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THE INFLUENCE OF NANOPARTICLES INCLUSION ON THE OPTICAL PROPERTIES AND HYGROTHERMAL PERFORMANCE OF AN INNOVATIVE WASTE-BASED POROUS ALKALINE CEMENT COMPOSITE

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Abstract
Sustainability is a major concern in all societal sectors, particularly civil construction and engineering. Hence, searching for new solutions that potentiate the reuse of building materials can be a key factor in achieving this important goal. These newly developed solutions should comprise mechanical, hygrothermal, thermal and durability properties at the level of the traditional ones. Besides, it is essential to relieving maintenance and repair costs. As such, this work aimed to formulate new coatings for innovative façade system solutions, to improve reflectance. Three different nanoparticles were tested on a commonly used black acrylic paint to analyse the effect of the nanoparticles on the optical properties of façade systems. The application of the nanoparticle-doped black acrylic paints was tested in a highly porous waste-based alkaline cement composite for application in façade systems. The optical properties were measured using a modular spectrophotometer, which allowed observing the influence of nanoparticles in the near-infrared region. The porous alkaline cement, tested with the function of a ventilated façade cladding, presented very interesting results and a clear increase in the reflectance. Regarding the façade cladding function, the liquid water permeability was also measured using Karsten tubes. Further research should focus on including more reflective nanoparticles and carry out a long-term hygrothermal test to monitor the optical and superficial changes, particularly the UV radiation action.

1. INTRODUCTION
The construction sector is one of the energy-consuming industries worldwide. It is already reported that buildings use almost 40% of the total final energy consumption and emit around 30% of greenhouse gases [1-3]. Therefore, progress and improvement of sustainability in buildings is a great need for the consolidated development of the sector. High-energy performance buildings are proposed as a possible solution to reduce environmental demand [4].
In buildings, façades are an important part of the envelope system, influencing thermal performance and total energy consumption. As such, the necessity of developing sustainable façades to protect building from climatic change conditions, such as heat, is raising interest in the sector [5, 6]. A strategic solution to achieve this goal is to reduce the amount of solar radiation absorbed by building envelopes to provide indoor comfort [7, 8]. Employing coatings that reflect a large portion of solar radiation

is crucial. Essentially, nanomaterials with tuned optical properties, particularly in the near-infrared reflective region, can be implemented in buildings envelope for a lower surface heating potential [9]. In this research, the development of sustainable light-weight cladding systems was intended, hence an innovative substrate was to be combined with reflective coatings.
The research in highly porous pastes using alkaline cement, and incorporating construction and demolition waste (CDW) or industrial wastes, is not yet very explored. Each year, a substantial volume of CDW is generated with the potential to be recycled and reused, such as alkaline cement, further to incorporate wall components [10, 11]. Through geopolymerisation with an alkali-activated method, which has already been used effectively with CDW and urban wastes, such as fly ash, blast furnace slag, plastic, or timber, it is possible to manage and reduce waste disposal [11].

This study underlines the influence of reflective nanoparticles on the optical properties of such new façade solutions, aiming to evaluate the suitability of new formulate coatings by nanoparticle inclusion to improve the reflectance applied on innovative waste-based porous alkaline cement composite. Combining these two strategies is a possibility to lowering the amount of waste produced and simultaneously improve the thermal comfort and façade durability.

2. MATERIALS AND METHODS

2.1. PREPARATION OF MATERIAL SAMPLES

Four samples of the new composites were produced from CDW and other industrial wastes for the ventilated façade cladding panels. Mainly, they are constituted of fly ash (90 % w/w), polyurethane (% 5 w/w), timber (% 5 w/w) and aluminium powder (< 0.1% w/w). The mixtures were alkali-activated with sodium hydroxide (NaOH, 3M) and sodium silicate (ratio of NaOH/silicate was 0.3). The 0.6 solid/liquid ratio was to provide adequate workability. After the activator's addition, the specimens were cured in controlled ambient for about 20h. The experimental procedure is illustrated in Figure 1.

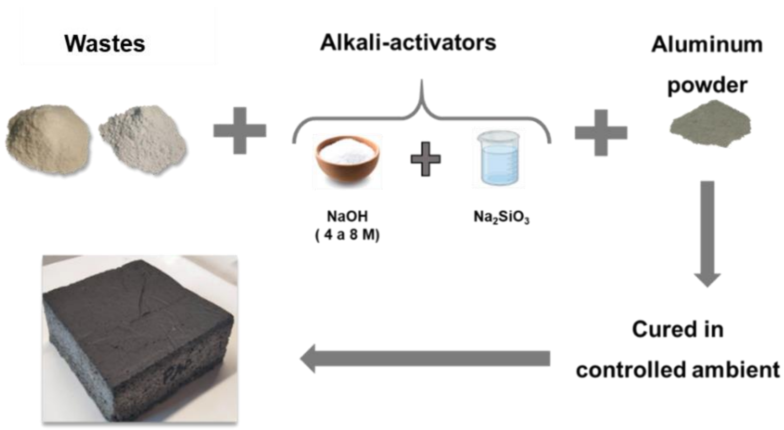

Figure 1. Experimental methodology applied in the production of the waste-based alkali-activated cement composite.

2.2. INCLUSION OF NANOPARTICLES IN THE FINISHING COATING

SiO_2 60-70 nm, TiO_2 30 nm and ZnO, 500 nm size nanoparticles (from US Nano) were used ≥ 99.9% trace metals basis and were employed as obtained without further purification. The standard matrix is a commercial acrylic water-based paint (PBk7 index) commonly used on façade systems. The four samples (100×100 cm^2) were coated with the acrylic-based black paint doped with the nanoparticles (Figure 2) to understand their effect in the visible and near-infrared range. The commercial nanoparticles were dispersed directly in the acrylic paint at 8% w/w concentration. All the doped samples were mixed at room temperature until a homogeneous mixture was obtained and then applied on the substrates with a spatula.

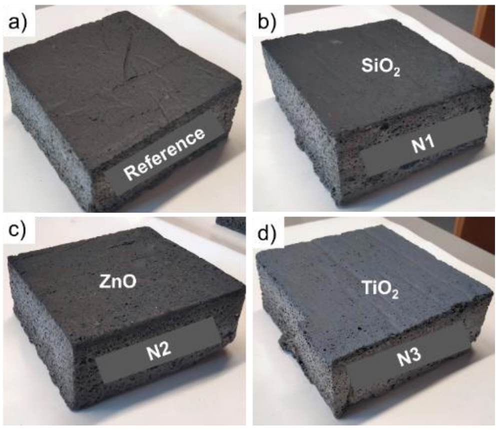

Figure 2. Waste-based alkaline cement composite for ventilated façade cladding coated with (a) commercial black acrylic paint and black acrylic paint doped with (b) SiO_2 60-70 nm, (c) ZnO 500 nm and (d) TiO_2 30 nm.

2.3. TEST METHODS

3. To properly assess the optical characterisation and the influence of the nanoparticles, a modular spectrophotometer was used, for evaluating the Total (R_{Total}) and NIR-reflectance (R_{NIR}) behaviour and colour properties. The solar reflectance measurements were performed according to ASTM E903 [12]. The CIE L*a*b colour coordinates, as weel as, the colour difference (ΔE) and lightness (ΔL), were determined using a 10º observed angle and D65 illuminant.

Determining liquid water permeability is of great importance regarding the façade cladding function of the developed systems. The L-shape Karsten tube method was used to measure the referred property according to RILEM-MS-A4 [13], comprising three measurements in each specimen. The water level decrease (V_t) was recorded at 5, 10, 15, 20, 30 and 60 min and the respective water absorption rate (C) was calculated.

4. RESULTS AND DISCUSSION

Table 1 presents a summary of all the optical properties.

Table 1. Summary of the measured properties.

Sample	Nanoparticle	Size (nm)	R_{TOTAL}	R_{NIR}	ΔE	ΔL
Porous alkaline cement composite (without paint)	----	----	0.320±0.061	0.376±0.102	----	----
Acrylic paint without nanoparticle doping	----	----	0.139±0.020	0.165±0.035	----	----
N1	SIO_2	60-70	0.146±0.012	0.168±0.015	2.2	-1.1
N2	ZNO	500	0.175±0.010	0.207±0.017	4.8	3.2
N3	TIO_2	30	0.195±0.023	0.209±0.035	9.6	6.8

Figure 3 illustrates the results for the spectral reflectance, total and NIR averaged reflectance and colour variation for each sample with the doped acrylic paint applied as a finishing coating. Analysing Figure 3(a) and (b), it is verified that there is a positive effect in the reflectance, especially with the inclusion of TiO_2 nanoparticles, followed by the ZnO nanoparticles. Concerning the colourimetric parameters [Figure 3 (c)], the results demonstrated that the SiO_2 nanoparticles have satisfactory performance, as the ΔE is below 3, which is a frequently used limit [7, 14]. On the other hand, although, N2 (ZnO nanoparticles) and N3 (with TiO_2) samples presented an improvement in both total and NIR reflectance, the colour difference is ΔE is above 3, turning the colour greyish.

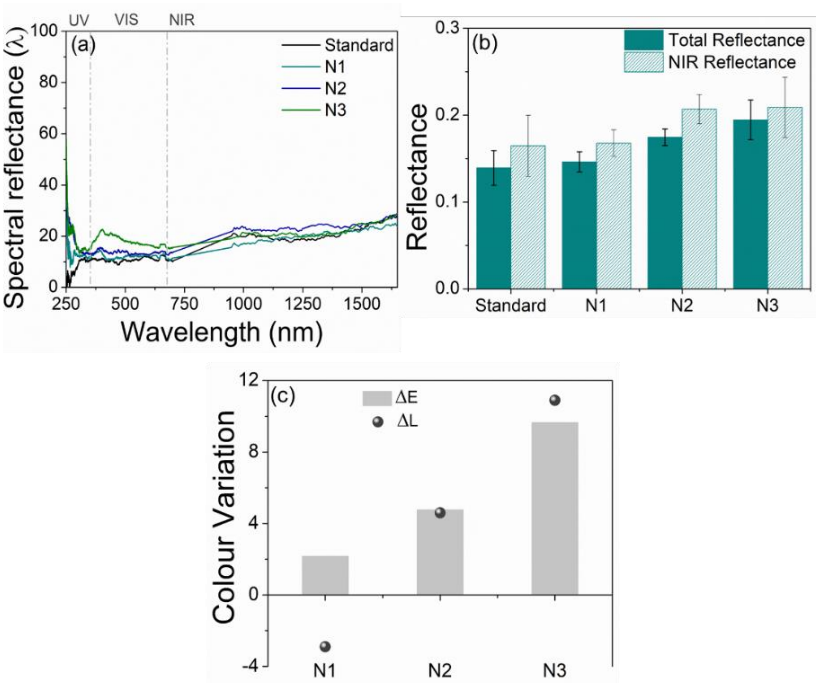

Figure 3. (a) Spectral, (b) total and NIR averaged reflectance calculated from ASTM E903 and (c) colourimetric variation for the waste-based alkaline cement composite coated with nanoparticles inclusion.

The liquid water permeability results are shown in Figure 4. As can be seen, the incorporation of nanoparticles reduced the absorbed water, especially in the initial test time. Also, the inclusion of TiO_2 resulted in a lower amount of absorbed water. The water absorption ratio is similar but higher for the standard acrylic paint.

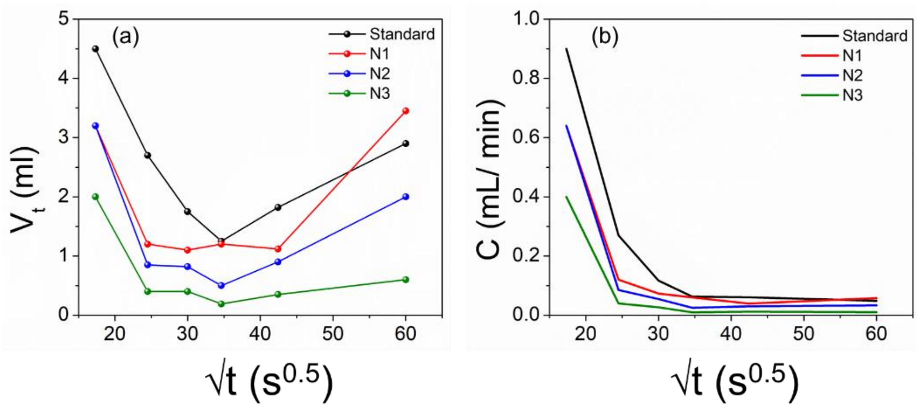

Figure 4. Liquid water permeability test results: (a) water level decrease (Vt) and (b) water absorption ratio.

5. CONCLUSIONS

This research focused on analysing the impact of nanoparticle inclusion on the optical properties and performance of an acrylic-based black paint for new innovative porous alkaline cement produced from CDW residues with a ventilated façade cladding function. The optical properties assessment, with a modular spectrophotometer, allowed to verify that the incorporation of the nanoparticles had a positive effect on the reflectance. Regarding the liquid water permeability test, useful to understand water transportation through coatings, it was observed that the incorporation of nanoparticles had lower water absorption, particularly in the initial test period. Also, the TiO_2 inclusion showed a lower amount of absorbed water.

Further research should include the study of more reflective nanoparticles with different doping concentrations and perform a long-term hygrothermal assessment to understand the influence of such nanoparticles on superficial changes.

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