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Combined effect of Polypropylene fibers and Silica Fume to improve the durability of concrete with natural Pozzolans blended cement

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HIGHLIGHTS

- Durability parameters of Natural Pozzolan Cement concrete (NPC) were studied.
- Silica Fume (SF) and Polypropylene short fibers (PPF) were used to improve durability.
- Short fibers reduced early age cracking and permeability although increased shrinkage.
- Against expected, SF enlarged shrinkage, cracking, permeability and carbonation.
- Combined SF and PPF reduced shrinkage, cracking, permeability and carbonation.

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ABSTRACT

Early age shrinkage and cracking, water permeability and carbonation depth of concretes with natural Pozzolans blended cement (NPC) were investigated in order to assess the combined effect of Polypropylene short fibers (PPF) and Silica Fume (SF) on some durability parameters.

The addition of 10% of SF increased compressive strength, shrinkage and cracking, permeability and carbonation depth. But, the combination of 10% SF and 0.07% PPF volumetric fraction mitigated early age cracking and significantly reduced water permeability and carbonation depth.

The use of PPF in NPC concrete combined with SF can be recommended to reduce long-term impact of early age cracking, and enhance durability. However, cement should not be reduced when SF is added to mixtures without PPF, because lower CaO reserves may affect final pH, leading to concretes more sensible to carbonation.

1. Introduction

Natural Pozzolans Cements (NPC) are used in concretes exposed to aggressive chemical conditions, due to their improved chemical resistance resulting from its pozzolanic capacity [1,2]. Pozzolanity refers to the chemical ability of silicate based fine materials to produce hydrated calcium silicates, through a reaction with Portlandite, which are more stable in time and with smaller CaO: SiO_2 molar ratio than those formed on the hydration of tri-calcium and bi-calcium silicates [3]. NPC also improves sulfate resistance, reduce water permeability and saline moist diffusion [2,4]. NPC produce less hydration heat than conventional Portland Cement (PC), reducing the risk of early age micro-cracking due to autogenous shrinkage [5,6].

However, as any other concrete, NPC concretes are prone to early age cracking due to drying shrinkage, which can compromise durability, as far as the material resistance to external attacks depends both on intrinsic permeability and cracking pattern, shape and size. The early cracking and capillary network become the first gateway to external agents that may reduce the lifespan of concretes [7–10]. Permeability is a key point in concrete durability, as it conditions carbonation, chloride and sulfate attack [2,9,11]. In order to study the cracking patter, the cracking area and length of cracks of the concrete mixtures with SF, PPF and combined SF–PPF have been reported in concrete slabs submitted to double-restrained slab's displacement during early age (24 h) [12].

During the first hours after mixing, the tensile strength of young concrete is very low and it is very sensitive to internal tensions due to drying shrinkage. If severe external conditions occur during setting, a fast water migration and a deficient hydration of the cement grains in the external layer of concrete would happen [13], leading

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Table 1
Bulk oxide composition of natural Pozzolan, Silica Fume and CEM II/B-P 32.5 R blended cement.

Composition	LOI	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	IR	ND	Cl−	LOI	H_2O
Natural pozzolan	11.20	55.00	15.90	4.20	2.20	1.50	4.60	4.90	–	–	–	–	–	–
Silica Fume	–	92.00	0.5	2.10	0.8	0.3	1.0	0.1	0.2	–	–	–	–	–
CEM II/B-P 32.5R	–	35.67	6.31	3.14	45.39	2.01	–	–	2.74	16.36	1.38	0.05	3.57	1.06

Table 2
Physical and chemical properties of aggregates.

Property	Standard	Specification	Sahara fine sand (0–1 mm)	Coarse sand (0–5 mm)	Coarse aggregate (5–10/10–20 mm)
Particle density (g/cm^3)	UNE-EN 1097-6	None	2.64	2.48	2.60
Fines content (%)	UNE-EN 933-1	1.5–8/1–3.5%	0.8	9.2	1.4/0.9
Water absorption (%)	UNE-EN 1097-6	<5%	0.65	2.7	0.95/0.75
Friability Micro-Deval	UNE 83115 EX	<40%	15%	12%	–
Wear Los Angeles (%)	UNE-EN 1097-2	<40%	–	–	13/13
Shape index	UNE-EN 933-4	<0.20	–	–	–/0.17
Flakiness index	UNE-EN 933-3	<35	–	–	17
Weight loss test (%)	UNE-EN 1367-2	<15%	2.25	3.15	2.45/2.45
Soft particles	UNE 7134	<5%	–	–	0.4/0
Clay clods (%)	UNE 7133	<1%	0	0	0/0
Organic mater (%)	UNE-EN 1744-1	Nul	0	0	0/0
Total sulfur (%)	UNE-EN 1744-1	<1%	0.07	0.09	0.09/0.09
Acid soluble sulfate	UNE-EN 1744-1	<0.8%	0.06%	0.07%	0.07/0.07
Soluble chloride (%)	UNE-EN 1744-1	<0.05–0.03%	0.04	0.015	0.01/0.01
Alkali-silica reactivity	UNE 146507 1-2	No reaction	No reaction	No reaction	No reaction

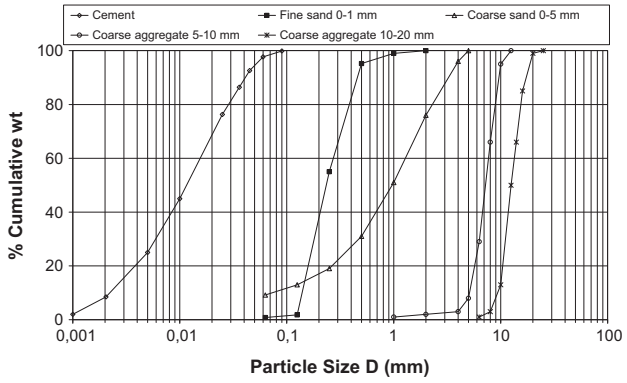

Fig. 1. Particle size distribution of cement, sand and coarse aggregates used (cumulative finer mass fraction).

to early age cracking [14,15]. Cracking would affect permeability, diffusion, and, as a consequence, the lifespan expectations of concrete members [5,6].

This paper reports a study of the effect of Polypropylene fibers (PPF) and Silica Fume (SF) on durability related parameters of NPC concretes. These additions are used simultaneously in the concrete mixtures to improve concrete durability, through the reduction of both the porous network and the size and amount of early age cracking.

In a previous paper, the effect of PPF on NPC concretes on durability parameters was assessed [16].

Silica Fume (SF) is a well-known addition in concretes due to its small size (0.15 μm) and its pozzolanic activity [17–22]. SF improves mechanical performance (mainly compressive strength), reduces permeability (due to its small and spherical shape acts as filler) and increases adherence between aggregates and matrix in concretes [23]. Moreover, the addition of SF can also reduce the

Table 3
NPC Concrete compositions.

(kg/m^3)	NPC1	NPC2	PPFC1-300	PPFC1-600	PPFC2-600	PPFC1-900	PPFC2-900	PPFC1-1200	PPFC2-1200
CEM II/B-P32.5R	320	320	320	320	320	320	320	320	320
Fine Sahara sand 0/1	326	326	326	326	326	326	326	326	326
Coarse sand 0/5	489	489	489	489	489	489	489	489	489
Coarse aggregate 5/10	382	382	382	382	382	382	382	382	382
Coarse aggregate 10/20	623	623	623	623	623	623	623	623	623
HRWRA ADVA 115	–	1.28	1.92	1.92	1.92	2.08	2.24	2.24	2.24
Water	195	160	195	195	176	195	176	195	176
PPF (% VF)	–	–	0.030	0.07	0.07	0.1	0.1	0.13	0.13
W/c (by weight)	0.6	0.50	0.6	0.6	0.5	0.6	0.5	0.6	0.5

(kg/m^3)	SFC1	SFC2	SFPPFC1-600	SFPPFC2-600	SFPPFC1-900	SFPPFC2-900
CEM II/B-P32.5R	288	288	288	288	288	288
Fine Sahara sand 0/1	326	326	326	326	326	326
Coarse sand 0/5	489	489	489	489	489	489
Coarse aggregate 5/10	382	382	382	382	382	382
Coarse aggregate 10/20	623	623	623	623	623	623
HRWA (ADVA 115)	2.08	2.56	2.08	2.56	2.65	3.20
Water	195	176	195	176	195	176
Silica Fume	32	32	32	32	32	32
PPF (% VF)	–	–	0.07	0.07	0.1	0.1
W/c (by weight)	0.6	0.5	0.6	0.5	0.6	0.5