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Title: Do Unprotected Small Diameter Service Penetrations in Fire Rated Constructions Hasten Gypsum Plasterboard Failure?

Key words: - Fire, Service Penetrations, I-Joists, Building Regulations.

Abstract

'*Technical guidance to the Building Regulations within the countries which make up the United Kingdom (UK) and also the Republic of Ireland permits services of limited diameter, including plastic waste pipes, to penetrate fire resistant wall or floor constructions without protection other than fire-stopping the annular space around the penetration.*

Many European Governments consider growth in the use of timber in building construction as an important factor in reducing greenhouse gas emissions. In addition to traditional rectangular timber sections, engineered timber products have become popular as they offer a number of benefits. Timber I-joists are one such product and comprise thinner section sizes than traditionally sawn joists or studs. When directly exposed to fire it would not be expected that they would not perform as well as a rectangular joist or stud due to the modest thickness of the web. It is therefore imperative that the gypsum plasterboard used to provide fire protection remains in-situ for as long as possible. This paper examines whether the inclusion of these unprotected service penetrations may adversely affect the 'fall-off' time of the gypsum plasterboard from such a construction.'

Introduction

Although within the United Kingdom (UK) and the Republic of Ireland Building Regulations are performance based, the prescriptive technical guidance documents which accompany these Regulations nevertheless remain a dominant influence on building design and construction. These guidance documents, either explicitly or implicitly support sustainability. Some sustainable measures such as the conservation of fuel and energy, building accessibility or the management of surface water drainage are clearly evident. However as this guidance has developed over a considerable period in a piecemeal fashion, it is unclear whether some of the fine detail within the guidance, which may have been developed decades ago, truly aligns with the development of innovative and sustainable building products.

When sourced from appropriately managed forests, timber represents a sustainable construction material [1], which is both renewable and locks away carbon absorbed during its growth [2]. Many European Governments consider growth in the use of timber in building construction as an important factor in reducing greenhouse gas emissions [3]. In addition to traditional rectangular timber sections, engineered timber products have become popular as they offer a number of benefits. Timber I-joists are one such product, which offer advantages such as: greater clear spans, which in turn offer design flexibility and construction economies; economy and sustainability in the use of forest products; structural economy, and construction economy as a result of lighter weight and improved performance in service [4][5]. I-joists are formed from rectangular softwood or Laminated Veneered Lumber (LVL) flanges, joined by a 9.5- 12mm thick web, which is commonly manufactured from Oriented Strand Board (OSB) (See Figure 1).

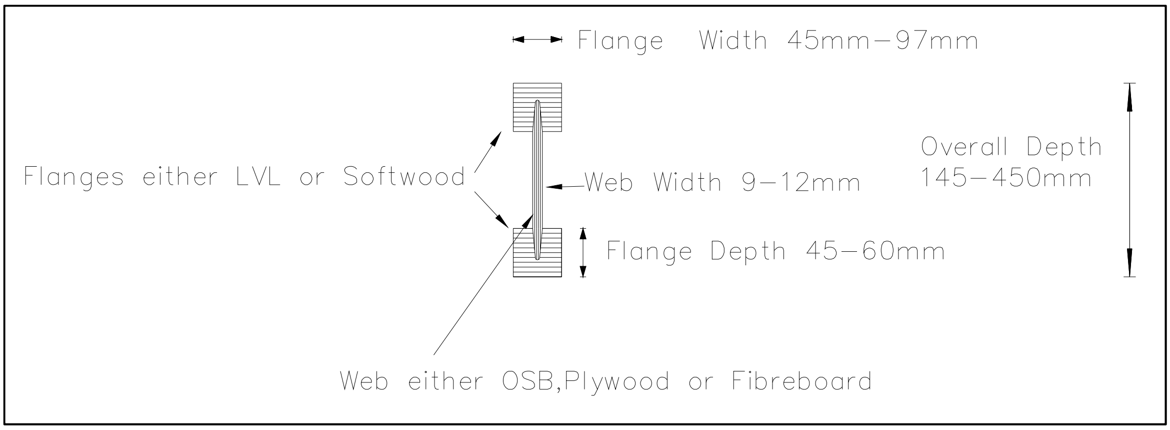

Figure 1: Section through an I-Joist

When heated, the strength of timber reduces until, at around 300°C, a char is formed which has no strength. Due to the modest web thickness, if directly exposed to fire, I-joists would not be expected to perform as well as rectangular sawn joists or studs [6]. With a rectangular timber section a residual rectangle of relatively unaffected timber would remain within the core of the section below the char and heated layers. With an I-joist however, as the web is 9-12mm thick initially, it would be expected to lose strength rapidly.

Floor and wall constructions containing I-joists are typically protected from fire by gypsum plasterboard. Therefore premature failure of the gypsum plasterboard would lead to direct exposure of the I-joist and precipitate structural failure. In order that these products can optimise their sustainable potential, it is therefore necessary to ensure that such constructions can maintain their fire resistance for some prescribed period of time. Manufacturers of such products have both standard fire resistance tests and expert assessments made to ensure that particular specifications which include their products can achieve such prescribed periods of fire resistance. However, as TRADA [7] point out, whilst timber framed constructions have been extensively fire tested over a long period, usually the samples tested are 'notionally 'perfect' elements'.

The building regulation guidance documents in both the Republic of Ireland [8] and the United Kingdom (UK) [9-13], require walls and floors which serve a fire separation, or compartmentation, function to achieve specific periods of fire resistance depending on: building type, compartment size and building storey height. Where such constructions are penetrated by services, the penetration must not undermine this fire resistance. In the case of waste pipe penetrations this is often achieved by the use of an intumescent fire collar, which seals the penetration when heated. However, both the guidance documents in the Republic of Ireland [8] and the UK [9-13] allow 40mm diameter waste pipes to penetrate these constructions without such protection; fire-stopping the annular space around the pipe is considered adequate. Scotland is singular amongst these countries in additionally specifying a maximum number of waste pipes in close proximity and also a minimum distance between adjacent pipes.

The authors concern is that these unprotected service penetrations may allow hot gases to enter the construction cavity of a timber floor or wall. This could be detrimental to the timber members exposed within the cavity and also lead to heating of the rear face of the gypsum plasterboard protection, effectively meaning that the board is being heated both from the fire exposed side and from within the construction cavity simultaneously. As 'fall-off' of gypsum plasterboard is related to its dehydration [5], this simultaneous heating from both sides could influence the time until: plasterboard failure, subsequent direct exposure of the I-joist to the fire, local structural failure of the I-joist due to this direct fire exposure, and hence premature failure in terms of fire resistance of the wall or floor in question. There are two dehydration reactions associated with heating gypsum, the first is initiated at around 100^{o}C. There is wide variation in the literature as to the second dehydration reaction temperature; however Wakili and Wullschleger [14] indicate a peak at around 200^{o}C.

In order to examine the effect of the limitations peculiar to Scotland three reduced scale fire resistance tests were conducted on 2 m x 2 m floor samples. The first test followed the Scottish Guidance, which would also be acceptable in the other countries of the UK and the Republic of Ireland. The remaining two tests did not follow the Scottish guidance, but would nevertheless be acceptable in the rest of the UK and the Republic of Ireland. The discussion in this paper relates only to the first test.

The floor sample consisted of 18 mm flooring grade particle board on 195 x 45 mm timber I-joists at 400 mm centres. The I-joists comprised 45 mm x 47 mm softwood flanges at the top and bottom, connected to each other by a 9 mm thick OSB web. The underside of the I-joists was lined with a base layer of 19 mm gypsum wallboard and a further layer of 12.5 mm gypsum wallboard. This specification was identified within an I-joist manufacturer's technical manual as one providing 60 minutes fire resistance [15]. The samples contained both a construction cavity which was penetrated by plastic waste pipes and a control cavity with no penetrations (see Figure 2). In all cases the plastic pipe material used was Acrylonitrile Butadiene Styrene (ABS). The pipe penetrations were tightly fitted within the apertures in the particle board flooring and gypsum plasterboard. The minimal annular space around the pipe penetrations remaining were then sealed with inert gypsum based plaster filler; this type of fire-stopping material being permissible in the guidance to the Building Regulations.

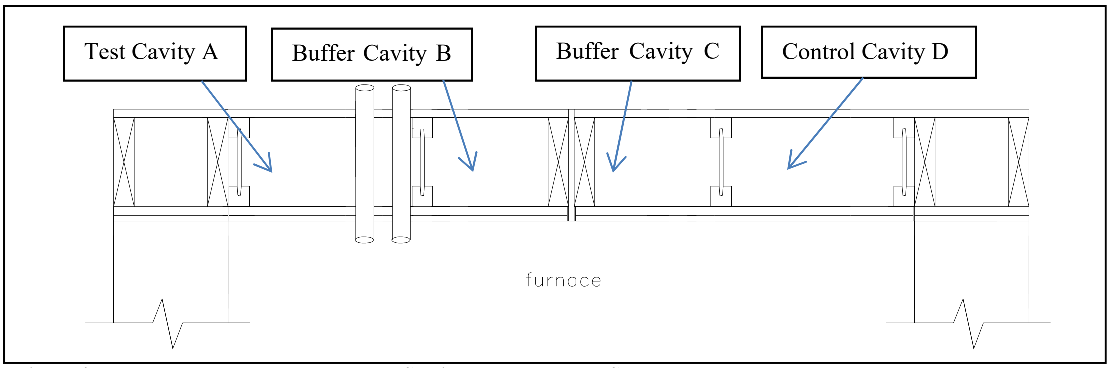

Figure 2: **Section through Floor Sample**

The time/temperature curve followed during the test was that of a BS 476-20:1987 test; variations from the standard curve during the test were within the permitted tolerances [16]. As the test was at a reduced scale it was not possible to load the sample. The temperature of the construction cavity and the rear of the gypsum plasterboard exposed to the construction cavity, both in the test and control cavities were measured using Type K thermocouples linked to a data logger.

Test 1 had a pipe configuration which followed the guidance to the Scottish Building Regulations. Figure 3 shows that after 6 minutes the test cavity average gas temperature was consistently higher than the control cavity temperature, suggesting that the pipe penetrations did lead to increased temperatures within the construction cavity.

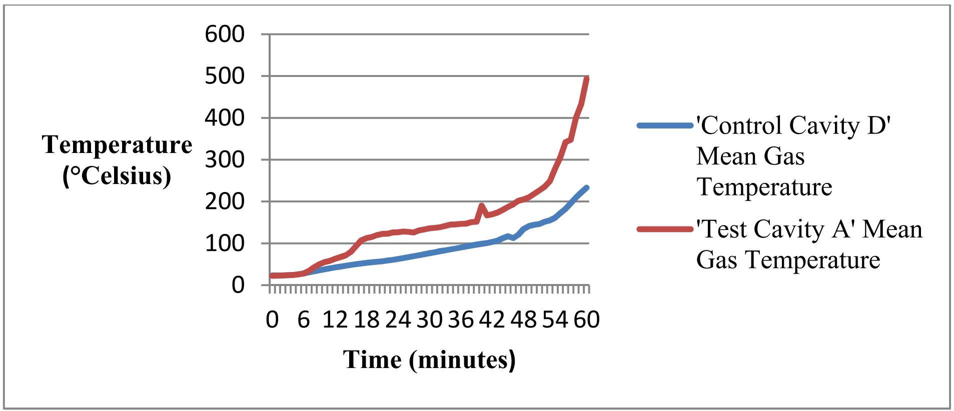

Figure 3: Mean Gas Temperatures 'Test Cavity A' and 'Control Cavity D'

Figure 4 indicates that after about 12 minutes the test cavity's mean gypsum plasterboard temperature was consistently above that in the control cavity, suggesting that the inclusion of the pipe penetrations did lead to additional heating of the rear of the gypsum plasterboard.

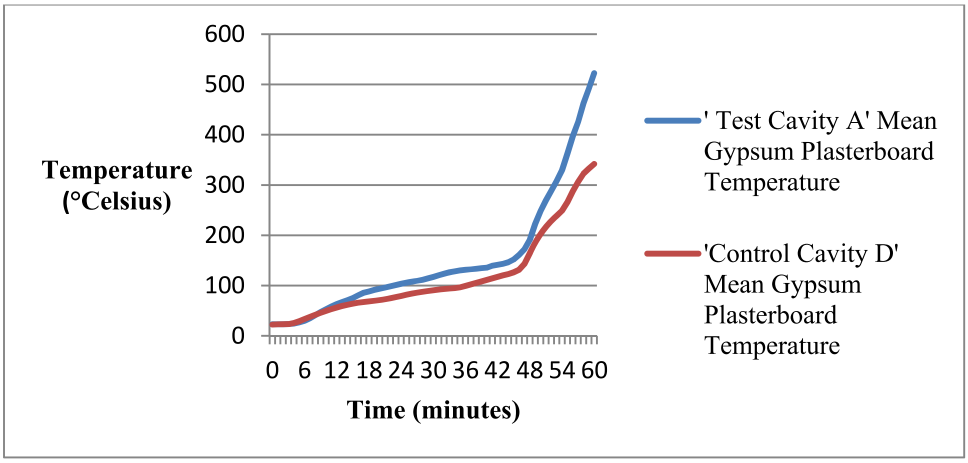

Figure 4: Mean Gypsum Plasterboard Temperatures 'Test Cavity A' and 'Control Cavity D'

By visual observation through the furnace window, after approximately 30 minutes the first layer of 12.5 mm gypsum plasterboard had predominantly fallen off; thereafter cracks appeared in the 19 mm inner layer of gypsum plasterboard. The inner layer of gypsum plasterboard to 'Test Cavity A' failed to a greater extent than the inner layer gypsum plasterboard to 'Control Cavity D'. It appeared that cracks eventually connected the apertures for the pipe penetrations to each other and to other cracks and a single larger hole developed. It seems probable that the proximity of the 40 mm diameter apertures for the pipe penetrations to each other, led to particular stress concentrations in the gypsum plasterboard. A larger piece of this gypsum plasterboard fell from the sample prior to the termination of the test, forming a larger hole. This can be seen in Figure 5 as the sample was being lifted from the furnace.

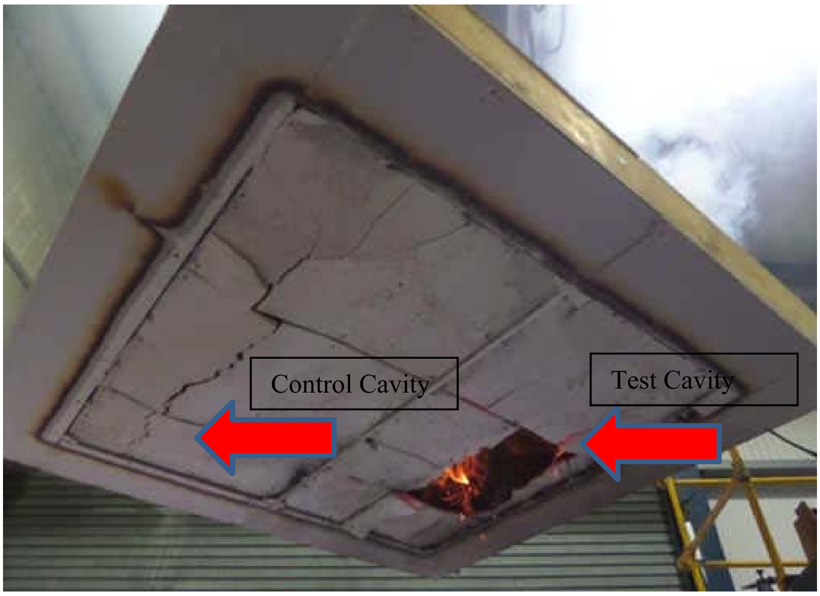

Figure 5: **Test 1 Floor Sample being lifted from Furnace**

It was noted that even before the pipe penetration apertures joined and formed a single larger hole some combustion was evident in the test cavity; flames appeared sporadically through the 40 mm apertures into the furnace. This sporadic flaming combustion was probably limited by the amount of oxygen available for combustion within the cavity and by the oxygen available within the furnace.

It can be seen from Figure 6 that the mean gypsum plasterboard temperature in 'Control Cavity D' was consistently higher than the mean gas temperature; presumably due to conductive heat transfer through the gypsum plasterboard.

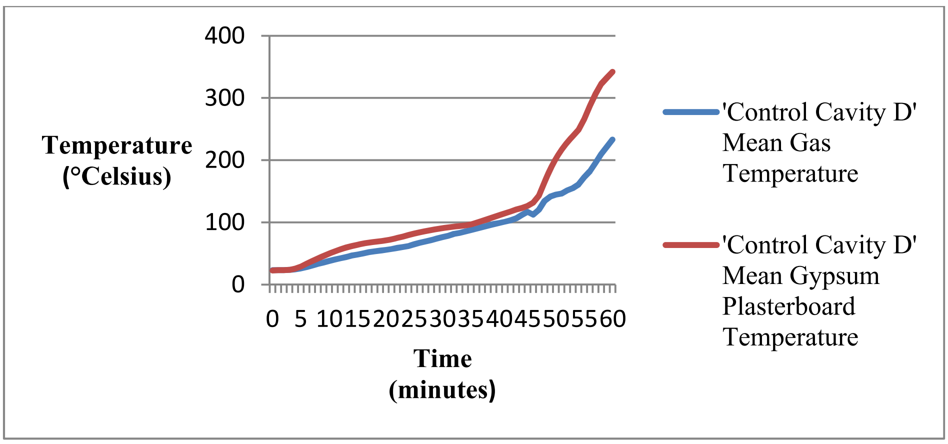

Figure 6: **Mean Gas/Gypsum Plasterboard Temperatures 'Control Cavity D'**

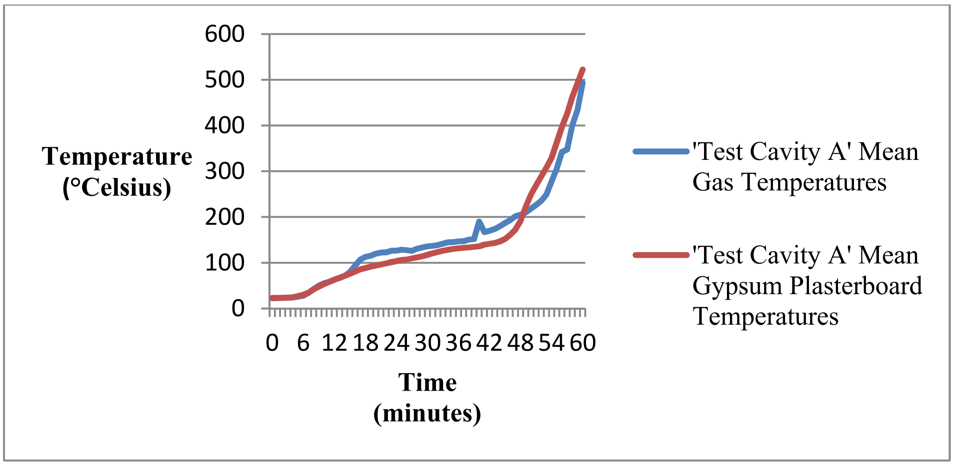

Figure 7: **Mean Gas/Gypsum Plasterboard Temperatures in 'Test Cavity A'**

In 'Test Cavity A', for part of the test period the converse was true, which can be seen in Figure 7. This reversed towards the end of the test period when the gypsum plasterboard temperature exceeded the gas temperature, which approximates with the time that cracks between the penetration apertures joined, forming one larger hole in the inner layer of 19 mm gypsum plasterboard.

Conclusions and Future Work

The results from Test 1 show:

- The two indicative dehydration temperatures, 100°C and 200°C, were reached on the rear of the gypsum plasterboard to the test cavity containing service penetrations sooner than in the un-penetrated control cavity.
- The 'fall-off' of the inner layer of 19 mm gypsum plasterboard was more extensive to the test cavity containing the service penetrations than the control cavity with no penetrations.

The main limitation of the research discussed here was that the fire tests were at a reduced scale. This is pertinent as the volume of the construction cavity, which is a function of joist depth, span and the joist spacing, will have an effect on the rate at which the void increases in temperature. Additionally at reduced scale it was not possible to load the floor sample and as such the effects of deflection were excluded.

Although these experiments are indicative of a potential problem with building regulation guidance regarding unprotected service penetrations, further fire resistance tests require to be carried out which better represent realistic spans and loadings. These tests should utilise a full sized furnace and include loading of the floor specimens in order to determine whether failure would actually occur.

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