Fire Hazard of Sandwich Panels –

The Effect of Fire Load

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Following my summary paper '*Sandwich panels for external cladding: fire safety issues and implications for the risk assessment process*' published in the January 2001 FEJ, it was a pleasant challenge to read the article by Gordon Butcher and Alan Parnell in the March 2001 FEJ '*Fire hazard of sandwich panels - the effect of thermal insulation*', and the accompanying letter inviting further debate.

Butcher and Parnell [who I shall now refer to as 'the authors'], point out that the high thermal insulation properties of sandwich panel constructions can influence the speed of fire development and time to flashover, irrespective of the combustible or non-combustible content of the panel core material.

As evidence, the authors point to a BRE Information Paper IP19/79, which summarises theoretical work by Thomas and Bullen in the 1970s. The paper showed that the thermal inertia of the compartment lining material – the product of thermal conductivity (k), density (ρ) and specific heat (C) – has an effect on the rate of fire development: the higher the kρC, the slower the rate of development. This is a good starting point and I agree with this hypothesis, but will demonstrate herein that any claim that time to flashover is predictable should be viewed with caution, whether or not the kρC of the enclosure is the issue.

The authors have written their article in such a way that the unwary reader could infer that flashover is directly proportional to kρC, when it is not. Thomas and Bullen, in a comprehensive theoretical treatment [1] state that '*the product of kρC of inert linings has a role in the fire growth but hardly as powerful as producing flashover times in proportion to kρC*'. They add that '*kρC affects time for flashover as (kρC) - or a lesser power*'.

There can be little doubt that predicting time to flashover is fraught with difficulty. In the following summary of test results, I show that in a large room having walls, floor and ceiling of high kρC, the time to flashover is greatly affected by the fire load density (fire load per unit floor area). And, bearing in mind the fire processes described, it poses the question as to whether of not such variations could be accurately forecast.

Time to flashover in large scale experiments

The complexity of the fire process near flashover can be illustrated by reference to some experiments I arranged at the BRE Large Laboratory at Cardington in the late 1990s. They were conducted under closely controlled conditions in a large well-insulated enclosure 23m long x 6m wide x 3m high [2]. A side view is shown in Figure 1.

One end of the compartment was completely open for ventilation (the ventilation opening was 6m wide x 3m high). The fire load was made up of 33 timber cribs arranged on plan in 11 rows of 3, equispaced apart. Each crib was 1m square in plan and comprised 50mm square sticks laid in a criss-cross fashion, each stick separated from the next by 50mm. The crib sticks were kiln-dried to a moisture content of 8-10% by weight. The kρC for the 50mm thick ceramic linings to the walls and ceiling was 2.892×10^3. The concrete floor of the test rig was protected with a 125mm layer of dry silica sand having a kρC of 1400×10^3. Hence the test scenario should encourage very rapid fire spread.

The dramatic and complex effect of changing a single variable - the fire load - is illustrated by two of the test results outlined below. In Test A the fire load density was 20 kg/m^2 of floor area using 7 layers of sticks in each crib. In Test B the fire load density was 40 kg/m^2 using 15 layers of sticks. These cribs are described as 'low' [Test A] and 'high' [Test B] in the following discussion because one is twice the height of the other.

In both tests the row of cribs at the rear of the compartment was lit simultaneously, and fire was allowed to spread naturally to the front of the compartment. Fire progressed by the successive ignition of the tops of the cribs from rear to front by downward radiation from the hot gas layer.

Detailed observations were made of :

- time of ignition
- time for the flames from the rear row of cribs to reach the ceiling, a significant point in the fire development, see Figure 1 (a)
- time for the cribs at the front of the compartment to ignite spontaneously, which corresponded to flashover time (since all the combustibles in the compartment were involved in fire - a criterion of flashover), see Figure 1 (b). These data are given in Table 1.

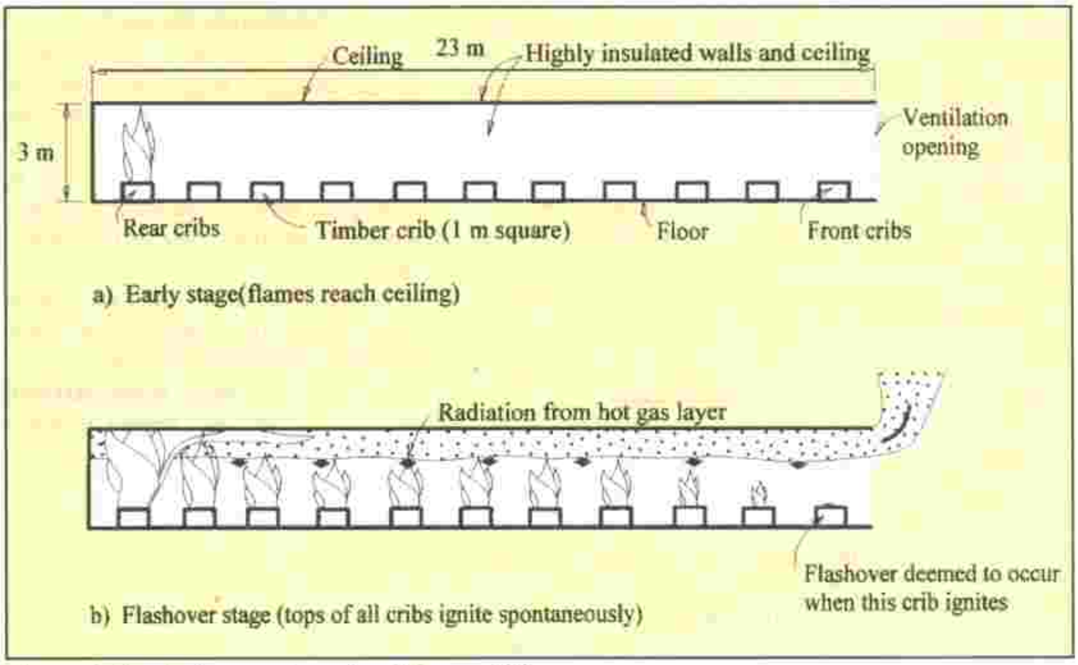

Figure 1. Fire test compartment and fire conditions.

Test	Fire load density *kg/m²*	Time for front cribs to ignite after ignition of rear cribs *(min)*	Time for rear crib flames to reach ceiling *(min)*	Time for ceiling fire spread‡ *(min)*
Test A	40	9.0	3.0	6.0
Test B	20	17.3	6.2	11.10

‡Time for ceiling fire spread' is the time it takes for the flames from the rear row of cribs first reaching the ceiling to the time when the tops of the front cribs ignite. It is a measure of the speed of fire development due solely to the hot gas/flame layer below the ceiling. Data taken from Annex 'Visual observations of fire behaviour' in Reference 2

Table 1.

We see that the time to flashover is roughly doubled when the fire load density is halved (compare 17.3 with 9.0 min). Taking as our datum the time when the flames from the rear cribs first reach the ceiling, we get the same result (compare 11.10 with 6.0). These are dramatic results. We can speculate on some reasons.

1. The heat release rate (HRR) for the high cribs is greater than that of the low cribs. This causes higher temperatures in the hot gas layer flowing under the ceiling resulting in greater radiation from the layer. The greater the radiation intensity, the earlier that spontaneous ignition of the cribs occurs on their upper face and the lower the flashover time. Because radiation intensity is proportional to the 4th power of the absolute temperature, small increases in temperature have a large effect on radiation intensity (I_1). This follows from the well known relation $I_1 = \varepsilon\sigma T^4$ where ε = emissivity of the surface of the radiator (value from 0 to 1), σ is the Stefan-Boltzmann constant ($5.67x10^{-8}$ W m^{-2} K^{-4}) and T is the absolute temperature of the radiator (the hot gas layer in this case).
2. The high cribs (for a given hot gas layer thickness) experience a greater radiation intensity on their upper surface because the radiation configuration factor (ϕ) is larger, Figure 2. This is because the configuration factor can be regarded as a solid angle and this means that ϕ, when the hot gas layer is at AB, will be greater for point E (the high cribs) than for Point F (the low cribs) because the angle AEB is greater than angle AFB. This follows because the intensity of radiation received (I_2) at a point some distance from the radiator is geometrically related to the emitted radiation intensity by the configuration factor ϕ such that $I_2 = \phi I_1$. The smaller the value of ϕ the smaller the intensity of radiation received (ϕ has a value between 0 and 1).

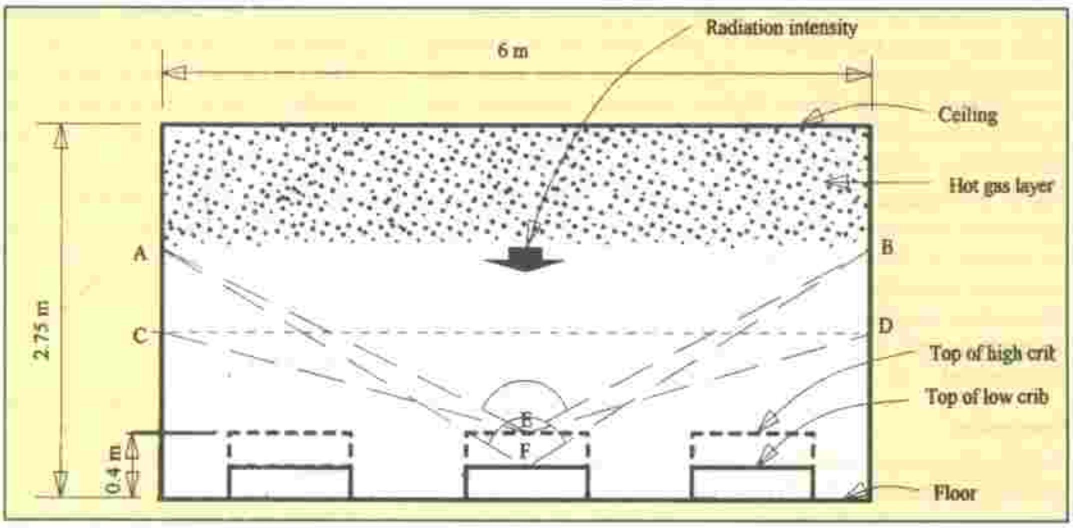

Figure 2. View of front of compartment.

3. The hot gas layer associated with the burning of the high cribs may be thicker, thus increasing the configuration factor (angle CED is greater than angle AEB) and increasing the radiation intensity emitted, Figure 2.
4. The hot gas layer associated with the burning of the high cribs may (or may not) contain more particulates [soot] thus increasing (or decreasing) the emissivity of the radiator and the radiation intensity emitted.
5. The flames from the higher cribs are longer (because the HRR is higher) and there is greater flame extension under the ceiling. Flame extension is the phenomenon which results in the extension of a flame that is forced to travel horizontally rather than freely rise vertically. The greater the flame extension, the higher the radiation intensity emitted.

This discussion does not, of course, illustrate the effect of enclosure insulation on flashover on which the debate began. It does however illustrate, qualitatively, some of the heat transfer mechanisms and highlights just a few of the difficulties that modelling has to cope with. And it demonstrates unequivocally that doubling the fire load halves the flashover time - a fact that would not occur to many of us.

Of course, this result is scenario-specific and one cannot say that this relation would apply to other scenarios. I would go further and say that it is doubtful if a theory could predict this result, therefore we must exercise caution when deliberating on time to flashover, whatever the thermal properties of the enclosure.

I have shown above that fire load can have a large effect upon flashover. This leads me to reflect on the questionable current practice of some ad hoc fire test promoters whereby the fire load used in tests for sandwich panel walls and ceilings is a small fraction of the fire load present in real buildings. This was the main point of my Report [3] which started the current debate and the authors (Butcher and Parnell) are wrong to say, in their opening paragraph, that my paper 'deals only with the dangers associated with combustible sandwich panels'. It is possible that they say this because this was not covered in the IFE summary paper (my original 60 page report contained a section on *'Flashover and sandwich panels'*). Nevertheless I concur that the Report does not provide totally comprehensive coverage of the topic.

Fire load used in IACSC ad-hoc test on sandwich panels

I would now like to extend the debate to cover the subject of fire loads used in ad hoc fire tests on sandwich panels - a topic which is extensively addressed in my original Report. Since its publication last November, I have read with incredulity an account in another journal [4] of tests made in a test room 8m long x 3.6m wide x 3m high in which metal faced sandwich panels with expanded polystyrene (EPS) cores formed the walls and ceiling with openings for ventilation which included a doorway in one wall.

The tests were sponsored by the International Association of Cold Storage Contractors (IACSC) and were carried out to authenticate a '*Fire Stable Certification Scheme*'. The fire load was a single softwood crib 1.0m x 0.75m in plan, placed in the centre of the room, and had a mass of nominally 200 kg. Thus the fire load density was a trivial 7 kg/m^2 (i.e. 200/(8 x 3.6). Since the calorific value of softwood is approximately 18 MJ/kg, the fire load density used in the test is nominally 126 MJ/m^2 .

A noteworthy point is the comparison between the ad-hoc IACSC test fire load density and the professionally-accepted benchmark range of values. Surveys of fire loads in real buildings reported in the BSI DD 240 Fire Safety Engineering guide [5] show that average fire load densities range from the lowest value of 230 MJ/m^2 for hospitals up to 1180 MJ/m^2 for manufacturing and storage buildings while the 90% fractile values, often used for design, are even higher.

As I have discussed, the fire load plays a key role in time to flashover, and I find it worrying that certain tests are not representative of a typical fire and may give misleading results. It is time for us to harmonise our testing standards to resolve this issue.

References

1 Thomas P H and Bullen M L, *On the role of $k\rho C$ of room lining materials in the growth of room fires*, Fire and Materials, Vol 3, No 2, 1979

2 Cooke G M E, *Tests to determine the behaviour of fully developed natural fires in a large compartment*, Fire Note 4, Building Research Establishment, 1998

3 Cooke G M E, *Sandwich panels for external cladding: fire safety issues and implications for the risk assessment process*, Commissioned by Eurisol, November 2000, pp 60

4 *EPS sandwich panels – get the green light*, Roofing Cladding and Insulation, January 2001, pp 16/17

5 BSI, DD 240, *Fire safety engineering in buildings, Part 1 Guide to the application of fire safety engineering principles*, 1997