Large sandwich panel fire resistance assessment

Assessment of fire resistance for long span sandwich wall panels based on fire resistance test data for small assemblies 3m square (the largest size that can be tested in UK fire resistance furnaces), needs particular care to ensure that fire integrity is preserved. Fire safety consultant Gordon Cooke describes the process

Eurobond Laminates Ltd has for many years manufactured the FireMaster range of fire resisting steel-faced sandwich panels with non-combustible rockwool cores. With the recent commissioning of its new £5M continuous production line near Cardiff there was a need to expand the market for its panels. The firewall market was attractive especially if panel assemblies could be safely specified for large fire walls, particularly in large volume industrial and storage buildings, requiring up to 2h fire resistance. Eurobond's answer was to develope the Performa system and provide a 'one stop' for design and installation using well-trained approved installers.

The standard fire resistance test

Two fire resistance tests have been successfully conducted in the Warrington Fire Research Centre on vertical assemblies of 1150mm wide Performa panels of 100mm and 150mm thickness and each assembly has attained more than a 2h rating. The furnace test gives essential information on which to base a professional quantified assessment of fire resistance for elements substantially larger than the fire tested specimen (an oversize element is an example of an 'extended application' in CEN terminology and requires careful assessment)

The BS 476 fire resistance test on a firewall is a severe test of the stability, integrity and insulation characteristics of a fire separating wall in the post-flashover stage. It simulates a fully developed fire after flashover and is not to be confused with several of the *ad hoc* room-and-crib tests in which flashover does not occur, or occurs for only a short time, and it should not be compared with real fire scenarios. In the fire resistance test the furnace combustion gas temperature reaches approximately 1200°C at the end of the 2h exposure and is accompanied by a high level of radiant heat.

The most important aspect of fire resistance of non-combustible steel-faced panel construction is integrity of panel joints – i.e. the ability to prevent gaps from forming through which flames and hot gases may pass. Thermally induced deformations in large constructional elements can greatly affect fire integrity. Since, in a sandwich panel assembly, the fire exposed steel face may be expected to delaminate early in a real fire (and within the first 5mins of a standard fire resistance test) causing opening of unstitched panel joints, the important factor is integrity of the joints in the unexposed steel face.

It should be noted that steel-faced panels having combustible cores may need their joints stitched (usually by riveting) in order to prevent access of air which allows consumption of the core by flaming combustion rather than by pyrolysis. Once the core is involved in flaming combustion it reduces in thickness and has a reduced insulating effect. With a rockwool fibre core it does not matter if the joints open up in the exposed steel face as the core material is unaffected.

Deformations of long panels

Any differential bowing of adjacent panels could cause unstitched panel joints to dislocate in the unexposed face causing a loss of integrity. The magnitude of bowing of the unexposed steel face (which is position fixed at its ends in horizontal spans) is much greater in a 9m span than in a 3m span. I have developed equations which can be used to predict both thermal bowing along a steel stud due to a temperature gradient across the section, and of relevance to this project, the bowing which occurs when a panel face is heated along its entire length while its ends are position-fixed[3].

Before attempting a large-scale fire test it was thought prudent to erect three 9m long panels spanning horizontally between robust vertical columns and then remove one steel face from the three panels to establish any instability effect when only one steel face (the unexposed face) was supporting the 150mm thick rockwool core. This would simulate the loading condition after the fire exposed face had delaminated. This room-temperature test proved that the assembly was stable and the end fastenings were unaffected.

However this test did not show what happened when the unexposed steel face slowly rose in temperature and bowed as in a furnace test exposure or a real fire. In Performa panels spanning horizontally, the steel faces at the ends

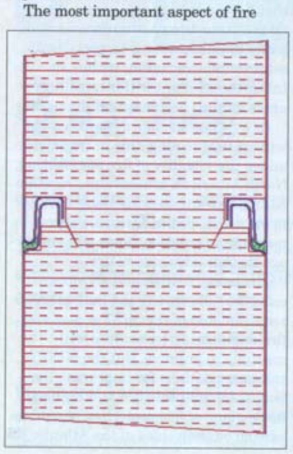

Fig1. (left) Performa system installation

Fig 2. (right) Performa panel joint

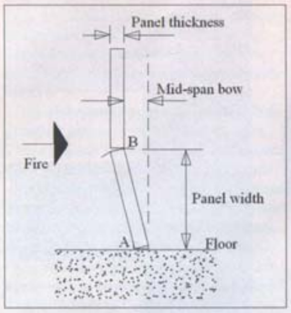

Fig 3. (left) Forced rotation of lowermost panel next to floor

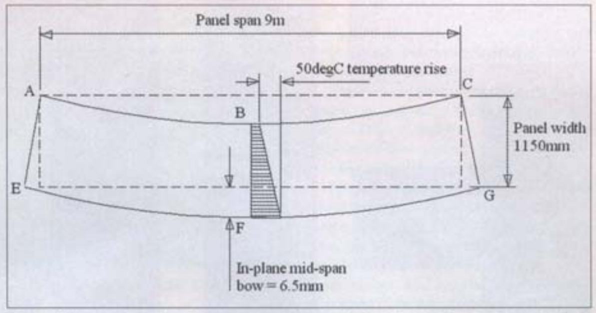

Fig 4. (right) In-plane bowing of panel face due to a temperature gradient across panel width

are rigidly attached via 5mm diameter steel fastenings to the supporting steel columns and when restrained in this way any rise in temperature due to heat flowing through the rock wool would be accompanied by bowing. 150mm thick Performa panels experienced a temperature rise on the unexposed face of nominally 80°C at the end of a 2h exposure in the standard fire resistance test.

If the ends of a heated panel are prevented from moving axially, the mid-span bow (assuming circular bowing) is given by[1]:

$$\Delta_N = [0.375 L \Delta_L]^{0.5}$$

where L = span of panel;
and Δ_L = unrestrained axial expansion = αLT in which α = coefficient of linear thermal expansion and T = temperature rise.

Fig 5. (below) Assembly of fire test panels on site

Fig 6. (bottom) Delamination of exposed steel faced before test using gas flame

Using this equation gives, for instance, a mid-span bow of nominally 180mm in a 9m span heated through 80°C, but less for smaller spans. Thus ideally any large-scale *ad hoc* fire test should impose a temperature rise on the unexposed face of nominally 80°C during the period of maximum fire severity on the exposed face. This could be achieved, for example, with low voltage electrical heating tapes applied to the three lowermost panels.

If all panels bowed to the same amount no panel joint dislocation could occur. But the lowermost panel cannot freely bow along its lowermost edge since in normal practice the lower edge is located within a light steel channel section fixed to the concrete floor slab, (Fig 3).

The potential weakness in joint integrity is therefore along the joint between intermediate panels and the lowermost and the uppermost panel at mid-span in the assembly, as shown in Fig 3. It can be seen that as the upper panel bows it drags the upper edge of the lowermost panel and rotation about point A occurs with potential loss of integrity at point B. In the Performa system the bowing is limited by using a core thickness that keeps the temperature rise of the unexposed face as low as possible and the joint at B is stitched on both sides as an additional precaution.

Another thermal distortion effect that has been examined in the Performa system is in-plane bowing when there is a temperature difference across the face of a panel. In Figure 4, the temperature of edge EFG is assumed to be 50°C above that of edge ABC and, for a 9m long panel face, this causes a mid-span bow of 6.50mm. This is far less than the 18mm design overlap in the tongued and grooved steel roll formed edge, and so integrity is not lost.

The large scale *ad hoc* fire test

To check the bowing behaviour and stability of a large Performa panel assembly a full-scale fire test was deemed necessary. Information is available to guide the choice of *ad hoc* fire test conditions[4,5]. Many fire test simulations were considered. It was clearly not possible to have an enclosure fire because of the large size. Nor was it practical to have a fire which, as in the furnace test, continued to burn for 2h, unless oil or gas was employed. The obvious choice of fire load was timber – the classic choice of fire test scientists and engineers and a choice that would lead to an environment-friendly fire producing very little particulate matter. Although, as pointed out above, it would be desirable to impose a temperature rise on the unexposed face of approximately 80°C, and this could be done with, for example, an assembly of electrical heating tapes applied over the lowermost three panels, it would not be possible to arrange this within the timescale. Besides, the tapes would need insulating to prevent heat loss and the assembly of tapes and insulation would obscure sight of the lower panel joints – the joints of principal interest.

An assembly of panels each spanning 9m horizontally and stacked to give a 10m height was assembled in the open air, fixed as in practice to a robust rectangular frame made of steel I-sections (Fig 5). A row of timber cribs each 1m square and 1.25m high using 50mm square sticks were spaced roughly 250mm apart and placed along the bottom to produce a 'line fire'. This represented a fire load of 30MJ. This is six times the fire load used in the Factory Mutual large corner test for panels and linings (Class 4880), and was expected to give a severe fire. Measurements were made of deflections and temperatures of the exposed and unexposed steel faces.

In an extended application assessment one has to assume that the whole wall face is exposed to a uniform fire as in the 3m square BS furnace test specimen. In the furnace test the exposed face is delaminated over the whole area, and if the *ad hoc* test was to be meaningful the whole of the 10m high face of panels would similarly have to be delaminated. This means that the dead load of the unexposed steel face becomes that of the steel face and rockwool core which remains bonded to it, and this could add to the loading on the lowermost panels in the stack and instability, bearing in mind that the composite sandwich action has been destroyed. The peak flame height calculated using fire engineering guidance in

BS 7974[6] was expected to be around 9m so the exposed steel faces of panels above 7m level were intentionally delaminated after installation but before the fire test using a hot, diffuse gas flame torch operated from a cherry picker, see Fig 6.

The fire lasted approximately 90mins from ignition to the point of major decay – a point, admittedly, difficult to define. There was a cross wind blowing during the test assessed to be force 4 on the Beaufort scale. However, once all the cribs had become involved in fire the strong upward flames mostly dominated over the effect of wind

As predicted, the fire exposed steel face delaminated early in the *ad hoc* fire test and underwent massive bowing as it attained a temperature of more than 130°C over the lower two panels. However, again as predicted, the unexposed steel face remained cool. Although the lowermost panel was subjected to severe distortion caused by upward bowing of the base perimeter steel beam (Fig 7) (a beam that would not be present in a normal site installation), the panel joints remained engaged and the rockwool core, similarly subjected to very high local temperatures, remained in place. Distortion did not dislodge the protecting core material despite the very severe fire. The test proved good joint integrity was achieved and this was because the unexposed steel face temperature was kept low and uniform, achieved by the good elevated-temperature insulation properties of rockwool. It was noted that inevitable buckling of the fire exposed steel face did not disrupt or remove any of the rockwool core despite massive and widespread buckling.

As a result of this development and test programme the Performa firewall system has been assessed to have a 2h fire resistance for 9m horizontal spans and for 8m vertical spans. In the case of horizontal spans the lowermost inter-panel joint needs stitching to prevent joint dislocation due to the differential bowing described above. Similarly, vertical panels need to be free to bow in the fire condition and this is allowed in the design of panel head detail, and a special joint at the boundary of the vertical panel assembly. The panels do, of course, require support from beams or columns having at least the same fire resistance as the panels. The fire exposed steel face should not detach and fall down from a large enough height to be an unseen missile hazard to fire fighters. The height at which this is assumed to be hazardous is arbitrary and a matter of professional judgment, and the height from floor level is taken as 7m for horizontal Performa panels. It is noted that BS 476 makes no such requirement for the fire exposed face of a specimen although any such phenomena should be noted in a fire resistance test report. To avoid detachment of the fire exposed steel face on horizontal panels used at a height above floor of 7m or more, the number of panel end fastenings is increased.

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Conclusions

A large scale *ad hoc* fire test has been successfully conducted to examine the effect of a severe fire on the integrity of the unexposed steel face of a 10m high assembly of panels spanning 9m horizontally. The qualitative and quantitative results of the severe test together with fire safety engineering calculations has enabled an assessment of fire resistance to be made for large assemblies requiring up to 2h fire resistance.

It should be noted that the purpose of the *ad hoc* fire test was not to attempt to simulate a particular fire, as in practice fires may be more severe at different parts of the assembly. Depending on a wide range of fire parameters the fire could be more severe at the top of a fire wall when a 'crown' fire occurs, as in a high-rack storage building, or the fire could be more severe at the base, as in the case of a local fire on the floor immediately next to the panels. Furthermore, the severity in a fire compartment would be different for different fire load density and ventilation conditions.

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Further reading

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