VÉDELEM TUDOMÁNY
KATASZTRÓFAVÉDELMI ONLINE TUDOMÁNYOS FOLYÓIRAT

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FIRE LIMITATIONS ON THE USE OF GLASS FIBER REINFORCED COMPOSITES IN BUILDING STRUCTURES

Abstract

It is a mandatory requirement that the buildings have to be sized for heat and fire. In case of concrete, we use the EUROCODE standard. If the structural material contains materials whose thermal behaviour is unknown, then we have to expect hidden dangers. Such a common material is the fibre reinforced composite plastics. In the paper the authors investigated the properties of this composite that are necessary for design, sizing and use: changes under the influence of heat, electron microscopic structure examination, special burning behaviour and mechanical tensile strength. The authors made the heat treatment in a furnace and the combustion of the composite rods with an oxygen index measuring device under special conditions. Knowing these, it is possible to calculate what durable strength reductions will result from a fire in the building structures.

Keywords: glass fibre reinforced composite, test, specimen

ÜVEGSZÁLLAL ERŐSITETT KOMPOZITOK FELHASZNÁLÁSÁNAK TŰZVÉDELMI KORLÁTAI ÉPÜLETSZERKEZETEKBEN

Absztrakt

Kötelező előírás, hogy ez épületeket hőre, tűzre kell méretezni. Ha betonról van szó arra használatos az EUROCODE szabvány, de ha a szerkezeti anyag tartalmaz olyan anyagokat, amelyek hőtani viselkedése nem ismert akkor rejtett veszélyekkel kell számoltunk. Ilyen gyakran használt és egyre inkább elterjedt anyag az üvegszállal erősített kompozitok. Munkánkban ennek a kompozitnak, azokat a tulajdonságait vizsgáljuk, amelyek a tervezéshez,

méretezéshez és felhasználáshoz szükségesek: változások hő hatására, elektronmikroszkópos szerkezetvizsgálat, különleges az égési viselkedésre és mechanikai húzószilárdságra. A hőkezelést égető kemencében, míg a kompozit rudak égetését különleges körülmények között oxigén indexmérő készülékben végezték el. Ezek ismeretében ki lehet számítani, hogy milyen tartószilárdság csökkenéseket eredményez az épület szerkezetekben egy tűz.

Kulcsszavak: üvegszállal erősített kompozit, mérés, minta

1. INTRODUCTION

Traditional building materials are increasingly being replaced by "plastics". Glass reinforced plastics (**GRP**) is widespread and it has many types of uses in the construction industry, for example various cable ducts, scaffoldings or stair elements. Composite plastic concrete is an alternative system that is often used instead of the reinforced concrete. One of its great advantages is the high tensile strength and the other is the durability. Its design life is the same as the design life of concrete, so a hundred years. The most significant physical characteristics of a structural material in concrete in terms of sizing are its density, tensile strength, and modulus of flexibility [1]. Other properties such as high corrosion resistance, high chemical resistance, electrical insulation, non-magnetic light machining and very low thermal conductivity are also important. One of the critical requirements is to work together. The essence of this is to create the best possible adhesion surface. This can be improved by applying some scattering material (usually sandblasting) to the surface. Before the application, the fire resistance of the material must also be examined in accordance with the European Union and Hungarian fire protection regulations in force. The changes in the physical and chemical parameters of the specimen made from the sample material must be examined under the influence of temperature.

2. STRUCTURE OF THE GRP MATERIAL

The structure of the material can be divided into two main components. These two are synthetic resins and reinforcing materials. In this mixture, it is important that the resin should be thermosetting. The components form a chemical bond that provides adequate mechanical and chemical properties. Polyester resin, vinyl ester resin, phenolic resin, epoxy resin and acrylic resins are suitable for the above-mentioned properties. In general, we can state that the matrix of these resins builds up the composite material and positively influences its properties. Polyester resin is the most commonly used component. This is because it has a lot of features [2].

Additives are added to the matrix which (like in case of the concrete) improve the properties: These affect the fire resistance, corrosion resistance, mechanical properties of the composite and prevent the formation of cracks on the surfaces [3].

The group of reinforcing materials always means some fibrous material. There are three most often used materials for this purpose, but beyond these, there are many other options. The most often used material is the fiberglass, which is woven from molten glass and has a circular cross section. The average cross-sectional size of glass fibres is 20-25 micrometres, which means quite small fibres. The biggest advantages of these are that they are cheap, have good tensile strength, are light and have high heat resistance (1000 - 1200 °C). Carbon and aramid fibres are also often added to the system. More than 90% of the carbon fibres consist of pure carbon. Their special feature over fiberglass is that they have exceptional strength even at higher temperatures. It also conducts heat and electricity and is extremely corrosion resistant. In general, we can determine that composite plastics have a high strength at normal temperatures with small weight. On the other hand, they tend to break brittle. We compared it to the reinforcing steel (which has a higher density) in Table 1 [4].

Table 1 - Comparison of the mechanical properties of reinforcing steel and composite. Created by the Authors.

Properties	**GRP composite plastic**	**Steel**
Density	1,9-2,2 g/cm³	7,85 g/cm³
Tensile strength	800-1300 MPA	360-550 MPA
Tensile modulus (E)	35000-100000 MPA	210000 MPA
Elongation at the break	2,2%	25%
Available diameter of products	4-35 mm	8-60 mm
Available length of products	infinite	12 m

It is important to mention the high corrosion resistance in relation to the chemical properties of the material, as this is a great advantage over the steel. Many times we can see that during the pitting of the concrete cover, the steel starts to corrode, so the structure loses its tensile strength which is very dangerous. Actually, this fault is not present in case of composite plastic, because it does not corrode. It has a low thermal conductivity (0.5 W / m * K) compared to the high thermal conductivity of steel (60 W / m * K). This may be important due to the increasingly strict energy considerations. If this is used instead of steel, no thermal bridges are created within the structures.

2.1. Application of the composite plastic

GRP profiles are often used in the construction industry. This is due to its easy installation, its good mechanical strength and low weight. [5] [6] [7]. The designers and investors are increasingly replacing the steel structures with it, because it provides great freedom in geometry and properties [8]. In the followings we show some applications in Figures 1-4.

Figure 1 - Composite pedestrian bridge (Ikast-Brande, Denmark, Fiberline.com) (left) Figure 2 - Apartment made of composite plastic concrete, Zurich (Photo by Andreas Zimmerman Architekten Ag.) (right).

Figure 3 - Rio Tinto Alcan, Iceland (Source: https://www.schoeck.com/en/case-studies/rio-tinto-alcan) (left)

Figure 4 - Apartment made of composite plastic concrete, Zurich (Photo by Andreas Zimmerman Architekten Ag) (right).

2.2. Test specimens

Spirally rolled GRP rod fittings, diameter 6 mm.

Figure 5 - GRP type test specimens (other properties in Table 1).

3. SELECTION AND PRESENTATION OF THE TESTS

Before the application, the fire resistance of the material must also be examined in accordance with the European Union and Hungarian fire protection regulations in force. It is useful to learn about the behaviour of a material from several directions: for example in addition to the mechanical and flammability properties, the changes in the microstructure of the sample must be investigated due to the heat. The changes in the physical and chemical parameters of the specimen made from the sample material must be examined under the influence of the temperature. We have selected measurements from which it is possible to know how the material behaves under the influence of high temperatures within the structure [9]. After that, we would like to suggest in which segment within the construction industry it can be applied so that it meets with the Hungarian fire protection regulations. From the studies in connection with thermal analysis (DTA, DTG) we can reveal what processes take place in the material. We can read with temperature accuracy when and what kind of chemical and physical processes take place in the examined specimen. The oxygen index gives us an idea of how resistant a

material is to fire. From the electron microscopic image, in addition to the numbers, it can give a visual picture of what changes take place in the material after heat load.

3.1. Heat treatment in a furnace

The main purpose of the heat treatment is to test the load-bearing capacity of the support structure at a high temperature in the mechanical model. In this case we examine the building structures one by one. In this case, we remove the elements from the structure one by one as if we were performing a fire test on them with a standard fire curve (ISO 834). The concrete completely loses the strength of the support at 500 °C, so it breaks. Nevertheless, the properties of the embedded fittings must be checked. The 500 °C method is suitable for this. We observed the type of the behaviour of the specimen at 300 and 600 °C. To do this, we cut several small (10 cm long) pieces. These two temperatures were chosen, because the EUROCODE isotherms develop temperatures of 300 and 600 °C in a building in case of 30 and 60 minutes at typical concrete coverings (20-40 mm deep).

Figure 6 - Samples in the furnace before heating and the consistency of the samples after 24 hours at 300 °C. Source: Authors.

Our observation after heat retention: our material is worse than the steel, which begins to lose its strength at 500 °C. The test at 600 ° C is no longer established in this respect, because drastic changes can be observed already at 300 °C. The material was actually destroyed, losing its strength (Figure 6). We made further tests in the framework of the thermal analysis

(derivatographic test). Here we get a better picture of the processes taking place in the material under the influence of heat.

3.2. Burning in not nor al air

We made the combustion in an oxygen index test apparatus. For the purposes of the international standard [ASTM 2863.], the following definition applies. Oxygen index: the minimum concentration of oxygen by percentage volume in a mixture of oxygen and nitrogen introduced at 23±2 °C that will just support combustion of a material under specified test conditions Technical data of apparatus: FIRE Instrumentation and Research Equipment Limited, UK (ISO 4589 Part 2 Oxygen index test apparatus). (Figure 7) The apparatus consists of five basic modules: (1) digital interface panel, (2) automatic conditioning system for sample environment, (3) electronic flow measurement device, (4) oxygen measurement system, (5) mixing chamber. Test column and sample holder assembly [10].

Observations: In our study initially the samples do not show any ignition phenomena, and are non-flammable at 21 % oxygen concentration. By increasing the oxygen content, at the beginning only burning marks appear, then as the oxygen concentration increases, the length of the burnt area becomes greater.

Figure 7 - Typical apparatus for the determination of oxygen index and damage to the specimens after burning in 35 and 40% oxygen. Created by the Authors.

3.3. Thermoanalytical method

Thermal behaviour of the studies materials were followed by thermoanalytical methods (TG/DTG/DTA) using Derivatograph-Q 1500 D. This equipment is able to collect TG/DTG/DTA data from the same measurement simultaneously. For computational evaluation of the thermoanalytical test results Winder (Version 4.4.) software was used. There is a simultaneous procedure where the TG (Thermogravimetry) and DTA (Differential Thermal Analysis) thermoanalytical methods can be combined. As the result of thermogravimetry (TG) the first derivative of thermogravimetric curve (DTG) is also obtained We had the opportunity for this thermal analysis at the Department of Geology and Geotechnics of the Budapest University of Technology and Economics. The type of the equipment is a MOM Derivatograph Q-1500.

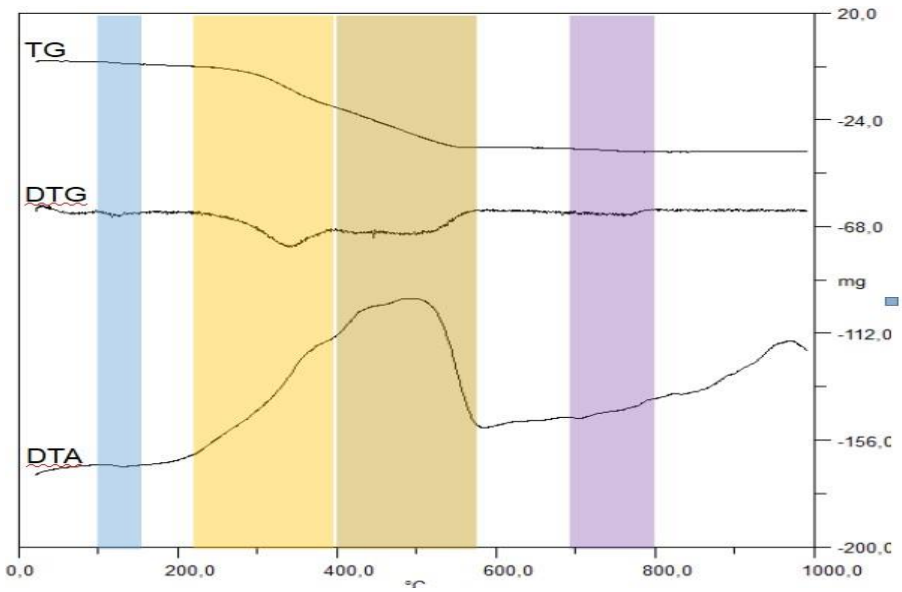

Figure 8 - Thermal behaviour of GD samples based on derivatography up to 1000 °C.

Heat reactions with weight loss:

1. 100-150 °C: Drainage of sticky water, possibly here Tg (glass transition temperature),
2. 220-400 °C: Thermal decomposition (thermal decomposition), (pyrolysis if the test is carried out in an inert atmosphere),
3. 400-580 °C: Combustion - the most intense exothermic (heat generating) reaction during

the test,

4. 700-800 ° C: Thermal decomposition of small amounts of CaCO3.

Thermal reactions without weight loss:

- at 575 ° C no small endothermic peak of α-quartz (SiO2) is visible on the DTA curve (recrystallization to β-quartz),

5. 880-980 °C: An endothermic reaction, probably melting of the glass + other residues, or the formation of a new phase.

We consider it important to emphasize that in case of a fire in an air atmosphere, the synthetic resin no longer works with the glass fibre bundle above 200-220 °C. In this case, only the tensile strength of the glass fibre bundle can be exploited until the glass melts.

3.4. Scanning electron microscopic (SEM) observations

To study the morphology of the samples SEM images were obtained by a Phenom XL scanning electron microscope. For the observation of the samples they surface (horizontally oriented samples) and cut cross section (vertically oriented samples) was studied. It is also very important, because it gives us an idea of how the spatial structure of a material is built up and if necessary, how it changes under the influence of heat load (Figure 9). Especially in case of complex materials, where there are not only one but three components (fiberglass, resin, sandblasting).

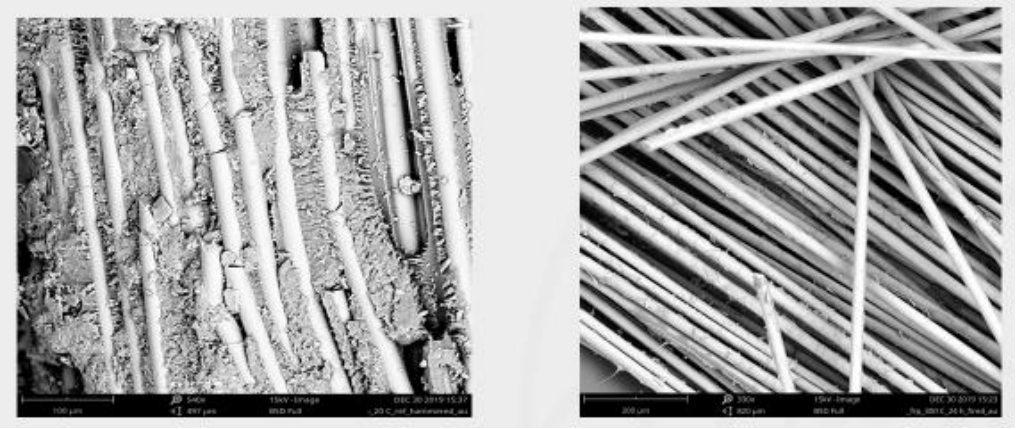

Figure 9 - Composite matrix with glass fibres at 20 °C and after combustion of the resin.

Source: Authors.

3.5. Tensile test

The purpose of the tensile test is to determine the tensile strength of the GFRP. We can also determine the modulus of elasticity and ultimate strain of the material. During the test, the test specimen is subjected to a monotonically increasing uniaxial tensile load.

We made the tensile measurement with an Instron 5989 pneumatically operated tensile machine. The machine is able to save the measured data and diagrams in digital form. Tensile test is not an easy task in case of composite plastics. This is because if we want to capture these materials they are easily broken. Fortunately, colleagues at the Budapest University of Technology and Economics have already experimented with similar elements so they helped us during the test. We were weighed the specimens and determined their cross-section, length (10-15 cm) and weight. Then we heated them to 80 and 120 °C. This simulated its heat effect. As the derivatographic examination revealed that the epoxy resin starts to burn out at the temperature of 200 °C and thereby the material decomposes to break down, we experimented in the temperature level below 200 °C (Figure 10).

Figure 10 - Specimens captured in the machine and the prepared specimens. Source: Authors.

Measurement diagrams

The rods were preheated at three different temperatures: Number 1 and 2 at normal temperature, No. 3 and 4 at 80 °C and No. 5 and 6 at 100 °C. Their density is 1900 kg/m³. The cross sections are 6 mm in diameter. The specimens are summarized in Table 2.

Table 2 - Physical parameters of samples captured in a tensile machine. Created by the Authors.

Sign	Temperature (°C)	Diameter (mm)	Full length (mm)	Length without capture (mm)	Weight /g	Weight after heat load (g)	Force (KN)
1	**20**	6	541	330	35,90	-	28,13
2	**20**	6	609	395	40,86	-	27,59
3	**80**	6	337	150	22,11	22,11	24,69
4	**80**	6	610	413	40,91	40,90	30,36
5	**100**	6	323	128	22,53	22,52	32,37
6	**100**	6	480	281	32,36	32,35	28,69

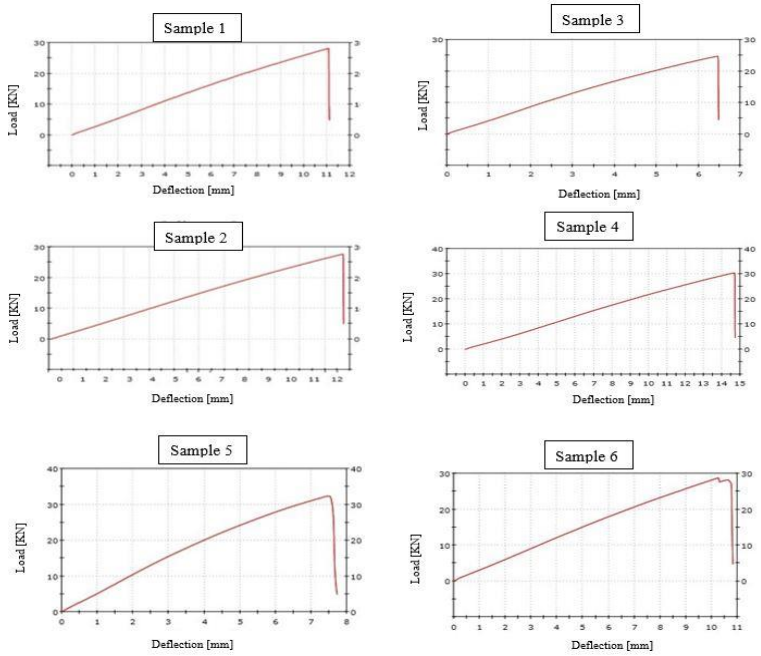

Figure 11 - Tensile diagrams of samples 1-6: X axis: deflection (mm), Y axis: load (kN). Source: Authors.

It can be seen that the variance is quite large between the different fibres. There are several reasons for this. One is that the manufacturing process does not have a uniform fibre - matrix ratio. The more the proportion of fibres within a specimen, the greater its strength. The fourth is the heat load effect. The diagrams do not show the destructions. While the specimens treated at 20 and 80 °C did not show deformation at the destruction, the two specimens treated at 100 °C weakened at the capture and even one of them was torn (Figure 11). We observed no such changes in case of the heat-free specimens. After performing the load test, we can calculate the tensile strength of each specimen.

The procedure of the calculation of the known and obtained data was as follows:

In case of specimen 1:

Replacement cross-sectional area of the test rod: $A = \frac{M}{\rho * l} = \frac{35,90}{1,9 * 54,1} = 0,3493 cm^2 = 34,9\ mm^2$

Replacement diameter of the test rod: $d0 = \sqrt{\frac{4xA0}{\Pi}} = \sqrt{\frac{4x34,93}{\Pi}} = 6,66\ mm$

tensile strength: $\sigma = \frac{R}{A} = \frac{28,13x10^3}{34,90} = 806,017\ N/mm^2$

Extension: $\varepsilon = \frac{\Delta L}{L0} = \frac{11mm}{541mm} = 0,02$

Based on the average of six samples, a tensile strength of 800 (MPA) is obtained, which does not change at 80 and 100 ° C.

Figure 11 - Destruction of specimens 5 and 6. Source: Authors.

4. DISCUSSION, CONCLUSION

We examined how our material is destroyed by different heat loads. The combined results of several test gave us a complete picture of the behaviour of the fiberglass composites. In case of fire, the resin will no longer work with the glass fibre bundle above the temperature of 200-220 °C. Only the tensile strength of the glass fibre bundle can be exploited until the glass melts. These processes also affect the safe firefighting [11] [12] [13].

We also determined from the thermal analysis tests that it occurs exactly at 220 °C. The destruction point of a material occurs when the epoxy resin burns out and thus the co-operation of the fibres already works. This can also be seen in case of a detachable spiral on the surface (Figure 7), when it detaches together with a sand cover. As a result, it can be stated that the material is destroyed at the temperature of 220 °C.

Due to these temperature criteria, in higher buildings, where the building is rated AK, KK or MK, it is not recommended to use it independently in supporting structures because of the unexpected loads that may arise and possible fires. In case of smaller detached houses where there is no high fire protection requirement and it would be expensive to build with a monolithic

reinforced concrete slab, it can provide a suitable alternative. For "very low risk" category family house, basement + ground floor + first floor, the material can be utilized in many ways. Its application can be useful and economical.

The real alternative may not be to steel, but to use it with the steel. The two substances should not be used against each other but together. Due to the high strength of grp, it has poor fire resistance and can easily to break. The steel is expensive and it has less strength, so it can be logical to use these together. Our research can also be a good basis for other series of publications on similar topics [14] [15].

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