

Fire resistance of “high-tech plastics” Results of a test series about the fire resistance of glass-fibre reinforced polyester composite (FRP)

Johan Koudijs¹, Jhon de Wild¹ and Jack Smit²

¹ DGMR PO Box 153, 6800 AD Arnhem, The Netherlands

² Polux B.V. PO Box 137, 1670 AC Medemblik, The Netherlands

Abstract. The mechanical properties, thermal insulation, durability and the production technology make Fibre Reinforced Polyester Composites an interesting material to use as a façade cladding system or as unitized sandwich panels. Before the FRPC material became readily available for large façades, technical aspects had to be investigated and solutions had to be found for fire resistance/reaction to fire, aesthetic properties such as colour fastness, durability and strength calculations.

This paper concentrates on the development of a composite material, especially in the form of sandwich panels as a unitized façade system, to meet certain requirements of “Fire resistance” and “Reaction to fire” according to the relevant European standards.

INTRODUCTION

Over the years materials such as aluminium, concrete, wood and brick were used to build façades. With the introduction of Fibre Reinforced Polyester Composite (FRPC) materials organic forms and shapes were made possible, creating a new kind of façade. Architects were given a brand new material to work with and they were given the freedom to design any shape they wanted, even double curved and rounded corners. Besides the application as an add-on single-layer cladding (Figs. 1-3), the material is highly suitable for the production of sandwich panels (Figs. 2 and 3).

Composite sandwich panels are lightweight, but strong (load bearing). In combination with the correct sealing they can be used as a unitized façade system and therefore they are an excellent lightweight alternative for e.g. precast concrete (sandwich) and masonry walls.

It has to be clear that a FRPC material, which is a kind of high-tech plastic, in itself does not have ideal properties to perform well on the aspects “Fire resistance” and “Reaction to fire”. This paper introduces the development and test results of fire resistant FRPC.

REQUIREMENTS ACCORDING TO THE DUTCH BUILDING CODE

Reaction to fire (EN 13501-1) [2]

“Reaction to fire” is often defined as the properties of a product that determine how and how much it contributes to the generation and spread of fire and smoke in the initial stages of fire. It is well known that the reaction to fire of a product not only depends on the product itself, but also on the details of how

This is an Open Access article distributed under the terms of the Creative Commons Attribution License 2.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.



Figure 1-3. (1) Single layer cladding – Project LVI Groningen, the Netherlands. (2) (3) Sandwich (insulated) Façade element – project SKU Utrecht, the Netherlands.

it is mounted in its environment, i.e. its “end use application”, and the fire scenario, i.e. the position and strength of the ignition source and the thermal environment in which the fire develops.

A relevant regulatory test method ideally replicates all the factors determining the behaviour of the product: the product itself, its end use application, and the potential fire scenario, including the ignition sources. The number of combinations is clearly too large to be practicable. Most national regulations therefore decide upon a small number of scenarios, accepting that products applied in other scenarios are not always judged fairly.

This is visible e.g. in the assessment of construction products meant as wall or ceiling lining. Many national regulations, and also the European Construction Products Regulation, refer to a test method based on one fire scenario: a small ignition source in a room ignites a vertical product, leading to fire growth over the product, possibly [2]. A product applied as ceiling lining is heated in a different way from the same product used as wall lining, and may react quite differently. A façade cladding is never subjected to a growth to flashover due to the lack of heat buildup outside. A critical ignition scenario for a façade is external flaming emanating from a fully developed fire through the windows. These flames present a much stronger ignition source than the relatively small sources taken as representative for compartment fires. This explains why research institutes and manufacturers are supporting the development of a European regulatory test method specifically meant for assessing the contribution of façade cladding to fire propagation [1]. For the time being however, façade claddings are assessed as all wall and ceiling products, using the EN 13501-1 classification standard and the test methods it refers to.

The considered end-use application is a façade construction. The Dutch Building Code, requires D as a minimum classification for all façades, C on the outside of protected evacuation routes, B for the first 2.5 m from ground level if the building has two or more storeys, and also B above 13 m height. For the internal exposed surface of the façade construction, smoke production is restricted through the requirement: S2. To reach the classification of B – S2, the following tests are necessary according to EN 13501-1:

1. Single burning item test (EN 13823): This test evaluates the potential contribution of a product to the development of a fire, under a fire situation simulating a single burning item in a room corner near to that product.
2. Ignitability test (EN ISO 11925-2): This test evaluates the ignitability of a product under exposure to a small flame.

A product applying for class B, C or D shall be tested in accordance with EN ISO 11925-2 and additionally tested in accordance with EN 13823. The classification S2 for smoke production is deduced from the measurement data obtained in the test in accordance with EN 13823.

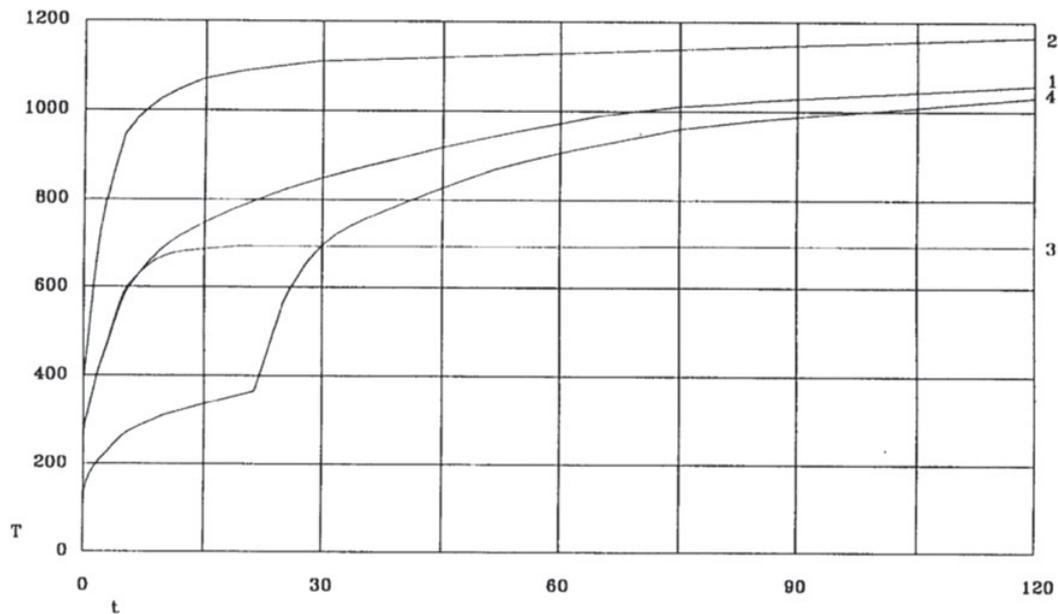


Figure 4. Temperature/time curves EN 1363-2:1999 [4]; 1 = standard; 3 = external; 2 = hydrocarbon; 4 = slow heating; T = temperature °C; t = time minutes.

Fire Resistance (EN 13501-2) [2]

If it is required, a construction part (load bearing and/or separating function) has to prevent the spread of fire during a certain time (30, 60, 90 or more minutes). Fire resistance of loadbearing and/or separating elements shall be assessed using one or more of the levels of thermal attack defined in the European Standard EN 13501-2. That European Standard identifies which attack(s) shall be used for which elements.

The purpose of the sandwich construction explained in this paper is to be used as an external enclosure of the building envelope. The construction is considered a non-loadbearing wall (not to be subjected to any load other than its own weight and wind load) with separating function. Three fire scenarios can be considered:

- a) Fire from the inside: the façade has to protect other parts of the building
- b) Fire from the outside: the façade has to protect the interior of the building from a fire occurring outside.
- c) Combination of both.

According to the European Standard, the basis for testing scenario a) (fire from the inside), the standard temperature/time relationship shall be applied for the full duration of the test. The relationship, which is a model of a fully developed fire in a compartment, is given in the European standard EN 1363-2:1999 [4] and shown on Figure 4.

For scenario b), the so-called “external heating curve” can be applied (Fig. 4). This is a temperature/time relationship which represents the exposure of the external face of a wall to fire which may emerge from a window of a building, or from a free-burning external fire. It is assumed, that outside the building the temperature level cannot reach the same level as in a closed compartment.

The EN 13501-2 also determines which performance criteria of the building construction can be considered to reach a certain fire resistance. Every country has then the choice to determine which

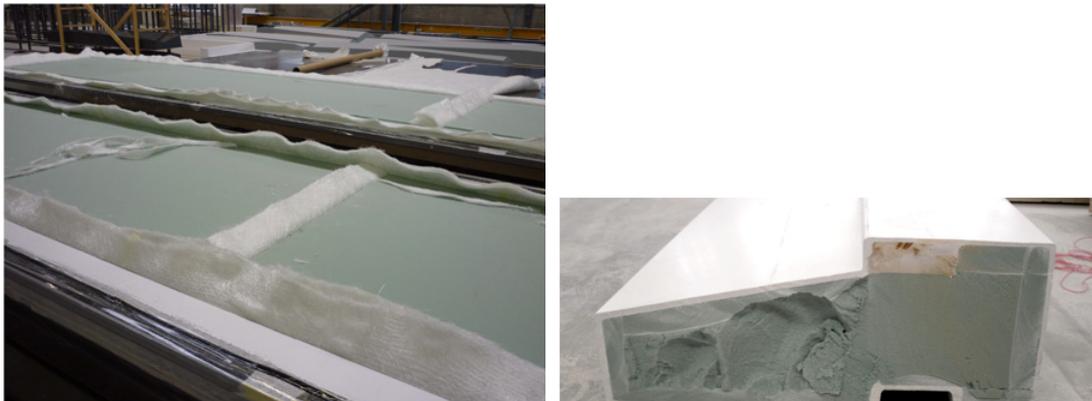


Figure 5-6. Examples of laminate; left – production process; right – sandwich element.

criteria apply for a certain case. The building code in The Netherlands requires the following criteria during the full duration of the test:

- a) Fire from the inside: integrity (E) and radiation (W) according to the standard heating curve during at least 30 minutes: EW 30 ($i > o$)
- b) Fire from the outside: integrity (E) and insulation (I) according to the external fire heating curve, during at least 30 minutes: EI30-ef ($o > i$).

To achieve the classifications EW 30 ($i > o$) and EI30-ef ($o > i$) the construction has to be tested according to EN 1364-1. The test method is applicable to façade systems or partitions, supported by the floor slab(s), designed for the purpose of providing fire resistance. The exposed width and height shall not be less than 3 m. The element has to be fully representative for the purposed use. Because the composite sandwich panels are fully symmetrical, the test results from one side can also be applied to the other side. To reduce the test numbers to one it is decided to test the construction according to the standard heating curve and it is assumed to reach at least the classification of EI 30.

Summary of requirements

For widely application as a façade construction, especially as a complete (unitized) non-loadbearing external wall, the FRPC material has to meet the following requirements:

- At least class B for the external surface according to EN 13501-1
- At least class S2 for the internal surface according to EN 13501-1
- EI 30 but preferably EI 60 from both directions according to EN 13501-2.

INTRODUCTION OF FRPC

FRPC sandwich constructions are composed by two skin layers called Laminate and an inner core of insulation materials. The laminate is composed by different kind of fibres and injected with polyester resin. The fibres act as reinforcement of the product. The laminate can also be used as a single layer for the purposes of (external) cladding material.

BEHAVIOUR OF FRPC DURING THERMAL ATTACK

The primary reason why it is so difficult to develop a fibre-reinforced polyester composite that complies with all the fire regulations is, because in essence it is an oil based product and a delicate mix of materials and components which all react differently when exposed to fire. The resin used is basically a by-product from the oil industry and therefore will burn. Secondly, the fibres used have components in them that cause smoke (polypropylene) and thirdly, insulation used can cause smoke or add to the total heat release when exposed to fire. FRP reacts on thermal attack as follows.

Absorbing energy: The FRP laminate is heated by an external heat source (a flame), and by thermal feedback when combustion has started. When the heating provides sufficient energy, endothermic decomposition occurs.

Decomposition: Decomposition occurs when the high binding energies between the individual atoms in the polymer is overcome. In general one may say that decomposition occurs via free radical chain reactions initiated by oxygen or oxidising impurities which are trapped in all composites during manufacture. These free radicals are responsible for the flame spread in the combustion process.

Ignition: The flammable gases formed by the decomposition process are mixed with atmospheric oxygen and ignite by an external flame, or alternatively by self-ignition if the temperature is sufficiently high in relation to the oxygen to flammable gases ratio. When ignition occurs there will be thermal feedback due to the exothermic nature of the combustion process.

Flame spread: Thermal feedback from the combustion process provides more energy to the decomposition process in which new flammable gases are produced, thus feeding the combustion process. During flame spread the temperature of the polymer is typically 500°C while the temperature of the flame where a reaction with oxygen takes place is approximately 1200°C.

Smoke constituents: According to J. Troitzsch [5] smoke is a result of incomplete combustion and is a dispersion of solid or liquid particles in a carrier gas consisting of combustion gases and air. The liquid particles are tar-like droplets or mist composed of liquid products of pyrolysis, or their partially oxidised derivatives, and water. The solids contain carbon flakes, soot beads, ash, sublimed pyrolysis products and oxides of inorganic compounds.

Products of combustion: The composition of gases during combustion of solid composites is mainly dependent of the combustion temperature and the availability of oxygen. The supply of oxygen and the temperature will vary during a fire; as a result of this the composition of the combustion gases will vary throughout a fire. It is therefore too complex and too difficult to measure the composition of the gases throughout the whole duration of the fire.

During combustion of a fire retardant polyester laminate, using a halogenated resin, formation of gaseous HCl and/or HBr will result in addition to the above mentioned combustion products.

HOW TO PREVENT FRPC FROM BURNING?

Retarding flames

In FRP laminates there are four different modes of action to retard flames: by cooling, by dilution, by termination, by free radical acceptors and formation of intumescent layers.

The temperature of a fire might be lowered below the minimum temperature required to sustain fire, thus putting the fire out or slowing down its flame spread. Cooling may be achieved by introducing additives such as Alumina trihydrate (ATH), which releases water at temperatures over 200°C, into the solid laminate. The decomposition of ATH and the evaporation of the released water is endothermic, which gives the cooling effect.



Figure 7. SBI test example.

Putting inert fillers into a laminate reduces the fuel available in the solid phase as well as introducing inert gases into the gaseous phase. The total amount of combustible material is cut and the lower temperature limit for ignition is shifted upwards. Termination by free radical acceptors is achieved by e.g introducing halogens such as Cl and Br. This is often done by reaction into the backbone of the polymer, but may also be done by way of an additive. The decomposition of the solid composites will then produce free radicals which will stop the exothermic process in the gaseous phase which in turn suppresses the flammable gases.

An intumescent layer is a physical barrier between the solid phase and the gaseous phase. This layer is formed by the combustion process and consists of inert gases and/or a solid crust that cools the solid phase by reducing heat transfer as well as shielding it from oxygen, which is vital to the combustion process. An intumescent layer may be formed by introducing phosphorous additives.

Designing considerations of fire resistant laminate (skin layer)

When designing and producing a laminate using a fire retardant resin, a resin based on fire test criteria and application should be selected. Once this is done, it has to be taken into consideration how the following points influence the performance of the end product:

- Content of glass fibre
- Air voids, surface smoothness and geometry
- Thickness of laminate
- Post curing.

The content of glass fibre in products requiring fire retardancy is important not only by acting as reinforcement, but also due to its inertness to fire. Thus, in general one should try to maximise the content of glass fibre in products requiring fire retardancy.

Air voids, surface smoothness and geometry of the end product are other factors that may impact the total performance of a fire retardant laminate. In general, one should attempt to reduce air voids as well as having a surface which is as smooth as possible since these factors may contribute positively in preventing the propagation of flames.

Selecting the optimal laminate thickness is a balance between opposing factors: total amount of combustible material available, time to ignition and speed of fire propagation. By keeping the laminate thickness low one ensures that the total amount of combustible material is low. On the other hand, a thin

laminate will be heated up to the temperature at which decomposition occurs much sooner than a thick laminate.

Due to the low thermal conductivity of GRP laminates it will take longer to reach the decomposition temperature in a laminate of 4–8 mm, thus delaying both time to ignition and the propagation of fire. Once ignition has started the total heat release will be higher for a laminate of 4–8 mm compared to a laminate of 3 mm or less.

To get optimal fire retardancy out of a laminate it is important that post-curing at elevated temperature takes place. The process of post-curing reduces the amount of residual styrene in a laminate. Since styrene is highly flammable, as well as volatile, post-curing will contribute positively with respect to the fire retardant properties of a laminate. Thus, when possible, post-curing at elevated temperature is highly recommended.

Designing considerations of sandwich construction

As it is explained in the introduction, FRP composite materials can be used in façades in two ways: as an external cladding or as a complete wall element with a finished surface (sandwich construction). The orientation of the product is in both cases vertical and facing an open space, but the end-use application is different. The external cladding is considered a product which forms a cavity with a substrate behind. The sandwich construction is considered a product *on a substrate*: glued, mechanically fastened or simply in contact with other materials. Therefore, the test results of these products related to the property Reaction to Fire according to EN 13501-1 cannot be interchanged. Both products must have their own classification.

The main difference between the two, in regard to the reaction to fire is that sandwich panels, consisting of two layers of FRP with an insulation core of PIR foam have a better fire resistance.

Where cladding – single layer products, will burn away so that flames can reach the structure behind the cladding, Sandwich panels will withstand fire for a much longer period of time.

Resume

By combining the modes of action to retard flames by using various kinds of base resins and additives, some of which give positive synergy effects with each other, it is possible to design composites with different degrees of smoke and flame spread performance (EN 13501-1) by combining these different modes of action. This is achieved by careful formulating with various base resins and additive types, some of which have positive synergistic effects when used in combination.

DEVELOPING FRPC FOR FAÇADE PURPOSES

Design considerations

In the previous section has been explained that it is possible to develop fire resistant FRPC laminates to prevent spread of smoke and flames over the surface and to reach a certain classification according to EN 13501-1. But before the composite material became readily available for façades, different technical aspects had to be investigated and solutions had to be found for fire resistance/reaction to fire, aesthetic properties such as colourfastness, durability and strength calculations together. In addition to these qualities, the production method was set on VARTM and/or Infusion. Both are closed mould production techniques and using these techniques the highest quality of products can be achieved.

The closed mould technique (VARTM and/or Infusion) requires a closed mould system. The so called “dry materials”, such as fibres for the laminate and insulation for the core, are placed into the mould. After closing the mould, injection of the resin take place. The product is finished after



Figure 8. Fabrication of sandwich elements.

curing of several hours. This technique is very suitable to produce sandwich elements where both sides (inner and outer surface) need to have a certain aesthetic finish without coating or painting afterwards.

Creating a composite material that complies with all the fire resistance properties, and still offers the same aesthetic properties as the high performance composites used in for example yacht building and being able to produce the façade panels using VARTM production techniques has proven to be quite difficult. The reason is that changing one aspect to reach a certain fire resistant property has (negative) influence on one or more other important aspects of a façade construction of the production process.

All the following aspects have to be considered simultaneously during the product development:

1. Aesthetic qualities (gelcoat properties) such as colour fastness, durability and weathering
2. Resin – Fire retarding qualities (halogenated or dispersed ATH)
3. Core material and fibres (using ingredients that cause smoke)
4. Production techniques (VARTM – infusion)
5. Technical properties (strength and thermal expansion).

Developing a single layer laminate with fire resistant gelcoat

For façade panels usually the architect and/or building owners set standards for durability, acceptable weathering, colourfastness etc. In this case the requirements were based on what the higher quality gelcoats, commonly used in yacht building, can offer. Problem was that none of these gelcoats were available in a fire retardant version.

Commonly, gelcoats with fire retardant qualities are standard gelcoats with fillers. These fillers reduce their UV resistance and lose their glossy appearance much sooner than the other gelcoats.

Also, as a result of these fillers the gelcoat leaves dust-like particles on the surface making it look grey and dull. In white gelcoats the yellowing is substantial and undesirable. These effects are unacceptable in case of a building envelope. The façade, thus also the FRPC material, has to keep the same appearance during at least 20 but preferably 50 years.

Having tested all available standard fire retardant gelcoats, Nord Composites has offered their facilities to us to work together on developing a brand new series of gelcoats. Over the period of almost a year, Polux worked closely together on this and were able to develop a highly fire retardant gelcoat with excellent weathering qualities.

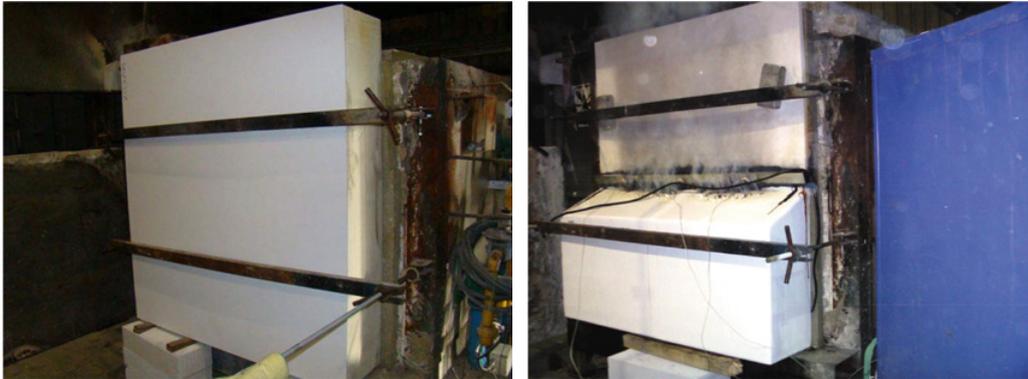


Figure 9-10. Small scale test of FRPC sandwich elements.

After five or six SBI tests, Polux has created a *single laminate* (resin filled with ATH and using the newly developed gelcoat) and succeeded in getting the first B-s1-d0 qualification. The next series of tests were to create the same result with a sandwich panel using the Infusion technique (vacuum production under a foil).

Problems with production process VARTM and/or infusion

As described before, a single layer laminate with gelcoat which has the classification of B-S1-d0 contains a certain amount of ATH-filler. Problem however, is that with the closed mould production methods, which should be used for the production of *sandwich* constructions, adding fillers such ATH to the resin has to be avoided. During the production of larger façade elements, the resin travels through the layers of fibre. Fillers thicken the resin, making it more difficult to travel through these layers. With infusion this is even more difficult because the foil actually compresses the layers, making them less permeable.

As it turned out the percentage of ATH filling the resin in order to get the correct SBI result was too high for it to work in vacuum production. The ATH clogs the fibre layers and will stop the resin flow. That is the reason why it should be avoided to add ATH to the resin. Another problem was that the more ATH is added, the more brittle the laminate becomes, losing its strength. A resin with a low level of fillers was required to meet all demands. Producing the sandwich panels with a halogenated resin low on fillers worked well with vacuum production but did not give us the correct SBI results.

In the end a practical solution was found by putting some components of the skin layer in the mould before putting in the dry fibre matting and core materials. The composition of the skin layer is available upon request.

Testing fire resistance according to EN 13501-2

After the clear composition of the laminate skin is developed, the production technology optimized and the finished product also accepted from the aesthetic point of view, the testing of the fire resistance according to EN 13501-2 could take place. Because of the good flame retardant property of the laminate (class B) and the core material used (PIR) there was little doubt that the sandwich construction can withstand the heat of approx. 1000 °C during at least 30 minutes. It is also demonstrated in several small-scale tests (Figs. 9–10). For the core materials PIR foam was used. In order to keep the amount of smoke produced as small as possible, the FRP layer should prevent the inner core from burning.



Figure 11-12. First full-scale test of composite elements; left – during test; right – inside of the construction after test.



Figure 13-14. Series of full-scale tests.

The difficulty is created by inserting a glazed window to the composite panels. The window is not supported by internal (steel/aluminium/wood) profiles. At normal temperatures the skin of the composite panel (laminates) is strong enough to support the window construction against wind loads and its dead load. During thermal attack by a fully developed fire the skin has to retain the same function. Delamination, melting or burning of the skin can cause the construction to collapse before the end of the required classification period. How the composite behaves under the dead load of the window, which can be several hundreds of kilograms, was unpredictable.

The first test is applied to a full-scale construction with an aluminium window and double fire resistant glazing (Figs. 11, 12). The window and the glazing itself were previously tested, but not in this size. After approx. 20 minutes, one of the glazing panels starts to move downwards. Before the end of the heating, a gap at the top of the glazing appears and the test fails.

The composite panel does not react exactly the same as a concrete masonry wall, the skin laminate on the fire side was black but still intact. Therefore, the composition has the ability to bear the dead load of the window construction. The temperature on the ‘cold side’ did not even reach 20 °C (air temperature inside the hall). The problem of the failure was found in the aluminium profile system.

For the following full-scale test the aluminium profiles were optimized and the test is succeeded. The results of a series of tests show (Figs. 13, 14), that the fire resistant property of EI 30 from both directions can already be reached with a sandwich thickness of 45 mm.

CONCLUSION

FRP – composite materials have given architects the possibility to create a new generation of buildings with organic shapes and forms. But in order to use this “new” building material to its full potential, firstly it should comply to all the regulations. Creating a fire retardant FRP composite façade that complies with EN 13501-1 (class B-S2-d0) and EN 13501-2 (class EI30) is the first step and many will follow.

DISCUSSION

Composite has a great potential to use in revitalising buildings by exchanging the old façade for a new composite façade. It also helps to create a more durable building industry. Don't demolish, (re)use what you can, add what you need. This way the use of composite material helps in creating a circular economy in the building industry. The use of FRP helps to further reduce CO₂ in the atmosphere (less energy needed than standard building materials) and the first results of creating a C2C composite have been demonstrated by Hitachi – Japan, where the hardening process of FRP panels have been reversed and almost all base materials (95%) were reused in a new product.

What has been described here has been a development process of nearly three years. Nord Composites has kindly offered their help, support and made their lab facilities available to develop the recipe for the fire retardant laminate which can be used as cladding or insulated sandwich elements.

References

- [1] Messerschmidt, B. and Fellman, J., “Fire Testing Of Ethics A Comparative Study”, Interflam Congress 2013, London, England. Interscience Communications Ltd. 1269–1278, 2013
- [2] European standard “EN 13501-1; Fire classification of construction products and building elements - Part 1: Classification using data from reaction to fire tests”
- [3] European standard “EN 13501-2; Fire classification of construction products and building elements - Part 2: Classification using data from fire resistance tests, excluding ventilation services”
- [4] European standard “EN 1363-2; Fire resistance tests - Part 2: Alternative and additional procedures”
- [5] Troitzsch, J., “Plastics Flammability Handbook”, 3rd Edition, Hanser Gardner Publications, ISBN 1-56990-356-5, 2004