Exploitation of secondary products coming from the perlite process in building materials

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In its natural form, perlite is an amorphous mineral, coming from volcanic deposits and mainly consisting of SiO_2 and Al_2O_3. Additional constituents maybe also detected in its structure, however in a low proportion (i.e. sodium, potassium, iron, calcium, magnesium). Perlite, generally presents a relatively high water content (2–5% w/w) that is rapidly evaporated during its industrial process (heating at 900-1200°C); micro air voids are created, expanding its volume up to 20 times (Rashad, 2016; Papa et al., 2018).

Expanded perlite (EP), deriving from the perlite's industrial process, presents low density and insulating properties, whilst its application in the constructional sector is increasing (Turkmen and Kantarcı, 2007; Wang et al., 2018; Palomar and Barluenga, 2018). It is usually applied in concrete and mortars for substituting natural aggregates and binders. The outcoming products present low bulk density (32-150 kg/m^3), low thermal conductivity (0.04-0.06W·m^{-1}K^{-1}) and high heat resistance (melting point: 1260–1343°C) (Rashad, 2016; Papa et al., 2018; Turkmen and Kantarcı, 2007; Wang et al., 2018), used for specific applications (i.e. light-weight concrete, fire resistant plasters).

Perlite mining shows low environmental burden, while during the last 60 years less than the 1% of the worldwide reserves have been exploited. The most important producers are China, Greece, Turkey and the US, resulting in the 95% of the worldwide perlite production (4.6 million tons for the year 2016) (U.S. Geological Survey, 2017). During its industrial process, a short, however countable amount of by-products derives (named after 'waste perlite'). Relevant studies (Rózycka and Pichór, 2016; Kotwica et al., 2017; Pachta et al., 2019) have documented that specific types of waste perlite could be exploited for the production of efficient and environmental friendly building materials (mortars, concrete, grouts).

In the studied plant of Greece (Perlite Hellas), which consists of one the mayor exporting industries of expanded perlite, the production line includes three stages (crushing, heating and expanding), during which an amount of 10% of secondary products is created. Since these, gradually increasing products cannot be further exploited, remain outdoor, inducing the environmental burden.

This paper focuses on exploiting the secondary products coming from the heating stage of perlite (D1S, D1C), in traditional mortars and grouts. According to their properties (Table 1), D1S concerns a fine material with enhanced pozzolanic properties (pozzolanicity index: 6.1MPa), while D1C presents a higher apparent specific density, increased grain diameter, and lower pozzolanicity (1.2 MPa). Their chemical composition mainly refers to alumino-siliceous compounds, with slight differences.

Table 1. Physico-mechanical and chemical properties of D1S and D1C.

Type	App. Specific density	Pozzolanicity index ASTMC311:77 (MPa)	Particle size analysis (laser granulometry) Grain diameter (μm) of volume fractions (%)		Chemical analysis
			d_{50}	d_{90}	
D1S	2.437	6,01	7.96	24.78	Na_2O:3.02, K_2O:3.07, CaO:2.93 MgO:0.45, Fe_2O_3:1.80 Al_2O_3:15.74, SiO_2:67.49, L.I.:4.65
D1C	2.541	1.20	77.48	209.48	Na_2O:3.19, K_2O:2.88, CaO:2.26 MgO:0.24, Fe_2O_3: 1.57 Al_2O_3:16.84, SiO_2:69.17, L.I.:2.95

During the experimental study, eight lime-based mixtures where manufactured and tested, including five mortars and three grouts, where natural pozzolan was gradually replaced by D1S and D1C (Table 2). A reference mixture in all types was made, consisting of lime and natural pozzolan. In all mortars, the Binder/Aggregate ratio was maintained at 1/2, whereas aggregates were natural of siliceous origin and gradation 0-4mm. In order to reduce the water demand a short proportion of polycarboxylate superplasticizer (1% w/w of binders) was added in all cases.

Table 2. Constituents and proportions (parts by weight) of the mixtures.

Material type	Code nr	Binders				Natural sand	Superplasticizer (1% w/w)
		Lime	D1S	D1C	Pozzolan		
Mortars	M1	1	-	-	1	4	√
	M2	1	0.5	-	0.5	4	√
	M3	1	1	-	-	4	√
	M4	1	-	0.5	0.5	4	√
	M5	1	-	1	-	4	√
Grouts	G1	1	-	-	1	-	√
	G2	1	1	-	-	-	√
	G3	1	-	1	-	-	√

The fresh and hardened state properties of all mixtures were recorded, while in the case of grouts flow time (ASTM C939-02, EN 445: 2007), penetrability (EN 1771:2004), volume stability (ASTM C 940-98A) were also measured. The physico-mechanical properties of the specimens were tested at the age of 28 days, including shrinkage deformations (due to volume and weight changes), porosity, absorption, apparent specific gravity, water absorption coefficient due to capillary action, dynamic modulus of elasticity, flexural and compressive strength.

From the correlation of the results, it was asserted that the partial or even total substitution of natural pozzolan by perlite secondary products, may positively influence the materials' physical and mechanical properties. It maybe therefore concluded that the exploitation of perlite secondary products in the constructional sector is feasible, leading to the development of effective, low-cost and environmental friendly products for specific applications.

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