

# Fire resistance of 'high-tech plastics'

*Results of a test series about the fire resistance of glass-fibre reinforced polyester composite (FRP)*

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## INTRODUCTION

During the last decade composites as building materials have been used more and more. The mechanical properties, thermal insulation, durability and the production technology make composites an interesting material to use as an internal or external cladding system.

Besides the application as an add-on single-layer cladding, the material is highly suitable for the production of sandwich panels. 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 form an excellent lightweight alternative for e.g. precast concrete (sandwich) and masonry walls.

In the Dutch buildingcode, named 'Bouwbesluit', the property 'Reaction to fire' according to EN 13501-1 requires class variants from A2 to D at the internal and external surface and class S2 at the internal surface. Furthermore, in some cases the façade must have a certain fire resistance according to EN 13501-2, for example EI 30, EI 60. It has to be clear, that a composite material made of polyester, which is a kind of high-tech plastic, in itself does not have ideal properties to perform well on these aspects.

Polux, however, have developed a composite polyester skin to meet these fire properties. In co-operation with DGMR the properties 'Fire resistance' and 'Reaction to fire' have been tested according to the relevant European standards. The results of these tests will be introduced in the case study of a highrise (80 m) office building for the administration of the city of Utrecht.

## MATERIAL

The primary reason why it is so difficult to develop a fibre reinforced material that complies with all the fire regulations is because in essence it is a 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.

Knowing what to do and how to overcome these issues has been a several year roller coaster ride of trial, error and testing. They developed a solution suitable for most fire related issues in façade building. The material will be described in more detail in the paper.

## **TEST METHOD**

Part 1 of the paper concentrates on the 'Reaction to fire' property according to EN 13501-1. The paper will discuss the end-use application configuration in the SBI test stand for sandwich panels. Several tests have been performed to achieve a high classification. Composite sandwich panels or claddings with classification B-S1-d0 are since available on the market. The tested configurations and their results will be introduced by Polux.

Part 2 of the paper concentrates on the 'Fire Resistance' property according to EN 13501-2. Several tests have been performed on sandwich panels and sandwich panels with aluminium windows according to EN 1364-1. For the case study at hand it was necessary to achieve the classification EI 30 (both directions). The testing procedure, tested configurations and results will be explained by DGMR.

## **DISCUSSION**

In the final paper the results from the fire tests will be presented and a discussion of the possible field of application will be presented. The focus will be to determine and discuss differences between the scope of a product with the classification 'Fire Resistance' and 'Reaction to Fire'.

## **REFERENCES**

1. EN 13501-1; Fire classification of construction products and building elements - Part 1: Classification using data from reaction to fire tests
2. EN 13501-2; Fire classification of construction products and building elements - Part 2: Classification using data from fire resistance tests, excluding ventilation services
3. Test reports, numbers will be listed in final paper.

## **REACTION TO FIRE (EN 13501-1)**

The potential contribution of a product to a fire does not only depend on its intrinsic properties and the thermal attack, but also to a large extent on its end use application in the construction. Therefore, it shall be tested so as to simulate its end use application.

The considered end-use application is a façade construction. The classification B or A2 shall apply (according to the building regulation) to the outside surfaces of the construction. Composite materials can be used in façades in two ways:

- a) As an external cladding
- b) 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.

To the internal exposed surface of the façade the following requirement applies: **S2-d1**

The position of the product is different. The external cladding is considered a product which forms a cavity with a substrate. The product shall be tested as such. The sandwich construction is considered a product on a substrate: glued, mechanically fastened or simply in contact with other materials. In this case the product shall be tested with a substrate and fastening representing the end use application.

A product applying for class B shall be tested in accordance with EN ISO 11925-2 and additionally tested in accordance with EN 13823.

A product applying for class A2 shall be tested in accordance with either EN ISO 1182 or EN ISO 1716. Additionally, all products applying for class A2 shall be tested in accordance with EN 13823.

Classifications s1, s2 and s3 for smoke production are deduced from the measuring data obtained from testing in accordance with EN 13823.

Classifications d0, d1 and d2 for flaming droplets/particles are deduced from observations of flaming droplets and particles:

- for classes B, C and D in EN ISO 11925-2 and EN 13823
- for class A2 (and under the conditions specified in 8.3.2) in EN 1382.

### Explanation of test method:

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.  
Class B and A2: No lateral flame spread (LFS) to the edge of the specimen.
  - FIGRA (= FIGRA 0,2 MJ)  $\leq$  120 W/s
  - THR 600s  $\leq$  7,5 MJ
2. Ignitability test (EN ISO 11925-2)  
This test evaluates the ignitability of a product under exposure to a small flame.  
Class B: Under condition of surface flame attack and, where required, edge flame attack with 30 s exposure time, there shall be no flame spread in excess of 150 mm vertically from the point of application of the test flame within 60 s from the time of application;
3. Non-combustibility test (EN ISO 1182)  
This test identifies products that will not, or not significantly, contribute to a fire, regardless of their end use. Class A2:
  - $\Delta T \leq 50$  °C and
  - $\Delta m \leq 50$  % and
  - $t_f \leq 20$  s.
4. Heat of combustion test (EN ISO 1716)  
This test determines the potential maximum total heat release of a product when completely burning, regardless of its end use. It allows the determination of both the gross heat of

combustion (PCS) and the net heat of combustion (PCI). The criteria for Class A2 is:  $PCS \leq 3,0$  MJ/kg

What does it mean in layman's terms?

Over the years materials such as aluminium, concrete, wood and brick were used to build façades. With the introduction of FRP composite materials, organic forms and shapes were made possible creating a new kind of facade. Architects were given a brand new material to work with and they were given the freedom to design any shape or form they wanted. Double curved and rounded corners, no problem. If you can design it, it can be produced in composites. Engineered creativity so to speak.

But before this 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 colourfastness, durability and strength calculations. In addition to these qualities production should take place in a closed mould system (VARTM production)

Creating a composite material that complies with all the fire resistance properties, and that 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.

We had a number of aspects to look at.

- 1) Aesthetic qualities ( gelcoat properties)
  - a. Colour fastness – anti yellowing
  - b. Durability
  - c. Loss of gloss, weathering
- 2) Resin – Fire retarding qualities
  - a. Halogenated
  - b. ATH dispersed in resin.
- 3) Core material and fibres.
  - a. What insulation material can be used
    - i. low smoke
    - ii. good fire resistance properties
  - b. What fibres to use
    - i. Kinds of fibre (Glass, Aramid, Biobased.....)
    - ii. Powder bonded materials
    - iii. Polypropylene bonded
- 4) Production techniques
  - a. VARTM closed mould production.
    - i. Permeability of fibre material used
    - ii. Creating a long "open time" for injecting large panels
    - iii. Filtering of resin through the fibre matting (ATH)
  - b. Infusion
    - i. Compressing fibre reducing permeability
    - ii. Creating a long "open time" for injecting large panels
    - iii. Filtering of resin through the fibre matting (ATH)
- 5) Technical properties
  - a. Strength (cur 96)
  - b. Thermal expansion

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.



Problem however is that with the production methods you should avoid fillers such as ATH to be added to the resin. When you produce 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 it less permeable. For the core materials PIR foam was used. In order to keep the amount of smoke produced as little as possible, the FRP layer should prevent the inner core from burning.

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 gloss 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.

Having tested all available 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 we worked closely together on

this and were able to develop a highly fire retardant gelcoat with excellent weathering qualities.

For the production we polished the mould (thus smoothening the surface of the product) and Post cured all products before offering them for SBI testing.

After five or six SBI tests, we created a single laminate (resin filled with ATH and using the newly developed gelcoat ) and succeeded in getting our 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)

As it turned out the percentage of ATH filling the resin with 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.

Another problem was that the more ATH we put in, the more brittle the laminate becomes, losing its strength. A resin with 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 a skin layer of gelcoat and a ATH filled resin skin layer in the mould before putting in the dry fibre matting and core materials.

Extra precautions were made to prevent pre-release during the injection process and preventing the resin to flow in between the mould surface and the skin layer causing the injection to fail.

What has been described here has been a process of nearly three years and we are very grateful that Nord Composites has kindly offered their help , support en made their lab facilities available to us to come up with this recipe. A fully fire retardant laminate which can be used in cladding or fully insulated façade elements.

## **FIRE RESISTANCE (EN 13501-2)**

### Requirements according to Dutch Building code

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) with separating function. Three fire scenarios can be considered:

- a) Fire from the inside: the facade has to protect other parts of the building
- b) Fire from the outside: the facade has to protect the interior of the building from a fire occurring outside. This can be the case if the fire occurs for example at a lower level, see figure <>.
- 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 by the following relationship (see figure <>):

$$T = 345 \log_{10} (8t + 1) + 20$$

For scenario b), the so-called ‘external heating curve’ can be applied. 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 curve is defined by the relationship (see figure <>):

$$T = 660 (1 - 0,687 e^{-0,32t} - 0,313 e^{-3,8t}) + 20$$

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 criteria applies 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).

The meaning of the criteria is explained in the following.



Integrity (E) is the ability of the element of construction that has a separating function, to withstand fire without the transmission of fire to the unexposed side as a result of the passage of flames or hot gases. They may cause ignition either of the unexposed surface or of any material adjacent to that surface. The assessment of integrity shall generally be made on the basis of the following three aspects:

- cracks or openings in excess of given dimensions;
- ignition of a cotton pad;
- sustained flaming on the unexposed side.

Failure of the loadbearing capacity criterion shall also be considered failure of integrity.



Thermal insulation (I) is the ability of the element of construction to withstand fire exposure without the transmission of fire as a result of significant transfer of heat from the exposed side to the unexposed side. Transmission shall be limited so that neither the unexposed surface nor any material in close proximity to that surface is ignited. The element shall also provide a barrier to heat, sufficient to protect people near to it.

For all separating elements except doors and shutters the performance level used to define thermal insulation shall be the mean

temperature rise on the unexposed face limited to 140 °C above the initial mean temperature, with the maximum temperature rise at any point limited to 180 °C above the initial mean temperature.



Radiation W is the ability of the element of construction to withstand fire exposure so as to reduce the probability of the transmission of fire as a result of significant radiated heat either through the element or from its unexposed surface to adjacent materials. The element may also need to protect people in the vicinity. Elements for which the radiation criterion is evaluated shall be identified by the addition of a W to the classification (e.g. EW, REW). For such elements, the classification shall be given by the time for which the maximum value of radiation, measured as specified in the test standard, does not

exceed a value of 15 kW/m<sup>2</sup>. An element which satisfies the thermal insulation criterion is also deemed to

satisfy the W requirement for the same period.

#### Testing of the construction

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 facade 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.

For separating elements that are required to be fire resistant from both sides, two specimens shall be tested separately (one from each direction) unless the separating element is fully symmetrical and the required fire exposure conditions for both directions are identical. However, where information is required under different exposure conditions, additional tests shall be undertaken for each situation using separate test specimens.

Because the composite sandwich panels are fully symmetrical, the test results from one side according can also be applied to the other side. The requirements for the direction were actually different. The test specimen has to withstand only Integrity and Radiation (EW) from one direction and Integrity and Thermal Insulation (EI) from the other direction, but according to the external fire curve. 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 the classification of EI 30.

#### Project Case 1: City hall of Utrecht

The facade of the building enclosure facing the 4 main elevations is considered a composite sandwich wall construction with a window element. The general panel size is 5.4 x 3.6 m, composed as one piece of a unitized system. However, the biggest panel measures 7.2 x 4.5 m.

According to the Integral Plan of Fire Safety, one complete floor elevation (composite panel inclusive the building element) has to be classified as EW30 (i>o) and EI30-ef (o>i).

#### Project Case 2: Hilton Hotel Schiphol Airport

The facade composition is similar to the City Hall of Utrecht. The difference is in the requirements: not only one floor elevation but all the composite sandwich constructions have to reach the requirements of EW30 (i>o) and EI30-ef (o>i). The window parts do not have to provide any fire resistance and can be considered open.

#### Difficulties (material properties of composite)

<Bijdrage Polux>

During a thermal attack of several hundreds degrees Celsius, almost all types of material will burn, melt or at least weaken. ...

### **The Burning of FRP**

#### **Heating**

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 compared 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/ 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 as well as the availability of oxygen. The supply of oxygen and the temperature will vary constantly 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.

## **OK.... Then, how do you prevent FRP from burning ?**

### **Mechanisms of flame retardation**

In FRP laminates there are four different modes of action to retard flames:

- By cooling
- By dilution
- By termination by free radical acceptors
- By formation of intumescent layers

The temperature of a fire might be lowered below that temperature in which a fire is sustained, 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.

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 gas phase which in turn suppresses the flammable gases.

An intumescent layer is a physical hindrance 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.

By combining these modes of action 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 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.

**And what else.... ?**

### **Optimal Laminate construction**

When designing and producing a laminate using a fire retardant resin one should select a resin based on fire test criteria and application. Once this is done one should take into consideration how the following points influence the performance of the end product:

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

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