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Pumice powder as filler of self-compacting concrete

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HIGHLIGHTS

- Pumice powder is introduced in self-compacting concrete mixtures as filler additive.
- Properties of SCC with pumice at fresh state and rheological model are investigated.
- Influence of pumice powder on SCC is compared to other fillers.
- Mechanical properties of SCC with filler of pumice are compared to other mixtures.
- Pumice pozzolanicity is verified to improve the mechanical behaviour of SCC.

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ABSTRACT

An experimental study on the rheological and mechanical properties of self-compacting concrete with pumice powder used as filler additive is presented. Self-compacting concrete (SCC) shows its peculiar characteristics in the fresh state and many researches have been developed with reference to its rheological characteristics paying attention to the techniques of self-compacting properties assessment. One of the most important aspect in concrete mix-design is the type and the amount of fillers with respect to water and cement: this amount has great influence not only on self-compacting properties (fluidity, segregation, etc.), but also on the mechanical properties of the mixture. Volcanic materials like white pumice have pozzolanic properties, so that it is possible to use powdered pumice in SCC manufacturing with a double effect: on one hand as filler and on another hand as a pozzolanic element in the mixture. The experimental campaign investigates SCC properties when white pumice powder is used as filler with or instead of silica fumes or flying ashes. From the rheological model of the paste, varying the components of the mixture, the determination of pumice powder amount and the consequences on the rheological properties of SCC are investigated. SCC with pumice powder is compared to other mixtures with silica fume and marble powder as filler, through tests on fresh and hardened concrete. Compressive and tensile strength tests were carried out together with the evaluation of fracture energy with the aim of characterizing the constitutive law of SCC with pumice powder. Results from shrinkage tests in the first days of curing are reported and comparisons with ordinary concrete manufactured with the same basic components are shown in order to evaluate the suitability and effectiveness of pumice powder added as filler to self-compacting concrete mix-design. Pozzolanicity of pumice strictly influences the mechanical properties with a significant increase of compressive strength after 28 days of curing.

1. Introduction

The use of self-compacting concrete (SCC) is nowadays common for projects of structures and infrastructures. The aesthetic quality of casts is appreciated very much in architecture and the aspects related to workability and durability increased its popularity. On the other hand the peculiarities of this material lead to problems in finding the optimal mix design for the requested application as well as in-site complications for casting, like special formworks due to the fluidity in the fresh state. Moreover the extreme variability of mixtures has direct consequences on the properties of concrete in fresh and hardened states, especially on the final mechanical properties.

It is well known that in order to decrease the quote of coarse aggregates and to avoid the addition of a too big quantity of cement, self-compacting concrete contains an important percentage of very small size aggregates, called fillers. The most common fillers used are silica-fume, fly ashes and marble powder. In the following sections the results of an experimental study on self-compacting concrete are reported in which the mixtures contain

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pumice powder as filler, comparing them to other mixtures with different fillers. Properties in the fresh state are investigated by varying the principal components of the mixture and the quantity and kind of fillers; afterwards three mixtures are compared, obtaining from laboratory tests their mechanical properties in the hardened state. Because of pumice powder has volcanic origin, the pozzolanicity of the mixture is investigated together with tests on chemical and physical properties and microscopy investigation.

In the manufacturing of self-compacting concrete the classical laws established for mix-design of ordinary concrete have to be modified in order to introduce the effects of filler, which can be reactive or not and which can contribute to the final mechanical properties or not. Moreover workability and segregation aspects become of primary importance in finding the optimal mix-design. In many cases this implies a trial-and-error procedure in which the proportion of each component in the mixture is changed several times until the final result is obtained [1]. The most important characteristics of a self-compacting concrete are: flow ability, anti-blocking, filling ability and segregation resistance. The first ones are related to the ability of concrete to pass through reinforcements, without the need of vibration; the latter is related instead to the uniformity of properties inside the formworks, avoiding the segregation of fine particles with respect to aggregates of major size which can subside on the bottom of formwork [2].

In the mix-design the flow ability is achieved through the addition of superplasticizers (HRWRA, High Range Water Reducing Admixture) and the limitation of the coarse aggregate by adopting an appropriate granulometry. Filling ability and segregation are strictly related to the mixture viscosity in the fresh state and often this property has to be modified through the addition of a Viscosity Modifying Admixture (VMA).

The flow ability is evaluated directly through the flow test of Abrams cone even though this property is indirectly evaluated through all tests performed in the fresh state of concrete. The filling ability concerns the capacity of coarse aggregate to be trailed among steel reinforcements avoiding obstruction and facilitating the complete filling of formworks [3]. The addition of fine aggregates as filler, modifying the granulometry used for the mix-design of an ordinary concrete, helps to achieve these characteristics.

Tests to be performed in the fresh state for the flow and filling ability are those of U-box, L-box, J-ring while the viscosity can be investigated through the V-funnel test.

In this study the effects of the addition of pumice powder (coming from Aeolian Islands in Sicily, Italy) as filler in the mixtures are compared to those attributable to other kind of fillers. Tests on compressive and tensile behaviour, fracture energy and shrinkage were performed and results are shown and commented in order to evaluate if pumice powder can be suitable for SCC manufacturing and the consequences of its presence among the components of the mixtures investigated.

2. Literature review

For a preliminary mix-design of self-compacting concrete, Okamura and Ozawa [4,5] indicated practical rules for choosing the quantities and proportions of the different mix components, operating on fine and coarse aggregate content, on the volumetric ratio between water and binder (cement and fillers) and on the quantity of admixtures.

Pumice has been used often for mixtures of lightweight concrete as reported in the studies by Açıkel et al. [6] and Anwar et al. [7], where pumice has been used taking advantage of its reduced weight if compared with other aggregates; in these cases it is introduced in the mix design as coarse or fine aggregate. Alternatively pumice can be powdered obtaining size of particles with the same order of magnitude of other well-known fillers and then it can be introduced in the mix-design of high-strength or self-compacting concrete. In this connection the provenience of pumice, which is a volcanic product, can have an effect on the mechanical properties of hardened concrete, due to its pozzolanicity. Recently a first study on properties at the fresh state of SCC mixtures with addition of pumice powder was presented by Guneyisi et al. [8], while studies on hardened concrete are still lacking in the literature. Pumice powder has been used also in remediation of contaminated groundwater for its peculiar characteristics of filter agent, related to internal micro-pores [9].

Although pumice powder used in this study is directly obtained through a process of mechanical powdered of pumice grains extracted from quarries located in the Aeolian Islands of Sicily (Italy), volcanic materials can be found in nature or considered wastes to be disposed of, after volcanic eruptions. In the latter case the use of volcanic products such as pumice powder can be useful in waste management. Many mixtures of ordinary and high-strength concrete are manufactured with recycled aggregates or waste materials as rubbered concrete [10,11] with effective contributions to waste disposal and environmental issues. Moreover, due to its pozzolanic power, pumice can be associated to recycled aggregates because the increment of strength due to pozzolanic properties (associated to ordinary Portland cement) can counterbalance the weakening of mechanical properties attributable to rubbers or other recycled aggregates. In the present work tests on compressive strength of SCC with pumice powder demonstrate a significant increase of failure strength for long times of curing (90 or 120 days) with respect to concrete with other fillers, which maintains the failure value quite unchanged after 28 days.

3. Materials and methods

In this section the analyses of the different physical components of the mixtures are reported together with the results of tests performed on the fresh state.

3.1. Rheological model of cement paste

The rheological model adopted in the present study allows the designer to establish which are the minimum requirements of the cement paste for a fixed quantity of aggregates of known properties. The model is based on a study of Bui et al. [12]. The paste is considered a viscous fluid characterized by two parameters: the plastic viscosity and the initial shear stress (yield stress), following the so-called Bingham model [13,14]. These two parameters can be correlated to the aggregates through the measures d_{ss} and d_{av} to be used in the concrete mixture (d_{ss} is the average spacing between two grains and d_{av} is the average diameter of the grains). As a consequence the fundamental factors which influence the fresh concrete behaviour are:

- the volume of paste per unit volume of mixture;
- the distribution of coarse and fine aggregates;
- the ratio between coarse and fine aggregates;
- the shape and superficial properties of aggregate grains.

In order to obtain a mixture having a high grade of reproducibility a preliminary study on pastes was carried out for characterizing the rheological properties.

First a large number of pastes was investigated with different water/binder ratios, different proportions of binder components and different typologies of fillers. The aim was to evaluate the influence of these components on the rheological behaviour of the cement paste.

Afterwards the investigation regarded different self-compacting concrete mixtures, establishing an initial formulation and slightly changing it. Every mixture has been qualified through tests recommended by the Italian codes UNI 11040÷11045 and by European code EN 12350. In order to compare the results obtained, tests on an ordinary concrete mixture with the same basic components were carried out.

3.2. Components of mix-design

The mix-design components adopted in the following study are:

(1) Cement. A Portland cement classified II-A/L 42.5R was used.