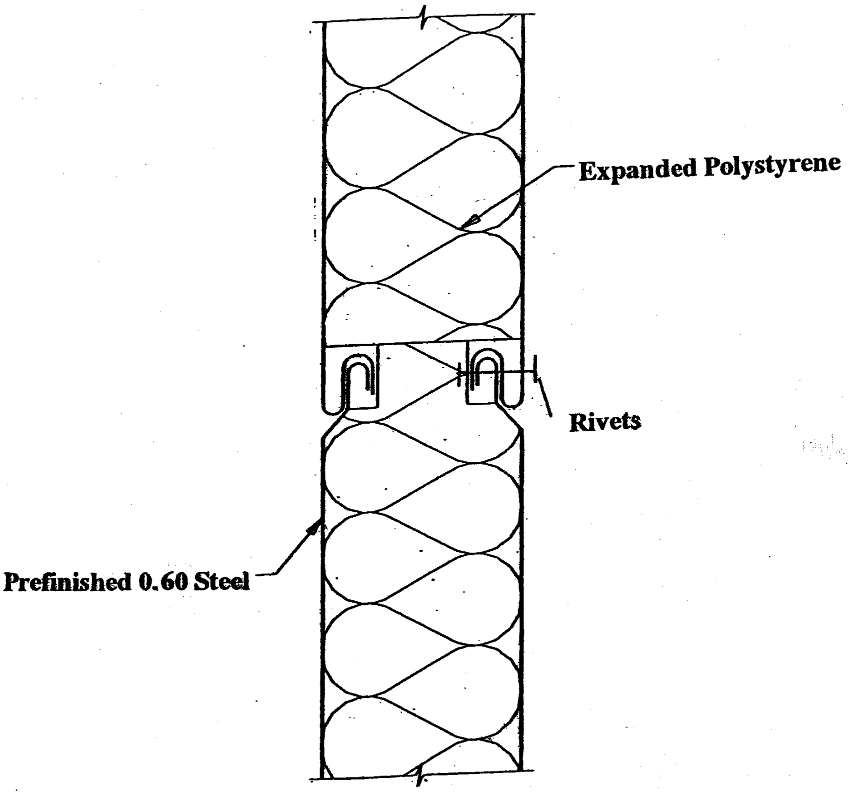

Figure 4.34: Interlocking joint.

Each panel section was mounted inside 3600 x 2400 x 2400(h) mm ISO Room with a 2000(h) x 800 mm opening. In each trial, the joint was exposed to a propane burner at 100 kW for 10 minutes and then this was increased to 300 kW for a further 10 minutes (see Figure 4.36) in accordance with ISO 9705 (1993E) prescribed conditions. Fifteen thermocouples were installed at a nominal depth of 50 mm within the panel in a grid pattern at 600 mm centres covering the perimeter and the joint being evaluated.

Figure 4.37 shows the thermocouple positions for the interlocking and angle joint panels. Temperature rises within the panel indicated the progress of melting and pyrolysis of the core within the panel.

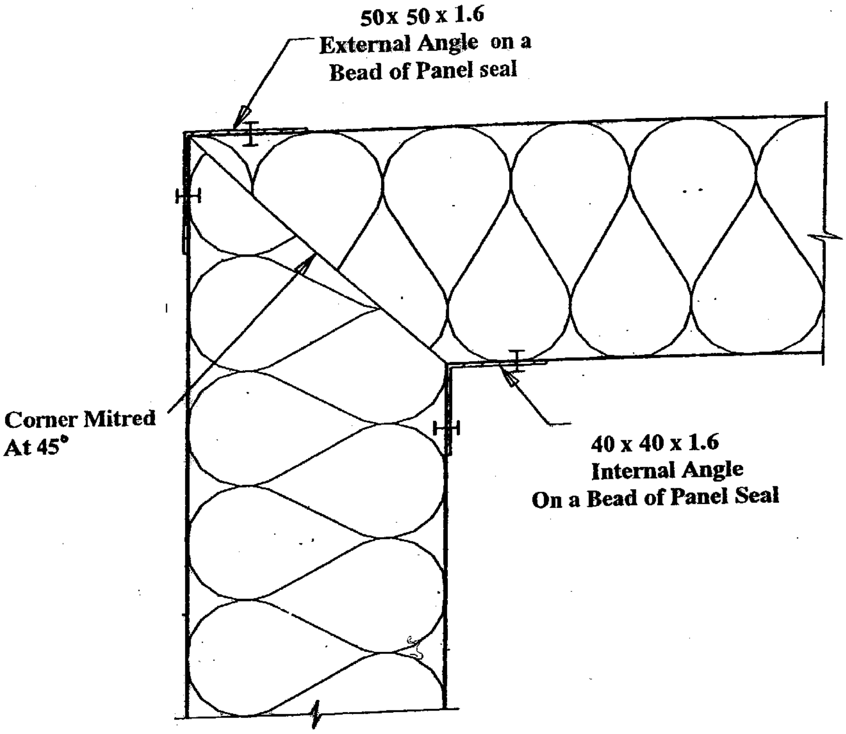

Figure 4.35: Mitre joint.

Figure 4.36: ISO9705 Room and joint 1 panel.

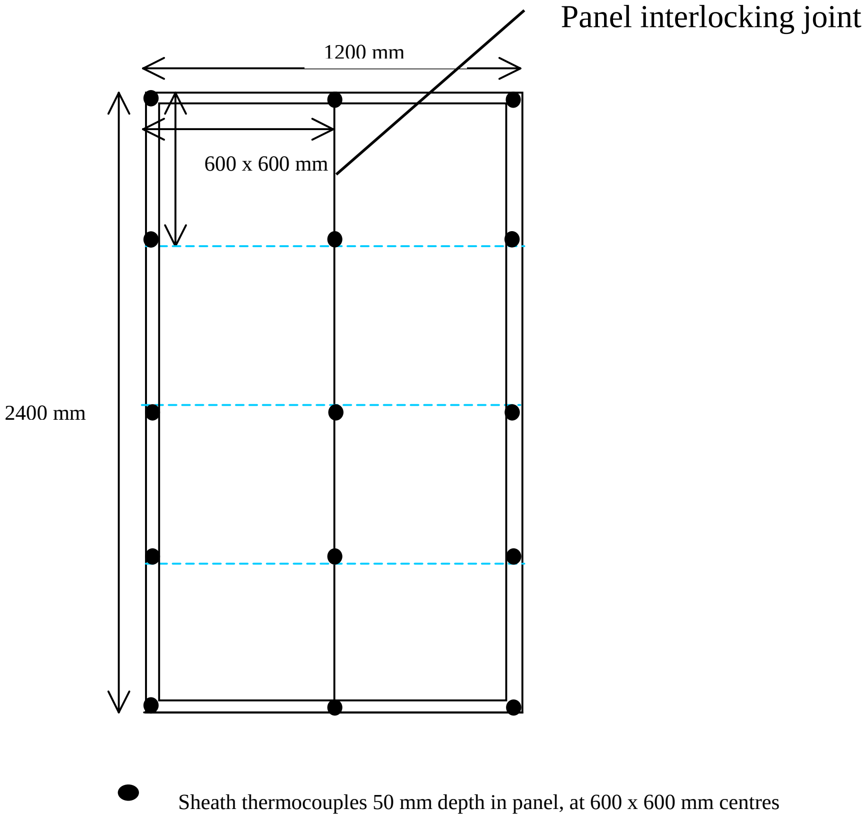

Figure 4.37: Joint panel instrumentation.

Oxygen consumption calorimetry to ISO 9705 conditions was used to calculate heat release (in excess of the 10 minute exposures of 100/300kW from the gas burner) and smoke production was measured as indicators of the effectiveness of the panel joint detailing.

4.4.1 Joint trial results and discussion

The heat release rate is summarised in Table 4.8 and indicates a trend of decreasing average and peak heat release rates with closer rivet spacing on the interlocking joints and an improvement with steel angle over aluminium angle for the corner joints.

Table 4.8: Performance of joints.

Trial	Average, kW	Peak, kW	At Time, secs	Total heat ,MJ	Joint/Rivets ctrs, mm
1	228	527	1065	296	Interlocking, 2400
2	227	469	933	273	Interlocking, 1200
3	212	325	1122	259	Interlocking, 600
4	236	648	768	283	Mitre alum angle, 200
5	222	415	801	265	Mitre steel angle, 200

Individual graphs of the heat release rate are shown in Figure 4.38, Figure 4.39, Figure 4.40, Figure 4.41, and Figure 4.42, where RHR is the total heat release calculated from oxygen consumption and BHR is the gas burner heat release. The graphs indicate the increasing delay in the involvement of the core in the fire growth, characterised by the rate of heat release exceeding the burner output, and being attributable to closer rivet spacing for the interlocking joints or in the case of the corner joints the superiority of the steel angle compared with the aluminium angle.

Further improvements in the performance of the joint details are likely to delay the spike in the HRR closer to or beyond 20 minutes (1200 seconds) exposure.

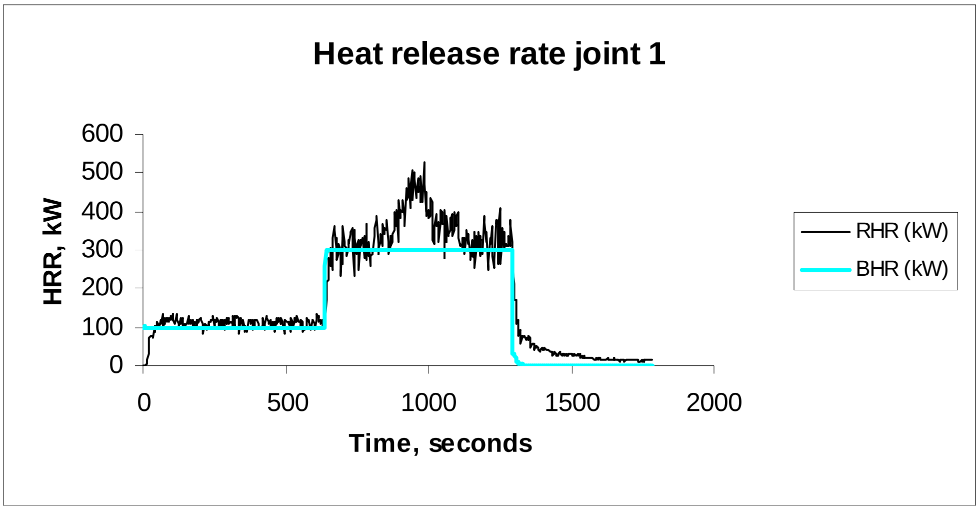

Figure 4.38: Heat release rate joint 1.

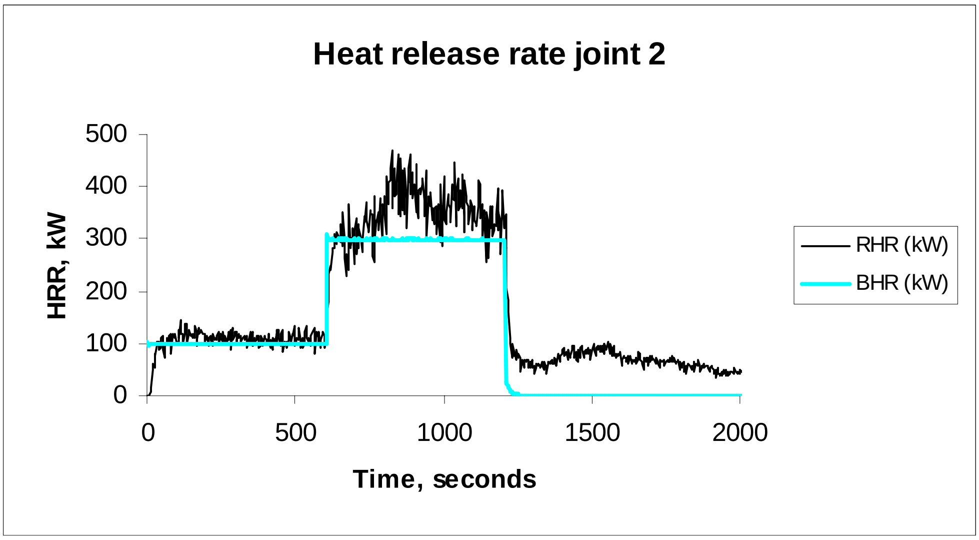

Figure 4.39: Heat release rate joint 2.

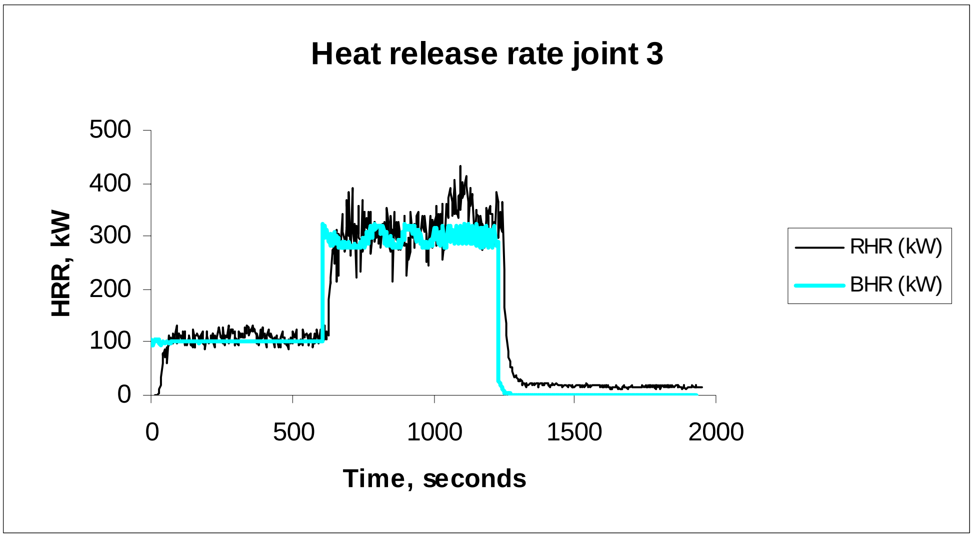

Figure 4.40: Heat release rate joint 3.

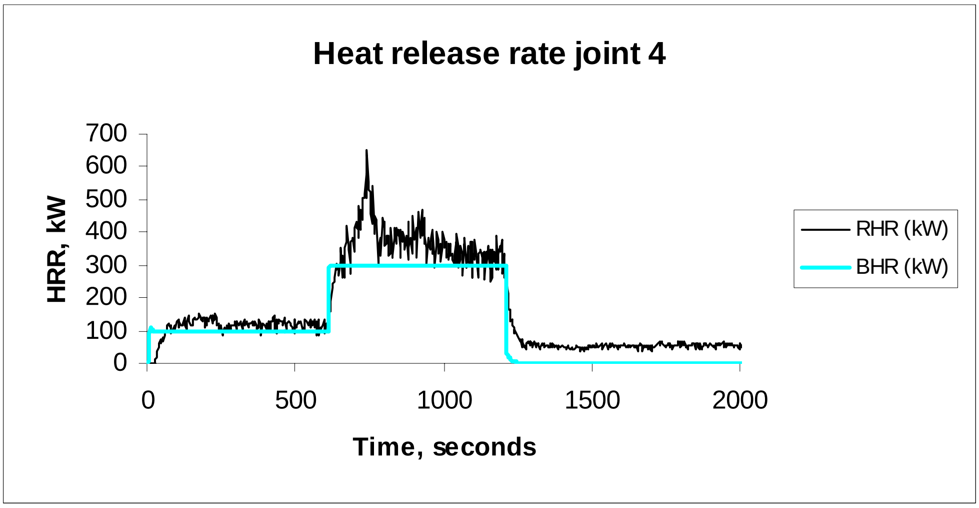

Figure 4.41: Heat release rate joint 4.

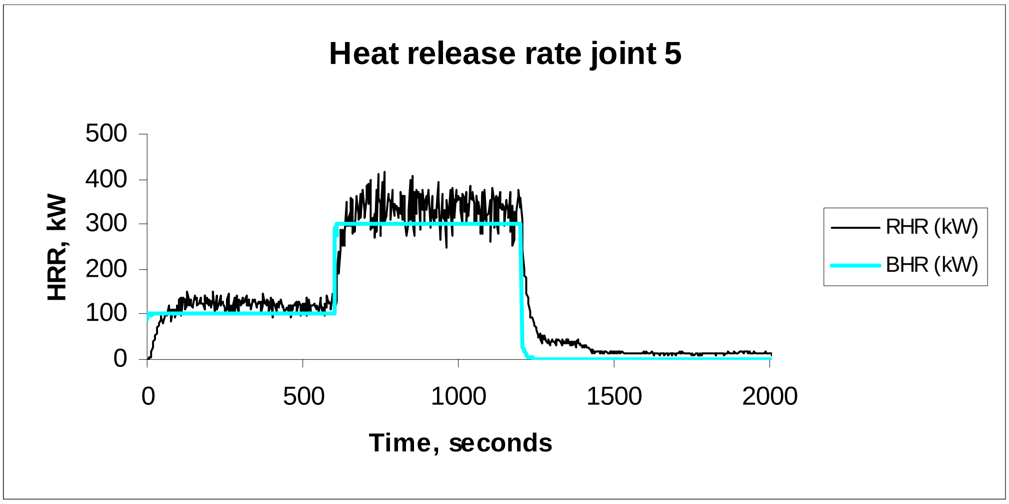

Figure 4.42: Heat release rate joint 5.

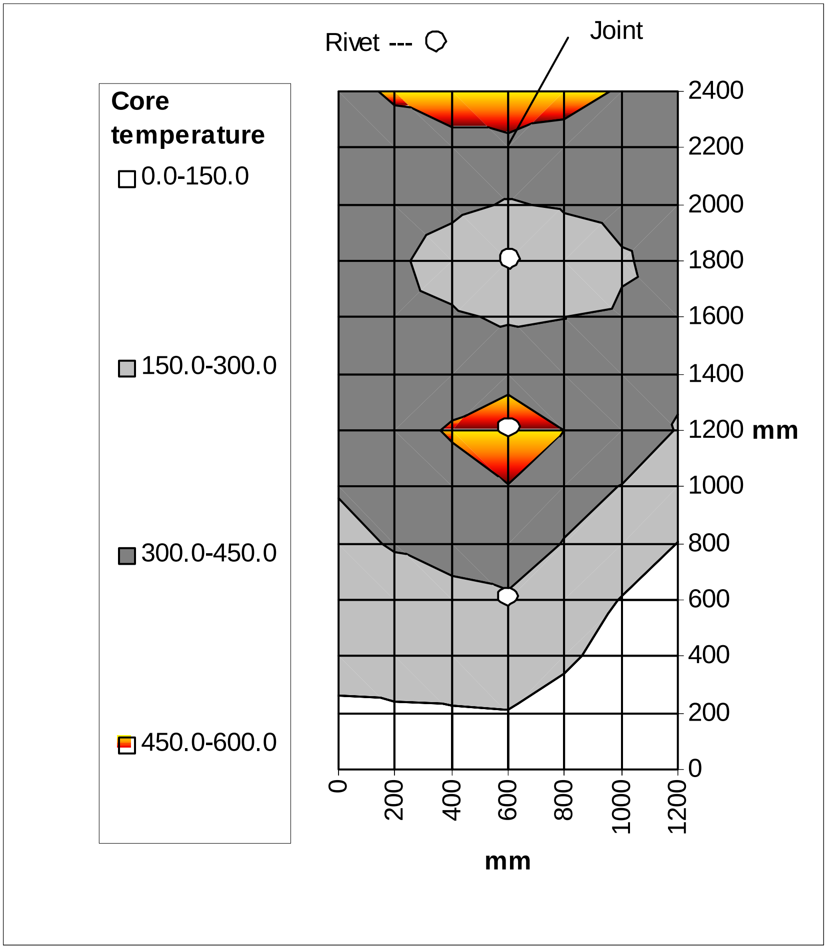

Figure 4.43: Temperature contours in joint 3 panel at 20 minutes.

Temperature contour maps were prepared for all five trials, with Figure 4.43 being an example for trial 3 with the 600 mm rivet spacing on the interlocking joint. The results of these analyses are shown in Figure 4.44 and Figure 4.45 giving the extent of core melting and burning based on temperature contours. Similarly, with the identical analysis of the cavity fire spread analysis in section 4.3 the actual burning, when it occurs happens over a relatively small area, and is generally confined to opening of the joints or edge capping.

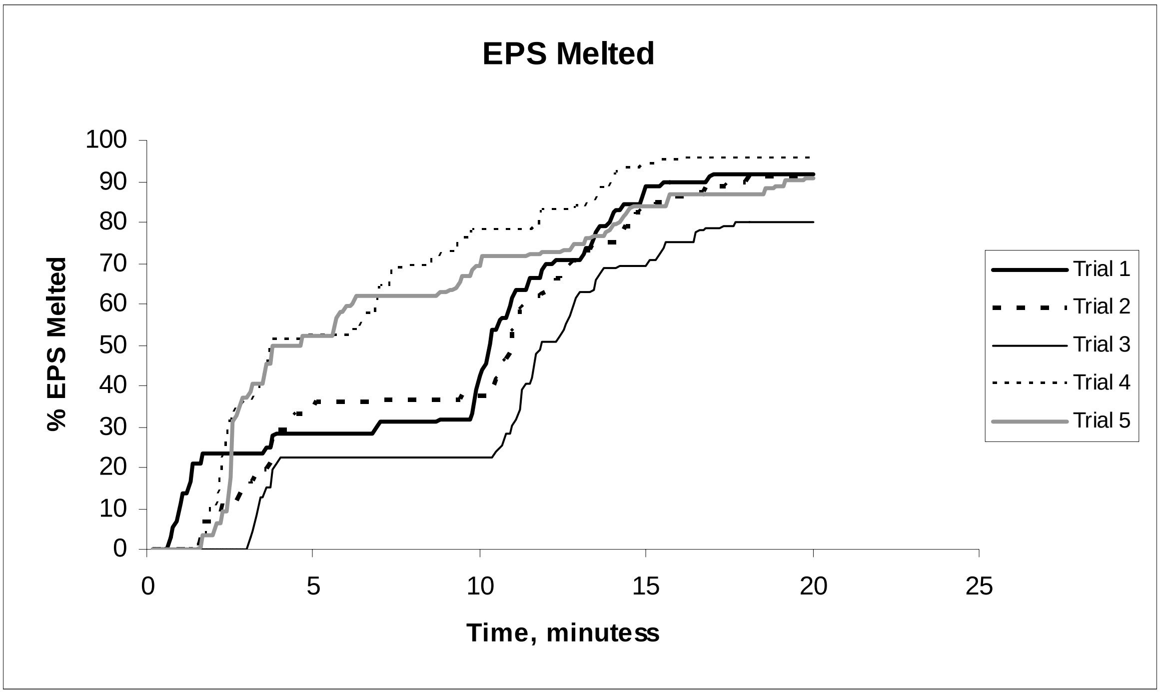

Figure 4.44: EPS core temperature greater than 150°C and assumed to be melted.

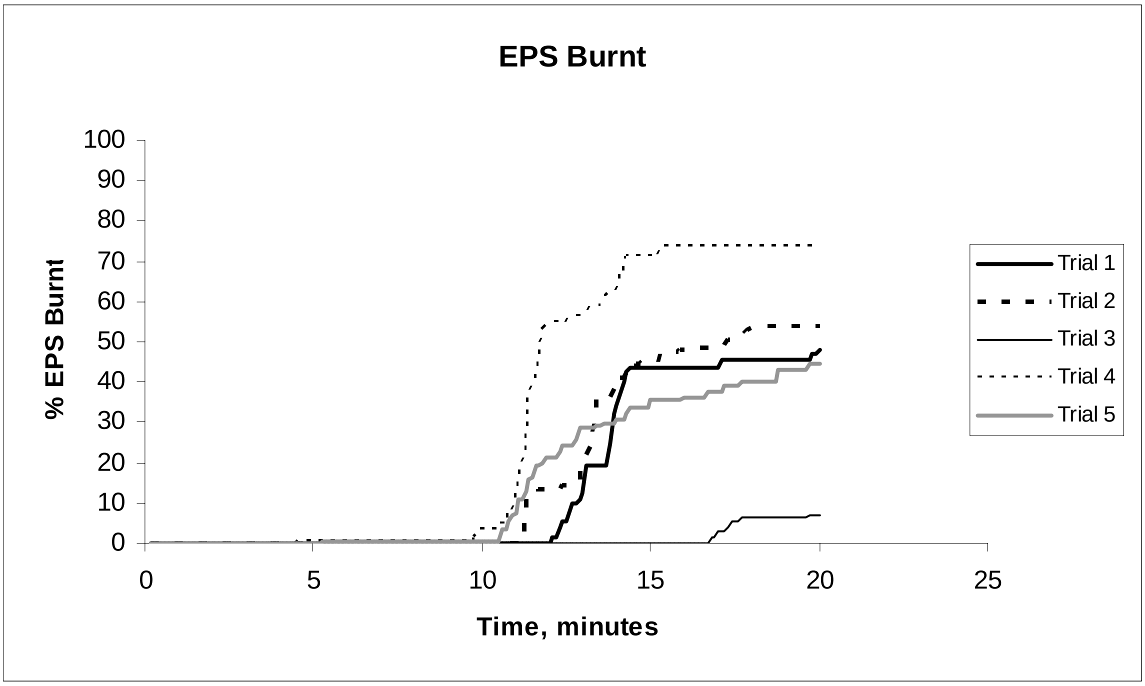

Figure 4.45: EPS core temperature greater than 450°C and assumed to be burnt.

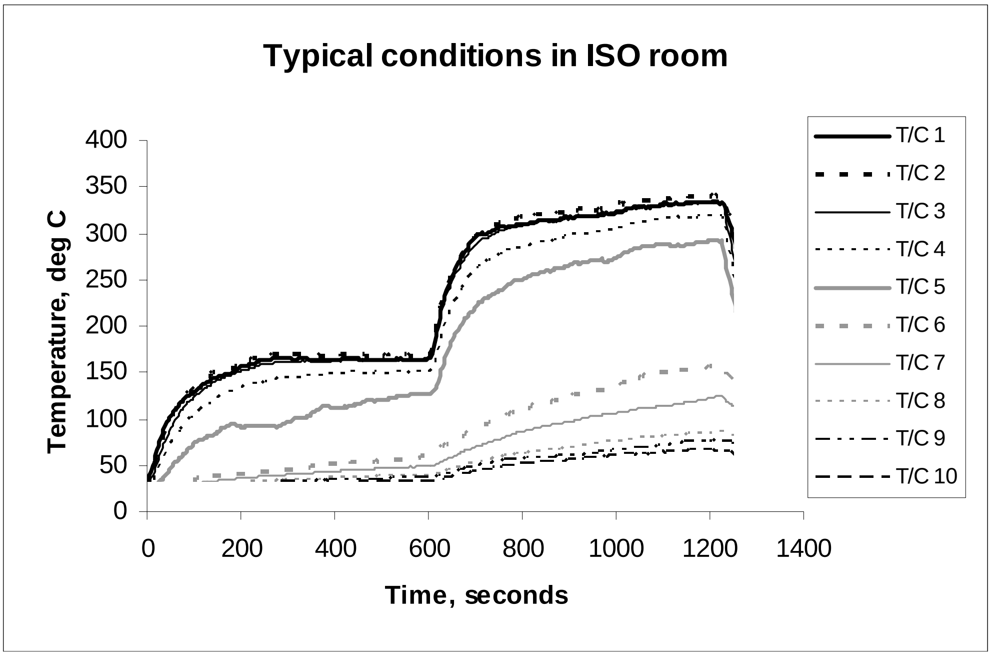

Figure 4.46: Conditions in ISO room trial 3.

Figure 4.46 shows the temperature conditions in the ISO9705 room at relatively evenly spaced heights where the legend numbers 1 to 10 represent thermocouple readings at the elevations indicated in Table 4.9. The thermocouples are positioned in the opposite corner to the burner and specimen at a distance of approximately 3000 mm. Trial 3 was the least severe exposure due to the limited involvement of the panel core in the fire so in the other trials 1, 2, 4, and 5 the temperatures would have been higher. Assuming that the EPS panel core melts at approximately 150^{o}C, and then in the upper half of the room, where 150^{o}C was exceeded significantly (indicated by thermocouples 1 to 5) it would melt over the entire horizontal length (width) of the panel independently of the burner flame impinging on the panel. As a result, the top half of the panels would not be expected to have any EPS remaining in the core, irrespective of the width.

Table 4.9: Thermocouple elevations in ISO 9705 room.

Thermocouple number, T/C	Elevation above floor, mm
1	2300
2	2100
3	1910
4	1720
5	1570
6	1420
7	1270
8	970
9	670
10	250

4.4.2 External post-test inspection and discussion of joint samples

The samples were inspected externally for the extent of damage after the fire exposure and Figure 4.47, Figure 4.48, Figure 4.49, and Figure 4.50 show the flame affected surface, but the actual degree of opening of joints is unclear.

Joint 1 with no rivets on either side

On the fire-exposed side, the interlocking joint had opened up over 100% of the height above the burner (350 mm high) which is a distance of 2150 mm of the 2400 mm height of the panel. On the unexposed side, the joint had not opened at all over its entire height. The edge capping had opened up over 40 % of the perimeter, the entire length of the top edge and 30-40 % down each side.

Joint 2 with rivets at 1200 mm centres on the fire exposed side and no rivets on the unexposed side

On the fire-exposed side, the interlocking joint had opened up over 100% of the height above the burner (350 mm high) which is a distance of 2150 mm of the 2400 mm height of the panel the single centre rivet had sheared. On the unexposed side, the joint had opened approximately 50 % of its entire height, centred in the upper half. The edge capping had opened up over 40 % of the perimeter, the entire length of the top edge and 30-40 % down each side.

Joint 3 with rivets at 600 mm on the fire exposed side and no rivet on the unexposed side

On the fire-exposed side, the interlocking joint had opened up over 50% of the height above the burner (350 mm high) which is a distance of approximately 1200 mm in height. Of the three rivets, the top two had sheared. On the unexposed side, the joint showed no sign of opening, but the soot marks in the right hand specimen in Figure 4.48 indicate there was some leakage and ignition of the gases from the pyrolysed core. The edge capping had opened up over 40 % of the perimeter, the entire length of the top edge and 30-40 % down each side.

Figure 4.47: Interlocking joint specimens, fire exposed side, trials 1 to 3 from left to right.

Figure 4.48: Interlocking joint specimens, unexposed side, trials 1 to 3 from left to right.

Joint 4 with mitred corner and aluminium angle on each side secured with rivets at 200 mm centres.

The entire length (2150 mm) of the aluminium angle on the fire-exposed side above the burner had melted, and the joint had open up extensively. On the unexposed side, the aluminium angle had detached, above the burner height, by shearing or melting of the rivets.
The edge capping had also opened up on the top edge and 50% down one side and was intact on the other side.

The unequal thermal expansion of aluminium angle and steel skin is a disadvantage, the greater expansion of the aluminium angle opens up the joints earlier as the aluminium buckles and/or shears rivets and eventually melts.

Joint 5 with mitred corner and steel angle on each side secured with rivets at 200 mm centres.

On the fire exposed side, the rivets securing the steel angle had either sheared or melted above a height of 1100 mm. On the unexposed side, the steel angle had detached, above 2000 mm height, by shearing or melting of the rivets. The edge capping had opened up only on the top edge, and had remained intact on each side.

The steel angle expands equally with the steel skin and there is considerably less strain on the aluminium rivets delaying failure, and more importantly core involvement, until the aluminium rivets soften and melt.

Figure 4.49: Corner joint specimens, fire exposed side, trials 4 to 5 from left to right.

Figure 4.50: Corner joint specimens, unexposed side, trials 4 to 5 from left to right.

4.4.3 Internal post-test inspection and discussion of joint samples

Internal inspection of the cavities showed less EPS foam remaining than would be indicated by the percentages given in Figure 4.44 after 20 minutes exposure. Some reasons for this include the isolated fires that continued to burn within the panel and the elevated temperature remaining in the ISO room for a period after the burner was extinguished. In all five trials, the post-test inspection revealed pools of solidified EPS in the bottom edge channel, the depths varied proportionately according to the contribution of the panel core to the overall heat release rate recorded. Table 4.10 records the depth of solidified EPS in the panel bottom channel of each specimen.

Table 4.10: Molten EPS remaining in specimens.

Trial #	Depth of molten EPS, mm
1	30-40
2	25-30
3	10
4	30
5	15

Figure 4.51: Totally consumed/melted core joint 2 panel.

Figure 4.52: Remaining EPS core in lower portion of joint 3 panel.

Figure 4.51 and Figure 4.52 show the EPS core remaining in the post-test inspection. For joint 2 all of the EPS had melted and that which did not become involved in the flaming inside and outside of the panel remained as a solidified pool. In joint 3, where the additional rivets in the joint afforded more protection to the core a small portion of the core remained below the burner height. Considering the five joint trials there is a correlation between closer rivet spacing and more secure jointing methods in general and a reduction in the involvement of the panel cores indicated by the magnitude of additional heat generated from the burning panel and the quantity of core remaining.

4.5 Suspension of ceilings

The objective was to investigate the hazards of falling PIP ceiling panels in fire, as reported in various fire incidents, and evaluate the risks associated with current practice in the industry in New Zealand.

4.5.1 Tests on suspended ceilings

Three fire resistance tests to AS1530.4: 1997 (SA,1997) were conducted on the suspended ceiling panels described in Table 4.11 to evaluate the integrity of the attachment of the panel to the suspension systems. The ceiling comprised four panel sections, two 1200 mm wide in the centre and two 300 mm wide on the outside edges making a total combined width of 3000 mm. The sections were 4000 mm long and were joined together at the interlocking joints and riveted with 4.8 mm aluminium rivets at 500 mm centres. The perimeter was capped with 100 x 25 x 1.6 mm aluminium channel and riveted with 4.8 mm aluminium rivets at 200 mm centres. All joints were sealed with silicone sealant.

The suspension system tested utilised 10 mm threaded studs through both panel skins with the lower skin secured with a 22 mm diameter washer and nut capped with a moulded plastic mushroom head. Each suspension point was then attached to a stirrup and chain, which was in turn attached to a loading frame about 1000 mm above. A schematic view of the suspended ceiling is illustrated in Figure 4.53.

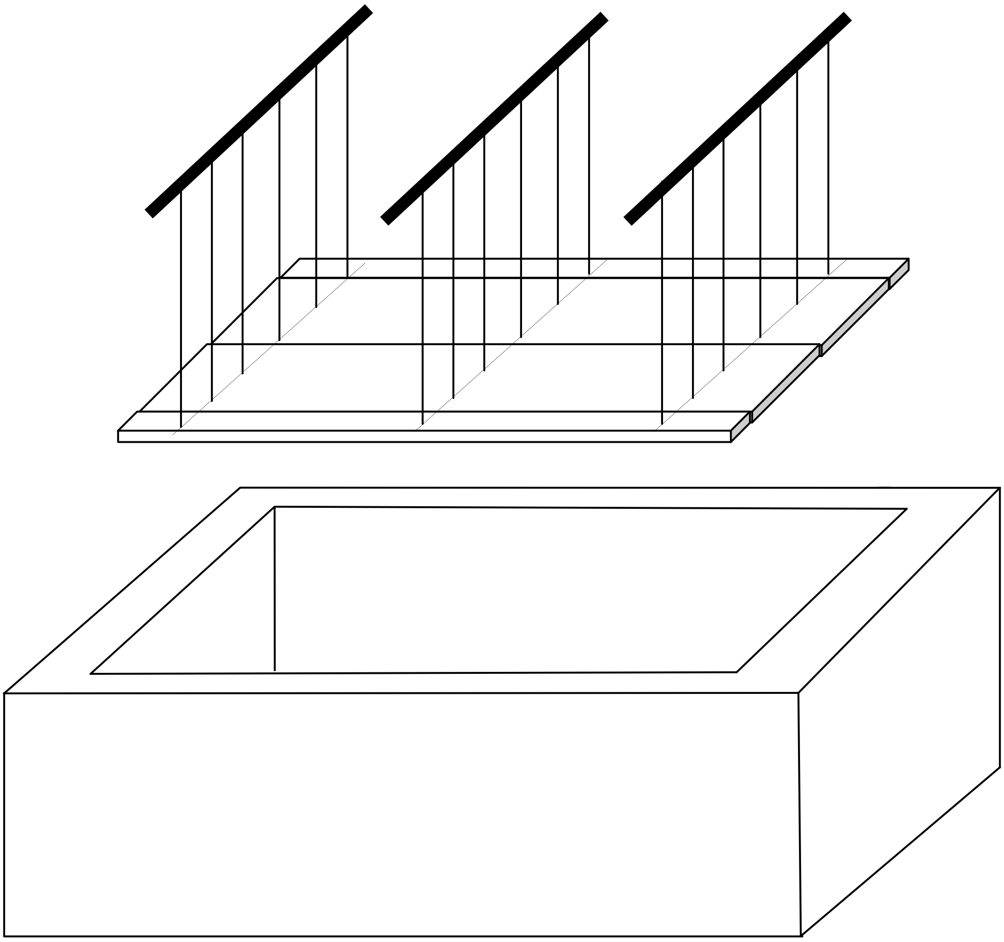

Figure 4.53: Suspended ceiling and fire resistance furnace.

Figure 4.54: Suspended ceiling and weighted hangers on fire resistance furnace.

Table 4.11: Schedule of fire resistance tests on ceiling panels.

	Dimensions	Hangers	Load per hanger
Test A: 60 mins	4000 x 3000	2 x 6	32 kg
Test B: 90 mins	4000 x 3000	3 x 6	32 kg
Test C: 120 mins	4000 x 3000	3 x 6	64 kg

The ceilings in tests A and B were loaded to the equivalent of a 4.5 m span between hangers equivalent to a ceiling load of 0.12kPa, additional weight around hangers was added to compensate for reduced span limited by the 4000 mm long furnace. In test C, the weight at each hanger was increased to 64 kg to give an equivalent ceiling load of 0.24 kPa.

The standard time-temperature curve was modified to incorporate a slower start, so as not to damage and stress the panel adversely early in the test. This approach was also justified, as it is unlikely that a real fire in a large space would grow that quickly. The slow start only equated to a 3 minute delay in time-temperature curve beyond 20 minutes compared with the ISO curve. So in the case of test C the test was run for 123 minutes and this is equivalent to 120 minutes to the standard conditions. The modified time-temperature curve is shown in Figure 4.55.

Figure 4.55: Modified time-temperature curve used in suspended ceiling tests.

The behaviour of the specimens in the three tests was very similar and the various phenomena occurred at much the same times.

Typical observations were as follows with times in minutes and seconds:

3:30	A slight deflection downwards of the ceiling of 10-20 mm in the middle was observed, with some creaking sounds from within the panel.
4:00	Deflection downwards had increased to 30-40 mm and the panel was visibly moving.
6:00	The plastic caps on the nuts on the underside suspension points were melting and starting to form droplets. Smoke was beginning to evolve from the perimeter capping.
8:40 to 10:30	Intermittent external flaming was observed as smoke periodically ignited and extinguished itself.
10:30	Flaming was now continuous.
11:30	Vigorous flaming on upper surface.
13:00	Flaming had spread to the entire upper surface of panel. Furnace was turned off to prevent temperature overrun. Panel was deflection about 500 mm.
14:00	Some flaming from panel joints.
15:00	Flaming (external) was almost extinguished.
15:30	Flaming stopped, EPS burned out, large gap in centre of panel at joint.

16:00 Vision into furnace through a gap 200 to 300 mm wide at a localised vertical separation of panel joint.

27:00 Chains supporting panel still under similar tension to beginning of test, no sign of hanger studs and nuts pulling through panel.

30:00 Loud crack (noise) heard on upper surface- joint popping open, rivets had let go, no vision into furnace. Horizontal gap of 30-40-50 mm on top surface (skin) at panel joint.

33:00 Joints on the fire exposed underside were opening up.

34:00 Joint on exposed side with vision through both skins had opened to a ~ 6mm horizontal gap when viewed vertically upwards. A rivet further along had popped, unzipping of the joint was slowing.

.

42:00 The lower surface deflected to obscure the centre row of hanger nuts.

49:00 There was no apparent evidence of the nuts and washers pulling through panel skins. Quite a few gaps opened up on upper surface 100 mm at widest and some flames visible, sagging is quite significant.

70:00 Joints on underside open but not increasing, same on upper surface. There was no imminent indication of failure.

80:00 Joints showed some deformation over hanger points.
123:00 Test stopped, no failure of ceiling or hangers.

Significant milestones in the tests were the melting of the plastic caps at 6 minutes, the involvement of the EPS core between 11 and 15 minutes (see Figure 4.57) requiring the furnace to be turned off to prevent a temperature overrun. Progressive opening of joints occurred from 30 minutes to 70 minutes and then some deformation (cupping) of the ceiling panel over the suspension nuts and washers. Not a single failure or pull through of a suspension point was noted or appeared likely to happen, even if the tests had continued (see Figure 4.58 and Figure 4.59). The ceilings had reached a stable condition and appeared likely to have remained attached beyond the 120 minutes of test C.

Figure 4.56 shows the ceiling temperature on the upper surface of the ceiling and in the furnace. The temperature spike between 11 to 15 minutes is due to the involvement of the EPS core and the subsequent trough is after it had been consumed and the furnace burners restarted. Recording of the upper surface temperature was only possible to approximately 40 minutes when the thermocouple became detached from the surface, at that time the surface temperature was lagging behind the furnace temperature by approximately 300^{o}C and the projection beyond 40 minutes is based on that. After 120 minutes, it is estimated the upper steel skin of the panel was at 700 to 750^{o}C and the lower skin appreciably more, without any structural failure.

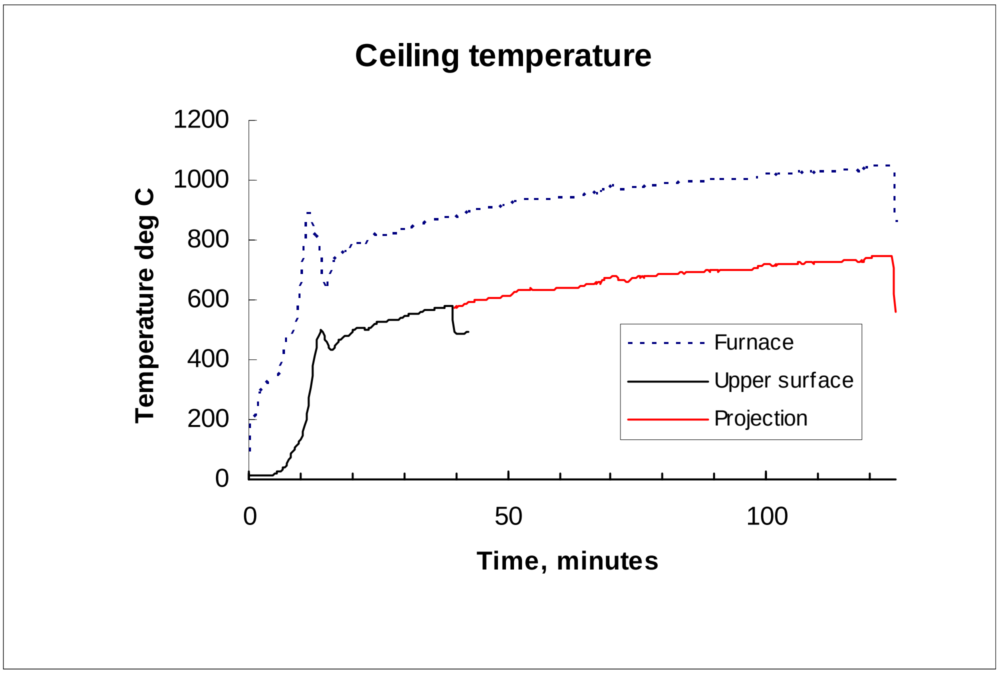

Figure 4.56: Typical temperature of ceiling and furnace.

Figure 4.57: Suspended ceiling test showing flaming between 11 and 15 minutes.

Figure 4.58: Suspended ceiling after test.

Figure 4.59: Cupping around hanger point.

4.5.2 Supplementary test on hanger systems

Following the successful demonstration of the structural integrity of the suspension system with fire from below, the performance in the event of fire exposure from above was considered. The individual hanger systems from three manufacturers were tested in full immersion to 60 minutes of ISO fire conditions in the BRANZ pilot furnace.

Table 4.12 Hanger fire test in pilot furnace.

Suspension system	1	2 *	3
Initial weight, kg	33.785	33.195	32.950
Post-test weight, kg	21.12	28.96	28.15
Cable/chain length, mm	1002 (1)	1018(2)	970(3)
Stretched cable/chain length, mm	1210	1073	985
% stretch of cable/chain	20.7	5.4	1.5
Total stretch cable/chain and L bracket, mm	228@ 33min	123	80
Failure time, min	33	60**	60**

* Suspension system as used in the ceiling tests

**No failure

(1) L bracket and 2.6 mm medium carbon steel wire
(2) Stirrup and 4.75 mm chain
(3) L bracket and 7.7 mm chain

Figure 4.60 and Figure 4.61 show the experimental assembly for testing the hangers, from left to right the systems are numbered 3, 2, and 1.

Figure 4.60: Suspension systems prior to hanger test.

Figure 4.61: Suspension systems after 60 minutes exposure.

The suspended weights were nominally 32kg (concrete) and some of this was lost due to spalling as recorded in Table 4.12.

At 33 minutes the number 1 suspension system failed at the top connection, the steel wire snapped in the top loop rather than the copper ferrules (talurits) melting/softening or otherwise slipping, there was no visible deformation of the ferrules. It was estimated the system had stretched 228 mm. The L bracket had straightened out similarly to the number 3 L bracket in the after test photo Figure 4.61.

The number 2 hanger system had dropped a total of about 123 mm over the total height (2.2m), noticeably by a straightening of the stirrup sides and elongation of the chain.

The number 3 hanger system dropped about 80 mm, mostly from straightening of the L bracket.

In all three cases, 30 minutes of fire exposure was exceeded. Considering the suspended ceiling tests when no collapse (at the hanger points in the panels) was observed after 2 hours with double the normal dead weight on the ceiling and hangers (fire from below) there does not appear to be a serious weakness in the current suspended ceiling systems with PIP's.

Further consideration needs to be given to what fire load or duration is likely in a ceiling space. In the furnace ceiling tests there was observed to be about 3 minutes of intense flaming (between 11 and 14 minutes into the tests) on the upper surface as the fuel load in the 100 mm thick panel burnt off, after that there was no further flaming on the upper surface. By establishing the likely fire exposure in a ceiling space for actual buildings it is very likely that this will be equivalent to less than 30 minutes exposure to an ISO standard time-temperature curve fire.

5. CONCLUSIONS

In terms of improving the fire performance of PIP’ some benefits in joining panels were identified which will delay the core EPS involvement in a fire. The current practices for suspending ceilings were shown to be satisfactory as far as preventing panels from falling.

5.1 Cone testing

The cone calorimeter testing compared critical heat fluxes and total heat release, and confirmed the superior performance of flame retardant (FR) treated EPS compared with non-flame retardant (NFR) grade EPS. The attachment of steel skins, also improved fire performance, and the addition of fibre-cement board under the steel skins was shown to improve the performance markedly.

5.2 Cavity spread

5.2.1 Vertical panel

For the vertical panel no appreciable fire spread or significant sustained combustion was indicated within the panel cavities themselves. The area of the EPS core that was consumed by fire was limited to the heat affected zone. The value of the flame retardant was demonstrated. No significant opening of joints occurred, which meant the flame retardant performed its function, as there was minimal circulation and exchange of vaporised EPS gases and outside air.

5.2.2 Horizontal panel

For horizontal panel with a penetration in the panel such as a light fitting, the potential exists for the molten EPS to drain onto the fire source and contribute to the growth and spread of the fire. Gaps that open up in the panel joints may also allow the spread of fire by dripping molten EPS onto or near a fire source.

5.3 Joints

The ISO room calorimetry tests on the PIP assemblies of three interlocking joints and two mitred corner joints showed improvements in fire performance based on a reduction in the magnitude of the heat release, delays in the time that the increase in heat release commences. Reduction in the rivet spacing of the interlocking joint to 600 mm slowed a discernible improvement, but the difference between 2400 mm and 1200 mm spacing was less distinct. The performance of the two mitred corner joints demonstrated the superior performance of the joints attached by steel angle compared with the aluminium angle as this melted allowing the joints to open on both sides and allow earlier involvement of the EPS core. The steel angle and rivets remained intact for the duration of 20 minutes and the involvement of the EPS core was limited to combustible gases escaping from the distorted joints. There is potential for further improvement in performance by making the joints more resistant to opening under fire conditions.

5.4 Suspension of ceilings

The suspension system proved to be more than adequate in retaining a ceiling under fire resistance test conditions. Even if the tested ceilings were loaded to twice the expected dead load and exposed to the equivalent of the standard ISO fire exposure curve from below for a period of 120 minutes it showed no indications of collapse or detachment. Significant deformation around the fixing points was noted, but there was no failure by the suspension points pulling through the steel skin.

The alternative scenario of a fire from above in a ceiling space was considered where the upper portion of a suspension system is exposed to fire was trialled for 60 minutes to ISO fire conditions. One manufacturer's system using high carbon steel wire failed at 33 minutes and the other two using chains had not failed at 60 minutes. In all cases some deformation and elongation was indicated.

The current methods of using steel shafted bolts and mushroom caps for suspending ceiling installations do not appear to be a weakness in the PIP buildings, in terms of minimal risk from falling ceiling panels, with the possible exception of the steel wire system beyond 30 minutes exposure. On the basis of the observed 3-4 minutes of intense flaming on the upper surface of the ceilings in the three ceiling tests, some assumptions about the likely exposure of the suspension systems are possible. If it is accepted that a fire in a ceiling space would remain centred in one location for a similar time of 3-4 minutes and as the fuel in the form of the EPS core is consumed the seat of the fire moves to a new location in the ceiling space. As the minimal fuel load contribution of the EPS core is consumed, it is unlikely that the fire exposure to a hanger system would reach 30 minutes. This will depend on various factors including the occupancy and risk and the support structure to which the suspension system is attached to and each case should be considered on its merits.

5.5 Potential Improvements

The value of FR EPS was demonstrated, provided the skins remained intact without opening up, thus appreciably restricting an exchange of the halogenated gases with air within the panels maintaining the flame retardant effect. In instances where the panels opened forming larger gaps, it was observed that some cavity burning/extinguishment and re-ignition were occurring.

The most significant problem with fire exposure is that the originally rigid and secure panels become very flexible and unstable steel skins. Providing a satisfactory method of joining the skins together and attaching them to a structure will reduce the rate at which the core becomes involved in the fire and slow the progression of a fire by impeding the availability of the core as a source of fuel. It has been demonstrated that cavity spread is not a mechanism for the spread of fire and that other factors such as the opening of joints allowing escape of the retardant halogen gases does permit some core burning.

Improvements to the fire performance of PIP's are directly related to the security of the steel panels when not supported by the EPS core. The areas of weakness are primarily in the joints, both interlocking and corner, which are prone to opening even when secured by rivets. Also preheating of the panels in excess of 150°C ahead of the fire spread potentially has the effect of melting the EPS core and weakening the panels before they are directly exposed to fire. The fixing of ceilings was not shown to be a major problem provided steel studs with plastic mushroom caps are used and are securely fixed to a frame, similar fixing of wall panels will ensure equivalent security.

The most significant improvement that can be realised is to fix the panels together in such a way as to minimise the opening of joints. Some escape of vaporised EPS from the core is tolerable and impossible to eliminate, this will produce some smoke and limited burning outside the panels. If the gaps between the panels can be kept to a minimum, the flame retardant halogen gases will minimise fire spread within the panels. The most practical solution to the problem is that a PIP building where the EPS core is progressively melted as a fire moves throughout the building and the EPS does not become involved except where it unavoidably escapes from the building envelop, but makes no real contribution to the available fire load. In such a scenario the rate of fire progress will be slowed to a minimum and with no falling panels positive fire fighting will be possible, rather than the 'let it burn' philosophy currently adopted due to the dangers apparent from past and present experience.

The experimental trials conducted in this project focused on small scale testing targeted at better understanding the specific performance characteristics that were identified in the strategy. This enabled the performance of specific aspects such as suspension systems, joint detail, and the phenomenon of cavity spread to be examined and evaluated. It is acknowledged that in a full scale test or a real building fire that the overall performance may be different. A full scale test is better suited to evaluating the total system performance, where an observed failure may be attributed to any one or more causes. So conducting a full scale test is better justified once there is a sufficiently high degree of confidence that the performance of various sub systems that make up a construction will not fail and thus demonstrate that the performance of the overall construction method has been improved. Otherwise, if there is some failure in the construction it is possible there will be some doubt as to the actual cause.

5.6 Fire fighting issues

The fire fighting issues raised in the earlier stages of the project were:

- Hazard to fire fighters due to falling ceiling panels
- Way finding is impeded by the dense smoke
- Fire spread in cavities means fire can travel unseen and appear at new locations.

The findings of this project indicate that the risk of falling ceiling panel, using the construction methods that are currently employed in New Zealand, is minimal. The only minor question is with steel wire (as opposed to chain) suspension systems where the fire exposure in the ceiling space exceeds the equivalent of 30 minutes to the standard fire test. A fire engineering assessment of fire load in the ceiling panel (see section 5.4) and ceiling space, if any, could form the basis for determining the likely fire exposure of the suspension system.

Way finding inside a burning building is an issue related to the integrity of joints between panels. Improvements in the joint performance have a direct relationship with the quantity of pyrolysis products escaping and the level of smoke.

Fire spread within cavities, beyond the heat affected zone, was not observed in the experimental phase. In the case of the ceiling system, the fire spread further than in the vertical panel tests. However, this was due to the wider area of exposure due to the ceiling plume and molten EPS flowing from the opening on to the fire source. Some EPS also escaped from an opening in the joint on the underside of the panel, but improved jointing such as the addition of rivets would reduce this.

In conclusion, the problems identified in the Industry Workshop and the Literature Survey relate to the security of panel attachment and fixing. For the products and systems manufactured in New Zealand, some aspects of performance exceeded expectations, but there is some scope for further improvement in jointing detail.

6. RECOMMENDATIONS

The first part of this section of the report makes recommendations that come directly from the experimental and theoretical research undertaken as part of the project. In addition, a series of recommendations are also presented which, although not directly addressed by the project, are considered generally covered by the scope of the research and relevant to the project objectives.

6.1 Recommendations from the experimental programme

The following recommendations for improving the fire performance of the polystyrene insulated panel were derived directly from the findings of the experimental programme.

6.1.1 Cone calorimeter

The testing of samples in the cone calorimeter demonstrated the benefits of flame retardant treated EPS. On this basis, it is recommended that flame retardant EPS be used in all construction applications. The cone calorimeter testing also demonstrated the effectiveness of flame barriers. It is recommended that flame barrier materials be used to protect exposed EPS as extensively as possible. It is also noted that all EPS used in construction in New Zealand currently uses flame retardant treated EPS.

6.1.2 Cavity fire spread

The trials to investigate the phenomena of cavity spread between the metal skins of the PIP failed to produce any significant burning beyond the zone that was externally preheated by the flame from the burner. The experimental findings suggested little to be gained by incorporating non-combustible barriers within the core of the PIP. As a result, there are no recommendations to improve the fire performance of PIP in relation to the issue of cavity fire spread.

6.1.3 Joints between panel sections

The trials on the joints showed there is scope for improvement in the performance by making the joints more secure. It is recommended that those who design and install PIP can improve the fire performance of PIP by using the following methods to improve the integrity of panel joints:

- Closer rivet spacing on joints
- Substitute aluminium rivets with a higher melting point alternative
- Use light-gauge steel angle on corner joints instead of aluminium angle.

6.1.4 Suspended ceilings

The current practice of using steel-shafted mushroom bolts to secure the ceiling panels to the suspension system was demonstrated to be satisfactory. Accordingly, it is recommended that steel-shafted mushroom headed bolts continue to be used to suspend PIP ceilings and that in no circumstances should all-plastic mushroom headed bolts be used in this application. Although one of the suspension systems failed in a severe fire immersion trial, it is considered that the current systems that use either chain or steel wire will perform satisfactorily and their continued use is recommended, unless specific fire engineering design suggests otherwise.

6.1.5 Future research

It is recommended that future areas of research investigate:

- a more thorough examination of potential improvements in jointing systems
- more realistic alternatives to the current flame barrier test methods contained in the Approved Documents of the Fire Safety Clauses of the NZBC.

In the interests of conformity, there is a strong case that any new test method be internationally acceptable.

6.2 Future considerations

In the course of the project, from the initial industry workshop, literature survey and steering committee meetings, a range of topics related to improving the fire performance of PIP were discussed. These topics, although not specifically addressed by this project, were however considered to warrant further recommendations.

6.2.1 Adequacy of supports for suspension systems

Although it was shown that the suspension systems tested in this project performed adequately in fire exposure situations, it is recommended that designers give careful consideration to the design of the structure supporting such suspension systems to ensure that PIP ceilings do not collapse prematurely in a fire.

6.2.2 Purpose groups

There is little evidence to suggest that the life safety of building occupants is threatened in typical PIP applications, due to “alert” occupancies (i.e. non-sleeping) and low occupant numbers. If PIP is being considered for use in purpose groups (refer to Approved Documents for the Fire Safety Clauses of the NZBC for definition (BIA, 2001)) where there are either large occupant numbers or sleeping occupants, it is recommended that the designer give careful consideration to the fire performance properties of PIP and hence to the overall fire safety strategy that will be adopted for the particular building.

6.2.3 Scale of experimental research

The experimental trials conducted in this project focused on small and medium-scale testing, targeted at better understanding the specific performance characteristics of PIP. This enabled the performance of specific aspects such as suspension systems, joint detail, and the phenomena of cavity spread to be examined and evaluated. It is acknowledged that in a full-scale test, or a real building, that the overall performance may be different. It is therefore recommended that designers take care when applying the results from this project to actual situations that are at a larger scale.

6.2.4 Hangers and support of PIP on load bearing walls

At ambient temperatures, PIP is a rigid material with good structural properties. However, at elevated temperatures in a fire such properties are rapidly lost. Whenever a designer is considering the use of PIP as a loadbearing element, it is recommended that the possibility of the structural failure of this element in a fire be factored into the overall fire performance of the building.

6.2.5 Active fire protection systems

Active fire protection systems such as sprinklers are proven to be effective. It is recommended that all relevant stakeholders be consulted at the earliest stage of a project when deciding whether sprinklers should or should not be used in a building constructed from PIP.

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8. APPENDIX 1 – STRATEGY

The third phase of the project was to identify the key fire performance issues and then develop a strategy for the experimental phase of the research followed by a fourth phase which consisted of an assessment of the responses to the strategy paper. The responses of the stakeholders generally supported the proposals of the steering committee and included some valuable suggestions on the future dissemination of the findings.

The following strategy document was circulated to key industry stakeholders for comment. The paper summarised progress to date and the proposed experimental programme for addressing the key performance issues. Based on the comments and feedback received the experimental programme was further refined and is presented in sections 8.5.3 and 8.7.

8.1 Purpose of strategy paper

The strategy paper was based on the outputs from the workshop and the literature survey. The strategy paper was developed jointly by the project research team and the project steering committee – and was intended to be a consultative document to allow key PIP industry stakeholders to be involved in the development of the strategy.

8.2 Review of industry consultation workshop

An industry consultation workshop was held at BRANZ's premises at Judgeford, Wellington. The workshop brought together approximately 45 representatives from various sectors of the PIP industry. Delegates at the workshop heard presentations from a number of experts who each gave a different perspective on their respective segment of the overall PIP industry. Breakout discussion groups also gave delegates the opportunity to formulate questions, which the presenters responded to in panel discussion sessions.

Eight major themes came out of the workshop, as follows:

1. Adequacy of current requirements for PIP contained in C/AS1, the Acceptable Solution for the Fire Safety Clauses of the New Zealand Building Code
2. design/construction methods to improve fire performance of PIP
3. fire fighting issues
4. causes of fires
5. sprinklers
6. insurance
7. fire behaviour
8. environmental issues.

In consultation with the project steering committee, this list of eight topics was consolidated down to five areas for the international literature survey to focus upon. The three topics eliminated from the scope of the literature survey were:

- Causes of fires – it was considered that this was outside the general scope of the project in that it was a generic issue relevant to any fire scenario, not just fires involving PIP.
- Sprinklers – this again was considered to be outside the scope of the project in that the focus of the research was upon "passive" rather than "active" performance improvement measures. In addition, the effectiveness of sprinklers is already widely accepted in the

fire safety community, and is considered to be an economic decision for a PIP building owner to make.

- Insurance – although insurance issues were seen as being very topical, they did not fall within the coverage of the project as such.

8.3 Summary of international literature survey

An extensive survey of a wide range of New Zealand and international literature was conducted. Unfortunately, while being generally relevant, the majority of the literature did not relate specifically to the scope of this particular research project.

The following subsections summarise the information that was identified as being relevant to the project.

8.3.1 Adequacy of NZBC requirements

There were no specific references in the literature to the NZBC requirements for PIP. The research team was concerned, however, that the test methodology for flame barriers stipulated in C/AS1 was not adequate, and that more realistic testing procedures were required.

8.3.2 Design/construction to improve fire performance

Various references identified the panel joints as being an important area to focus on in seeking ways of improving fire performance. It was also noted that preventing the collapse of ceiling panels was an important issue.

8.3.3 Fire fighting

The literature identified a number of fire fighting issues relevant to the scope of the project such as the involvement of the core in fire growth, the amount of dense black smoke produced in PIP building fires and the risk posed by collapsing ceiling panels.

8.3.4 Fire behaviour

The literature gave no clear guidance as to whether fire spread within panel cavities was an important issue or not. There was general agreement that fires in PIP buildings are generally under-ventilated, which results in high levels of smoke production. There were also a number of references to using realistic test methods to assess performance.

8.3.5 Environmental issues

It was difficult to find references that dealt specifically with environmental issues associated with PIP. The risk of contaminated fire fighting water runoff would appear to be slight. Depending on ventilation conditions, large amounts of dense smoke are produced by burning PIP. The major toxic product from the combustion of the core of PIP is carbon monoxide, similar to other organic materials.

8.4 Strategy development

The first step to developing a strategy for the New Zealand PIP industry to improve the fire performance of the product was to identify the key fire performance issues. The second component in the development of the strategy involved an experimental programme to quantify existing levels of fire performance and, which could then be used as a baseline for proposing amendments to improved performance.

8.4.1 Key fire performance issues

The project research team and the project steering committee spent considerable time discussing and prioritising the various issues relating to the fire performance of PIP. The key issues finally agreed upon were considered to be both important and within the scope of the project, as well as likely to have the greatest chance of successfully achieving the project objectives. It was also decided that the opportunity should be taken to quantify some important material performance characteristics, which would be a valuable and additional output from the research.

In identifying key fire performance issues, the project research team and project steering committee also identified specific issues relevant to the New Zealand Fire Service to ensure inclusion, where relevant, in the development of the strategy. It was identified that the four key fire performance issues addressed, either directly or indirectly, the following NZFS issues:

- Contaminated fire fighting water runoff
- Collapse of panel ceilings
- Smoke production (visibility)
- Toxicity
- Fire growth and spread.

8.4.1.1 Fire spread in cavities

This phenomenon is defined as self-sustaining combustion that occurs in the cavity (gap) between the metal skins of PIP when the EPS core has melted in a fire situation. The project research team and steering committee felt this was an important issue to investigate and quantify because there was considerable disagreement at both the Industry Consultation Workshop and in the literature as to its significance.

8.4.1.2 Structural collapse

The collapse of PIP ceilings in fires was clearly identified as a major safety issue for fire fighting personnel. It was agreed that the effectiveness of existing ceiling suspension systems when exposed to fire should be thoroughly investigated.

8.4.1.3 Core involvement in fire growth

The contribution that the exposed core of PIP can make to fire growth and severity has been identified on a number of occasions during the project. It was considered that ways of protecting the core of PIP from involvement in fire growth would help achieve overall project objectives.

8.4.1.4 Fire performance characteristics

The project research team and steering committee felt that there were a number of significant gaps in the current knowledge of the fire performance characteristics of PIP and that useful information could be generated by this project.

8.4.2 Experimental research programme

8.4.2.1 Fire spread in cavities

It is proposed that full-scale PIP specimens be subjected to a fire source where flames are directly impinging upon the core of the sample. Measurements will be taken to monitor how susceptible the specimens are to self-sustaining fire spread.

8.4.2.2 Structural collapse

It is proposed that PIP ceiling specimens, complete with proprietary suspension systems, be subjected to realistic fire exposure conditions in the BRANZ full-scale furnace. Variable levels of load will be applied to the ceiling to test the effectiveness of the suspension systems.

8.4.2.3 Core involvement in fire growth

It is proposed that various joint configurations be tested to ascertain the effectiveness of various methods for minimising core involvement, as well as monitoring fire growth and smoke production.

8.4.2.4 Fire performance characteristics

Cone calorimeter testing of FR and NFR PIP samples with variable radiation levels and duration will determine critical ignition fluxes. The ignition characteristics of EPS in a molten state, including the effectiveness of flame retardant treatment when the EPS is molten, will be useful data in evaluating the effectiveness of other protection measures such as the importance of containing the EPS within the panel.

8.5 Summary of comments on strategy

The comments and feedback received generally concurred with the steering committee and research team conclusions regarding which themes identified in the first industry consultation workshop, and confirmed as being relevant by the literature search, should be pursued.

8.5.1 Peripheral fire issues

The three topics, which had earlier been eliminated from the scope of the project by consultation with the steering committee stimulated some further discussion as follows.

The issue of **insurance**, although a primary driver is not a direct objective of the project, nevertheless any positive findings for improving the performance of PIP will require the support of the insurance industry for there to be an economic benefit. The type of structural system may be taken into consideration when determining the premium that the owner pays.

The effectiveness of **sprinklers** was again promoted as the most effective means of early fire suppression. Partial solutions proposing the use of drencher systems on the PIP walls stimulated some discussion, but it was eventually conceded that only a system protecting the whole building would meet the sprinkler standard. Finally, it was reiterated that sprinklers were considered outside the scope of the project and that installation in cold stores presents another set of challenges.

No significant pattern in the **causes of fire** has been identified to differentiate PIP from any other construction materials. However, it was acknowledged that once a fire has established beyond a critical size the PIP contribute fuel increasing the fire severity and loss expectancy.

8.5.2 Ongoing education

In addition to the proposed experimental research, there is a need for an extensive education programme that targets the PIP design and installation industry with safe specification, design, detailing and installation practices, including monitoring of hot work. The scope of education would include knowledge already available for the design and specification of PIP construction, which could have prevented recent fire losses that instead have been blamed on the poor fire performance of PIP. Issues of proper maintenance of the building envelope including the importance of repairing uncovered penetrations that leave exposed polystyrene are a fire risk that needs to be addressed. The findings of the research could also be integrated into and support such an education programme.

8.5.3 Research programme

The stakeholders were in general agreement with the direction of the experimental research. Some relevant comments reiterating the importance of several aspects of the key fire performance issues are summarised as follows.

8.5.4 Ignition characteristics

Determining the ignition characteristics of PIP and EPS, in particular critical heat fluxes for different fire sources and configurations of panel with and without flame retardant treatment, were noted as being worthy of investigation.

8.5.5 Fire spread within panel cores

Fire spread within cavities was stressed as an important issue and worthy of attention.

The problem occurs when fire penetrates the panel skin and ignites the EPS core, often as a result of uncovered penetrations and other holes in the steel skin. It is also important to establish whether impingement of heat on the panel surface leads to spread of fire in the core.

Means of limiting fire spread between panels such as passive barriers were proposed.

8.5.6 Construction through the panel fixing

There was a strong response advocating research into methods of improving existing structures to retain their stability and a means of stitching/joining panels together where joined. The benefit of containing EPS cores within panels to prevent or at least limit involvement in fire was also strongly advocated.

The use of stainless steel bolts to fix panels is proposed, because of a lower thermal conductivity compared with steel of approximately one third. Nylon bolts have been favoured in applications where insulation of the enclosure is a primary consideration such as freezers and coolers, but they melt when exposed to fire allowing detachment of panels.

8.5.7 Fire fighting issues

After improvements have been made to the fire performance of PIP, in particular reducing the likelihood of falling panels, improving wayfinding by reducing smoke production and fire spread in cavities, but a question remains. How can the confidence of fire fighters be increased so that they will not consider themselves endangered to any greater extent entering burning PIP buildings compared with any other building type? Without some benefit to fire fighter safety being recognised, there is unlikely to be any change to the ‘let it burn’ principle currently adopted. Some means of colour coding of panel types on the basis of fire performance was proposed to aid identification and assess risk.

8.6 Miscellaneous comments

Alternatives to combustible cored panels should be considered, but EPS cores offer many advantages over the alternatives except in fire. The advantages are the strength of the panel and they are hygienic and easy to keep clean. In Australia, some problems with mineral wool products have been encountered in relation to food processing environments. In addition, if the core material is other than EPS, possibly with a higher melting point, the problem of delaminating sheets will not be improved significantly because the glue line will be affected by a temperature rise similar to that at which the EPS melts.

It is anticipated that as a result of the findings of this research, panels with improved fire performance will be installed in new buildings and in renovations and extensions to existing buildings. Even so, fire fighters are likely to be reluctant to enter burning buildings, for fire fighting or rescue, unless there is some reassurance that the fire behaviour of the building has been improved. A means of identifying the improved fire-safe construction has been suggested, such as colour coding of panels. It is acknowledged that if vision is impaired inside a building due to smoke levels or the panels are discoloured from heating, then colour coding will be of limited value in determining safer areas within buildings but it may be an improvement on the current situation.

Ventilation of the building space by purposely allowing selected areas of panel ceiling to open or collapse in the event of fire was suggested as a means of allowing smoke and heat to escape. It is acknowledged that this conflicts with the provision of ensuring fire fighter safety within the building and protecting them from falling panels. Some means of allowing panels to swing open without falling to the floor would be preferable. Similarly, a means of identifying which panels are designed to open in fire is required and colour coding has been suggested. If every building were required to have a colour-coded floor plan at the main points of entry to the building, or adjacent to fire hose reels, then fire fighters could see quickly which areas are "safe" from falling panels, and which are not.

8.7 Experimental programme

The experimental programme proposed in the strategy paper was universally endorsed, with some of the proposals receiving particular support.

The issues identified as being crucial to a better understanding and improving the fire performance of polystyrene insulated panel in decreasing order of importance were:

- fixing of panels to prevent structural collapse and delamination
- fire spread within panels, establishing whether and how it may occur in practice, and if so trial methods to reduce it
- containment of EPS within panels by improved joint details and fixing to minimise involvement in fire
- demonstrate the value of flame retardant treatment of the EPS
- ignition characteristics including critical radiation fluxes, configurations, and durations.

These issues formed the basis of the experimental programme and the individual trials were designed to address the issues raised.