THE PERFORMANCE OF INSURER CERTIFIED PIR (POLYISOCYANURATE) CORE STEEL FACED SANDWICH PANELS IN REAL BUILDING FIRE SITUATIONS.

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Abstract. With reference to test requirements and investigations carried out into real life fires, this paper looks closely at the enhanced fire performance that can be achieved using insurer certified steel faced sandwich panels with a polyisocyanurate (PIR) insulation core.

INTRODUCTION

Commercially available sandwich panels utilise a number of alternative insulating core materials which most commonly include expanded polystyrene, mineral fibre and rigid urethane (including polyurethanes and polyisocyanurates).

Polystyrene is a thermoplastic polymer which means that the molecules are linear chains without cross-linking. The lack of cross-linking means they have a low melting temperature. Rigid urethanes are not thermoplastics and have varying degrees of cross linking between molecular chains which results in a thermoset behaviour. This means that much higher temperatures can be sustained before the material degrades and better fire performance can be achieved.

Mineral fibre insulation core panels comprise non-combustible inorganic fibres held together by an organic resin and bonded to the steel skins of the sandwich panels typically using a polyurethane adhesive.

VERIFYING PERFORMANCE IN THE FIELD

It is inevitable that building products will be occasionally exposed to real fire events. When this happens it is important to use the opportunity to assess how the product behaved. Since 2002 Kingspan has commissioned a number of fire investigations to assess the performance of its products in real fire events and a selection of these are discussed below.

Fire resistance

PIR core sandwich panels are specified for internal walls and ceilings that need to provide fire compartmentation and external walls that need to be fire resisting to protect adjacent properties. PIR core sandwich panel systems can deliver up to 60 minutes insulation and integrity performance to the standard fire test conditions specified by EN1364-1 Walls and EN1364-2 Ceilings. To satisfy the requirements of the fire test, the panel must be resistant to flame penetration and limit the temperature rise to a maximum of 180°C above ambient temperature on the unexposed surface.
How this fire resistance performance manifested itself in the field was illustrated quite clearly by a fire in the Irish Republic in 2008.

The truck shown in Figure 2 was parked directly outside a transport business depot and was deliberately set on fire. This resulted in complete destruction of the vehicle and some significant damage to the building as shown in Figure 3.
Despite the direct impact of the fire on the outside of the building, the PIR cored sandwich panels provided sufficient integrity and insulation performance to prevent fire spread to the inside of the building. The business was able to continue trading on the morning after the fire.

**Reaction to fire (resistance to fire propagation)**

Due to large fires where there has been evidence of insulated sandwich panels contributing to severity of the fire, insurance bodies have been keen to establish that the buildings they insure are not constructed from materials which will promote fire growth and spread. Insurer standards have therefore been introduced to verify that insulated sandwich panels will have an appropriate performance in terms of providing no significant contribution to the severity of a fire event in the building.

Typical insurer standards that are used in this respect are LPS1181 (UK) and FM4880 (US and globally). See Figure 4 and Figure 5. Both these standards include a range of tests to establish that the construction of the sandwich panels does not contribute to fire spread on either the surface of the panel or via the insulation core material.
A fire at the Suffolk Food Hall in 2010\(^4\) demonstrated the benefit of using PIR cored sandwich panels that satisfy these insurer standards. A fire occurred at about 0500hrs in electrical equipment located in a plant mezzanine area directly below the roof which was constructed from large section timber portal beams supporting PIR cored sandwich panels.

The fire spread along the plant mezzanine involving all exposed combustible materials and including the timber supporting structure of the roof. Figure 7 shows the effects of the fire on the main roof structure where the depth of timber charring of 15mm was equivalent to what would be expected in a standard fire resistance test after approximately 23 minutes duration\(^5\), at which time the furnace temperature would be approximately 800°C\(^6\).

The attending fire service cut a hole through the roof construction directly above the fire and in the location of the damage shown in Figure 7 to ventilate the area. Figure 8 shows the hole which was cut (which has been temporarily re-covered). The effect of the heat of the fire on the PIR core can be seen
showing delamination of the exposed steel skin of the sandwich panel from the core, the formation of a carbon char layer and unaffected material at greater depth in the section which has been insulated from the fire.

Figure 8. Hole cut in roof by fire service to vent fire area

Fire spread in the building was confined to the mezzanine plant area and the combustible materials therein. Immediately beyond this area roof timbers were scorched but not charred indicating temperatures less than 450°C. PIR roof panels were not delaminated indicating that the fire had not been propagated by the PIR core.

Achieving functional fire performance objectives for fire-stopping

In 2009, a fire occurred at RA Wood Adhesives in England completely destroying the part of the building occupied by that business.7

A marked-up satellite image of the building taken before the fire is shown in Figure 9.

Figure 9. Satellite view (marked up) of the building before the fire

The part of the building occupied by RA Wood Adhesives was to the left of the dotted line indicating the position of fire compartmentation from the business next door. The roof across the building was constructed using PIR cored sandwich panels. For compliance with UK Building Regulations
guidance\textsuperscript{6}, the roof construction would need to include the detail shown bubbled in Figure 10 at the interface with the compartment wall.

Figure 10. Detail to comply with UK Building Regulations guidance\textsuperscript{6}

The aftermath of the fire shown in Figure 11 demonstrated that the fire compartment wall performed its intended function in preventing fire spread to the business next door which was able to continue trading.

Figure 11. Compartment wall location after the fire

In this case the PIR cored sandwich panel insulation had been continuous over the top of the compartment wall and had not been interrupted by a 300mm wide band of limited combustibility
material (e.g. mineral fibre) as recommended by design guidance. An examination carried out of the panel interface at the head of the wall (see Figure 12) showed that the PIR core had charred to form a stable and effective seal between the steel skins of the sandwich panel to prevent fire transmission to the protected side of the wall. It should be noted that UK design guidance now recognises that an alternative approach might be to use a panel system which has been shown in a large scale test to resist internal and external surface flaming and concealed burning.

**HOW DOES PIR PROVIDE ENHANCED FIRE PERFORMANCE?**

PIR insulation, also referred to as polyiso, ISO or IPN (a Kingspan tradename signifying panels system certification to FM 4880 Class 1 and B-s1, d0 to EN13501 Part 1) is a part of the rigid urethane polymer insulation family. This polymer family consists of a range of materials that are generally described as either polyurethanes (PUR) or polyisocyanurates (PIR). Importantly, there is no clear cut-off point that defines where a polyurethane finishes and a polyisocyanurate starts – all variants contain a mixture of urethane and isocyanurate chemical bonds.

The basic chemistry of these materials is well documented. The chemical constituents are a polyol, methylene diphenyl disocyanurate (MDI), catalysts, surfactant, water and blowing agent along with additives such as fire retardants in specific formulations. The blowing agent is a gas that forms from a liquid additive during the exothermic reaction to create the closed cell structure of the insulation. A large proportion of this gas therefore remains contained within the structure of the finished insulation product.

PIR formulations used to meet insurers’ stringent fire performance standards are proprietary technology but in general terms the improvement in fire performance is a result of higher cross-link density which is achieved by systems based on polyester polyols, a high MDI content, specialised catalyst systems and high temperature processing. Figure 13 shows key differences in thermal response influencing fire performance.

*Figure 13. Graph showing key thermal properties*
Of particular importance, as observed in standard tests and investigation of real fires, is that the PIR insulation formulations meeting insurers’ test requirements do not exhibit the same degradation as other polyurethane insulations. In their research into fire behaviour of flexible polyurethane foams, Shields and Ohlemiller\textsuperscript{10} reported that this degradation starts to occur at approximately 200°C and when temperatures in excess of the order of 270°C are reached then the material decomposes into the constituent liquid polyol material. This degradation of the thermoset polyurethane is not a true “melting” phenomenon since the degraded material does not re-solidify when the temperature reduces.

This degradation behaviour has been observed by the authors as a surface phenomenon on rigid polyurethane insulations which have been heated to the point of ignition by the application of a gas flame in ad-hoc demonstration (Figure 14). In this demonstration, apparent liquefaction of the heated surface of the rigid insulation occurs as the material degrades and then ignites with significant smoke emissions. It is this mechanism that gives the appearance that the heated surface of the rigid polyurethane insulation is “shrinking back” when it is ignited.

Figure 14. Ad-hoc gas flame demonstration test on rigid polyurethane insulation

Isocyanurate chemical bonds or linkages are stronger than urethane bonds so in insurance industry certified systems this feature, combined with their aromatic ring structure and higher cross-link density, results in a more chemically and thermally stable product. By comparison, polyurethane products with predominately urethane bonds have a relatively low cross link density. The greater bond strength and higher cross link density of insurance industry approved PIR core systems means that the polymer does not exhibit degradation into the polyol component and instead reduces into a carbon char when exposed to fire.

Figure 15 shows a sample of PIR insulation removed from the Suffolk Food Hall fire and indicates the way in which the material reacts to fire exposure. As evidenced by the formation of pockets within the material, when the insulation reaches a certain temperature then the blowing gases trapped in the closed cell matrix of the insulation expand and are emitted from the insulation as it becomes permeable by the formation of the larger voids.

As the material gets hotter then it reduces to leave a stable graphite-like carbon char that continues to provide insulation to the material beneath.
It is this behaviour which is fundamentally different to the other polymer insulations. The simple experiment shown in Fig. 16 illustrates the relative stability of the PIR material which allows it to achieve the fire performance noted in the RA Wood Adhesive case study.

In this experiment, a cylindrical sample of the insulation material with a diameter of 33mm is placed on top of a flat aluminium plate and beneath a solid aluminium block. The mass of the block is such that it places a compressive stress on the sample of approximately 0.009N/mm² (9.0kPa). A gas torch is used to heat the aluminium block and a thermocouple used to monitor the temperature of the block close to its interface with the sample. The detection of thermally induced shortening of the sample is achieved by a copper strap attached to the plate and just in contact with the top of the block. The block and plate are both wired to a multi-meter which monitors the resistance of the resulting circuit. As soon as there is any thermally induced shortening of the sample, the circuit is broken and the temperature can be noted.
Figure 17 shows a graph indicating the results of the experiment. Polystyrene insulation material demonstrated significant melting of the sample at a block temperature of 130ºC. A sample of single part aerosol-applied rigid Polyurethane foam material indicated initial collapse of the foam structure at the block interface at a temperature of 162ºC. A sample of PIR insulation material taken from the Suffolk Food Hall fire responded very differently. At a block temperature of 300ºC, the interface of the sample with the block shows darkening of the sample material and it can be noticed that, whilst there is no shortening of the sample, it is widening and fissuring at the top. This phenomenon continues to the end of the test at a block temperature of 428ºC. At this temperature there was still no shortening of the sample. Figure 18 shows the PIR sample at the end of the experiment. Figure 19 shows the sample cut in-two and the effects of the heat from the block on the sample can be seen. The experiment confirmed that degradation of the material to a stable char included a slight intumescent effect that prevented reduction of thickness of the sample under the compressive load.

Figure 17. Experiment results

Figure 18. PIR sample at end of experiment
CONCLUSIONS

1. To satisfy the exacting standards for steel faced sandwich panel systems required by insurers’ test requirements, PIR insulation formulations have been developed by manufacturers that exhibit significantly improved thermal response to fire than traditional rigid urethane insulations.
2. The key difference in this thermal response is the reduction of the material into an insulative carbon char rather than decomposition into the liquid polyol.
3. This feature enables the insulation to retain sufficient physical integrity under fire exposure to achieve both fire resistance and prevention of fire propagation within the material.

An on-going programme of real fire investigations is verifying these features and adding to a database that supports the use of steel faced sandwich panels systems with a PIR insulation core in performance based fire engineering designs.

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