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# The effect of different passive fire protection systems on the fire reaction properties of GFRP pultruded profiles for civil construction

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ABSTRACT

In order to study the viability of using GFRP pultruded profiles in floors of buildings, as structural elements, experimental investigations were carried out to analyse their behaviour when exposed to fire. In particular, the feasibility and efficacy of using different protective coatings/layers (an intumescent coating, a vermiculite/perlite cement based mortar and a calcium silicate board) to provide fire protection to GFRP pultruded profiles was investigated. Previous experiments showed that the above mentioned passive fire protection systems allow fulfilling fire resistance requirements for the envisaged application. This paper presents the results of the investigations concerning the fulfilment of the fire reaction requirements of those solutions. The experimental programme included dynamic mechanical analyses (DMA) and thermogravimetric and differential scanning calorimetry (TGA/DSC) experiments on both the GFRP and the fire protection materials. Subsequently, fire reaction tests were carried out on GFRP pultruded laminates, both unprotected and protected with the different fire protection systems, using a cone calorimeter. Results of these experiments allowed defining the field of application of each investigated solution, according to building code requirements.



## 1. Introduction

Fibre reinforced polymer (FRP) materials in general and glass fibre reinforced polymer (GFRP) pultruded profiles in particular are finding an increasing number of applications in civil construction. In fact, there are already several examples of application of these materials in bridges and buildings, in both new constructions and rehabilitation of degraded structures [1].

The main advantages of using GFRP pultruded profiles rely on their lightness, high specific strength and stiffness, free formability, low maintenance requirements and high durability, even under aggressive environments [2]. However, as for most FRP materials, there are concerns regarding the use of GFRP pultruded profiles in buildings, where construction materials are required to have adequate fire reaction behaviour, avoiding fire ignition, flame spreading and excessive smoke production and spreading, and structural elements are also expected to present sufficient fire resistance, in order to prevent structural collapse under fire.

With this regard, the concerns associated with the fire behaviour of FRP materials are legitimate. When heated to moderate temperatures (100–200 °C), FRP materials soften and creep, causing a considerable reduction of both strength and stiffness. Furthermore, when FRP materials are exposed to high temperatures (300–500 °C), their organic matrix decomposes, releasing heat, smoke, soot and toxic volatiles [3]. However, in spite of such unfavourable response under fire, FRP materials present a low thermal conductivity, thereby slowing the spread of fire from room to room, and present a reasonable burn-through resistance, providing an effective barrier against flame, heat, smoke and toxic fumes [3,4].

The considerable amount of investigations on the fire reaction of FRP materials has already allowed achieving a good level of understanding regarding the fire reaction properties of most common FRP materials used in civil construction (e.g. [5–8]). Presently, the commercially available resins and flame retardants allow fulfilling most flammability requirements [9–11]. However, if changing the matrix formulation, by using flame retardants or inherently flame retardant resins, allows overcoming fire reaction restrictions, in terms of fire resistance this approach does not allow to achieve the performance typically required for primary structural elements (60–90 min). In fact, most flame retardants cause considerable reductions in the mechanical properties of FRP materials. Similarly, the mechanical properties of FRP materials produced with the inherently flame retardant phenolic resins are usually considerably lower than those obtained with more current thermosetting resins. Furthermore, according to Dodds et al. [4], the thermal insulation of phenolic composites exposed to a hydrocarbon fire is not too different from that of epoxy and polyester composites. Mouritz and his co-workers [12–14] reported also very similar retention of mechanical properties for phenolic, polyester and vinylester composites, subjected to increasing heat flux or heat-exposure time.

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In this context, in order to improve the fire resistance of FRP structural elements used in civil construction, several authors tested the efficacy of using different types of protective coatings or thick layers and active fire protection systems with FRP materials.

Active protection, basically consisting of internal water cooling systems, has been already successfully tested by Davies and Dewhurst [15], Keller et al. [16,17] and Correia et al. [18], having allowed to attain 120 min of fire endurance in fire resistance tests of glass–epoxy and glass–polyester composites.

In what concerns with passive protection, the use of intumescent coatings has already proved to improve several fire reaction properties, such as the time to ignition, the flame spread rate, the heat release rate and the smoke production [19,20], leading also to significant improvements on the post-fire mechanical properties [19,21].

Mouritz and Mathys [19] used a cone calorimeter to investigate the effect of using a 0.5 mm thick intumescent coating and a 3.0 mm intumescent mat on the time to ignition and the post-fire flexural properties of 11.5 mm thick glass–polyester laminates. With the intumescent protections, time to ignition increased by, at least, one order of magnitude. With regard to the post-fire flexural strength, both protections were quite effective in reducing the loss of flexural properties, particularly for relatively short exposure periods. However, after 30 min of exposure, the flexural strength loss, particularly for the thinner intumescent coating, was already similar to that of the unprotected laminate. In this study, the authors investigated also the efficacy of a 3.2 mm thick ceramic fibre mat and obtained similar fire protection results, in both ignitability and flexural properties retention.

Sorathia et al. [21] studied the efficacy of different fire barrier treatments to protect glass–vinylester and graphite–epoxy laminates. Surface coatings included a ceramic fabric, a ceramic coating, different intumescent coatings (solvent based and water based), a hybrid of ceramic and intumescent coating, a silicone foam and a phenolic sacrificial layer. Fire protection was assessed through flexural strength retention after 20 min of exposure to a 25 kW/m$^2$ heat flux and also by the temperature profiles through the depth of the materials. Fire performance of the unprotected materials was greatly improved by the incorporation of the fire barriers and the use of a water-based intumescent coating proved to be one of the most effective solutions in retaining the flexural strength.

The use of fire insulation schemes to protect FRP-strengthened reinforced concrete (RC) slabs, columns and beam-slab assemblies has already been object of experimental and numerical investigations in Canada [22–24]. In these studies, the efficacy of using different thicknesses of a spray-applied fire-resistant plaster together with an external intumescent epoxy surface-hardening coating was evaluated. For 150 mm thick FRP-strengthened RC slabs, with fire protection thicknesses of 19 mm and 38 mm, fire endurances ranged from 2 h to 4 h – this conclusion was based on temperature measurements and numerical calculations, as the slabs were tested under self weight only. For FRP-strengthened RC columns, with fire protection thicknesses varying from 32 mm to 57 mm, the authors reported fire endurances under service load of more than 4 h.

Recently, Correia et al. [18] carried out fire resistance tests on glass–polyester pultruded tubular beams, both unprotected and protected with an intumescent coating, a vermiculite/perlite based mortar and a calcium silicate board, in order to investigate the viability of their use in floors of building, as structural elements. Fire endurances of the loaded beams exposed to the ISO 834 fire ranged from 65 min to 76 min which, taking only into account the fulfilment of fire resistance requirements, validates the structural use of the tested systems.

This paper presents results of additional experimental investigations, now focused on the fire reaction properties of GFRP pultruded profiles, both unprotected and protected with the above mentioned materials. In order to determine the thermal and thermomechanical material properties of the GFRP pultruded material and also the thermal properties of the fire protection materials, dynamic mechanical analyses (DMA) and thermogravimetric and differential scanning calorimetry (TGA/DSC) experiments were first carried out. Fire reaction tests were then performed in a cone calorimeter, in order to: (i) determine the fire reaction properties of the GFRP material, (ii) assess the improvements on those fire reaction properties when using the different fire protection systems and (iii) define the end-use limitations of each solution, 'taking into account the fulfilment of fire reaction standards' requirements.

## 2. Materials

The GFRP material used in the experimental investigations was supplied by Mitera and produced by Fiberline. It consisted of square-section tubular GFRP profiles (100 mm × 100 mm, 8 mm thick), produced by pultrusion. This material is constituted by alternating layers of unidirectional E-glass fibre rovings and strand mats (69% in weight) embedded in an isopthalic polyester resin matrix, containing no flame retardants. A dissection of a laminate showed that the rovings are positioned in the centre of the cross-section, while two mats are positioned next to the material surface.

Three different materials (supplied by TRIA, Portugal) to be used as passive fire protection systems for GFRP pultruded profiles were investigated, namely a calcium silicate (CS) board, a vermiculite/perlite (VP) based mortar and an intumescent coating. The CS board, produced by Promatec (Type H), is made of agglomerated calcium silicate, presenting a dry mass density of $\rho = 870$ kg/m$^3$ and a thermal conductivity of $\lambda = 0.164$ W/mK. The VP mortar, produced by TRIA, is composed of lightweight expanded vermiculite and perlite aggregates, refractory compounds and cementitious binders, mixed with water (0.67–0.80 l/kg), presenting a dry mass density of $\rho = 450$–$500$ kg/m$^3$ and a thermal conductivity of $\lambda = 0.0581$ W/mK. The solvent based intumescent coating used in the experiments (UNITHERM 38091) was produced by DuPont Performance Coatings and has a mass density of $\rho = 1240$ kg/m$^3$, a solid weight of 69% and a volatile organic compound content of 400 g/l. The above mentioned properties of the fire protection materials, reported in the technical sheet of the supplier [25], are referred to ambient temperature.

### 2.1. Dynamic mechanical analyses

Dynamic mechanical analyses (DMA) were performed on the GFRP pultruded material, according to ISO 6721 [26], in order to determine the glass transition temperature, $T_g$. Experiments were performed on a Q800 dynamic mechanical analyzer from *TA Instruments*, using a dual-cantilever flexural test setup to impose the cyclic loads. Tests were run from ambient temperature to approximately 250 °C at heating rates of 2 °C/min, 5 °C/min and 10 °C/min. A strain amplitude of 0.05% was adopted. For each heating rate, experiments were conducted on two specimens (60 mm long × 15 mm wide × 3 mm thick) obtained from sawing the tubular profile in the longitudinal direction at middle depth of a laminate.

Fig. 1 presents the curves of the storage modulus and the loss modulus at the different heating rates for a dynamic oscillation frequency of 1 Hz. The results obtained allowed defining the $T_g$ between 117 °C and 142 °C (the peak value of the loss modulus curve at a heating rate of 10 °C/min occurs for a temperature of 142 °C).