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Comparison of ground waste glass with other supplementary cementitious materials

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ABSTRACT

Finely ground glass has pozzolanic properties that make attractive its recycling as supplementary cementitious material. This paper compares the behaviour of waste glass powders of different fineness with that of natural pozzolana, coal fly ash and silica fume. Chemical analysis, compressive strength measurements and durability tests were carried out to investigate the effect of ground glass on strength and durability performances of mortars. Blended both with Portland cement and lime, ground glass improved strength, resistance to chloride penetration and resistance to sulphate attack of mortars more than natural pozzolana and similarly to fly ash. Mortars with ground glass immersed in water for seven years did not show any sign of degradation and increased their compressive strength. The ranking of ground glass with respect to the other mineral additions was not affected by fineness.

1. Introduction

Due to the rising demand of infrastructures in industrialised and developing Countries and to the high environmental impact of the cement and concrete industries, the recycling of industrial wastes in the concrete manufacturing is of increasing interest worldwide [1–8]. Of particular relevance are those materials that have pozzolanic properties. Used as a partial replacement of Portland cement clinker, waste materials with hydraulic or pozzolanic properties can contribute to the hydration of the cement paste and, after proper curing, may lead to beneficial refinement of the pore structure [9]. Consequently, these mineral additions delay the penetration of ionic species through the concrete, thus preventing effects of corrosion of embedded steel induced by chlorides or degradation of concrete due to sulphate ions [10].

Interest in recycling waste glass in the production of concrete has recently increased and a significant number of research works have been published showing advantages and side effects. Waste glass has been considered for the use as recycled aggregate for concrete [11–19]. As far as durability is concerned, it was suggested that, due to low absorption capacity, recycled glass aggregate is potentially able to improve resistance to freeze–thaw attack, drying shrinkage [15] and abrasion [19].

Since glass is essentially made by amorphous silica, it has some analogies with traditional pozzolanic materials and, when it is finely ground, it may be used also as a supplementary cementitious material [20–33]. Several studies have shown that, in this case, expansive disruptive action due to ASR is not observed [12,28,29,33] but, conversely, particles finer than 100 μm may even oppose to expansion of coarser glass particles [17]. Conversely, it was shown that the use of finely ground glass may contribute to the strength of mortar or concrete due to the pozzolanic reaction with lime produced by the hydration of Portland cement clinker [20–29]. Some works, which have also investigated possible effects on durability of concrete structures, suggested that, recycled ground glass leads to the refinement of the concrete pore structure (e.g. indirectly evaluated by sorptivity [31,32] or electrical resistivity [30,32] measurements), and delay in the penetration of aggressive ionic species [31–33].

These results encourage recycling of glass as a supplementary cementitious material. Nevertheless, in order to evaluate the real advantages of this addition in relation to the life cycle of reinforced concrete structures, the performance of ground glass should be compared to that of currently most used pozzolanic materials. Furthermore, long-term behaviour of cement materials incorporating glass powder should be investigated. Some researches in literature have characterized the durability properties of ground glass, used as replacement of cement, especially in relation to ASR risks and taking on account as a reference only one traditional mineral addition (typically fly ash or silica fume) [21–23,31,33]. Conversely, the other papers, which concern a broad comparison of glass powder

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with different traditional mineral additions, are limited to the study of pozzolanic reactivity and strength-related properties [20,24].

This paper describes the results of a study aimed at comparing the effects of ground waste glass and traditional types of pozzolanic materials (natural pozzolana, coal fly ash, silica fume) as well as an inert siliceous addition (quartz sand) on the strength and durability properties of mortars. A comparative evaluation is made on the basis of short-term and long-term compressive strength of cement and lime mortars and the resistance to chloride and sulphate ions penetration.

2. Experimental

Waste green bottles were crushed and ground in order to obtain powders with target specific surfaces of about 400 and 600 m^2/kg (respectively indicated with *G*4 and *G*6). Fig. 1 shows particles of *G*6 ground glass observed at the scanning electron microscope and X-ray EDS analysis of the particles.

2.1. Materials and characterization

For comparison, Portland cement (CE) and traditional mineral additions were also considered: a natural pozzolana from the centre of Italy (*PZ*), a silica fume (*SF*) and a coal fly ash (*FA*). Ground quartz sand (*QS*) was also studied, in order to consider an inert addition. Fig. 2 shows the X-ray diffraction patterns of the mineral additions. The fineness of mineral additions was evaluated by means of grading curves obtained by laser granulometry. The specific surface was then calculated from the grading curve. Fig. 3 shows the particle size distribution and the specific surface of the mineral additions and shows that fly ash, natural pozzolana and ground quartz were comparable in terms of fineness to the glass powder *G*4.

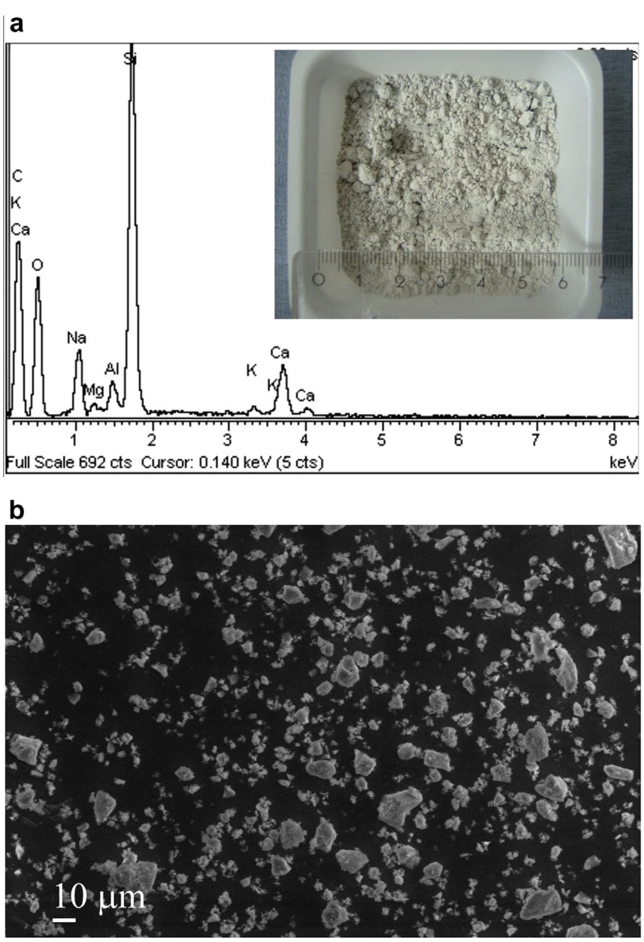

Fig. 1. EDS analysis (*a*) and SEM micrograph (*b*) of ground glass particles (*G*6).

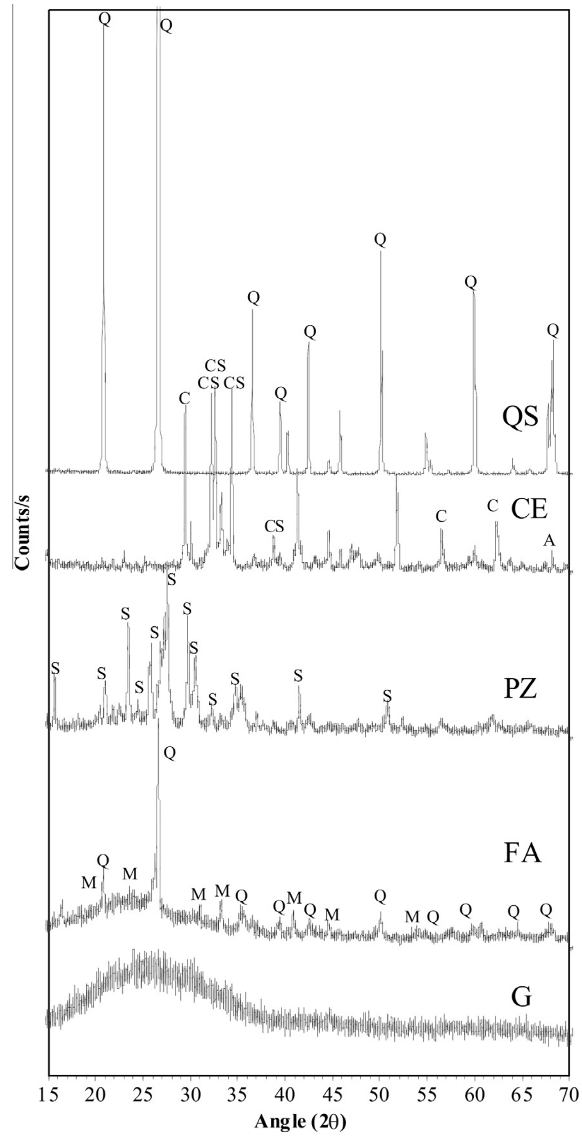

Fig. 2. X-ray diffraction pattern of mineral additions (M = mullite, Q = quartz, S = sanidine, C = calcite, CS = calcium silicate oxide and A = aluminium oxide).

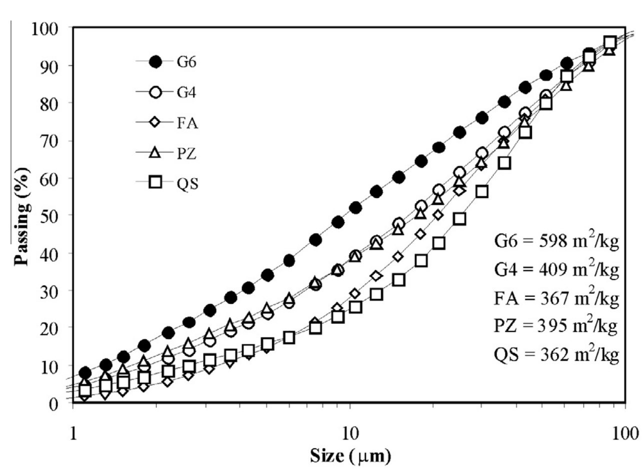

Fig. 3. Particle size distribution and specific surface of mineral additions.