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Experimental and numerical study of temperature developments in PIR core sandwich panels with joint

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ABSTRACT

This paper presents the results of an experimental and numerical investigation of temperature developments in sandwich panels consisting of steel sheeting and polyisocyanurate (PIR) core. Fire experiments were carried out on individual PIR sandwich panels and PIR sandwich panels with joint. The fire test results were used to validate a temperature dependent thermal conductivity model for PIR, through numerical heat transfer modelling using the general finite element package ABAQUS. The fire test results indicate that the temperatures at the joint on the unexposed side of a sandwich panel is initially lower than that on the panel. However, at high temperatures, the ablation of PIR core creates large gaps up to 25 mm. Due to high radiation within the gap, the joint temperature becomes much higher than the panel temperature. The results of a numerical parametric study indicate that if the joint gap can be controlled to be no greater than 5 mm, the joint and the panel temperatures on the unexposed surface would be similar. Joint gaps of 10 mm or greater would result in joint temperatures much higher than panel temperatures and would reduce the sandwich panel system insulation performance of less than 60 min even though the panel may be able to reach much longer standard fire resistance rating.

1. Introduction

Sandwich panels (also known as 'composite' or 'insulated panels') consist of two high strength, relatively thin facings that enclose a thicker, low density core material, see Fig. 1. The facings protect the low density core and are the main loadbearing components. The core material is critical in terms of insulation performance and should have sufficient shear stiffness in the direction normal to the facings. The facings of sandwich panels are usually manufactured out of steel. For the core, a range of materials can be used, including polyurethane (PUR), polyisocyanurate (PIR) and expanded polystyrene (EPS).

Sandwich panels are a pre-fabricated, high performance wall-cladding and roofing systems with superior insulating characteristics. Traditionally, sandwich panels have been specified for industrial buildings and warehouses (commonly known as 'big sheds') but are now a favourable choice in building construction, where they are being used in retail, leisure, cold stores, transport and energy sectors, in addition to uses in schools and hospitals. Sandwich panels may be used as standing alone components, or as part of Structural Insulated Panel (SIP) system in dwellings and apartment construction where the sandwich panels are connected to OSB panels, timber studs, gypsum plasterboards and other components [11,14,3]. This research is concerned with standing alone sandwich panels.

Joints play an important role both in terms of thermal and mechanical performance. As shown in Fig. 2, the joints between sandwich panels are weak points, therefore a better performing joint is the driver in prolonging fire resistance times. Although there has been a lot of testing of PIR panels, there is a lack of detailed explanations on how the joints affect sandwich panel fire resistance and how joint design may be improved to increase sandwich panel fire resistance time. Understanding how joints behave and affect sandwich panel performance in fire is fundamental to better design of sandwich panels for improved fire resistance.

The fire resistance of a sandwich panel is measured by its ability to contain a fully developed fire. In unloaded sandwich panels, fire resistance is quantified by either insulation or integrity performance, both strongly influenced by heat transfer through the joints. It is therefore critical that knowledge of heat transfer within a panel joint is available to develop thorough understanding of sandwich system performance in fire. Because sandwich panels are proprietary products, there is a general lack of publically available information reporting detailed research studies. In particular, there is very little reported research on sandwich panel joint performance in fire [4]. In the fire tests reported by Hopkin et al [11] on structural insulated panel

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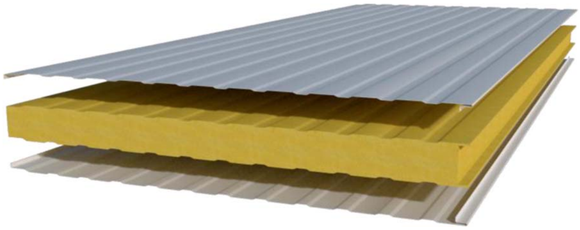

Fig. 1. Arrangement of a sandwich panel core and facing materials [16].

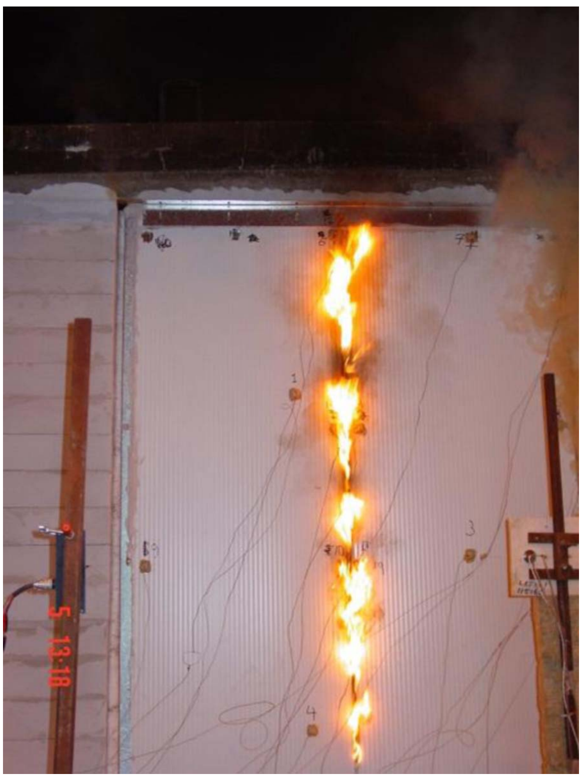

Fig. 2. Flames penetrating through sandwich panels at the joint [17].

systems, sandwich panels were connected to structural loadbearing components including OSB panels, timber studs and gypsum plasterboards. These structural loadbearing components govern the panel system fire performance. Furthermore, the emphasis of their study was on whole system performance, rather than on sandwich panel joint performance. This paper is focused on standing alone sandwich panels.

Whilst fire testing is indispensable to quantify sandwich panel fire performance, it is very expensive to conduct. Therefore, it is desirable to be able to use numerical modelling to predict sandwich panel fire performance. An important requirement of accurate numerical heat transfer modelling is accuracy of the input material thermal properties. Because PIR is lightweight, the key thermal property is its thermal conductivity. Sandwich panel manufacturers [5] typically only provide thermal conductivity values at ambient temperature. This was also assumed in numerical modelling by other researchers [3]. However, as will be explained in Section 3 of this paper, the high temperature thermal conductivity of PIR may be many times the ambient temperature value. It is important that the effects of temperature on thermal conductivity are included.

Therefore, the specific objectives of this paper are as follows:

- To carry out fire experiments to obtain temperature distributions in standing alone sandwich panels and their joints.
- To validate a temperature dependent thermal conductivity model for PIR.
- To carry out a series of numerical parametric studies to investigate the effects of joint gap on sandwich panel temperature developments in fire, so that methods may be developed to improve insulation performance of standing alone sandwich panels.

The research will be carried out by carrying out some fire experiments on individual sandwich panels and on sandwich panels with joint, and then use numerical modelling to investigate the effects of joint gap on sandwich panel insulation performance in fire, after comparison of numerical modelling and fire test results for validation of the temperature dependent thermal conductivity model for PIR.

2. Fire tests

2.1. Fire tests on individual panels

To validate the temperature dependent thermal conductivity model for the PIR core (see Section 3.1), two small scale fire tests were conducted on sandwich panels with PIR core. The two specimens had two different thicknesses, 80 mm and 100 mm, and were subjected to fire exposure from inside a furnace in a setup designed to monitor through-thickness temperature distributions. The planar dimensions of the samples were square with a length of 700 mm. The two panel specimens were cut from sandwich panels of lightly profiled steel sheets of thickness 0.5 mm with PIR foam core. The standard ISO 834 (International Organization for Standardization) [12] fire temperature-time curve was followed in the furnace.

Seventeen thermocouples in total were used in each test (T1 to T17); 5 on the unexposed side (T1, T10-T13), 5 on the fire side (T9, T14-T17) and 7 through the thickness of the panel (T2-T8). Figs. 3 and 4 show the panel dimensions and details of the thermocouple layout on the surfaces. The surface thermocouples were attached to the surface steel sheets of the sandwich panel specimens mechanically with staples. The mechanical fastenings ensured that the thermocouples stayed in position at high temperatures.

Fig. 4 shows the elevation view of through thickness positions of these thermocouples for both the 80 mm and 100 mm thick panels. The internal thermocouples were uniformly spaced through the thickness at a spacing of 10 mm and 12.5 mm, respectively.

Figs. 5 and 6 show the exposed surfaces of the samples after testing. The exposed side steel facing delaminated from the foam core. This happened quite early in the fire test (about 1.5 min as indicated by loud popping noise from inside the furnace) when the surface temperature was about 100 °C. This phenomenon plays a noticeable role in heat transfer through the panels which will be considered in the subsequent heat transfer analyses.

In addition to the above mentioned observations, hot spots were observed on the steel facings of the unexposed sides of the specimens, as can be seen in Fig. 7. These hot spots were areas of rapid heat transfer through the panel, most likely where the foam had cracked allowing for quick transfer of heat by radiation to the unexposed side of the panel. These hot spots appeared at random locations, resulting in relatively large variations in the recorded temperatures on the unexposed surface.

A section of the charred foam was broken in half to assess the pore size of the charged core. Fig. 8 shows the pore size of the fully charred foam is on average 2.5 mm.

2.2. Fire tests on sandwich panels with joints

The objective of these fire tests was to provide information for the assessment of sandwich panel joint fire performance. Due to a lack of suitable fire testing laboratory, the fire tests were carried out at the Lancashire Fire and Rescue Services facility, Chorley, Lancashire, United Kingdom. This is a very rudimentary fire testing facility used by the fire brigade for training. Fig. 9 shows photos of the metal