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Hydration study of ternary blended cements containing ferronickel slag and natural pozzolan

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HIGHLIGHTS

- Ferronickel slag and volcanic pumice pozzolanic additions to Portland cement.
- Physical and mechanical properties of binary and ternary mixes evaluation.
- Hydration degree and pozzolanic reaction confirmed by XRD, TG–DTG and SEM.
- All mixtures satisfied the requirements for the strength class 42.5 as per standard EN 197-1.

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ABSTRACT

The present investigation focuses on the hydration evolution of ternary blended cements composed by natural pozzolan (NP) and ferronickel slag (FNS), which is produced during the pyrometallurgical treatment of laterites for the production of ferronickel. The slag and pozzolan were grounded to a specific surface area of 4000 cm^2/g and twelve different cement mixtures were produced containing up to 20% Portland cement replacement with the above-mentioned cementitious materials. The produced blended cements were tested by determining their initial and final setting times, standard consistency, flow of normal mortar, soundness and compressive strength at 2, 7, 28, 56 and 90 days. X-ray diffraction and TG/DTG analyses were used for the determination of the hydration products, whereas the microstructure of the hardened cement pastes and their morphological characteristics were examined by scanning electron microscopy. According to the results, the ferronickel slag could be readily utilized together with natural pozzolan as substitutes for cement, presenting significant environmental benefits in waste management practice.

1. Introduction

Despite the notable progress during the last decades, cement sector not only has been one of the most energy intensive industries in the world, but accounts for around 5% of the global greenhouse gas emissions, because of the burning of fossil fuels during sintering process in rotary kiln and due to the limestone decomposition, the main constituent of the raw meal. The production of one tone of cement requires 60–130 kg of fuel oil or its equivalent and about 105 kWh of electricity, depending on the cement type and production process, whereas the average CO_2 emissions ranges from 0.60 to 1 tons of CO_2 per cement tone [1,2].

Although the production process is still very energy consuming, cement is the most widely used construction material today. Due to the regulations, policies and environmental sustainability, the need for energy consumption decrease, as well as for CO_2 emission lowering, implied the pure cement replacement from supplementary cementitious materials (SCM), which are used in order to produce what is generally called as “blended cements”. The most common SCM are natural pozzolans, generally derived from volcanic origins and artificial pozzolans, which are mainly industrial byproducts/wastes, such as fly ash, different type of metallurgical slags and silica fume. Blending Portland cement with pozzolanic admixtures is an effective way to improve workability, strength

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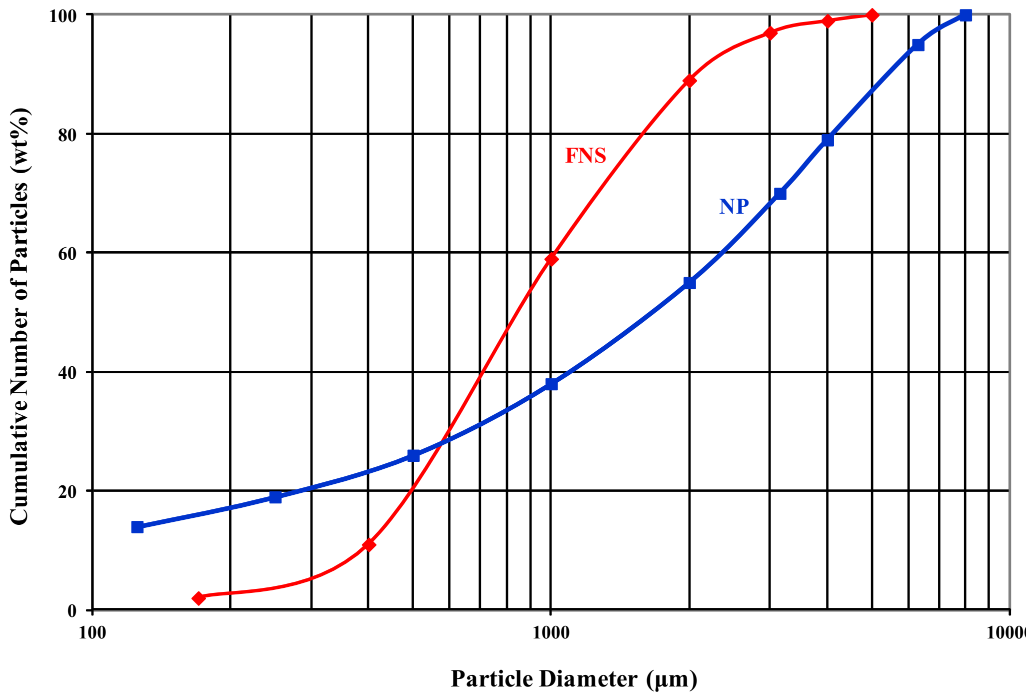

Fig. 1. Particle size distribution of FNS and NP used.

Table 1
Chemical analysis and physical characteristics of cement and slag used.

Oxides	Chemical analysis (wt%)		
	CEM I52.5	FNS	NP
SiO_2	21.25	41.18	72.14
Al_2O_3	3.77	5.98	12.81
Fe_2O_3	4.27	40.02	1.25
CaO	64.35	4.12	0.84
MgO	1.25	7.79	0.19
K_2O	0.44	0.37	4.09
Na_2O	0.12	0.09	2.38
SO_3	2.40	0.64	0.02
MnO	0.15	0.52	0.05
TiO_2	0.23	0.12	0.13
NiO	0.05	0.13	–
Cr_2O_3	0.13	2.75	0.04
Free CaO	0.15	–	–
LOI	1.25	−3.44	5.04
Physical characteristics			
Specific surface (cm^2/g)	3870	3985	3940
Specific gravity (g/cm^3)	3.14	3.18	2.37

Table 2
Composition and characteristics of cement mixtures.

Code	CEM I52.5 (wt%)	FNS (wt%)	NP (wt%)	Specific surface area (cm^2/g)	Specific gravity (g/cm^3)
C_{Ref}	100	–	–	3870	3.14
C_{S5}	95	5	–	3875	3.14
C_{S10}	90	10	–	3890	3.14
C_{S15}	85	15	–	3905	3.15
C_{S20}	80	20	–	3925	3.15
C_{P5}	95	–	5	3880	3.10
C_{P10}	90	–	10	3885	3.07
C_{P15}	85	–	15	3895	3.03
C_{P20}	80	–	20	3900	2.99
C_{SP5}	95	2.5	2.5	3870	3.11
C_{SP10}	90	5	5	3880	3.10
C_{SP15}	85	7.5	7.5	3890	3.08
C_{SP20}	80	10	10	3895	3.06

and durability (lower permeability, resistance to chlorides and sulfates, mitigation of alkali silica reaction) [2–5]. An additional benefit of the above approach is that many pozzolanic materials used for blending today would be otherwise stockpiled or disposed in landfills, presenting environmental hazards such as dust contamination or leaching of heavy metals in groundwater. As a result, this reuse and recycling approach in blended cement production contributes to the solution of major environmental problems. The present paper focuses on the properties and hydration of ternary blended cements, produced by pure Portland cement and two SCM; ferronickel slag and natural pozzolan.

Greece is rich in natural pozzolans (NPs), materials originated from volcanic eruption. The pumice used in this study is coming from Gyali, a small volcano islet in the Dodecanese islands, which belongs to the southern Aegean volcanic arc. The south-western part of the islet is formed by pumice whereas the north-eastern part by obsidian domes and rhyolitic lava flows [6,7]. The pumice stone quarry is operated using the method of vertical benches and the quarry's production capacity in the form of natural pumice is up to 800.000 t/y. It is characterized by a high content of vitreous components and its high pozzolanic reactivity is mainly attributed to the high content of active SiO_2; it can react with calcium hydroxide released during the hydration of cement to produce C–S–H gels. Studies of the influence of the pumice blended cements showed that in percentages up to 20% results in positive strength development [8–10].

On the other hand, the ferronickel slag (FNS) is a byproduct obtained from smelting of laterite ore in an electric arc furnace at a high temperature with the presence of a reducing agent, for the production of ferronickel alloy [11,12]. The FNS from the electro-reduction furnace is produced at a rate of approximately 2000 kt/y and for every tone of FeNi alloy the amount of FNS produced is estimated at 4 tones [11,13]. Currently, FNS is granulated through sudden cooling in sea water, leading to an amorphous material, which, due to its properties it has been classified as non-hazardous waste, according to the European Catalogue for Hazardous Wastes [14].