THE CAPABILITIES AND LIMITATIONS OF THE SINGLE BURNING ITEM (SBI) TEST

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ABSTRACT

The Single Burning Item test was published in February 2002. It was the last of the test standards needed in order to have the European reaction to fire classification (Euroclass) system in operation.

The SBI test was developed by a group of official European fire laboratories guided by the European Commissions Fire Regulators group. Having a harmonised reaction to fire classification system in Europe is a great achievement considering the wide spread of national tests used before. However, having just one system which is trying to cater to all the different national regulations also posses a challenge both to regulators, specification writers and manufacturers.

To understand the capabilities and the limitations of the SBI test it is necessary to know the basic philosophy behind the test. Especially the link to the reference scenario is of great importance. This paper will explain the background for the SBI test and discuss the challenges experienced when using the Euroclass system for CE marking purposes.

INTRODUCTION

At the end of 1988 the European Commission published the Construction Products Directive (CPD, 1988). The CPD deals with the approximation of laws, regulations and administrative provisions of the Member States relating to construction products. Six essential requirements with which construction products must comply are given in the CPD. Safety in case of fire is the second essential requirement given in the CPD.

To give concrete form to the essential requirements defined in the CPD, 6 interpretative documents were published. These interpretative documents give the links between the essential requirements set out in the CPD and the mandates for the preparation of harmonised standards and guidelines for European technical approvals.

Interpretative document no. 2 (ID 2, 1994) is about safety in case of fire. This document defines a number of measures for the satisfaction of the Essential requirement Safety in case of fire. One of these measures is the limitation of the generation and spread of fire and smoke within the room of origin (or in a given area) by limiting the contribution of construction products to the full development of a fire. ID 2 further states that the level of this limitation may be expressed only by different levels of reaction to fire performances of the products in their end use conditions.

The different levels of reaction to fire performance as required by ID2 were first presented in a Commission Decision from 1994 (Com. Dec., 1994). However, this decision does not give

the thresholds for several of the classes defined, as the decision required a new test method, the Single Burning Item (SBI) test to be developed.

The SBI test was developed by a group of 9 fire laboratories nominated by 9 Member States. The group was known as the Official Laboratories Group, OLG. The OLG worked under strict scrutiny from the European Commissions Fire Regulators Group making the SBI test the first fire test to be developed partly by Regulators. The other 3 tests methods used in the Euroclass system were based on existing ISO test methods and transferred into EN/ISO Standards by working groups under CEN TC127. The SBI test was transferred into CEN TC127 for the purpose of making it an EN standard after the test was developed by the OLG and agreed by the European Commissions Fire Regulators Group.

After the development of the SBI test the commission decision from 1994 was replaced with a new commission decision in 2000 (Com. Dec., 2000) which defines classes for reaction to fire performance of construction products, the so called Euroclasses. However, this Commission Decision was not operational until the SBI test was published as a European Standard (EN 13823, 2002) in February 2002.

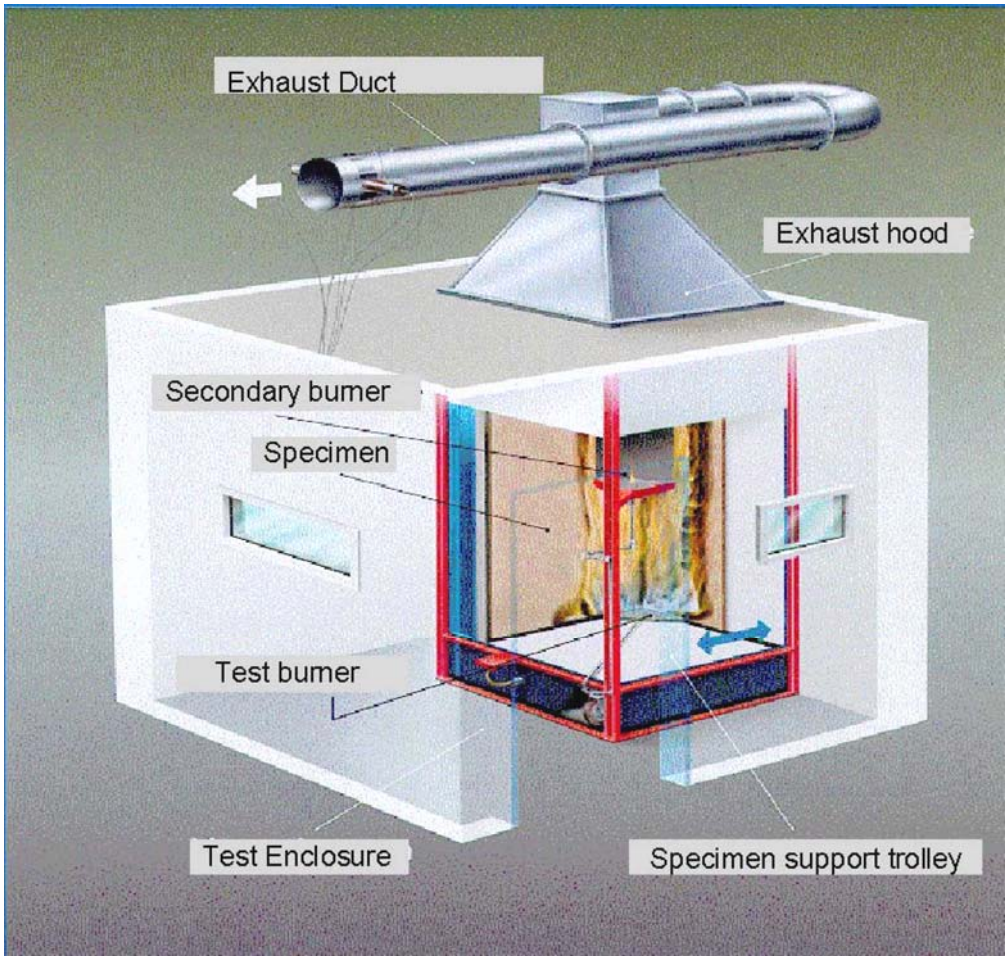

Figure 1. The SBI test

THE DEVELOPMENT OF THE SBI TEST

The OLG started working on the SBI test in 1994. The basis of the work was the ID2 where it was stated that the parameters to be considered were ignitability, rate of heat release, rate of spread of flame, rate of smoke production, toxic gases, flaming droplets/particles and/or a combination of these. The SBI test became an intermediate scale test with the test specimen in a corner configuration with the two wings measuring 1,0 m x 1,5 m and 0,5 m x 1,5 m. The test equipment is shown in figure 1.

Code	Product name
M01	Plasterboard
M02	FR PVC
M03	FR extruded polystyrene board
M04	PUR foam panel with alu foil faces
M05	Varnished mass timber, pine
M06	FR chip board
M07	FR polycarbonate panel 3 layered
M08	Painted plasterboard
M09	Paper wall covering on plasterboard
M10	PVC wall carpet on plasterboard
M11	Plastic faced steel sheet on mineral wool
M12	Unvarnished mass timber, spruce
M13	Plasterboard on polystyrene
M14	Phenolic foam
M15	Intumescent coat on particle board
M16	Melamine faced MDF board
M17	PVC water pipes
M18	PVC covered electric cables
M19	Unfaced Rockwool
M20	Melamine faced particle board
M21	Steel clad expanded polystyrene sandwich panel
M22	Ordinary particle board
M23	Ordinary plywood, Birch
M24	Paper wall covering on particle board
M25	Medium density fibre board
M26	Low density fibre board
M27	Plasterboard/FR PUR foam core
M28	Acoustic mineral fibre tiles
M29	Textile wall paper on calcium silicate board
M30	Paper faced glass wool

Table 1. The 30 products from the first SBI Round Robin

In 1997 the SBI test was ready for its first Round Robin. In that exercise 30 construction products were tested. These 30 products were chosen by the national fire regulators in FRG. The products ranged from chip board, thermal insulation and sandwich panels to PVC pipes and cables. A full list of the products is shown in table 1. The products were chosen to reflect

a broad selection of construction products which the SBI test was supposed to be capable of testing. Further more the test results from the first round robin would also be used to define the class limits for the SBI test in the Euroclass system.

THE REFERENCE SCENARIO

According to an agreement within the FRG the Euroclass system was to be linked directly to perceived hazards in a reference fire scenario. This is also reflected in article 1, section 2 of the Commission Decision (Com. Dec., 2000) where it is stated that: "If the classification based on the standardised tests and criteria listed in Tables 1 and 2 of the Annex is not appropriate, one or more reference scenarios (representative scale test(s) typifying agreed hazard scenario(s)) may be called on, within the context of a procedure providing for alternative tests."

The FRG had agreed that the relevant fire scenario for the Euroclass system was fire in a room and that ISO 9705 the Room Corner test (ISO 9705, 1995) should be the large scale reference test. Figure 2 shows the ISO 9705 test. The product to be tested is mounted on the back wall and the two sidewalls and in the ceiling.

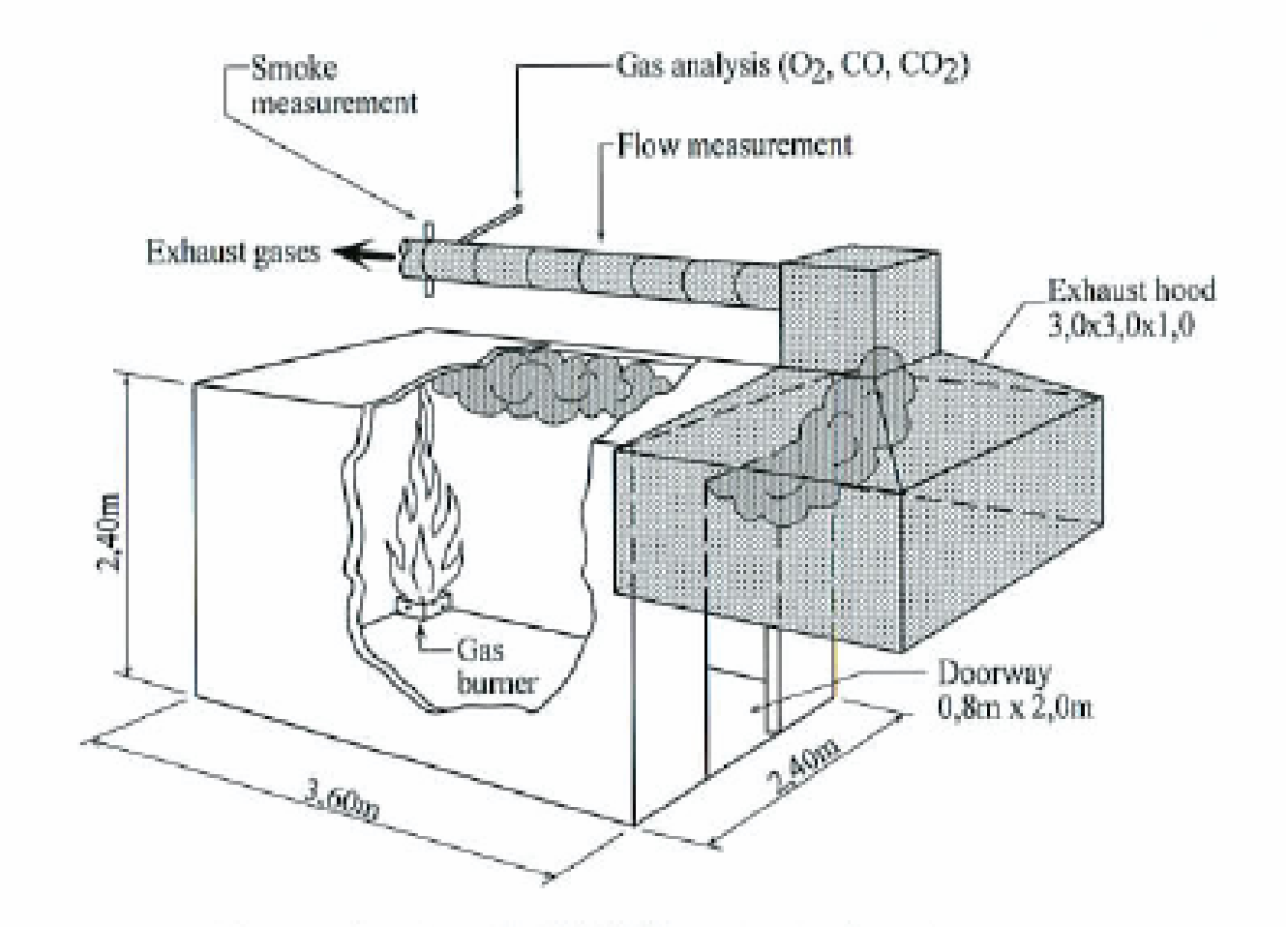

Figure 2. The ISO 9705 Room Corner test

The same 30 products from the SBI Round Robin were also tested in ISO 9705. The test results from ISO 9705 identified clearly 4 clusters of products: those that went to flashover

within 2 minutes of exposure, those that went to flashover between 2 and 10 minutes of exposure, those that went to flashover between 10 and 20 minutes after exposure, and those that never went to flashover. It was agreed that time to flashover was the most critical parameter as that is when a fire rapidly spreads from the point of origin. Consequently the 4 clusters of products were used to identify the class limits for the SBI test.

In order to use this procedure for defining class limits it was important that the behaviour of the products in the SBI test correlated with their behaviour in the large scale reference test. One of the main classification parameters chosen during this stage was the Fire Growth Rate (FIGRA) parameter introduced originally by B. Sundström. A detailed description of FIGRA can be found in the SBI test standard. When comparing the test results from the SBI test with those from the ISO 9705 test based on the FIGRA parameter a good correlation was found between the two test methods for 26 of the 30 products. It was therefore possible to define the classification limits for the SBI test based on the clusters found in the ISO 9705 test.

The following 4 products were deemed "exotic products" during the analysis of the test results: FR. Polycarbonate panel, PVC water pipes, PVC covered electric cables and Steel clad expanded polystyrene sandwich panels. These 4 products was not taken into account when defining the class limits for the SBI test or when reporting how well the SBI test correlated with ISO 9705 test.

The problem with the FR Polycarbonate panel and the Sandwich panel was that they both showed big variations in results in the SBI test and the behaviour in the SBI test could not be compared to that seen in the ISO 9705 test. The FR Polycarbonate panel did not give flashover in the ISO 9705 test even though several laboratories reported a high heat release when tested in the SBI. The sandwich panel did give a flashover in the ISO 9705 test even though more than half the laboratories reported a very low heat release in the SBI test.

For the PVC pipes and the cables it was agreed that the scenario was not correct and therefore a footnote was added to the Commission decision saying that: "The treatments of some families of products, e.g. linear products (pipes, ducts, cables, etc.) is still under review and may necessitate an amendment to this decision."

The lessons learned form the first round robin was that the SBI test was capable of testing 26 out of the 30 products selected and with a reproducibility and repeatability of the same order as other test methods using oxygen consumption calorimetry. Work done by B. Sundström (Sundström, 2007) shows that the SBI test is capable of predicting the fire hazard of approximately 90 % of construction products when using the FIGRA parameter as the main classification parameter.

GUIDANCE PAPER G

Based on the experiences from the round robin it was agreed that the role of the large scale reference test in the Euroclass system needed to be defined. It was also agreed that it should be possible to further develop the classification system or even request the use of another large scale reference test where this could be justified. In 1999 the principle behind the Euroclass system and possible routes for developing the classification system was given in the document (Construct 99/376, 1999). This paper became Guidance Paper G (GP G, 2003) one of the several Guidance Papers dealing with specific matters relating to the implementation of the CPD

According to Guidance Paper G the fundamental principles behind the existing Euroclass system are:

- The FRG, on the basis of real or perceived fire hazards, may decide upon appropriate reference scenarios. (The current Euroclass system for reaction to fire performance of all products other than floorings is based upon fire development within a room)
- The perceived hazard condition(s) associated with any reference fire scenario should be defined by the FRG in functional terms. (The current Euroclass system for reaction to fire performance of all products other than floorings uses the time to flashover as the behavioural reference)
- A large scale reference test representative of a particular reference fire scenario shall be agreed by the FRG as the fundamental basis for the evaluation of the fire performance of products in relation to their potential behaviour. (The current Euroclass system for the reaction to fire performance of all products other than floorings uses ISO 9705 Room Corner test. The time to flashover (and related parameters) in that test is identified as the underlying basis of the main classification)
- In the absence of any small scale test with correlated performance against the large scale test, products will be evaluated on the basis of their performance in the large scale test, against the agreed functional performance criteria. (Not applicable to the current Euroclass system)
- If a small scale test(s) with correlated performance against the large scale test is available, the FRG may endorse this and an associated classification system, as being appropriate for regulatory purposes within the EU. If this is the case, all products concerned shall be evaluated using the small scale test(s) and the related classification system. (The current Euroclasses system for the reaction to fire performance of all products is based on small scale tests)
- Subject to certain conditions (as indicated in Guidance Paper G), where the small scale test and related classification, is considered to be deficient, products may be submitted to the large scale test and their performance level evaluated against the functional criteria defined for that test. Any resulting classification will be expressed in the same manner as for the small scale test, unless there is a change in the reference scenario. Where relevant, the results of the small scale test shall always be reported in conjunction with the results of the large scale test.
- Finally, the current Euroclass system is, in principle, applicable to all construction products other than floorings. Deviations from this defined system, either relating to the reference scenario or recourse to the reference test, should only be considered where absolutely necessary.

FURTHER WORK RELATED TO THE SBI TEST

After the SBI test was published as a CEN standard an immediate revision of the standard was started by CEN TC127. The revision was to address issues which influenced the repeatability and reproducibility of the test method. This work has lead to a number of corrections and minor changes to the test equipment and test procedure which will be included in a new version of the SBI test standard which is to be sent out for vote in the fall of 2008. The work with improving the SBI test will continue and might lead to further changes to the standard in the future.

The classification standard EN 13501-1 requires the test results from the SBI test to be related to the end use application of the product as far as possible. The field of application of the test

result from this test will therefore include information about how the product is mounted and fixed in the test. Unfortunately the EN 13823 standard only provides very general information on how products are to be mounted and fixed in the test. A Technical Specification (CEN/TS 15447, 2006) was therefore developed by CEN TC127 which provides guidance on how products shall be mounted and fixed in reaction to fire tests.

Another important issue that needed attention was the direct and extended field of application of the test result. To make it possible for manufacturers to group their products for testing rules were needed on what is actually covered by a test result. The direct and extended field of application of a test result can be influenced by parameters related to the product such as thickness and density as well as end use application parameters related to how the product is mounted and fixed. A Technical Specification (CEN/TS 15117, 2005) was therefore developed by CEN TC127 which provides guidance on how to determine the direct and extended field of application of a reaction to fire test result.

CEN TC127 can only develop general guidance as they do not have specific product knowledge. Therefore the product technical committees need to develop product specific rules for mounting and fixing as well as direct and extended application to be included in the product technical specifications using the general guidance supplied by TC 127. This can be done in consultation with TC 127. Product technical committees are not obliged to work together with CEN TC 127 but they are encouraged to do so.

It has taken the product technical committees under CEN a long time to realise that they needed to write product specific rules for the field of application of the reaction to fire test results. These rules not only need to address the mounting and fixing of the products in the test but also the direct and extended application of the test result. Many product technical specifications have been published without any rules and it has therefore been necessary for the Notified Bodies Fire Sector Group (FSG) to develop recommendations for how such products are to be tested in order to have the same procedures used by all notified fire laboratories.

END USE APPLICATION

When the Euroclass system became operational in February 2002 it immediately was put to use as thermal insulation products could be CE marked from March 1st 2002. Thermal insulation products were the first group of construction products to include reaction to fire classification on the CE mark.

As mentioned above one of the open questions related to the SBI test was how products were to be mounted and fixed in the test. CEN TC88, the committee responsible for thermal insulation product standards was the first to be faced with this problem. It was obvious that there were very different understandings of what the SBI test was capable of and what it needed to do to satisfy national regulations. Further more national differences in how to test products also came into play. Some member states test not only the entire product but also every material within the product while others only test the product itself. A few member states do not really care about the performance of individual products but only care about the performance of the entire works.

When the SBI test was developed it was well defined that the reference scenario for the test was fire in a room. But whether the SBI test should be capable of testing materials, products

or entire constructions like a wall had never been addressed. It is written in ID2 and in EN 13501-1 that the test result shall be related to the end use application of the product and end use application is defined in EN 13501-1 as: “real application of a product, in relation to all aspects that influence the behaviour of that product under different fire situations. It covers aspects such as its quantity, orientation, position in relation to other adjacent products, and its method of fixing.”

This definition of end use application made some believe that reaction to fire testing of construction products should be done by testing the entire building element in which the product is included. This would have meant that if the product to be tested is to be installed on site within a building element then it should be tested within that building element and thereby not be exposed to the flames of the test. Others found that all construction products including those to be installed on site within building elements should be tested exposed directly to the flames of the test and the relation to end use is done by taking into account the mounting and fixing method used in the test.

To find the answer to this discussion it is necessary to look back at the development of the SBI test and the Euroclass system. The class limits for the SBI test in the Euroclass system is developed based on the products tested in the first round-robin. Looking at the list of products given in table 1 it is obvious that what the regulators believed at the time when developing the system was that the SBI test should be a product test where the product to be tested should be exposed to the flames of the test. Several products shown in table 1 will be incorporated within building elements on site but they were all tested exposed to the flames of the test in the round robin. It is also obvious that the intent was only to test products and not materials as the list also included several composite products which were all tested as whole products and not separated into materials.

The above interpretation was confirmed by a letter from the CEN consultant to CEN TC88 (Cuche, 2006). So when it comes to CE marking of construction products it is the product as placed on the market that shall be tested exposed to the flames of the test. The mounting and fixing procedure used in the test may influence the test results and therefore information on this shall accompany the CE mark. Manufacturers can provide information on reaction to fire classification of building elements which includes their products but this is additional information and shall be kept distinct from the information accompanying the CE mark.

When the discussion on mounting and fixing and the interpretation of end use application was finalised it was possible for CEN TC88 to develop a standard for mounting and fixing instructions for reaction to fire testing of thermal insulation products (prEN 15715, 2008). This standard will be out for its final vote in late 2008.

Product technical committees have now started working together with CEN TC127 to define appropriate mounting and fixing procedures for their products. The products and their intended use are assessed and a mounting and fixing procedure for the SBI test is developed. Most often the product groups going through this procedure are those very different from what was tested in the first round robin. It is therefore not possible to evaluate the behaviour of the product in the SBI test based on its behaviour in the large scale reference test unless test results are presented from the large scale reference test. Unfortunately it is very rare that tests are done in the large scale reference test and it is also very rare that the appropriateness of the SBI test is questioned and the possible use of alternative tests or the large scale reference test is considered.

LINEAR PRODUCTS

As mentioned previously a footnote had been added to the Commission Decision on the Euroclasses related to linear products. Linear products are products like cables, pipes and pipe insulation.

For cables a study was initiated which lead to the use of completely different test methods than the Euroclass system. A commission decision for the reaction to fire classification of cables was agreed in 2006 (Com. Dec., 2006). The development of the classification system for cables included both small scale tests and large scale reference test. It thereby followed the principles behind the Euroclass system as set out in Guidance Paper G.

Another linear product where work was initiated was pipe insulation. CEN TC88 started working on a possible test and classification system for pipe insulation in 2000. The work was assisted by an expert from CEN TC127. A large amount of tests were conducted in both the ISO 9705 and SBI test using a mounting and fixing procedure developed specifically for pipe insulation. Based on the test results from both tests a new classification system was developed specifically for pipe insulation. By performing tests in both the SBI test and the ISO 9705 test and ensuring correlation between the two tests for the defined mounting and fixing procedure the principles of Guidance Paper G had been followed. The proposal from CEN TC88 was accepted by the FRG and a Commission Decision (Com. Dec., 2003) agreed in 2003.

Both Cables and Pipe insulation are good examples of how the basic principles behind the Euroclass system has been taken into account when developing the system further to take these product groups into account.

METAL FACED SANDWICH PANELS

A product family which has caused a lot of discussion is metal faced sandwich panels. It was questioned whether an intermediate scale test such as the SBI would be able to truly reflect the actual hazard of this product family. Already in the first SBI round robin the metal faced sandwich panel tested showed very different behaviour between the SBI test and the ISO 9705 Room Corner test and there were also problems with inconsistent behaviour in the SBI test.

Metal faced sandwich panels consist of an insulated core covered on both faces by a thin metal facing. The metal facing will initially prevent flame exposure of the insulating core but heat will be transferred to the core. For sandwich panels with a combustible core the heat exposure will lead to flammable gasses to be developed within the panel. Consequently the mechanical behaviour of the metal facing and the joints will determine how such a panel will behave in a fire. During the fire the metal face of the exposed side of the panel will start to buckle causing the joints of the panels to open up leading to ignition of the flammable gasses from the core. Fire can also cause the panel to delaminate completely which will leave the insulating core exposed.

The heat exposure and the sample size of the SBI test are too small to cause any severe buckling of the panels. Therefore most panels with a combustible core will obtain the highest possible classification in the SBI test which essentially means that they should not cause flash over in a small room. However, many of those panels will go to flash over when tested in The ISO 9705. Consequently there is not a consistent correlation between the SBI test and the

large scale reference test ISO 9705 for this product group. Metal faced sandwich panels are among those 10% of construction products where the SBI test does not reflect the true hazard of the product. This is in agreement with the lessons learned from the first round robin.

This problem was first identified by Van Hees (Van Hees et. al., 2000) and later confirmed by Axelsson (Axelsson et. al., 2004). They found that the correlation between the SBI test and the ISO 9705 test for combustible cored sandwich panels was very weak.

Testing metal faced sandwich panels in small and intermediate tests had long been questioned leading ISO TC92 SC1 to develop two large scale tests specifically for metal faced sandwich panels (ISO 13784-1, 2002 and ISO 13784-2, 2002). The need for large scale testing of metal faced sandwich panels has also been acknowledged by insurance companies who relies on large scale testing for evaluation of this product family.

When a product standard was developed for metal faced sandwich panels the use of the SBI test for reaction to fire testing was questioned by CEN TC127. Unfortunately the Product technical committee broke of the cooperation with CEN TC127 and continued to work with only the SBI test. Despite negative comments to the standard due to the use of the SBI test the standard was approved and published by CEN in 2007.

EURIMA (European Insulation Manufacturers Association) launched an appeal procedure with the Commission Services asking for a correct reaction to fire test for metal faced sandwich panels. EURIMA argued that there was a need for another test method as there was no correlation between the SBI test and the large scale reference test ISO 9705 for metal faced sandwich panels. Unfortunately most Member States saw no reason for using another test than the SBI and the panel industry was eager to have a product standard using the SBI test. Consequently the appeal from EURIMA was denied.

The unfortunate consequence is that metal faced sandwich panels will soon be on the market with a CE mark where the reaction to fire classification is based primarily on the SBI test even though this classification has a high risk of not reflecting the true hazard of the product.

Metal faced sandwich panels are an example of what can go wrong when focusing only on the SBI test itself and forgetting what the Euroclass system was originally based on.

FACADES

The use of the Euroclass system for facades has long been questioned. Considering that the reference scenario for the Euroclass system is fire in a room it is only right to question the use of this for externally applied products. The challenge is to define a new reference scenario and a large scale reference test for facades. The commission services created a task group in 2005 consisting of fire regulators with the task of writing a mandate to CEN for “the evaluation of the functional reaction to fire performance characteristics of façade systems / facade cladding systems.”

Unfortunately this mandate was never completed and the work with defining a test method for facades was transferred to EOTA.

Hopefully EOTA will develop an appropriate façade test and not make the same mistake as for metal faced sandwich panels by taking the easy solution of using the SBI test because it is already there!

INNOVATIVE PRODUCTS

When faced with new product groups to be tested in the SBI it is of vital importance to consider if the SBI test is the appropriate test method and if the reference scenario is the correct one for that product group. Guidance Paper G opens up for the definition of other reference scenarios and use of other tests than the SBI if a need for that can be well documented.

Specification writers have an obligation to question the Euroclass system for their product groups. They are the experts on how the products are to be used and therefore how they should be tested. If specification writers are unsure of how to deal with reaction to fire testing of their product group they should consult CEN TC127 who are the fire experts within CEN. With an appeal system available as described in guidance paper G it is irresponsible to just specify the use of the SBI test without considering if it is appropriate. For some innovative products this can mean that a test programme in a relevant large scale reference test might be needed.

Doing a study into what the correct test method is for a product group can seem overwhelming and will most likely be expensive. But that is the price to pay for obtaining a fire safe Europe.

CONCLUSIONS

The development of the Euroclass system and the SBI test was a big step forward for the European harmonisation process.

The SBI test is capable of providing a classification which reflects the fire hazard of approximately 90 % of construction products. However, this will only remain true if we remember the lessons learned especially related to mounting and fixing of products in the test.

For the 10 % of construction products where the SBI test cannot provide a classification reflecting the fire hazard of the product, work has already been done for some of the big product groups to define alternative test and classification systems. Unfortunately a big product group like metal faced sandwich panels has failed to acknowledge that they are part of these 10 %.

The decision by the Fire Regulators Group to link the Euroclass system to perceived hazards in a reference scenario and thereby the SBI test to the Room Corner test has provided specification writers with the tools to create a safe system. This link cannot be forgotten if we want a fire safe Europe.

REFERENCES

Axelsson et. al, 2004	Jesper Axelsson and Patrick Van Hees, New data for sandwich panels on the correlation between the SBI test method and the room corner reference scenario, Fire and Materials, 2004
CEN/TS 15447, 2006	Mounting and fixing in reaction to fire tests under the Construction Products Directive, CEN, 2006
CEN/TS 15117, 2005	Guidance on direct and extended application, CEN, 2005
Com. Dec., 1994	94/611/EC Commission Decision of 9 September 1994, European Commission, 1994
Com. Dec, 2000	2000/147/EC Commission decision of February 2000, European Commission, 2000
Com. Dec., 2003	2003/632/EC Commission decision of 26 August 2007, European Commission, 2003
Com. Dec., 2006	2006/751/EC Commission decision of 27 October 2006, European Commission, 2006
Construct 99/376, 1999	Construct 99/376, European Commission, 1999
CPD, 1998	Construction Products Directive, European Commission, 1998
Cuche, 2006	CEN/TC88/WG2 N858, J. Cuche, 2006
EN 13823, 2002	EN 13823, Reaction to fire tests for building products - Building products excluding floorings exposed to the thermal attack by a single burning item, CEN, 2002
GP G, 2003	Guidance Paper G : The European Classification system for the Reaction to Fire Performance of Construction Products, European Commission, 2003
ID2, 1994	Interpretative Document No. 2, European Commission, 1994
ISO 9705, 1995	ISO 9705
ISO 13784-1, 2002	ISO 13784-1, Reaction to fire test of sandwich panel building systems – Part 1: Test method for small rooms, ISO, 2002-12-01
ISO 13784-2, 2002	ISO 13784-2, Reaction to fire test of sandwich panel building systems – Part 2: Test method for large rooms, ISO, 2002-12-01
prEN15715, 2008-08-07	Thermal insulation products — Instructions for mounting and ixing for reaction to fire testing — Factory made products, CEN, 2008
Sundström, 2007	Björn Sundström, The development of a European Fire Classification System for Building Products Test Methods and Mathematical Modelling, Doctoral Thesis, Department of Fire Safety Engineering, Lund University, Sweden, 2007
Van Hees et. al., 2000	Van Hees P, Johansson P. Development of a Test Procedure for Sandwich Panels using ISO 9705 Philosophy. Nordtest project nr 1432-99. SP Rapport 2000:26, SP Swedish National Testing and Research Institute, Fire Technology, Boras, 2001.