INSTITUTO FEDERAL
Pernambuco

RELATÓRIO DE ATIVIDADES DESENVOLVIDAS
SEMESTRE 2020.1

CAMPUS: ***PESQUEIRA***	COORDENAÇÃO Edificações	
PROFESSOR: **Ruan Landolfo da Silva Ferreira**	GRUPO **I**	REGIME DE TRABALHO: ( ) 20h ( ) 40h (**X**) DE

TODAS AS ATIVIDADES DESENVOLVIDAS DEVERÃO SER COMPROVADOS (ART. 21)

ATIVIDADES DE ENSINO

COMPONENTES CURRICULARES	CURSO	C.H. TOTAL DO COMPONENTE	C.H. SEMANAL	C.H. de PREPARAÇÃO DE AULAS
A12-PS.081 - MATERIAIS DE CONSTRUÇÃO I	Edificações Médio Integrado	40,5	2,25	2,25
A12-PS.085 - TECNOLOGIA DA CONSTRUÇÃO I	Edificações Médio Integrado	40,5	2,25	2,25
A12-PS.092 - TECNOLOGIA DA CONSTRUÇÃO III	Edificações Médio Integrado	54	3,0	3,0
A12-PS.097 - MÁQUINAS E EQUIPAMENTOS	Edificações Médio Integrado	27	1,5	1,5
A12-PS.104 - MANUTENÇÃO PREDIAL	Edificações Médio Integrado	27	1,5	1,5
SUBTOTAL		189	10,5	10,5

ATIVIDADE	C.H. Semanal
PARTICIPAÇÃO EM REUNIÕES SEMANAIS DE PLANEJAMENTO PEDAGÓGICO	2,0
GRAVAÇÃO DE VIDEOAULAS PARA O ATENDIMENTO AOS DISCENTES EM PLATAFORMA PROPÍCIA PARA O ENSINO REMOTO	2,0
ORGANIZAÇÃO DE EVENTOS, EM CONJUNTO COM ESTUDANTES DO IFPE, TAIS COMO CONGRESSOS, SEMINÁRIOS, COLÓQUIOS E AFINS, DIRECIONADOS AO CORPO DISCENTE DA INSTITUIÇÃO (EDIFLIVE)	2,0
ORIENTAÇÃO DE ESTÁGIO – ALUNO(A)S: ANA BEATRIZ NUNES LEAL E MARCO ANTÔNIO BARBOSA DA SILVA	4,0

ATIVIDADES DE PESQUISA

ATIVIDADE	C.H. Semanal
PUBLICAÇÃO DE ARTIGOS CIENTÍFICOS EM REVISTAS INDEXADAS - Fernandes, C. N., Ferreira, R. L., Bernardo, R. D., Avelino, F., & Bertini, A. A. (2020). Using TiO_2 nanoparticles as a SO_2 catalyst in cement mortars. *Construction and Building Materials*, 257, 119542.	4,0

ATIVIDADES DE EXTENSÃO

PARTICIPAÇÃO COMO COLABORADOR EM PROJETO DE EXTENSÃO INTITULADO POR "DESENVOLVIMENTO SUSTENTÁVEL NAS CONSTRUÇÕES DO POVO INDÍGENA XUKURU DO ORORUBÁ: ENSINO E APRENDIZAGEM POR MEIO DE REGISTROS E INFORMAÇÕES DO POVO XUKURU" – C.H. SEMANAL: 2,0

ATIVIDADES ADMINISTRATIVO-PEDAGÓGICAS

ATIVIDADE	C.H. Semanal
COMISSÃO DE REESTRUTURAÇÃO PPC EDFICIAÇÕES MÉDIO INTEGRADO E SUBSEQUENTE. DECLARAÇÃO CACC/DENS/IFPE – PESQUEIRA. PORTARIA Nº 057/2014 - DGCP05/2020	3,0

COMPLEMENTO / OBSERVAÇÕES

DISTRIBUIÇÃO DA CARGA HORÁRIA

AULAS	PREPARAÇÃO DE AULAS	APOIO AO ENSINO	PESQUISA	EXTENSÃO	ADMINISTRATIVO PEDAGÓGICO	TOTAL/SOMA
10,5	10,5	11,0	4,0	2,0	3,0	40

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DIREÇÃO DE ENSINO

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INSTITUTO FEDERAL DE EDUCAÇÃO, CIÊNCIA E TECNOLOGIA DE PERNAMBUCO
CAMPUS PESQUEIRA

COORDENAÇÃO DA ÁREA DE CONSTRUÇÃO CIVIL - CACC

DECLARAÇÃO

Declaro para comprovação junto ao IFPE que os professores citados na tabela abaixo, participaram de 20 reuniões regulares para o planejamento pedagógico da Coordenação da Área de Construção Civil, no período 22/02/2020 à 24/11/2020.

Docentes	Siape
ELÂNIA DE SOUZA MELO	1650623
ISNARD FERREIRA DA SILVA	1204757
JAQUELINE MATIAS DA SILVA	1397823
JOSE DENIS GOMES LIMA DA SILVA	1971579
JOSE MARIA DE ARAUJO	1229245
MANUELA QUEIROZ OLIVEIRA	2891298
MARCOS ANTONIO ARRUDA G. DE HOLANDA	1217759
MARIO JOSE RIBEIRO DA SILVA	1216014
RAFAEL RONEY CAMARA DE MELO	1959798
RICARDO GOMES FREIRE DUARTE	3131891
RONALDO ALVES DE OLIVEIRA FILHO	2961669
RUAN LANDOLFO FERREIRA DA SILVA	3087909

Pesqueira, 13 de novembro de 2020.

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CPF: 048.249.324-08

José Denis Gomes Lima da Silva / Siape 1971579
Coordenador da Área de Construção Civil
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CAMPUS PESQUEIRA

COORDENAÇÃO DA ÁREA DE CONSTRUÇÃO CIVIL - CACC

DECLARAÇÃO

Declaro para comprovação junto ao IFPE que os professores citados na tabela abaixo, organizaram a o evento EDIFLIVE, no período 20/05/2020 à 01/07/2020 de forma remota e com participação do público discente e externo ao IFPE.

Docentes	Siape
ELÂNIA DE SOUZA MELO	1650623
ISNARD FERREIRA DA SILVA	1204757
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Pesqueira, 13 de novembro de 2020.

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José Denis Gomes Lima da Silva / Siape 1971579
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Using TiO_2 nanoparticles as a SO_2 catalyst in cement mortars

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HIGHLIGHTS

- Mortars with TiO_2 incorporation (2.5–10%) were produced.
- The effect of adding TiO_2 on the mortars physical–mechanical properties was evaluated.
- The incorporation of TiO_2 in mortars in the degradation process of SO_2 was investigated.
- The nano-TiO_2 decontaminated the samples previously contaminated by the pollutant SO_2.

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ABSTRACT

Titanium dioxide (TiO_2) has been used in building materials to produce products that do not require major maintenance and also contribute to improve air quality and extend the life of buildings. Thus, this research evaluated the effects of incorporation of this substance into cement mortars in the process of degradation of sulfur dioxide (SO_2), one of the largest atmospheric pollutants. Mortars were developed at a weight ratio of 1:3 (cement: sand), incorporating 2.5%, 5%, 7.5% and 10% of TiO_2 relative to the cement weight. Mortars were evaluated in their fresh state (consistency and bulk density) and hardened (dry bulk density, water absorption by capillarity, open porosity and flexural and compressive strength). The samples were exposed to an accelerated aging SO_2 (pollutant) chamber, then moistened and exposed to ultraviolet radiation. For this exposure of the samples, two Light Emitter Diodes (LEDs) with wavelengths covering the UV-A range were used: UV (380–420 nm) and blue (420–493 nm). Fourier Transform Infrared measurements were also performed in three stages, which were: (1) before contamination, (2) after SO_2 contamination and (3) after radiation exposure. The nano TiO_2 incorporation in the mortars contributed to the increase in open porosity and favored the increase in dry bulk density of mortars this was due to the filler effect. In addition, there was an increase in both the compressive strength and the flexural strength for mortars with addition, compared with the reference mortar. It can be concluded that the incorporation of TiO_2 improved the physical, mechanical and photocatalytic properties, and enabled the decontamination of mortars due to the action of the SO_2 pollutant.

1. Introduction

Air pollution is due to the discharge of harmful substances into the atmosphere [1], which cause adverse effects especially in large cities. The problems related to this type of pollution in urban areas have been known for a long time [2]. About 3000 distinct compounds have been identified, most of them organic [3].

Among the main air pollutants are carbon monoxide (CO), nitrogen oxides (NOx), sulfur dioxide (SO_2), ozone (O_3), soot and particulate matter, represented by inhalable particles and in suspension [4]. The main degrading agents of constructions are the SOx and NOx [5]. In addition to affecting human health [6] and contributing to increased air pollution, these pollutants contribute to the emergence of pathological manifestations due to the incorporation of pollutants into building facades.

In 116 cities in China (the most populous city in the world), increased industrial SO_2 emissions were found to account for a 3.5% increase in the number of lung cancer patients, as well as

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an increase of 3% in mortality from respiratory diseases, causing the death of about one hundred thousand people a year [7]. These statistical data demonstrate the need to study ways to mitigate the effects caused by SO_2 pollutant. Some substances have been discovered and used to enable the reduction in negative impacts caused to the environment by polluting agents, and one of these is the titanium dioxide (TiO_2).

This nanomaterial is considered by many researchers to be an excellent agent in the degradation of pollutants found in atmospheric [8-10] and wastewater [11] due to its high oxidizing and reducing abilities [12]. When a TiO_2 material is irradiated by sunlight, its surface creates a barrier capable of retarding the rate of contamination of the underlying surfaces [10] due to the mineralization of polluting agents (organic and inorganic) through oxidation–reduction reaction [13], which may in particular be described as a photocatalytic process [14]. Harmful pollutants (such as NOx and SOx) are converted into less toxic forms and subsequently leached by rain [14,15]. As a result, the service life of buildings is extended and consequently the costs related to maintenance operations are reduced.

The TiO_2 is a photocatalyst that has more than one crystalline phase, and the main ones are: rutile, anatase and brookite [16]. Anatase and rutile have tetragonal structures. The brookite phase is orthorhombic in nature [17]. Brookite is a phase of TiO_2 that is not given much attention in terms of its properties and applications. This is due to the difficulty of producing pure particles from this phase. [18]. The most well-known phases used in building materials are rutile and anatase [19]. As anatase has the greatest photocatalytic effect [20], it is the most used phase in studies incorporating TiO_2 into building materials, whose main objective is to increase the useful life of buildings.

Thus, the worldwide scientific and industrial interest in this substance for the most diverse civil engineering applications has become clear [8]. Studies on the use of nano-TiO_2 have been developed for: air purification [21], asphalt pavement protection with NO_2 degradation [22], photocatalytic degradation of tetracycline-containing wastewater [23], degradation of wood pollutants [24], asphalt shingle [25], cementitious materials [13,26-33] (which is the focus of this study, in mortars) and others.

Incorporating TiO_2 nanoparticles in mortars can improve their mechanical properties due to the modification of their microstructure [31] and, consequently, help to increase their durability [34]. Studies on the use of TiO_2 nanoparticles in cement composites also show that these nanoparticles have a nucleation effect on the cement paste [34], which contributes to a better distribution of hydration products and to the formation of stronger clusters of C-S-H [35] in the microstructure of cementitious materials.

In recent years, there has been an increasing number of studies related to the use of TiO_2 in cementitious materials. However, some factors contribute to the effects of adding TiO_2 in mortars, which are not fully clarified. Firstly, studies concerning the synergistic effects of adding TiO_2 to the physical–mechanical and photocatalytic properties of mortars are scarce, which limits the obtaining of information that contributes to fill the existing gaps on the subject. Second, because the number of studies investigating the effects of SO_2 is also limited, despite the importance of minimizing environmental impacts. Finally, although there are studies [19,36-45] with optical or morphological analyses of TiO_2, there is also a very limited number of studies applied to construction materials, as there is little association between these evaluations and a physical investigation of the material. These aspects mentioned above need to be evaluated so that the existing gaps on the topic can be filled. Therefore, this study assesses the effects of TiO_2 incorporation on the physical, mechanical and photocatalytic properties of Portland cement-based mortars contaminated with SO_2.

2. Materials and methods

2.1. Materials

In this research, Brazilian Pozzolanic Portland cement (PC) (similar to ASTM C 595 Portland Pozzolanic) was used, with a density of 2.96 g/cm^3, a bulk density of 1.14 kg/dm^3, a specific surface of 0.44 m^2/g, and compressive strength of 32 MPa at 28 days. Silica sand obtained from the riverbed was used as an aggregate. This sand had a specific density of 2.61 g/cm^3, a unit mass of 1.4 kg/dm^3, a maximum diameter of 2.36 mm and a fineness modulus of 2.4.

The titanium dioxide (TiO_2) powder was commercially obtained from COREMAL S/A, with 99.5% purity and a specific mass of 3800 kg/m^3. The characterization for X-Ray Diffraction (XRD) was performed in the range of 20° to 90°, in 2θ, with a step size of 0.05° and time per step of 1 s, with the samples in powder form. (Fig. 1). For refinement, the Rietveld method was used. The readings were taken with radiation K-α of cobalt in the range 2θ/second of 20° to 90°. The diameter equivalent of the TiO_2 particles is 60. 64 ± 3.71 nm. This result is consistent with previous studies whose average TiO_2 particle diameter ranged from 532 to 40 nm [27,46-48].

2.2. Composition and manufacturing

The following criteria were established for the production of mortars:

- Produce mortars with a 1:3 (cement:dry sand) in weight.
- Replace PC by weight with TiO_2 percentages of 2.5%, 5%, 7.5% and 10%. The high levels of TiO_2 used in this work are due to the greater effect on the degradation of SO_2 gas. In addition, these dosage levels are compatible with previous studies [30].
- Produce mortars with flow within the range of 260 ± 5 mm, based on the consistency table test and the criteria established by the Brazilian standard NBR 13276: 2016 (similar to ASTM C1329/C1329M: 2016). The ideal amount of water for mixing the mortars was experimentally adjusted to strictly guarantee the specified workability.
- The mortars were mixed in a standard mechanical mixer according to the procedure described by Brazilian Standard NBR 16541:2016.

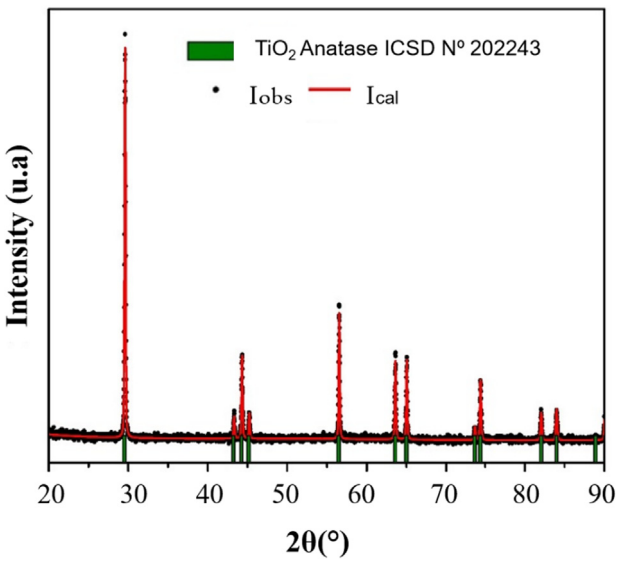

Fig. 1. XRD of TiO_2 (anatase).

Table 1
Composition of the mortar mixes (kg/m^3).

Mortar	%TiO_2	Cement	Sand	TiO_2	Water
M0 (Control)	0	750	2250	0	485
M1	2.5	750	2250	18.75	500
M2	5.0	750	2250	37.5	500
M3	7.5	750	2250	56.25	500
M4	10	750	2250	75.00	515

The percentage of PC substitution by TiO_2 was suffixed, where each series is presented by the substituted percentage. For example, a mixing ratio with 2.5% TiO_2 is a series, namely M1. Thus, five series were established and the compositions of the materials used to produce 1 m^3 of mortar are shown in Table 1.

2.3. Tests on mortar mixes

The methods used in the tests to evaluate the physical, mechanical and photocatalytic properties of mortars are shown below in Table 2. The samples were submitted to the following curing conditions: dry curing and in laboratory with relative humidity of 95 ± 5% and a temperature of 20 ± 2 °C for 2 days within the molds. After demoulding, the samples were kept in the same conditions mentioned above until the age of the physical and mechanical tests shown in Table 2.

Table 2
Tests performed on mortars and their respective methods and standards.

Properties	Standard	Specimens and size	Curing time (days)
Properties of fresh mortar			
Consistence by flow table	NBR 13276:2016[1]	3	–
Bulk density	NBR 13278:2005[2]	3	–
Properties of hardened mortar			
Dry bulk density	NBR 13280:2005[3]	3 Prismatic (40x40x160 mm)	28
Water absorption by capillarity	NBR 15259:2005[4]	3 Prismatic (40x40x160 mm)	28
Open porosity	NBR 9778:2009[5]	3 Prismatic (40x40x160 mm)	28
Compressive strength	NBR 13279:2005[6]	6 Prismatic (40 × 40 × 80 mm)	7 and 28
Flexural strength	NBR 13279:2005[7]	3 Prismatic (40x40x160 mm)	7 and 28

Equivalent to: [1]EN 1015–3 (1999); [2]EN 1015–6:1998; [3]EN 1015–10:1999; [4]EN 1015–18: 2002; [5]NP EN 1936:2007; [6,7]EN 1015–11:1999.

2.4. Photocatalytic properties

The prepared samples were exposed to the pollutant SO_2 in a chamber for accelerated industrial corrosion testing model UK-01 for a 24-hour machine cycle. The mortar compositions were exposed for 8 h to SO_2 inside the closed chamber, at a relative humidity of 20 ± 5. Then, they remained 16 h inside the open chamber. The degradation of organic compounds or pollutants occurs under the effect of humidity and UV radiation [10], where the pollution control mechanism is activated within a UV-A range [28], which comprises a wavelength (λ) of 320–400 nm [49].

Thus, the mortars were moistened and then KBr (potassium bromide) pallets were generated. A 2 mg sample was generated for each mortar composition and all samples were subjected to UV radiation. The pallets were placed in a centralized support inside the experimental box. The light wattage of the LEDs has of 65 W. To expose the pieces, two Light-Emitting Diodes (LEDs) (Fig. 2) with wavelengths that cover the UV-A range were used: UV (380–420 nm) and blue (420–493 nm). The LEDs were selected to ensure that the UV-A range was reached (Table 3). Two LEDs were used as a safety margin for this.

Infrared spectra were generated in a Shimadzu IRTracer-100 spectrophotometer in the range of 400 to 4000 cm^{-1} for each mortar type in three stages. The stages considered were: (1) before contamination, (2) after SO_2 contamination and (3) after radiation exposure. For this, one sample was used for each stage of each mortar produced, totaling 3 samples per type of mortar. This whole procedure was performed to prove the contamination of the sample through the behavior of the main bands of the elements present in the composition.

Then the spectra were generated in a FTLA 2000–102, ABB-MAN spectrophotometer, also in the region of 400 to 4000 cm^{-1}, but with an enlargement of the graph in the region of vibration related to SO_2. This localization was observed by the behavior of the previously obtained bands. This was done to verify for possible reductions in the amount of sulfur in the material. Verifying the reduction aims to show the decontamination of the parts with the addition of TiO_2 due to exposure to radiation for 100 min.

Table 3
Wavelength ranges of LEDs [50].

LED	Wavelength (nm)
UV	380 – 420
Blue	420 – 493
Green	484 – 581
Yellow	563 – 616
Red	594 – 659

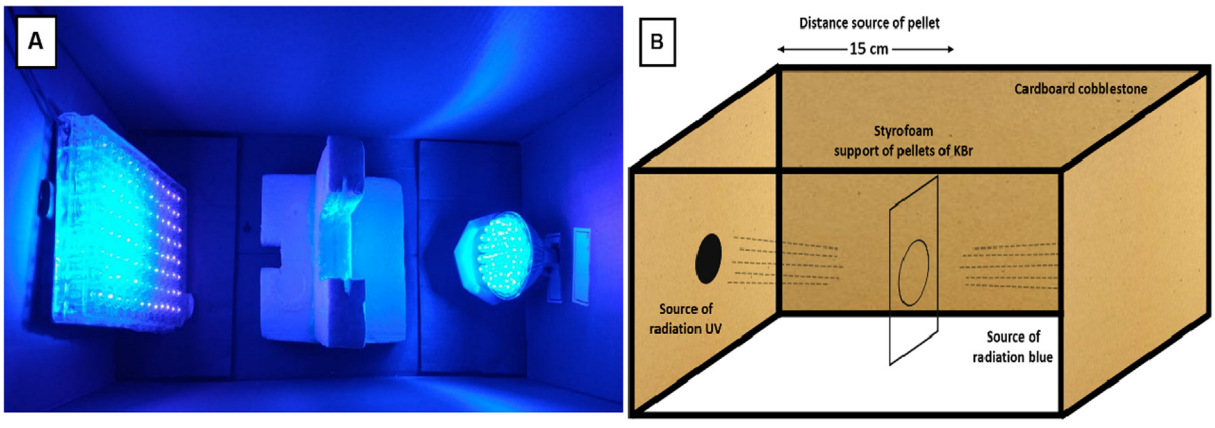

Fig. 2. Experimental apparatus for exposure to UV radiation (a) LEDs in operation (b) layout with material specifications.

3. Results and discussion

3.1. Properties of fresh mortar

3.1.1. Consistency

The consistency test (Table 4) was performed to quantify the water content to be added to the mortar, based on the consistency values set in the dispersion range of 260 ± 5 mm. In addition, it was important to set this parameter to ensure proper workability and to improve the mortar comparability.

The incorporation of TiO_2 resulted in a reduction in the water content/fines to maintain the same workability. The reason for this is due to the filling effect. The TiO_2 nanoparticles filled the voids between the sand particles and, as a result, the amount of water required for mixing was also reduced. On the other hand, increasing the content of nano-TiO_2 resulted in the reduction of workability, therefore water content had to be increased to maintain the same workability. This is due to the high surface area of the nano-TiO_2 that absorbs more water and also the non-dissolution in water of the nano-TiO_2 particles [31]. These results are consistent with those obtained by Noorvand et al. [51] and show that using higher TiO_2 contents contributes to the refinement of the porous structure of mortars and the amount of water in the mixture is substantially reduced. However, this phenomenon was different from the study by Hüsken et al. [28]. This is believed to be due to the fact that the authors added TiO_2 dissolved in water, while in our study we used TiO_2 mixed with cement for incorporation.

3.1.2. Bulk density

Although TiO_2 nanoparticles have a lower bulk density compared to cement and sand, the bulk density of mortars increased slightly to levels of TiO_2 incorporation above 2.5% (Fig. 3). However, the largest amount of fine particles fills the voids between the larger particles and those that would be occupied by water. The filling effect provided by the TiO_2 particles results in greater compaction of the mixture and, therefore, increases the bulk density.

The values found show that all mortars can be used for decorative monolayer coating, as they have a fresh bulk density between 1800 and 2200 kg/m^3, established by the NBR 13281:2005 Brazilian standard.

Table 4
Consistency of the mortars.

Mortar	Consistency (mm)	water/cement	water/fines[a]
M0	262	0.65	0.65
M1	265	0.67	0.65
M2	263	0.67	0.63
M3	260	0.67	0.62
M4	260	0.69	0.62

[a] water/(cemet + TiO^2) ratio

3.2. Properties of hardened mortar

3.2.1. Dry bulk density

Overall, dry bulk density results (Fig. 4) did not follow the same trend as in the fresh state. However, the incorporation of TiO_2 favored the increase of dry bulk density of mortars, except when the content was 7.5% (M3). This was due to the filler effect. For mortar M3, the mixing was probably performed inefficiently resulting in agglomeration of TiO_2 particles and, consequently, increased internal voids when the mortar became hardened.

3.2.2. Water absorption by capillarity

To analyze the results of the tests for water absorption by capillary at 28 days (Fig. 5) was used as parameter the capillary coefficient. The capillary coefficient was calculated using the mass of water absorbed between 10 and 90 min, per area unit and square roof of time. Thus, the parameter indicates the rate of water absorbed due to capillary rise in the first minutes of testing.

The capillary coefficient of mortars produced with TiO_2 decreases when compared to the reference mortar (M0). Certainly, the volume of capillary pores was reduced by incorporating a larger volume of very fine particles, which resulted in improved water absorption behavior of mortars. Another reason why the capillary water absorption of mortars was reduced using nano TiO_2 is due to the fact that the TiO_2 nanoparticles increase the content of the chemically combined water due to the higher hydration rate. As a result of this process, unbound water and, consequently, capillary absorption are reduced.

Overall, these results are consistent with previous studies [13,35,51] and reinforce that, due to this effect, TiO_2 mortars showed less initial porosity. This decrease in the capillary absorp-

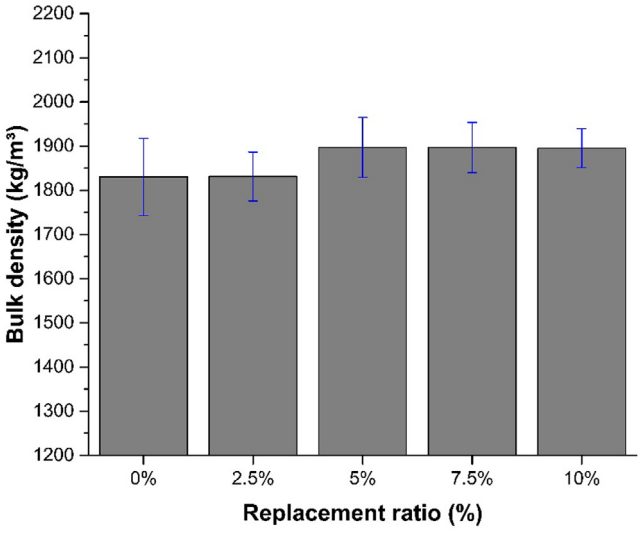

Fig. 3. Bulk density of fresh mortar.

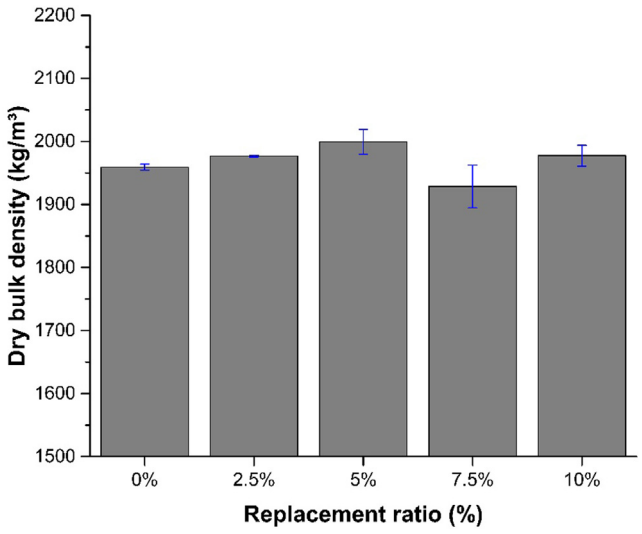

Fig. 4. Dry bulk density of hardened mortar.

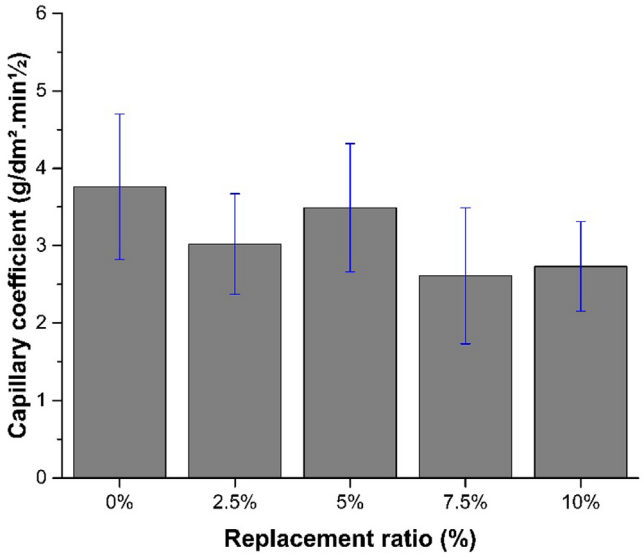

Fig. 5. Capillary coefficient of hardened mortar.

tion of mortars can indicate a significant improvement in the durability of cement mortars.

3.2.3. Open porosity

The volume of interconnected pores was estimated by the open porosity test and the results obtained are shown in Fig. 6. Based on the results, we observed that the extent to which TiO_2 was incorporated into open porosity also increased. This increase was not significant because the mortar with 10% TiO_2 (M4) showed an increase of only about 13% compared to the reference mortar (M0). The results are contrary to some previous studies [13,51] and indicate that the particle filling effect was not efficient for this property. This also shows that the effect of increasing the water/cement ratio affects the porosity of the matrix when the TiO_2 nanoparticles are incorporated, especially when their dosage is equivalent to 10%.

However, we observed that the water content increases when TiO_2 is incorporated (Table 1). Due to their larger specific surface, TiO_2 nanoparticles tend to agglomerate, leading to the formation of undisrupted pockets within the cementitious matrix [35]. As a result, mortars have a higher pore volume when hardened. These results corroborate those obtained in previous studies [12,35] and, therefore, confirm that there may be a joint effect of pore size reduction and porosity increase for mortars that incorporate a higher amount of TiO_2 [12]. In the mortar study carried out by Atta-ur-Rehman et al. [30] it is observed that that water absorption is reduced when nano-TiO_2 is added. This was because the TiO_2 particles were first deagglomerated and dispersed in water through ultrasonication using a sonic probe for at least 45 min. Thus, dispersants or ultra-sound would be required for agitation in future studies to prevent the particle agglomeration phenomena.

Davood et al. [35] showed that when TiO_2 content is greater than 3.5% by weight, the total pore volume and the number of pores in mortars tend to increase. However, the high open porosity of mortars produced with TiO_2 may contribute to the better diffusion of CO_2 in the atmosphere, which is beneficial for the environment over time [52].

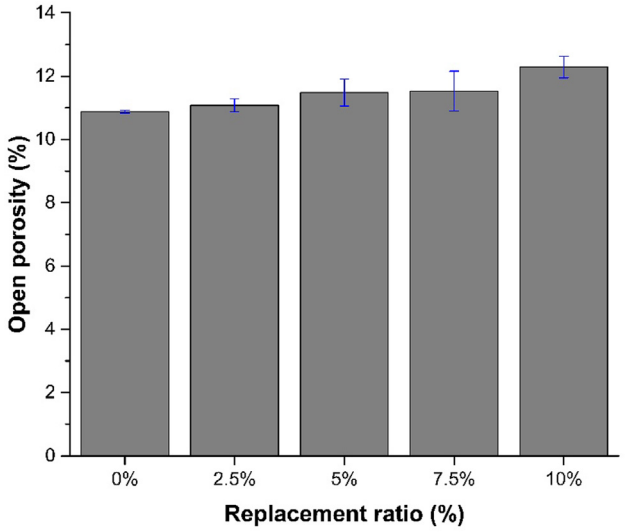

Fig. 6. Open porosity of hardened mortar.

3.2.4. Flexural and compressive strength

The results obtained in the flexural and compressive strength tests at 7 and 28 days of moist curing can be seen in Fig. 7. It is observed that mortars have values of flexural strength greater than 3.5 MPa and compressive strength greater than 8 MPa. Comparing the results obtained with the compressive strength classes proposed in NP EN 998–1: 2013, it should be noted that all mortars studied belong to the CS III and CS IV classes, making them suitable for most applications. Regarding the Brazilian standardization (NBR 1281: 2005), mortars may be suitable to be used as monolayer decorative coating mortars.

In general, it can be observed that the replacement of PC by TiO_2 caused increased compressive and flexural strength of mortars. The filling effect of TiO_2 nanoparticles made mortars more compact and denser, which resulted in improved compressive strength. These results corroborate those obtained in other studies [13,31,35,51,53]. Notwithstanding, other factors may have contributed to this performance, such as the nucleation effect in the cement paste [13,35,51,53]. As a result, hydration products defuse and envelop nano-particles acting as a kernel, which leads to a better distribution of hydration products and stronger clusters of C-S-H [30]. These observations corroborate the results obtained in the analysis of the open porosity of mortars (Section 3.2.3). .

3.3. Photocatalytic analysis

A great similarity between the FTIR spectra of the cement after incorporating sulfur dioxide (SO_2) was observed, as well as after

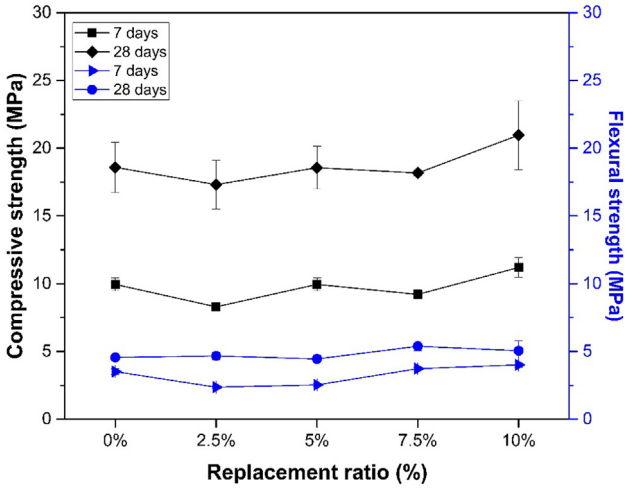

Fig. 7. Compressive and flexural strength of hardened mortars.

they were exposed to UV radiation (Figs. 8 and 9). The figures show the unpolluted mortar tablets (np), polluted with SO_2 (p) and after exposure to radiation (r). The presence of SO_2 in the cement can be confirmed by the appearance of absorption bands related to the S-O stretching, which are absent in the reference cement (M0). The main absorption bands and their assignments are summarized in Table 5.

The presence of SO_2 in the cement can be observed by the absorption band at 1140 cm^{-1}, which corresponds to the stretching of the S-O bond. According to the literature, when SO_2 is poorly adsorbed on a surface, bands appear between 1330 and

Table 5
Main absorption bands present in the FTIR spectra of cement mortars and their assignments.

Absorption band (cm^{-1})	Assignment	Reference
3400	ν (O – H)	[19,39,43]
1800	ν (Ti – O – Ti)	[40-42]
1640	δ (O – H)	[37,44]
1140	ν (S – O)	[36,38]
1090	ν_a (Si – O – Si)	[37,44,45]
870	ν_s (Si – O – Si)	[37,44,45]
470	δ (R_3Si – O – SiR_3)	[37,44]
460	ν (Ti – O – Ti)	[40-42]

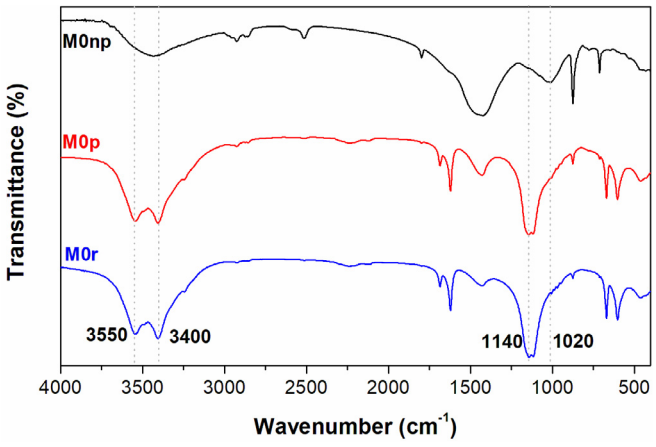

Fig. 8. FTIR spectrum of the reference cement.

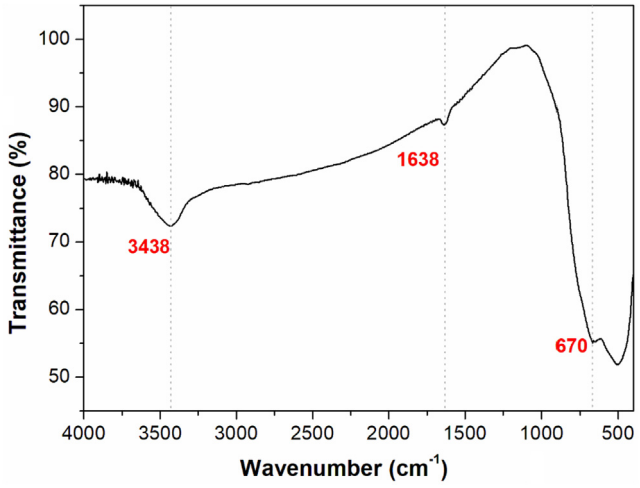

Fig. 10. FTIR spectrum of TiO_2 (anatase phase).

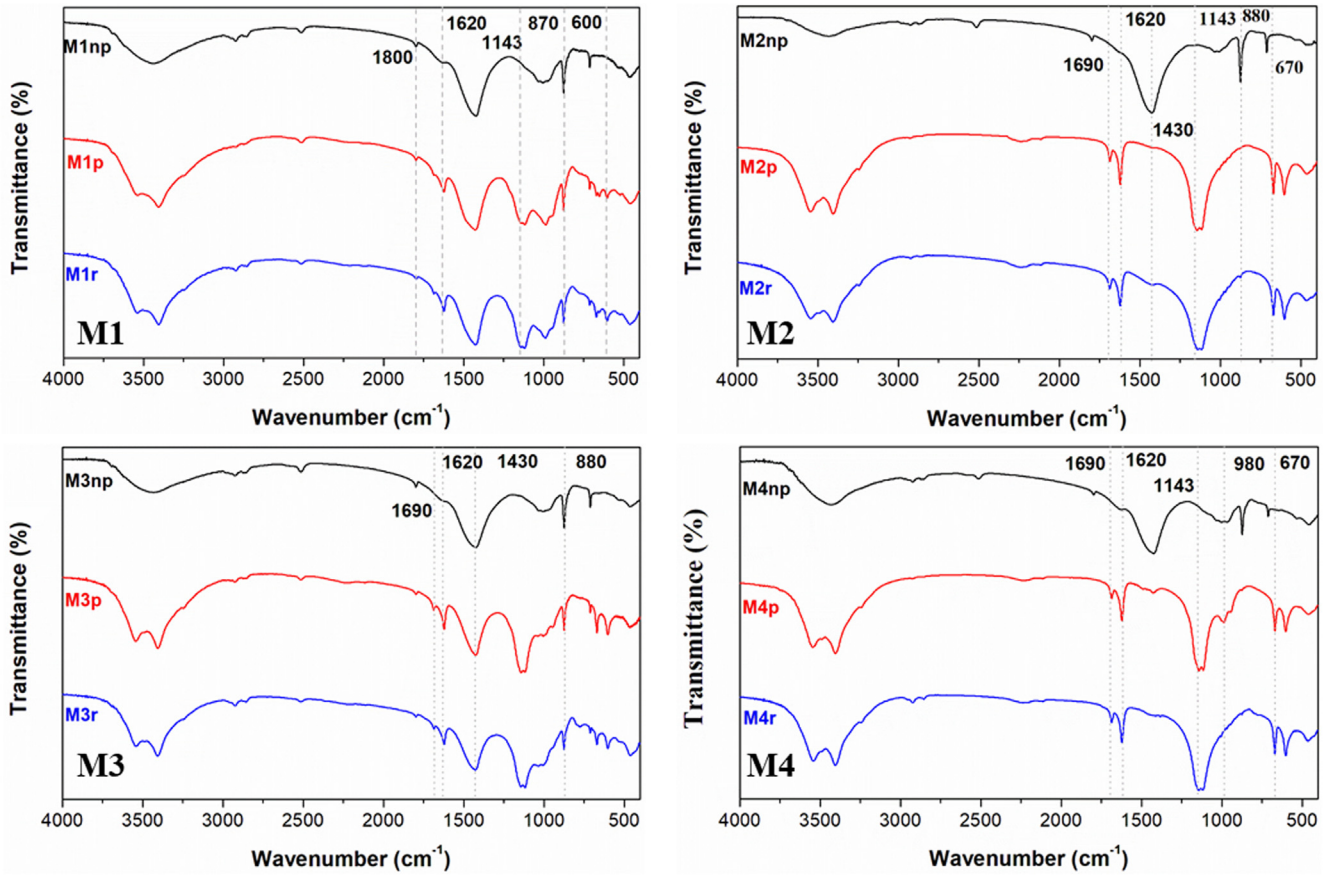

Fig. 9. FTIR spectrum of the cement incorporated with TiO_2.

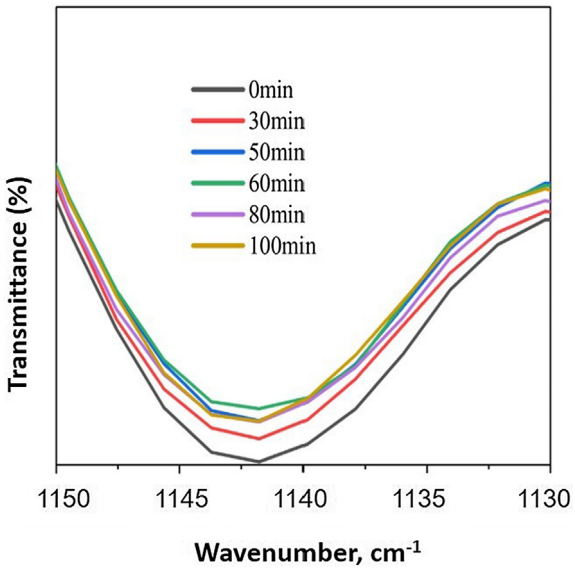

Fig. 11. FTIR spectra of reference cement (M0) for SO_2 release.

1140 cm^{-1} [36,38], which is consistent with the obtained spectra shown in Fig. 8.

The band at 3400 cm^{-1} can be attributed to symmetric stretching of hydroxyl groups, which can be present in the silanol groups or those present in the adsorbed water molecules in the surface of the cement or by the reaction between the electron pairs, which in the photocatalysis reaction migrate to the catalyst surface and react separately with other species adsorbed to this surface, such as water [19,39,43]. The adsorption of water molecules on the surface of the catalyst acts by preventing polluting molecules from being adsorbed on the surface, which makes additional reactions with TiO_2 difficult or do not occur [28].

The bands at 1090 and 870 cm^{-1} are related to the asymmetric and symmetric stretching of Si-O-Si groups, respectively [37,44,45]. Furthermore, the bands at 470 cm^{-1} can be attributed to the angular deformation of siloxane groups, while the band at 1640 cm^{-1} can be attributed to the angular vibration of the adsorbed water molecules [37,44].

In addition, the incorporation of TiO_2 to the cement was successfully proved by the appearance of bands at 460 and 1800 cm^{-1}, which are related to the Ti-O and Ti-O-Ti stretching, respectively. The presence of a band at 480 cm^{-1} in the neat cement (M0) can also be observed, as well as in the cements with TiO_2. This behavior can be explained by the fact that the SiO_2 groups also absorb the radiation in this region. Moreover, when TiO_2 (anatase) is strongly adsorbed, it will produce an absorption band at 480 cm^{-1} which is related to the stretching of the O-Ti-O bond [40-42], as shown in Fig. 10.

Figs. 11 and 12 show the FTIR spectra of the neat cement (M0) and the cements with TiO_2 (M1, M2, M3 and M4), respectively, in which the release behavior of SO_2 was monitored. The figures showed that there was no tendency to release sulfur for all formu-

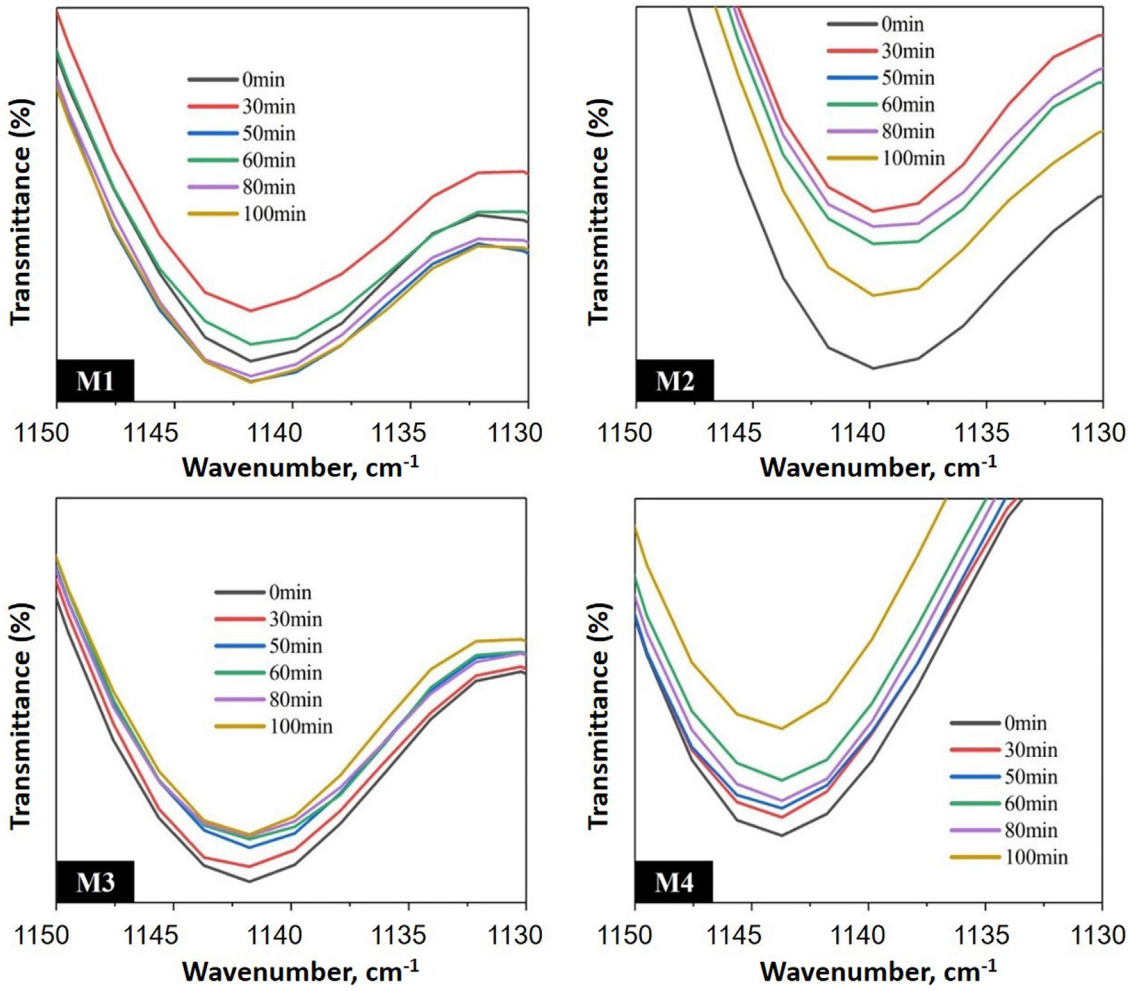

Fig. 12. FTIR spectra of cements with TiO_2 (M1, M2, M3 and M4) for SO_2 release.

lations/compositions. The degradation mechanism of SO_2 was proposed in the following Equations (1 to 6), based on a previous pathway proposed by Chen and Kou [54].

$$H_2O_{(g)} \rightarrow H_2O_{(ads)} \quad (1)$$

$$H_2O_{(ads)} + h^+ \rightarrow .OH_{(ads)} + H^+_{(ads)} \quad (2)$$

$$O_{2(g)} + e^- \rightarrow .O_2{}^-_{(ads)} \quad (3)$$

$$SO_{2(g)} \rightarrow SO_{2(ads)} \quad (4)$$

$$2.OH_{(ads)} + SO_{2(ads)} \rightarrow SO_4{}^{2-}_{(ads)} + 2H^+_{(ads)} \quad (5)$$

$$.O_2{}^-_{(ads)} + SO_{2(ads)} \rightarrow SO_3{}^{2-}_{(ads)} \quad (6)$$

TiO_2 nanoparticles are activated by the incidence of UV light in cement mortars, creating a gap (h^+) in the valence band (VB) and releasing an electron (e^-) to the conduction band (CB). Water molecules present in the atmosphere can be adsorbed on the cement mortar' surface as previously shown by FTIR spectra (Eq. (1)) and can undergo an oxidation reaction in the VB producing hydroxyl radicals (**.**OH) (Eq. (2)), which are highly reactive. Oxygen molecules also present in the air can undergo a reduction reaction in the CB producing superoxide species ($.O_2^-$) (Eq. (3)), which are also highly reactive. Then, SO_2 molecules in the air can be adsorbed on the cement mortar' surface (Eq. (4)), reacting with the reactive oxygen species, such as **.**OH and $.O_2^-$, producing sulfite (SO_3^{2-}) and sulfate (SO_4^{2-}) ions (Eqs. (5) and (6)), respectively, which are less polluting and aggressive species than SO_2.

When the behavior of M0 is observed, we notice that there is no tendency to release sulfur. It can be concluded that this is due to the fact that there is practically no distance from the curves over time. When we analyze mortars with TiO_2 nanoparticles, we see another configuration (there is a reduction trend, mainly of M2).

Fig. 12 clearly shows that the transmittance of the bands related to the S-O bond decreased faster in the cements with TiO_2 (M1 to M4) than those of the neat cement (M0). This can be related to the kinetics involved in the SO_2 release, indicating that the incorporation of TiO_2 particles to the cement combined to the exposure to the radiation catalyzed the release process, in which the M2 and M4 samples had the highest weight loss, specifically 1.5% wt. only during 100 min of exposure. Therefore, these results show the potential of using low contents of TiO_2 for obtaining fast and efficient responses in relation to SO_2 release, minimizing several environmental problems, as well as the deterioration of the cement.

4. Conclusion

It can be concluded from this study that the introduction of nano TiO_2 helped to improve the photocatalytic properties of the mortars. As the radiation exhibition time increases, the intensity of the adsorption band in the SO_2 region is reduced. Thus, the reduced SO_2 content in the mortars was observed, demonstrating that there was sulfur release from the made samples. Reduction is a positive factor for achieving sustainability in construction, through non-polluting materials that still act to provide greater durability to buildings. The results obtained from the physical properties show that it is feasible to use mortars with TiO_2 incorporation in decorative monolayer coating on facades. The reduction in SO_2 of the samples is due to the increase in its porosity. Notwithstanding, it is interesting to note that better results of physical properties probably could have been obtained when using ultrasonication using a sonic probe to de-agglomerate and disperse nano-TiO_2 particles in water instead of incorporating the fines (nanoparticles and cement) together.

CRediT authorship contribution statement

C. N. Fernandes: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing - original draft, Writing - review & editing. **R. L. S. Ferreira:** Formal analysis, Software, Validation, Writing - original draft, Writing - review & editing. **R. D. S. Bernardo:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing - review & editing. **F. Avelino:** Formal analysis, Software, Validation, Writing - review & editing. **A. A. Bertini:** Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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INSTITUTO FEDERAL DE EDUCAÇÃO, CIÊNCIA E TECNOLOGIA DE PERNAMBUCO
CAMPUS PESQUEIRA

COORDENAÇÃO DA ÁREA DE CONSTRUÇÃO CIVIL - CACC

DECLARAÇÃO

Declaro para comprovação junto ao IFPE que os professores citados na tabela abaixo, foram designados na continuidade emergencial da Portaria Nº 057/2014 – DGCP, visto uma demanda de caráter da PRODEN.

Docentes	Siape
ELÂNIA DE SOUZA MELO	1650623
ISNARD FERREIRA DA SILVA	1204757
JAQUELINE MATIAS DA SILVA	1397823
JOSE DENIS GOMES LIMA DA SILVA	1971579
MANUELA QUEIROZ OLIVEIRA	2891298
MARIO JOSE RIBEIRO DA SILVA	1216014
RAFAEL RONEY CAMARA DE MELO	1959798
RICARDO GOMES FREIRE DUARTE	3131891
RONALDO ALVES DE OLIVEIRA FILHO	2961669
RUAN LANDOLFO FERREIRA DA SILVA	3087909

Pesqueira, 13 de novembro de 2020.

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José Denis Gomes Lima da Silva / Siape 1971579
Coordenador da Área de Construção Civil
IFPE Campus Pesqueira

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DEX – DEPARTAMENTO DE EXTENSÃO
CEEG – COORDENAÇÃO DE ESTÁGIOS E EGRESSOS

DECLARAÇÃO

Declaramos para fins de direito que o professor **Ruan Landoufo da Silva Ferreira**, **Siape 3087909**, exerceu a função de orientador de estágio no curso Técnico em Edificações desta Instituição de Ensino no semestre de 2020.1 nos seguintes termos:

Aluno	***Matrícula***
Ana Beatriz Nunes Leal	20182A2-PS0170
Marcos Antônio Tenório de Almeida Filho	20151A12-PS0026

Pesqueira, 16 de Novembro de 2020.

Rafael Roney Camara de Melo
Siape 1959798
Coordenação de Estágios e Egressos – IFPE Campus Pesqueira
Portaria D.O.U. nº55 de 11/01/2018

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DEPARTAMENTO DE EXTENSÃO - DEX

DECLARAÇÃO

Declaro para fins de direito e comprovação que o servidor **RUAM LANDOLFO DA SILVA FERREIRA**, matrícula SIAPE: 3087909, é colaborador interno no projeto de extensão aprovado no Edital Nº 01/2019 – PIBEX/PROEXT/IFPE, com o título "**DESENVOLVIMENTO SUSTENTÁVEL NAS CONSTRUÇÕES DO POVO INDÍGENA XUKURU DO ORORUBÁ: ENSINO E APRENDIZAGEM POR MEIO DE REGISTROS E INFORMAÇÕES DO POVO XUKURU - VISITAS TÉCNICAS E CARACTERIZAÇÃO DOS MATERIAIS DA CONSTRUÇÃO CIVIL**", cadastrado neste Departamento de Extensão e que vem sendo executado de fevereiro de 2020 até a presente data, exercendo uma carga horária semanal de 02h.

Pesqueira-PE, 16 de novembro de 2020.

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Otávio Washington Lima Silva
Departamento de Extensão/IFPE – Campus Pesqueira
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Mat. SIAPE 2279405