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Mechanical behavior of coating mortars through the insertion of ash from the sewage sludge

Comportamento mecânico das argamassas de revestimento através da inserção de cinzas do lodo de esgoto

Comportamiento mecánico de morteros de revestimiento mediante la inserción de cenizas de lodos de depuradora

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Abstract
Through environmental policies that provide a gradual discussion about the disposal of waste produced in the most diverse industrial sectors, sewage sludge is emphasized by the problematic destination of the toxic compounds that compose it, compromising its disposal. Based on the need to implement measures to mitigate environmental impacts through the production of eco-efficient materials, the application of the ashes of sanitary sewage sludge as a partial substitute for Portland cement is currently being used as a coating mortars study. This replacement has a focus, besides reducing the large volume of sludge generated by Sewage Treatment Plants, to allow an attenuation in the consumption of cement, a large CO_2 generator during its manufacturing process. It could be observed that the use of the calcined residue applied in mortar, ratifies a relevant physical-mechanical performance to the material, which compared to the material without the use of it, has better results coming from its reactivity provided by action of the thermal process of degradation.
Keywords: Sewage sludge ash; Coating mortars; Mechanical behavior.

Resumo
Através das políticas ambientais que proporcionam uma paulatina discussão a respeito da destinação dos rejeitos produzidos nos mais diversos setores industriais, o lodo de esgoto é posto em ênfase pela problemática destinação advinda da quantidade de compostos tóxicos que o compõe, comprometendo o seu descarte. A partir da necessidade de implantar medidas mitigadoras dos impactos ambientais através da produção de materiais ecoeficientes, utiliza-se atualmente como estudo, em argamassas de revestimento, a aplicação das cinzas do lodo de esgoto sanitário como substituto parcial do cimento Portland. Essa substituição possui enfoque, além da redução do grande volume de lodo gerado pelas Estações de Tratamento de Esgoto, de possibilitar uma atenuação no consumo de cimento, um grande gerador de CO_2 durante seu processo de fabricação. Pôde-se observar que por meio do uso do resíduo calcinado aplicado em argamassas, ratifica-se uma relevante performance físico-mecânica ao material, que comparando ao material sem o uso do mesmo, possui melhores resultados advindos da sua reatividade proporcionada mediante ação do processo térmico de degradação.
Palavras-chave: Cinzas do lodo de esgoto; Argamassas de revestimento; Comportamento mecânico.

Resumen
A través de políticas ambientales que propicien una discusión gradual sobre el destino de los residuos producidos en los más diversos sectores industriales, los lodos de depuradora se enfatizan por el destino problemático derivado de la

cantidad de compuestos tóxicos que los componen, comprometiendo su disposición final. Partiendo de la necesidad de implementar medidas para mitigar los impactos ambientales a través de la producción de materiales ecoeficientes, actualmente se utiliza como estudio en morteros de revestimiento la aplicación de cenizas de lodos de depuradora sanitaria como sustituto parcial del cemento Portland. Esta sustitución tiene como objetivo, además de reducir el gran volumen de lodos generados por las Estaciones Depuradoras de Aguas Residuales, permitir una atenuación en el consumo de cemento, importante generador de CO_2 durante su proceso de fabricación. Se pudo observar que, mediante el uso del residuo calcinado aplicado en morteros, se ratifica un comportamiento físico-mecánico relevante al material, el cual, comparado con el material sin el uso del mismo, tiene mejores resultados derivados de su reactividad proporcionada por la acción de la temperatura de degradación del proceso.
Palabras clave: Cenizas de lodos de alcantarillado; Morteros de revestimiento; Comportamiento mecánico.

1. Introduction

Accelerated population growth and lack of infrastructure to accompany such growth generate problems related to basic sanitation, as it causes an increase in sludge production in treatment plants.

The production of sludge can be considered a problem of sanitation, due to the population growth that increases its production, and due to the growing demand of area for its final disposal environmentally adequate. Planning the final disposal of sewage sludge from Sewage Treatment Stations – STSs, requires technical and environmental knowledge and there are economic issues that guide the absence of this practice. According to Von Sperling et al., (2001), the processing and final disposal of sludge can represent up to 60% of the operational cost of an STS.

STSs have been looking for recycling solutions for the sludge generated in their treatment processes, as in some cities in Brazil the generated sludge is discarded in sanitary landfills, treatment plants (when they have it), and in some, it is only discarded due to problems related to the lack of basic sanitation that complies with current environmental regulations.

Fávero (2009) states that the environmental impact caused by the extraction of materials is increasing and their availability becomes less and less over time, in addition to the damage caused to nature, which is irreversible. To reduce this impact, the solution would be to use waste that is abundantly disposed. Furthermore, according to Cunha Oliveira, Meira & Chagas (2021), the strands of studies for unconventional materials nowadays emerge from the need to seek to cover, through laboratory studies, the creation of mechanisms that favor the realization of such a claim.

The sanitary landfills used for the destination of sewage sludge, make available a lot of area, causing deforestation, and harming the ecological balance of the region, since when receiving the sludge, the area hardly recovers its previous composition of fauna and flora.

A proposal to alleviate the problem about sewage sludge would be the introduction of techniques that seek its use through its insertion in the mortar, where the use of cement would be reduced, evaluating performance and potential of adhesion to the masonry substrate and traction in bending, which are some of the parameters of fundamental importance to ratify the final viability of the residue with application on a large scale. According to Cunha Oliveira et al., (2021a), the design of studies that seek to incorporate the eco-efficient potential into conventional materials is becoming increasingly present due to the considerable increase in the consumption of non-renewable raw materials.

Data from the National Cement Industry Union - SNIC (2012), indicate that in Brazil the consumption of cement exceeded the mark of 69 million tons. Linked to production and consumption, it is estimated that about 5% of all carbon dioxide production, which is highly polluting, originates directly from the cement industry (Damtoft et al., 2008). In absolute terms, more recent estimates point to a total volume of emissions in the order of 2.3 billion tons of CO_2 (IEA, 2012).

In this way, any measure aimed at reducing cement consumption will be of great help to the environment, in order to reduce the possible impacts generated to it. Given this context, research in various sectors is being developed seeking solutions that minimize design and environmental impacts and maximize the conservation of natural resources resulting from the use and production of materials and components used in the various stages of civil construction. According to Cunha Oliveira et al.,

(2021b), in view of the technological advances that the civil construction sector is immersed in, measures that can improve and bring benefits to the technical applications developed in each specified case are being increasingly palatable, with plausible solutions based on the needs arising in practice.

Therefore, the use of waste can be considered as a practice for sustainability in civil construction, and the use of sewage sludge ash from sewage treatment plants is an alternative for the final destination of this waste that in the urban environment is constituted today in an environmental problem faced by sanitary engineering, as they are generated daily and in large volume.

The insertion of residues in executive processes of civil construction is a way of minimizing the environmental impacts caused by the industry due to the use of so many natural resources, because according to Agopyan (2000), in the civil construction industry, the production of cement and concrete, due to high volumes, it has been a major consumer of waste, fulfilling the role of neutralizing materials that, if left in nature, would be harmful.

In this context, a sector that has enormous potential to contribute to the minimization of environmental problems using waste is the civil construction industry, since through the emphasized literature, there are several solutions for it to incorporate waste in its stages, and one of the possibilities of including sewage sludge is through its calcination so that it can be used in coating mortars, replacing Portland cement. According to Cunha Oliveira et al., (2021), this measure would directly impact the reduction of the amounts of Portland cement in cement-based compositions, which contributes to the reduction of the carbon footprint and sustainable development, due to the pozzolanic behavior presented by the sewage sludge after its calcination.

2. Methodology

As a methodology, a bibliographic search was carried out in the main scientific databases (ScienceDirect, Google Scholar, and Scielo), about the types of ecological concrete developed in Brazil and in the world, and ways of applying this unconventional technology. Thus, the ideas advocated at the beginning of this study will be explained according to the types of concretes that have practical application potential, according to each study location, as well as before the respective solid residues that are adopted as renewable inputs in their compositions (Cunha Oliveira, 2020).

3. Theory

In view of the technological advances that the civil construction sector is immersed in, measures that can provide innovation, economy, and less environmental impacts due to the use of natural resources are being increasingly popular.

The need for innovation in products and processes arising from construction activities due to the environmental impacts caused is directly linked to studies related to the use of alternative materials, as efforts to reduce environmental impacts due to the use of natural resources must be focused on the use of materials and components that provide the improvement of the quality of the works, in the reduction of energy consumption, in the reduction of the execution time of the activities related to the constructive stages, in the reduction of costs, in the reduction of waste, as well as in sustainability, making the project efficient.

Law nº 12.305 (2010) clarifies the prevention and reduction of waste generation, having as a proposal, the practice of sustainable consumption habits and a set of instruments to promote the increase of recycling and reuse of solid waste and the destination environmentally sound waste, that is, what cannot be recycled or reused. The Law is the basis of the Política Nacional de Resíduos Sólidos (PNRS), which, in terms of its guidelines, establishes the shared responsibility of waste generators, so that the destination of each waste is environmentally appropriate.

Law nº 11.445 (2007) establishes national guidelines for basic sanitation and for the federal basic sanitation policy; priority in government procurement and contracting for recycled and recyclable products and goods, services and works that consider criteria compatible with socially and environmentally sustainable consumption patterns; integration of collectors of reusable and recyclable materials in actions involving shared responsibility for the life cycle of products; encouraging the implementation of the product life cycle assessment; encouraging the development of environmental and business management systems aimed at improving production processes and reusing solid waste, including energy recovery and use, and encouraging environmental labeling and sustainable consumption.

According to Moura (2000), the concern with the serious problem of waste generation is increasingly raising awareness in society of the need to carry out studies with a view to improving the production cycle and adapting the destination of waste generated.

There are countless residues from urban activities that have not yet been studied for use in the construction industry and that have a great potential for reuse/recycling, minimizing their disposal in nature, one of them is the sewage sludge generated in STSs, because its application in agriculture is a practice used worldwide with abundant studies, but for the feasibility of use in the construction industry, studies need to be expanded.

The insertion of calcined sludge in the construction industry provides advantages such as: the reduction of the volume of waste in sanitary landfills, since its production is considered problematic due to the large amount of daily production; reducing the risk of contamination to the environment, as not all sludge produced is stored in environmental compliance; reducing the use of Portland cement, which is considered one of the biggest polluters of the environment due to its manufacturing process that emits large amounts of CO_2 into the air.

According to what was mentioned above, it can be observed that there is relevance in the studies of materials that make up the range of so-called sustainable in the sphere of civil construction at an international level, and thus, the state of the art regarding industrial by-products applied in materials of cement matrix, it becomes more supported and with greater perfection in the results expressed by each study made.

4. Discussion

The high energy consumption of industrialized materials favors the study of actions to plan the reuse of waste. Among the urban waste, one of the most problematic is that generated in the domestic sanitary sewage treatment processes, the so-called Sludge from Sanitary Sewage Treatment Stations. According to Cunha Oliveira et al., (2021), sludge production can be considered as a sanitation problem, due to the population growth that increases its production, implying an increasing demand for area for its environmentally adequate final disposal.

The reuse of the generated logo in STSs was tested in some scientific works; in relation to the insertion of sludge, it contributed to a 5% increase in resistance in compression tests, in addition to reducing production costs (Cordeiro, 1993).

Brosch et al., (1976), produced the first lightweight aggregates using sewage sludge. The sewage sludge from this study was first used in its raw state and then crushed and dehydrated from the Pinheiros Treatment Station, in the city of São Paulo. The process used was sintering, which consisted of the following steps: drying the sludge; pelletizing and transformation into lightweight aggregates through sintering, where the agglomerates are calcined by self-combustion. The quality of these aggregates was considered satisfactory in terms of abrasion resistance and mechanical resistance to crushing.

The sewage sludge produced in the city of Londrina was used to produce light aggregate. From the studies carried out, it was possible to conclude that the final product presented characteristics compatible with the requirements and criteria established by the Brazilian specifications regarding the production of concrete elements for masonry, production of structural concrete or for thermal insulation (Morales & Agopyan, 1992).

The researchers from the Instituto de Pesquisa Tecnológica (IPT) carried out experimental research on the use of digested sludge from the STS in Pinheiros - São Paulo, and obtained a material that, after crushing, was classified within the specifications of light aggregate for industrial use. of civil construction, with jobs in concrete structures, thermal insulation, filling of voids, prefabrication of buildings and blocks for masonry and floors. A semi-industrial facility, whose project was developed by Brazilian companies, was installed next to WQRS Leopoldina (Water Quality Recovery Station), with mechanical and electrical components of national manufacture, and was in operation from June until the end of 1989 (Santos, 2003).

The light aggregate production process, from sludge from sewage, went through the following unit operations: sludge dehydration; post-drying of the centrifuged sludge; dosing and mixing of components; pelletizing; drying the pellets by fluidized bed; sintering (Brosch et al., 1976).

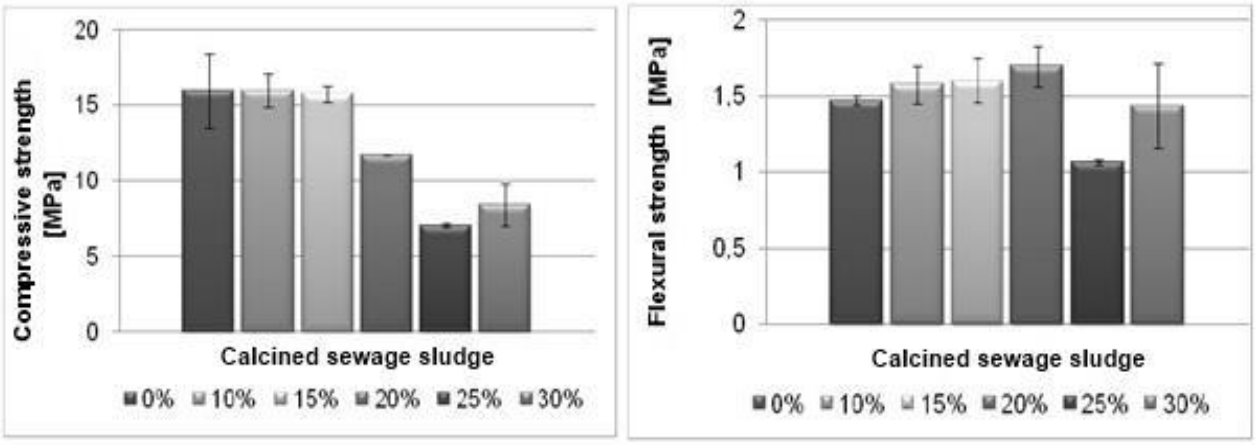
Onaka (2000) tested sludge processing for nine consecutive months in a cement factory, with good results. The process began with the drying of the sludge, transforming it into pellets, while conserving its content of organic matter and energy. These pellets, from 2 to 10 mm in diameter, were thrown into the kiln along with the rest of the cement raw material. The organic matter was used as a complementary source of heat and the inorganic part integrated the clinker. The traces of heavy metals were fixed at levels even more diluted in the cement mass. Gas monitoring and product quality control did not indicate any change in relation to the values without the use of sludge. The results revealed that the incorporation of 2% of dry sludge as a raw material in clinker kilns would allow consuming all the sludge generated in Japan.

It is observed that, for the evaluation of materials that promote the incorporation of the calcined residue in their composition, they denote balanced behavior in front of the tests with artifacts without the residue, which from previous studies can enable an effective application of an unconventional material with satisfactory properties, in addition to having eco-efficient potential.

4.1 Mechanical Performance

It was verified that the parameters used in the feasibility study to apply the sewage sludge in construction materials, show effective results of the application. Simoka, Reis & Boni (2016), when evaluating the application of sewage sludge in mortars, concluded that, through physical tests for the hardened state of the material, such as the performance of axial compression and flexural traction, in up to 15% of use, there is no damage to the material, being able to incorporate the sewage sludge calcined at 850°C and 3 hours of isotherm, to the mixture (Figure 1):

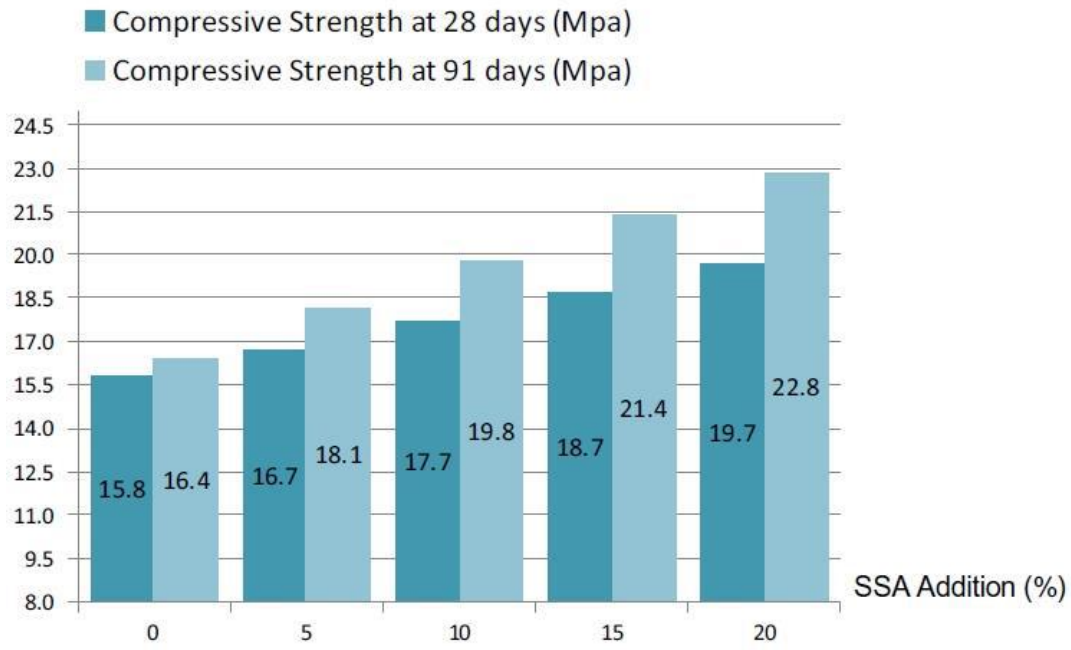
Figure 1 – Physical-mechanical analysis of mortars with calcined sewage sludge.



Source: Simoka et al., (2016).

Costa (2014), when incorporating the ash from the sewage sludge, calcined at a temperature of 850°C for 3 hours, in mortar as a mineral addition, realized that the percentage of 20% becomes ideal for application based on an analysis of all the parameters analyzed, corroborating even more satisfactory results when compared with the sludge-free mortar for the axial compression tests (Figure 2).

Figure 2 – Compressive strength of mortars at 28 and 91 days with SSA.



Source: Costa (2014).

Furthermore, Cunha Oliveira et al., (2020), evaluated the use of calcined SSA at 600°C and 700°C, incorporated in coating mortar in percentages of 10%, 20% and 30%, and evaluating the mixtures in terms of flexural strength, and adhesion to the masonry substrate. The authors concluded that both temperatures contribute to the SSA becoming reactive enough to be pozzolanic, a factor directly reflected in the increase in the flexural strengths and the adhesion of mortars, with emphasis on 700°C, which produces more dehydroxylated amorphous structure, that is, more reactive, so the resistance values are higher for the temperature of 700°C.

4.2 Eco-cement

In studies that aimed to apply the technique of developing an eco-cement, such as Yen et al., (2011), the compressive strengths and microstructural evaluations carried out at 28 days revealed the applicability of this new binder, involving during the manufacturing process, sewage sludge to replace limestone, the main raw material used in the world to obtain Portland cement. At levels of up to 50% of limestone replacement, it was possible to verify that the cement manufacturing products that form the clinker produce hydrated phases with an increase in the densification of the mixture as the material curing advances.

In view of the mechanical performance of the pastes where they tested the eco-cement, the authors noticed that the clinker composition with total use of the raw sewage sludge residue with sludge from the water treatment plant, reached strengths of the order of more than 100 MPa, while the reference mixture ranged from 85 to 90 MPa of strength at 28 days of hydration.

Lin and Lin (2005) also studied the feasibility of eco-cement with raw sewage sludge composing the matrix of Portland cement manufacturing products, which for additions of up to 20% of the material to replace the raw material, superior results are obtained. to those obtained with conventional cement. Furthermore, the production of Anhydrous cement compounds showed better compressive strengths at 90 days of hydration compared to the trace with 0% sewage sludge residue, reaching more than 100 MPa, with the reference in the range of 90 MPa.

In the studies by Malliou et al., (2007), a viable alternative was sought for the final disposal of sewage sludge from urban sewage treatment plants, using it as an additive for the development of cement-based materials, evaluating the flexural traction of mortars at 28 days of hydration mapping the originating products in the curing phase of the material through x-ray diffraction and scanning electron microscopy. The authors realized that, through the application of the residue, stabilizing and solidifying it in the mixture and applying calcium chloride and calcium hydroxide with accelerating additives in the hydration process, the compressive strength is improved, since this addition has a positive effect. The best results were observed for the samples containing 3% $CaCl_2$ and 2% $Ca(OH)_2$, through the equivalence in the amounts of cement and sewage sludge added, producing satisfactory properties for an eco-cement that used additives for the immediate advance in the production of the hydrated phases of the mortars.

5. Conclusion

Noting that there is total applicability of sewage sludge, both in its dehydrated raw state and its ashes from the calcination process, it was observed that in several locations, they seek to optimize the production process of unconventional materials from the most applied in everyday life, that through tests to evaluate the mechanical behavior of materials in specific compositions, it is possible to develop on a large scale products that have superior properties in terms of durability and useful life of buildings, comparing with the conventional sayings used worldwide.

It was possible to observe that data on axial compressive strength, and flexural tensile strength, obtained by the aforementioned studies, denoted full potential of applicability for calcination temperatures at 850°C with an isothermal time of 3 hours, producing an amorphous and reactive structure. to bring to the materials that have cement in their composition, a considerable advance in the evaluated properties.

Eco-cement acts in a similar way to the addition of sludge in mortars, contributing in a unique way compared to the direct insertion in the composite, but which is of fundamental importance to pay attention to the reduction of the use of raw materials such as limestone and clay, which are fundamental in obtaining Portland cement, but which lead to environmental problems such as the production of desertified spaces, erosion and drastic modification of the geographic space, involving the local fauna and flora.

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