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Effects of the addition of glass fibers, mica and vermiculite on the mechanical properties of a gypsum-based composite at room temperature and during a fire test

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ABSTRACT

This work presents thermomechanical experiments whose results have led to a new formulation of composite panels for building construction. This panel has the advantage to be lightweight and 2 h firebreak. Plaster, under the β-hemihydrate form, is used as a matrix and mineral products (vermiculite, mica, glass fibers) are added as lightweight additives, mechanical reinforcement and thermal insulator. The both effects of the particles size distribution of plaster, and of the amounts of additives, on the mechanical properties are investigated at room temperature. Three approaches are proposed and compared: experimental, analytical and numerical to quantify the impact of additives on the mechanical properties. Thus, the results obtained, including porosity, density and mechanical property, permit to retain a formulation of composite. This formulation is tested under ISO 834 fire conditions to validate its use as passive protection in building construction.

1. Introduction

Gypsum plasterboards are widely used in building construction due to its availability, its low price, its ease of production and also especially due to its quality as fire barrier. Indeed, when gypsum is subjected to fire, the endothermic dehydration process consumes a part of fire energy [1–3]. Nevertheless, the main disadvantage of plaster are its brittleness at room temperature and its poor resistance to cracking when it is subjected to fire conditions described by the standard ISO 834 curve [4]. In addition, the introduction of more and more restrictive standards (environmental materials, energy consumption, fire protection, etc.) needs to develop new material [5–10].

Gypsum plasterboards are elaborated from calcium sulfate hemihydrate, which can occur under two forms: α- or β-hemihydrate. The use of the α form is very limited in construction because of its brittleness as building material [11]. Nevertheless, because of the high specific area of the β form of hemihydrates, water needs to be used in excess during the preparation of the composite. For example, the weight ratio noted w/p, where w is defined as the mass of water and p as the mass of plaster, is at least equal to 0.4 for plasterboard preparation while in the stoechiometric proportions w/p is equal to 0.2 [12]. This excess of water is responsible for high rates of porosity in the material because of the departure of water during the material drying. The consequences are a lightweight material with good insulation properties but poor mechanical properties which can leads to the falling down of the structure. Previous works were investigated to find a compromise between thermal and mechanical properties. The additives usually used as thermal insulator are vermiculite, mica, alumina, perlite or ceramic hollow sphere [13–16]. In the present work, vermiculite and mica have been used. They were selected for their properties as thermal insulator and their low density to lighten the panels to satisfy the industrial requests (density $\leqslant$ 1000 kg m^{-3} to make easier the panels handling). In addition, previous works have shown that the addition of layered silicates (montmorillonite, vermiculite and kaolinite), in small proportions (usually less than 5 w%) in a polymer matrix increased many properties, as stiffness, fire resistance, fluid or/and gas barrier properties [17]. These results might be extending to a gypsum matrix. To overcome the effect on the mechanical properties, glass fibers are used. After a comparative study including mechanical strength and cost of various kinds of fibers (quartz fibers, basalt fibers [18], wollastonite fibers [19], glass fibers [20]), two kinds of fibers are selected: E glass fibers

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Fig. 1. Assembly of a horizontal smoke extraction conduit.

without sizing treatment and AR "Alkali Resistant" glass fibers with a sizing treatment in zircon oxide (ZrO2). They are used with a length of 12 mm. Indeed, Sing and Garg reported that shorter than 12 mm of length, glass fibers cannot improve the mechanical resistance of gypsum based composite [21].

The composite developed in this work will be used as 2-h fire-break for passive protection. Its applications in building construction will be smoke extraction, ventilation conduits and the protection of electrical networks (Fig. 1). The conduit is composed by six panels (4 horizontal, 2 vertical) of 40 mm of thickness per meter. Panels are assembled with grooves and a special adhesive. Every meter the conduit is hanging from the ceiling by two threaded rods of 8 mm diameter protected by a plaster protection mould.

In a first part, the effects of the particles size and the rate of plaster hydration (w/p) on the mechanical properties will be studied. Then, the effects of the nature and of the amounts of additives introduced on the mechanical properties are presented. Next, the experimental results are compared to analytical and numerical models at room temperature to determine the formulation in agree with the industrial requests. Finally, the formulation extrapolated from results is validated by a standard fire test.

2. Materials and methods

2.1. Gypsum matrix

The chemical characterization of the industrial plaster used in this study was described in previous work [22] The correlation between the performance of composite materials and their porosity rates in relation with the particle size distributions and their compaction are widely described in the literature [12,23,24]. Seven different particles size distributions of plaster were studied. They were obtained by grinding of the industrial plaster (β-hemihydrate form, $CaSO_4$, ½ H_2O) and are noted P_i with $1 \leqslant i \leqslant 7$. After the hydration of P_i the corresponding matrix (dihydrate form $CaSO_4$, $2H_2O$) are noted $M_{i,1 \leqslant i \leqslant 7}$. The particles size distributions were

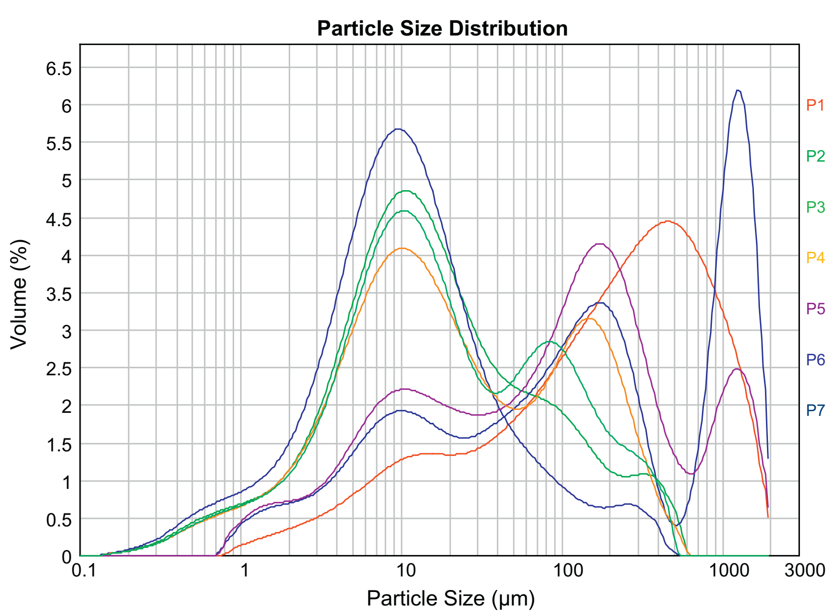

Fig. 2. Particles size distributions for plasters P_i, $1 \leqslant i \leqslant 7$.