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Self-compacting geopolymer concretes: Effects of addition of aluminosilicate-rich fines

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ABSTRACT

The presence of alunimosilicate based fine aggregates (2.5 to 7.5 wt%) effectively acted to densify the microstructure of the interfacial zone with a reduction of pore threshold and mean pore size jointly with change on the fracture mode of the Self-Compacting (SC) geopolymer concretes. From the results, pumice and recycled glass with amorphous structure improved the bi-axial four-point flexural strength from 5 to 8 MPa while semi-crystalline feldspar sludge (nepheline syenite) reached 11 MPa. The formation of additional geopolymer gels were responsible for the strengthening mechanism. The specimens with amorphous fines showed the tendency to delay the desorption in the laboratory conditions indicating the need for a very long curing time for the final consolidation. The semi-crystalline fines -nepheline syenite- appeared appropriate for the design of self-compacting geopolymer concretes due to their bulk composition, capacity to enhance densification and strength with low deformation rate, in a short range of curing together with a high rate of desorption, all important parameters for the prediction of the durability of concretes.

1. Introduction

Concrete is a multiphase, porous and strongly basic material with a mineralogical and chemical nature which submits the matrix to a possible disequilibrium with the environment. The pore network, the pore sizes and distribution, as well as the connectivity of capillary pores determine the transfer of aggressive species inside the matrix. Particular attention has to be focused to the interfacial zone to ensure the final characteristics of the geopolymer concretes since a proper design with the addition of fine materials will give the possibility to control the porosity, the packing process and improvement of the overall mechanical properties, permeability and durability of final concretes [1–4].

Self-Compacting Concrete (SCC) is nowadays one of the most efficient solutions in the world of concrete [1–3]. The design of SCC is based on the use of a large amount of fine particles and a high range water reducing admixture (HRWRA), also called super plasticizer [2]. Self-compacting concrete is a flowable matrix with the ability to resist segregation and filling the mould under gravity without the need of compaction. The final strength ranges from normal to high dependently on the mixes. Compared to conventional vibrated concrete, SCC mixes typically require higher content of fine materials, where the maximum nominal size of the coarse aggregate is typically no more than 19 mm [1–3]. According to the extensive studies available in the literature, the expansion due to the alkali-silica reactions (ASR) in concrete are associated with the osmotic pressure from silicate gels. The expansive gels are the results of the chemical disequilibrium of the matrices with the environment. Hence, the alkali content, the structure and texture of aggregates, the pore network characteristics, the capillary pore dimensions and connectivity determine the transfer of aggressive species inside of the matrix. Malek and Roy [2] studied the role played by Al_2O_3 which is released from feldspathoid rocks through dissolution and found that by increasing the Al_2O_3/SiO_2 ratio in fly ash geopolymers, the ASR changes its character from a destructive to a constructive zone. Moving to metakaolin based geopolymer, we focused the present study on the reactivity of fine

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aggregates with different mineralogical and chemical nature. These fines, namely recycled glass, pumice and feldspar sludge, have been chosen for their different SiO_2/Al_2O_3 ratio and amorphous/crystalline phase degree. They are also expected to play a significant role in modifying the alkali metal hydroxides, MH, content during hydration and geopolymerization developing the H-M-S and H-M-A-S gels that could act to close the pores at the aggregate surface through an adhesive bond, Another motivation for inserting fines in geopolymer formulation was an expected increase of the soluble reactive fraction of silica and alumina into the pore solution, the improve of the mechanical strength and a self-compacting behavior necessary for the design of high performance concretes [5–13].

In this work we aim at assessing the impact of the aluminosilicate fines on the porosity of geopolymer. In a previous work [4] it was proved that the densification of a metakaolin based geopolymer matrix, its final strength and microstructure were strongly dependant on the interface matrix/reacting fillers. In particular when the standard metakaolin was used for the formulation of the geopolymeric gel, the density was proved to be weaker, than in sand-rich geopolymeric gel. A significant increase in bulk density was also recorded: for MK formulation a value of 1.45 g/cm^3, was measured, while for sand-rich formulation the value was 2.52 g/cm^3. The presence of recycled glass, pumice or feldspar sludge will contribute to modify the Si/Al ratio into the matrix (pore solution), improving the reactivity/polycondensation. The workability and flowability are improved and good performance of the final product is expected.

Since the mechanical strength and the durability of concretes directly correlate to the volume and size of voids, we are trying to investigate how fines can be used to control the above properties of concretes. Moreover entrapped air, capillary channels and entrained air pockets are different types of pores that can be found into aluminosilicate concretes [1,2,4,6]. The aspect of the geopolymer concretes relevant to the permeability is the nature of pore network particularly at the interfacial zone. The interfacial zone is at the origin of earlier microcrakings that induces significant contribution to the permeability. By optimizing the packing system and the distribution of coarse aggregates, the action of fines would contribute to enhancing the densification and compaction imposing to any movement of fluids to follow a tortuous and longer road. The pores relevant to the permeability are those with a diameter higher than 120 or 160 nm [7]. Additionally, the use of appropriate fine aggregates in suitable proportion in geopolymer concretes will allow, while reducing the size of the interfacial zone, the formation of an envelope so that the pores in aggregates do not contribute to the permeability. Idorm and Thaulow [5] suggested that particles of supplementary cimentitious materials can be considered as "microaggregates" which improve the density of the hydrated cement. Fraay et al. [7] have shown that there is a significant change in the pore size distribution of fly ash based concretes from the alkaline reaction of fly ash with products that diffuse away and precipitate within the capillary pore system. Reduction of the capillary pores, increase of strength and resistance to crack propagation are the benefits. The final matrix is able to retain water which can be suitable for the long-term hydration [7]. The presence of Al ions into the pore solution, the Si/Al ratio and the structure of the aggregates together with their particle size distribution [8], when ideally chosen, will govern the development of homogeneous, strong and durable geopolymer concretes.

Combine metakaolin and some classes of wastes can sound as a promising solution. In this paper we want to propose fine aggregates derived from waste management cycles, in particular recycled glass, scraps from pumice extraction mines and feldspar sludge.

The experiments conducted in this study have aim to assess the impacts that fines from various source can have on the structural reinforcements of the geopolymer concretes, in particular on the bi-axial four points flexural strength, the fracture behavior, the porosity, the pore size distribution and the moisture control capacity, all parameters governing the durability of concretes. The biaxial four-point flexural strength is a multi-axial mechanical stresses testing found more suitable to describe the real mechanical solicitation states of thin plate structures such as pavement, slabs and roofs generally made with concrete composites. Correlating the behavior of IPC matrix-aggregates under mechanical strength, fracture behavior with the moisture control capacity which itself is governed by the pore volume and pore-size distribution sound promising in assessing the durability of the composites.

2. Experimental approach

2.1. Preparation of aluminosilicate polymer concretes

The concrete mixes were prepared from metakaolin, aggregates, sand and fines via alkali activation. Metakaolin (MK) was prepared from standard kaolin from Bal-Co, Modena (Italy) by calcination at 700 °C for 4 h. The standard aggregates, used in Italy for conventional concretes, were produced from granitic rocks with small mix of Ca-rich particles in the diameter range 3 mm to 9.5 mm. The sand was a conventional river sand with particles size between 0.1 and 2 mm. Three type of fines, chosen to have amorphous source of Si and Al (pumice and recycled glass) in comparison with semi-crystalline one (feldspar sludge), were investigated. Fines were obtained from reclycled glass of food containers collected by Modena municipality in Italy, pumice from mines exploitation in Lazio, Italy, respectively, and feldspar sludge (nepheline syenite) from MIPROMALO, Yaoundé, Cameroon. They were collected in form of relatively coarse particles, washed to remove clay and organic matters and ground to fine powder below 100 μm. Chemical and physical properties of metakaolin and fines are reported in Table 1. The river sand and aggregates were also washed before use.

Table 1
Physico-chemical properties and Reactive fraction of the Metakaolin and Fines used foir the formulation of APC concretes.

	Physico-chemical properties				Reactive fraction in ppm[a]		
	Chemical formula	Specific area/g/cm^2	Porosity/%	Particles under 10 μm	Si	Al	Ca
Metakaolin	$5.4SiO_2 \cdot 4Al_2O_3$	37	~56	74.8			
Glass waste	$7.1SiO_2 \cdot 0.2Al_2O_3 \cdot 1.3K_2O+Na_2O \cdot 0.2MgO$	38	~45	63.6	1051.00 ± 19	152.35 ± 3.58	< 5
Pumice	$7SiO_2 \cdot 1.7Al_2O_3$	45	~80	59.2	1600.67 ± 28	1063.38 ± 3.62	6.55 ± 0.005
Nepheline syenite	$6SiO_2 \cdot 2.3Al_2O_3 \cdot K_2O+Na_2O$	26	~15	65.4	163.80 ± 2.90	422.2 ± 1.44	< 5

[a] The reactive fraction of the Fines was determined by dissolution in NaOH, 8 M at 80 °C during 2 h of stirring and ICP analysis. Glass waste and pumice are essentially amorphous while nepheline syenite is semi-crystalline materials.