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Enhancement of durability of concrete composites containing natural pozzolans blended cement through the use of Polypropylene fibers

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ABSTRACT

A parametric experimental study of the effects of Polypropylene fibers (PPF) on early cracking due to drying shrinkage in concretes with Natural Pozzolan Cement (NPC) and its influence on its durability is presented.

Concrete composites containing natural pozzolan (toba trachite), point shaped crushed aggregates and different fiber volume fractions of PPF (0.03%, 0.06%, 0.09%, and 0.12%) were studied. This mixture is characterized by high permeability and carbonation ranges.

Early age cracking control ability and drying shrinkage of PPF in NPC concretes were measured under dry setting conditions. The cracked area due to drying shrinkage was measured to establish the positive effect of the different PPF volume fractions in concretes. Besides, bulk density and water permeability depth were determined. Finally these specimens were stored for two years and tested afterwards, measuring the natural carbonation depth. Then the cracking area was again measured to assess the control ability of PPF on this parameter after long time.

Finally a relationship of these indicators is analyzed to understand future lifespan of these concrete composites.

The results indicate that a volume fraction of 0.07% of PPF reduces cracking area due to drying shrinkage of NPC a 66%, but larger volume fractions did not increased linearly this effect, and even worse results were obtained. The increment of PPF volume fraction reduces the water permeability depth and even the carbonation depth. A reduction of the cracked area, due to early shrinkage, of a 66% in NPC concretes may reach in these concretes a 32% lower water permeability indicators (enclosed wet area) and a 43% shorter minimum carbonation depth attending to the results obtained.

So it can be considered that the cracking control ability of fibers on the exposed concrete surface reduced water permeability and CO_2 diffusion. However the use of fiber increased porosity and reduced bulk density and ultrasonic modulus of NPC concretes.

In conclusion NPC concretes with low amounts of PP fibers (upper to 0.07% volume fraction) are less permeable and the CO_2 diffusion is slower in time due to early age cracking control, producing more durable concretes.

1. Introduction

Durability of concrete structures has been largely studied in order to prevent steel corrosion of concrete reinforcement. Even though durability of concrete need a holistic approach, two main processes are usually considered: permeability and carbonation.

Permeability is related to the porous internal structure of the material and to the linkage with the external concrete surface. Parameters as density and compactness have a direct influence on permeability: the higher the compactness is, the lower the space for porous and capillaries and, therefore, the lower the entrance of external agents [1]. The amount and specially the diameter of pores must be considered as indicators of concrete permeability [2].

Carbonation is the chemical reaction of CO_2 with the Calcium hydroxides and cement gels, which decrease the pH of the material and activates steel corrosion of the concrete reinforcement. Carbonation has different phases, changing the pH of concrete from 12.5 (unexposed) to values lower than 10, when carbonation is fulfilled [3]. The lost of alkaline protection produces a decrease of concrete structure durability. Carbonation depth attends to second

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Fick's law and depends also on the reserves of carbonatable components and their concentration [2].

Cracking, from any origin (setting, thermal, mechanical etc.), is another important factor on concrete durability, because cracks become a gateway to external chemical attacks. External cracks increase the surface exposed to external agents and so the gross permeability of the cover concrete [4]. Many concrete regulations establish limit values of maximum cracking width, depending on the environmental exposure conditions of the concrete structure [5]. In coastal areas (those located less than 5 km from the coast) the limit of crack width specified by the Spanish concrete code is 0.2 mm, considered on structural elements under load [5], in order to control chloride attack. The majority of standards and regulations take consideration only to cracks in concretes under tensile stresses but not to those caused during the setting conditions.

In the literature found, feedback-controlled splitting tests [6,7] or steel dishes have been used in concretes to induce a determined width of crack. Thereafter the durability of these cracked concretes with a single crack has been studied. Other studies have correlated early cracking to durability, but cracking has not been measured [8,9]. The diffusion of acid soluble chloride in concretes with different crack densities has been also researched in some studies, and the diffusion coefficient has been determined as a constant for each crack density [10].

The research here presented is focused on the effects of early cracking on durability measuring the cracked area, the crack width and crack length produced during setting and hardening in concretes under dry setting conditions. The severe conditions here reproduced simulate real setting conditions with a fast water migration and a deficient hydration of the cement grains in the external layer of concretes [11].

Some authors have also studied the near-surface zone of concrete cured in dry conditions. This surface skin of concretes presented high porosity and a lower amount of hydration products (carbonatable compounds) that facilitate a faster progression of the carbonation front [4,11].

The use of fibers of different raw materials is effective to control crack growth due to early age drying shrinkage on the exposed concrete surface [12,13]. The effect of these fibers is beneficial for concrete during the first 8–72 h, when the material, with low tensional strength, is submitted to stress due to early shrinkage [14]. Polypropylene fibers (PPF) have been reported to reduce plastic shrinkage concrete and permeability [13].

The inclusion of fibers may also produce shear stresses due to the different mechanical stiffness of fiber and young concrete [15]. Fiber length influences stress intensity and modifies the time when maximum values occur. Fiber Volumetric Fraction (VF) of 0.05–0.1% can also modify the cracking risk. Larger amounts of PP fibers (1–2%) can also improve mechanical behavior. When alkali-resistant glass fiber was considered, it has been reported that the shorter the fiber, the lower the stress intensity at the fiber–matrix interface. The conclusion was that there is not a lineal relation between fiber VF and cracking control ability [15].

Concerning fibers influence on chemical aspects, it has been reported that polymeric fibers can modify the microstructure of hardened cement pastes, decreasing the amount, the size and the orientation of CH crystals and micro voids and a reduction of the voids and micro-cracking at the aggregate-cement paste interphase [16]. The addition of PPF in concrete reduces the drying shrinkage and early cracking because they restrained the movements of micro level in mortars by bridging and stitching the fine cracks [17–19]. Some authors also reported a reduction of water permeability, sorptivity and carbonation of fly ash concretes reinforced with PPF [17].

The use of polymers-based covers as a barrier on the external face has been also studied to improve the durability of concretes by the reduction of permeability [20,21]. The lifespan of this covers and its influence on the permeability of concretes has been studied [21]. These covers are used after concrete has hardened and their durability is reduced if these covers are damaged [21].

In this paper, a study of the influence of PPF on NPC concretes and also their influence on parameters or indicators related to durability is reported. As far as the authors' knowledge reaches, no studies relating PPF addition to early age cracking, permeability and carbonation of NPC concretes with crushed aggregates have been previously reported.

This study highlights the importance of effective control of cracking and chemical stability to reduce permeability and CO_2 diffusion in NPC concretes with PP fibers. It also correlates permeability and CO_2 diffusion with PPF VF, showing the importance of the integrity of the concrete exposed surface, rather than internal structure.

2. Experimental studies

2.1. Materials

The following materials were employed:

- NPC type CEM II/B-P 32.5 R (designated according to UNE-EN 197-1:2000 [22]) with natural volcanic pozzolans ("toba-trachyte" with high amounts of active silica, 18%, by weight of clinker) was used. The volcanic pozzolans were mined in the quarry owned by the company Cementos Especiales de las Islas, SA in Gran Canaria (Canary Islands (CI), Spain), and blended with the cement according to the European Standard UNE-EN 197-1:2000 [22]. Table 1 reports the bulk oxide chemical composition of the natural pozzolan and of the NPC.
- The coarse aggregates were crushed phonolite stones (volcanic origin, 10–20 mm, 5–10 mm and coarse sand 0–5 mm) and natural fine sand from Sahara dunes (0–1 mm). The coarse sand (0–5 mm) is the final result of the crushing process and is very irregular and dusty. The natural fine sand was more homogeneous and improved concrete workability. Table 2 presents the physical and chemical properties of the aggregates.
- The crushed coarse aggregates were irregular and sharp-pointed, producing concrete mixtures with low workability which required larger amounts of water and the use of a High Range Water Reducing Admixture (HRWRA). These crushed aggregates present problems with particle distribution, strength, permeability and gaseous diffusion [23]. Fig. 1 shows the particle size distribution (PSD) of the aggregates (cumulative finer fraction).
- Two HRWRA: ADVA™ 115 and ADVA™ Flow 340, manufactured by Grace Construction Products were used, according to UNE EN 934-2 [24].
- Polypropylene short fibers (PPF), Grace MicroFiber PP™ (19 mm length, 0.9 g/cm^3 net density and 3.45 GPa modulus of elasticity), supplied by Grace Construction Products were used to evaluate cracking control ability, water permeability and CO_2 diffusion.

2.2. Mixture proportions

Three reference mixtures, (*w*/*c* ratios 0.6, 0.5 and 0.4) and different amounts of PPF (0, 300, 600, 900, 1200 g/m^3; 0%, 0.03%, 0.07%, 0.1% and 0.13% Fiber Volumetric Fractions (VF) respectively) were considered (Table 3).