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Investigation of the potential use of waste from ornamental stone processing after heat treatment for the production of cement-based paste

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HIGHLIGHTS

- OSW can be used as raw material for production of building materials.
- A heat treatment of 1200 °C was able to enhance OSW's pozzolanic characteristics.
- The OSWHT met the chemical requirements for pozzolans.
- Cement pastes with addition of up to 10% of OSWHT were produced.
- SEM images of the pastes produced were captured at various ages.

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ABSTRACT

This paper aims at investigating the potential pozzolanic use of ornamental stone processing waste after heat treatment (OSWHT) as an admixture in Portland cement paste. Heat treatment at 1200 °C was carried out to potentialize the possible pozzolanic characteristics of the waste. The chemical composition of OSWHT was analyzed, together with its mineralogy, the visual characteristics of its grains, its specific surface area and fineness, and its pozzolanic capacity. The OSWHT was used as admixture at the rates of 5% and 10% by mass of Portland cement in preparation of the cement paste. The microstructural characteristics of these pastes were evaluated at the ages of 3, 7, 28 and 90 days. The results indicate that OSWHT has low pozzolanic activity when used in the production of cement-based pastes, being able to provide the final product with a denser microstructure due to the filler effect and possibly due to a small pozzolanic reaction.

1. Introduction

The total volume of waste generated in the ornamental stone industry is significant, being estimated to vary between 25% and 30% of the block volume after the sawing stage [24]. In 2012 in the state of Espírito Santo, 1.12 million tons of waste were generated at this stage [42]. The great volume of waste created by the ornamental stone industry has motivated researchers to study possible uses of benefits of this waste in many kinds of products, including concrete, mortar and ceramic tiles, among others [23,22].

The use of this waste contributes to the reduction of the environmental impact caused by the ornamental stone industry, given that such use decreases the need for large areas destined for industrial landfill [45,35]. Buzzi [18] has also identified the existence, within the marble industry, of budgetary as well as logistic difficulties caused by the need to adequately dispose of the ornamental stone waste (OSW). This suggests that the reuse of OSW might benefit both the ornamental stone-sawing industry (disposal of the waste) and the industries that incorporate OSW in their products (new and low-cost raw materials and product diversification).

Due to the characteristic of the building materials and their composition, it is possible to mix different residues in cementitious matrices, such as mortars and concretes, reducing consumption of natural resources in addition to improving the properties of construction materials [21].

Papers presented by Calmon et al. [19], Torres et al. [52], Topçu et al. [51], Segadães et al. [47], Bacarji et al. [16] and Arel [6] offer

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indications concerning the potential of ornamental stone waste in the production of concrete, mortar and ceramic materials. According to the authors, the use of the waste as mineral admixture or aggregate substitute might minimize the environmental impact of the ornamental stone industry. Vigneshpandian et al. [58] indicate that the substitution of up to 50% of the fine aggregate by marble dust was able to provoke an increase in compressive and bending strength of the concrete mixtures produced. Li et al. [31] explored a new approach that makes use of the ornamental stone waste by substituting the cement paste with marble dust.

Partial substitution of the cement paste for ornamental stone waste has been experimented with in several studies [32,16,2,50,36]. Abukersh and Fairfield [1] replaced 30% of the cement with recycled red granite dust in the production of concrete and observed, when compared to concrete produced with flying ash, an increase in compressive strength and elastic modulus at an early age but a reduction in compressive strength for other ages. Elmoaty [20] analyzed properties of concretes produced with partial substitution of cement or with mineral addition in the form of granite dust and observed that substitution of 5% of the cement by granite dust increased the mechanical strength and the resistance against corrosion of the concrete, while addition in higher percentages improved mechanical strength when comparing against the reference concrete. Mashly et al. [36] studied the technical viability of the production of cement matrixes with a partial substitution of the Portland cement for granite sludge of up to 40% by mass. For cement pastes the reduction in compressive strength was small, while for mortar and concrete the drop in resistant strength was greater. However, the substitution of Portland cement for granite sludge in the proportions studied did not rule out the use of the waste for the cement matrixes evaluated.

It is known that the use of pozzolanic materials for the production of cement-based materials usually leads to a significant reduction of CO_2 emissions resulting from the Portland cement production process [28,29,33]. Although there are many studies on the processing of ornamental stone waste, little is known about its use, after some kind of heat treatment, as pozzolanic material. It is known that this type of waste, if used in a cement-based matrix without any type of heat treatment, does not present pozzolanic characteristics, as demonstrated by Almeida et al. [3], Moura and Leite [41], Bacarji et al. [16], Rocha et al. [46] and Ural et al. [55].

Some studies, however, have applied some sort of heat treatment to the OSW. Medina et al. [38] applied thermal treatments reaching temperatures of 600 °C and 700 °C to the OSW and did not observe significant increase in the pozzolanic capacity of the waste. Mármol et al. [35] observed that the waste generated in the process of sawing granite using a mixture of water and metal shot might, after heat treatment (700–900 °C), bring benefits to mortar similar to those observed when making use of pozzolans in the production of cement-based matrixes. A similar behavior was observed by Uliana et al. [53] when applying different types of heat treatment to ornamental stone waste. The authors observed that after those treatments, reaching a temperature of 1200 °C, OSW was transformed into a glass material, presenting signs of some pozzolanic reactivity when used as partial substitute for Portland cement in the production of mortars.

This work aims to follow this line of research by studying the possible transformation of OSW into a pozzolanic material by applying a heat treatment reaching high temperatures. To provide a more detailed evaluation of the pozzolanic behavior in cement-based matrixes made with the addition of heat-treated ornamental stone waste (OSWHT), some evaluation criteria were established in accordance with the guidance of the Brazilian standards. The objective was to analyze the pozzolanic potential of OSWHT and the interactions of OSWHT in pastes of hydrated Portland cement. For this purpose, Portland cement pastes were produced with addition of different percentages of OSWHT in relation to cement mass.

2. Materials and methods

The cement adopted for the development of this research was the Brazilian Portland cement CPV ARI (which resembles rapid-hardening Portland cement – RHPC), for it is, in the Brazilian market, the one most similar in its chemical composition to ordinary Portland cement. The ornamental stone waste (OSW) used originated from a marble factory in the city of Serra/ES and it was characterized by Uliana [54]. Table 1 presents the chemical and physical characterization of Portland cement and of the waste when used without heat treatment.

2.1. Production and characterization of OSWHT

After being dried and loosened, the waste from the processing of ornamental stones (OSW) was placed in a container of refractory porcelain and heated in muffle furnace at a rate of 10 °C/min up to a maximum temperature of 1200 °C. The procedure was performed following instructions proposed by Uliana et al. [53]. After

Table 1
Properties of Portland cement and ornamental stone waste (OSW).

Properties		OSW		CPV ARI cement	
		Results	Threshold[1]	Results	Threshold[2]
Specific weight (g/cm^3)		2.53	N.E.	2.82	N.E.
Fineness	Specific area – Blaine (cm^2/g)	6179	N.E.	4459	3000
	Material held on the 0.075 mm sieve (%)	3.08	N.E.	0.1	N.E.
	Material held on the 0.045 mm sieve (%)	7.00	<20	–	N.E.
Chemical composition	Loss on ignition – (*LI*)%	3.50	≤10	3.84	4.5
	SiO_2 (%)	66.80	N.E.	18.65	N.E.
	Al_2O_3 (%)	13.50	N.E.	4.91	N.E.
	Fe_2O_3 (%)	3.79	N.E.	2.97	N.E.
	CaO (%)	3.44	N.E.	63.72	N.E.
	MgO (%)	0.93	N.E.	0.75	N.E.
	K_2O (%)	3.83	N.E.	0.80	N.E.
	Na_2O (%)	3.50	N.E.	–	N.E.
	C (%)	1.11	N.E.	–	N.E.
	TiO_2 (%)	0.16	N.E.	–	N.E.
	SO_3 (%)	0.06	≤4	2.87	4.5
	$SiO_2 + Al_2O_3 + Fe_2O_3$ (%)	85.87	≥70	–	N.E.
	Humidity content		≤3		N.E.
	Insoluble residue – IR (%)	–	–	0.75	1.0

Threshold[1] – Set to class N of pozzolans described in NBR Standard 12.653 [15].
Threshold[2] – Set based on NBR Standard 5.733 [59].
N.E. = Value not established.
Source: Adapted from Uliana [54].