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Application of sugarcane bagasse ash in mortars: systematic literature review

APLICAÇÃO DA CINZA DO BAGAÇO DE CANA-DE-AÇÚCAR EM ARGAMASSAS: REVISÃO SISTEMÁTICA DA LITERATURA

APLICACIÓN DE CENIZAS DE BAGAZO DE CAÑA DE AZÚCAR EN MORTEROS: REVISIÓN SISTEMÁTICA DE LA LITERATURA

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Abstract
To reduce the environmental impacts of civil construction and agro-industry, the sustainable development of construction materials through the reuse of sugarcane bagasse ash (SCBA) is a topic of scientific evaluation. This research aims to conduct a systematic literature review on the use of SCBA in mortars, a material thoroughly used in various stages of a building. Its method was guided by three evaluation phases: bibliometric research, scientometric analysis and systematic analysis, and it was possible to weigh up the main themes addressed by the scientific community on the topic in 75 publications: the verification of the pozzolanic activity, the SCBA performance as an alkali-activated material, and the evaluation of the behavior of general mortar properties with the partial substitution of Portland cement or fine aggregate for SCBA. To direct future works, in the publications of the period studied, in general, the authors used the cement replacement range of 10% to 20% for SCBA to guarantee the equivalence of compressive strength in mortars. In addition, they showed improvements in their durability thanks to the filler effect given by the ash, demonstrating the potential of using this residue sustainably, even indicating the possibility of reducing CO_2 emissions by reducing the production of Portland cement.

Keywords: ash; bagasse; sugarcane; mortar.

Resumo
A fim de reduzir os impactos ambientais causados pela construção civil e pela agroindústria, o desenvolvimento sustentável de materiais de construção por meio da reutilização da cinza do bagaço da cana-de-açúcar (CBCA) torna-se um importante tópico de avaliação científica. Dessa forma, o objetivo desta pesquisa é realizar uma revisão sistemática da literatura sobre a utilização da CBCA em argamassas, materiais amplamente utilizados em diversas etapas de uma edificação. O método adotado foi estruturado em três fases de avaliação: pesquisa bibliométrica, análise cienciométrica e análise sistemática, permitindo o exame de 75 publicações que indicam que os principais temas abordados na comunidade científica sobre o tópico incluem a verificação da atividade pozolânica, o desempenho da CBCA como material álcali-ativado e a avaliação do comportamento das propriedades gerais das argamassas com a substituição parcial de cimento Portland ou agregado fino por CBCA. Observou-se que, em geral, direcionar os próximos estudos para a faixa de substituição de cimento de 10% a 20% por CBCA assegura a equivalência de resistência à compressão em argamassas, além de demonstrar melhorias em sua durabilidade em virtude do efeito filler proporcionado pela cinza. Isso evidencia o

potencial de utilização desse resíduo de maneira sustentável e sugere até mesmo a possibilidade de reduzir a emissão de CO_2 pela diminuição da produção de cimento Portland.

Palavras-chave: cinza; bagaço; cana-de-açúcar; argamassa.

Resumen

Con el fin de reducir los impactos ambientales de la construcción civil y la agroindustria, el desarrollo sostenible de materiales de construcción mediante la reutilización de las cenizas de bagazo de caña de azúcar (CBCA) se convierte en un importante tema de evaluación científica. Por lo tanto, el objetivo de esta investigación consiste en llevar a cabo una revisión sistemática de la literatura sobre la utilización de la CBCA en morteros, materiales ampliamente utilizados en diversas etapas de una edificación. Su método es guiado por tres fases de evaluación: investigación bibliométrica, análisis cienciométrico y análisis sistemático, y fue posible ponderar en 75 publicaciones que los principales temas abordados en la comunidad científica sobre el tema son: la verificación de la actividad puzolánica, el desempeño del CBCA como material álcali-activado y la evaluación del comportamiento de las propiedades generales de los morteros con la sustitución parcial del cemento Portland o del agregado fino por CBCA. Se encontró que en general, para orientar futuros trabajos, en el rango de sustitución de cemento en un 10% a 20% por CBCA, se garantiza la equivalencia de resistencia a la compresión en morteros, además de mostrar mejoras en su durabilidad gracias al efecto filler proporcionado por la ceniza, demostrando el potencial de utilización de ese residuo de forma sostenible, indicando incluso la posibilidad de reducir la emisión de CO_2 mediante la disminución de la producción de cemento Portland.

Palabras clave: ceniza; bagazo; caña de azúcar; mortero.

Introduction

In times of concern for environmental preservation and sustainability, the large volume of waste generated by agro-industrial production draws attention because it constitutes potential markets to be explored, either as alternative sources or by-products, to minimize the impacts caused by the wrong disposal of such waste. In Brazil, the sugar and alcohol industry stands out due to its strong presence nationwide and government incentives for energy production from renewable sources. Alcarde (2015) highlights the main residues produced by the sugar and alcohol industry: bagasse and its ash, straw, filter cake, vinasse, and wastewater from sugarcane washing, all reusable. Because it depends directly or indirectly on the environment in which it operates, the productive sector of agribusiness benefits from the search for applications and adding value to the waste it generates.

According to the Brazilian Institute of Geography and Statistics (IBGE). Brazil's average sugarcane productivity in 2019 was 74.68 tons per hectare. In the municipality of Jataí, approximately 25,000 hectares were allocated for sugarcane cultivation, resulting in a total production of 3,000,000 tons and an impressive yield of 120 tons per hectare (IBGE, 2020). A substantial portion of this productivity can be attributed to Raízen, which positions itself as the leading producer of sugarcane ethanol in the nation and is committed to sustainable development.

According to Pinheiro (2015), after arriving at the industrial unit, the sugarcane goes through the juice extraction process to start the formation of sugar and ethanol. The juice is separated, and the plant needs to deal with an abundant amount of sugarcane bagasse, which, according to the author, is the main agroindustrial waste produced. Bagasse is burned in cogeneration boilers, defined as "the combined production of thermal and potential energy, mechanical or electrical, with the use of energy released by the same primary source of fuel, whatever the thermodynamic cycle" (Savastano, 2000).

In this context, ash is a by-product resulting from the combustion of sugarcane bagasse after its juice has been fully extracted. In the production of ethanol and sugar, energy generation in plants or distilleries involves burning sugarcane bagasse. As a result, ash is the largest type of residue produced (Oliveira; Barros, 2017). During the process of using biomass in steam production and energy cogeneration, residual ash from sugarcane bagasse is formed, tipically without control over the burning conditions. According to Cordeiro (2006), higher temperatures and longer exposure times during combustion lead to better control over the burning process, resulting in a greater the release of carbon, which can cause variations in the color of the ash. Despite the sustainability achieve through energy production from bagasse combustion, the resulting ash from this process often lacks proper disposal methods.

The carbon content in ash, along with the temperature and burning time of sugarcane bagasse, influences the formation of various silica phases, which can be either amorphous or crystalline. According to Cordeiro (2006), ash that containing silicon dioxide (SiO_2) in an amorphous structure possesses chemical and physical properties that can enhance pozzolanic activity.

Recent studies have demonstrated that pozzolanic activities are present in sugarcane bagasse ash (SCBA) when it is burned at high temperatures and under specific conditions, as noted by Joshaghani and Moeini (2018). In their research, the authors demonstrate that using ash as a partial replacement for cement improves the workability of mortars. Additionally, they found that these mortars achieve compressive strength parameters comparable to those of the control mortar that does not include ash as a partial cement replacement.

Among the various cementitious materials, mortars are usually applied in laying blocks, constructing walls, creating subfloors, and installing ceramic tiles. Mortars are primarily characterized by their adhesion and hardening properties. They are produced by thoroughly mixing one or more binders, fine aggregate (such as sand), and water, and may also contain additives and mineral supplements (Carasek, 2010). This research focuses on one specific application of mortar: its performance when incorporating sugarcane bagasse (SCBA) collected directly from the boilers of a sugar and alcohol plant.

Thus, throughBy conducting a systematic literature review that focuses on the keys findings regarding the use of Sugarcane Bagasse Ash (SCBA) in mortars, it will be possible to analyze the main research topics on the application of SCBA in mortars. Additionally, this review will help identify current research gaps concerning the use of SCBA in mortars and provide guidance for future research into the use of SCBA in civil construction.

Methodology

This study was conducted through a systematic literature review to map the existing knowledge on the topic at hand, with the goal of identifying research instances subsequently guiding future studies in the field (Yin *et al.*, 2019). Figure 1 illustrates the workflow of this study. The research methodology was structured around three evaluation phases: bibliometric research, scientometric analysis, and systematic analysis.

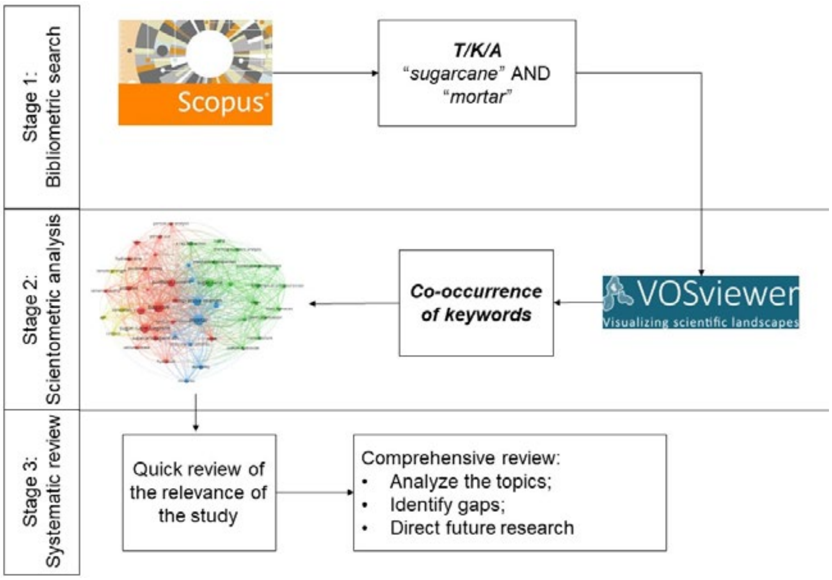

Figure 1. SCBA review workflow for use in mortars
Source: Own Author.

The initial step involves selecting an appropriate literature database. For this study, the authors chose Elsevier Scopus, as it is considered the best option for research topics in engineering.Scopus offers more recent publications and faster indexing compared to other database (Hosseini *et al.*, 2018; Mongeon; Paul-Hus, 2016; Yin *et al.*, 2019). The keywords used in the Scopus search were "sugarcane" and "mortar, aiming to gather relevant works that addressed the use of sugarcane bagasse ash" (SCBA) in mortars.

The VOSviewer is a text mining tool used for scientometric analysis, designed to generate the visualization maps in the research domain of SCBA in mortars. The maps produced by VOSViewer take into account the distance between nodes, which reflect the thematic proximity among them (Oraee *et al.*, 2017). The VOSViewer received the data downloaded from Scopus to create a network of keywords, enabling a bibliometric analysis process through a network of co-occurrences that illustrates the relationship among publications. The software also focuses on identifying in which spheres the studies are following and their main points, in which it can facilitate qualitative discussions and research approaches by defined categories (Park; Nagy, 2018). Terms with at least 20 occurrences in the title, abstract, and keywords are extracted from the selected works and filtered using the VOSViewer software to obtain the most meaningful terms.

For the systematic analysis, they used the groupings found in VOSviewer with the keywords based on co-occurrences. The words are clustered according to frequency which they appear together in the same document. Each defined group is referred to as a cluster, reflecting a specific theme and approach related to the proposition under study (Park; Nagy, 2018). From the clusters, the software produces a co-occurrence map, illustrating the main terms found and the relationship among them, analyzing a range of publications in an automated way, in a way that allows the presentation results in a systematized manner. The relevant studies were identified by reviewing the titles and abstracts of the articles, focusing on their themes and results, in order to explore more effective methodologies for the application of SCBA in mortars.

Results

Bibliometric analysis

In this stage, all works published on the researched topic were considered. A total of 75 papers were identified,which included journal articles, conference proceedings, review, and book chapter. It is also possible to observe that the number of studies in this area has increased in recent years (Figure 2).

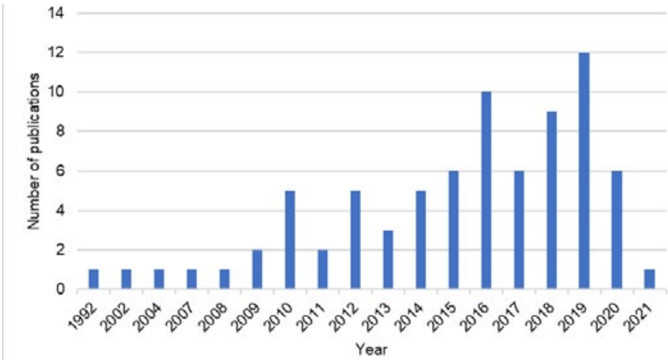

Figure 2. Annual publications
Source: Own Author.

Scientometric analysis – keyword network

The initial bibliographic research revealed several studies involving the use of SCBA in mortars. This diversity was illustrated through a bibliometric map of keywords obtained by the text-mining software VOSViewer. Figure 3 illustrates the clustering of 774 terms obtained by co-occurrences of keywords from the 75 publications analyzed up until October 2020.

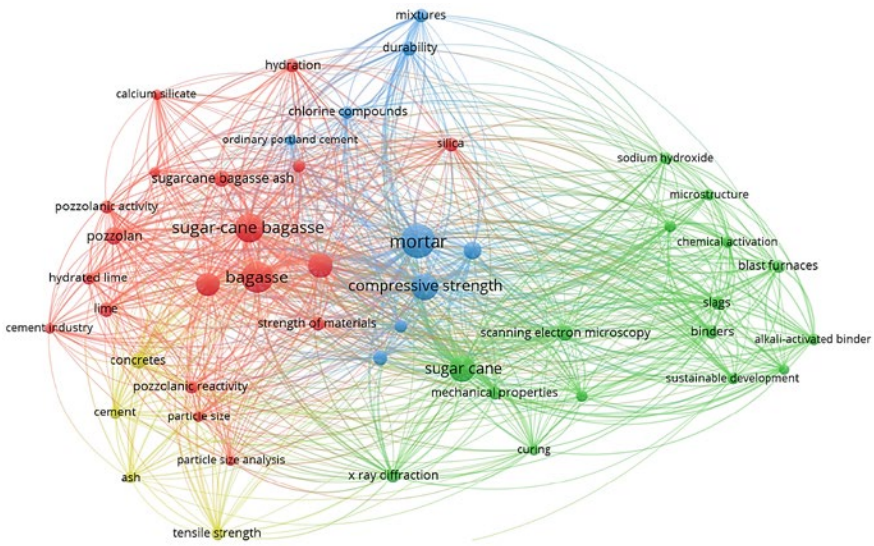

Figure 3. Bibliometric map of Keywords
Source: Own Author.

In this scientific panorama obtained, four clusters were identified, each represented by distinct colors. These colors correspond to various lines of research focused on the application or partial replacement of SCBA in cement mixtures. The initial classification of the reviewed works from the Elsevier Scopus system was conducted by reading the abstracts. At this stage, 12 publications were excluded due to their lack of relevance to the topic at hand, and thus were not included in the development of this research. Table 1 presents a summary of each cluster along with their respective main themes, which were defined through a manual examination of the associated keywords and their, co-occurrences frequency.

Cluster color	Research topic	Main keywords observed	Number of keywords	Quantitative of publications
Red	pozzolanic activity	*Sugarcane bagasse ash, pozzolanic activity, sílica, particle size, agricultural wastes*	19	21
Green	Alkali-activated binders	*Sugarcane, mechanical properties, alkali-activated binders, sustainable development, curing*	16	8
Blue	Mechanical properties in mortars	Mortar, compressive strenght, sugarcane bagasse ash, partial replacement, durability	9	22
Yellow	Use in concrete	*Ash, cement, concretes, tensile strength*	4	12

Table 1 - Scientific perspective of publications
Source: Own Author.

Systematic analysis

The red cluster explored the theme of investigating the pozzolanic activity of SCBA (Table 2). Its methods include forms to identify how ash responds to different forms of treatment in terms of pozzolanicity to obtain the best properties for its use as a pozzolan in partial replacement of Portland cement in mortars. Overall, the authors demonstrate the significance of particle size and fineness in enhancing pozzolanic activity., In addition, they also highlight the improvements observed in the physical-chemical characteristics of the tested mortars and how they obtain equivalences or mechanical advantages of resistance and durability and the possibility of environmental advantages in the reduction of CO_2 emissions by reducing the amount of cement used and consequently produced (Cordeiro; Toledo Filho; Almeida, 2011; Jagadesh; Ramachandra Murthy; Murugesan, 2020; Maldonado-García *et al.*, 2018; Torres *et al.*, 2020).

Author (year)	Title
Torres *et al.* (2020)	Evaluating the pozzolanic activity of sugarcane bagasse ash using X-ray diffraction
Jagadesh, Ramachandra Murthy and Murugesan (2020)	Impact of processed sugar cane bagasse ash on mechanical and fracture properties of blended mortar
Braz *et al.* (2019)	The impact of Aluminum Recycling Waste Addition on the Pozzolanic Activity of Sugarcane Bagasse Ash and Zeolite
Cordeiro, Andreão and Tavares (2019)	Pozzolanic properties of ultrafine sugarcane bagasse ash produced through controlled burning
Pereira *et al.* (2018)	Valorisation of sugarcane bagasse ash (SCBA) with high quartz content as a pozzolanic material in Portland cement mixtures
Frías *et al.* (2017)	Advances on the development of ternary cements elaborated with biomass ashes from different activation processes.
Arif, Clark and Lake (2016)	Sugarcane bagasse ash from a high-efficiency co-generation boiler: Applications in cement and mortar production

Rodríguez *et al.* (2016)	Reserarch on the Puzzolanic effect of sugarcane bagasse ash from Taretan, Michoacán, Mexico, on a portland cement mortar
Bonilla *et al.* (2016)	Study of pozzolanic properties of two sugarcane bagasse ash samples from Honduras
Embong *et al.* (2016)	Effectiveness of low-concentration acid and solar drying as pre-treatment features for producing pozzolanic sugarcane bagasse ash
Moraes *et al.* (2015)	Assessment of sugar cane straw ash (SCSA) as pozzolanic material in blended Portland cement: Microstructural characterization of pastes and mechanical strength of mortars
Rodrigues *et al.* (2015)	Biomass ashes as supplementary cement materials and their effects on the structure and properties of mortars and concretes
Thorstensen (2015)	Processing of sugar cane bagasse for making it Pozzolanic
Ribeiro and Morelli (2014)	Effect of calcination temperature on the pozzolanic activity of Brazilian sugar cane bagasse ash (SCBA)
Chi (2012)	Effects of sugar cane bagasse ash as a cement replacement on properties of mortars
Bentz, Durán-Herrera and Galvez-Moreno (2012)	Comparison of ASTM C311 strength activity index testing versus testing based on constant volumetric proportions
Cordeiro, Toledo Filho and Almeida (2011)	Influence of ultrafine wet grinding on pozzolanic activity of submicrometre sugar cane bagasse ash
Guzmán *et al.* (2011)	Pozzolanic evaluation of the sugar cane leaf
Cordeiro *et al.* (2008)	Pozzolanic activity and filler effect of sugar cane bagasse ash in Portland cement and lime mortars
Frías, Villar-Cociña and Valencia-Morales (2007)	Characterisation of sugar cane straw waste as pozzolanic material for construction: Calcining temperature and kinetic parameters
Mehrotra and Masood (1992)	Pozzolanic behaviour of bagasse ash: A derivative of sugar cane distillation, bagasse ash, has properties that might be suitable for use in building materials

Table 2 - Publications included in the red cluster: pozzolanic activity
Source: Own Author.

The green cluster has identified an approach of methods and solutions to eliminate the use of cement as a binder in mortars, replacing cement entirely with different proportions of blast furnace slag (BFS) and SCBA, known as alkali-activated binders. Through the chemical composition of the ash, the authors evaluated physical assessments of its particles and its different alkaline activating solutions in composition and proportion; They investigated how these substitutions influenced the properties of the mortars. Satisfactory results of development or equivalence of strength, reduced shrinkage, and improved durability when compared to common Portland cement mortars and mortars using only BFS as a binder, indicating one more use for these residues. Table 3 displays the papers included in this cluster.

Author (year)	Title
Akbar *et al.* (2021)	Sugarcane bagasse ash-based engineered geopolymer mortar incorporating propylene fibers
Moraes *et al.* (2018)	Optimum use of sugar cane straw ash in Alkali-activated binders based on blast furnace slag
Kazmi *et al.* (2017)	Pozzolanic reaction of sugarcane bagasse ash and its role in controlling alkali silica reaction
Moraes *et al.* (2017)	Effect of sugar cane straw ash (SCSA) as solid precursor and the alkaline activator composition on alkali-activated binders based on blast furnace slag (BFS)
Moraes *et al.* (2016)	Possibilities of reusing sugar cane straw ash in the production of alternative binders

Pereira *et al.* (2015)	Mechanical and durability properties of alkali-activated mortar based on sugarcane bagasse ash and blast furnace slag
Castaldelli *et al.* (2014)	Preliminary studies on the use of sugar cane bagasse ash (SCBA) in the manufacture of alkali activated binders
Castaldelli *et al.* (2013)	Use of slag/sugar cane bagasse ash (SCBA) blends in the production of alkali-activated materials

Table 3 - Publications included in the green cluster: alkali-activated binders
Source: Own Author.

In the blue cluster, there was a greater diversity of themes that sought to evaluate the properties of the mortars obtained with the use of SCBA, whether in partial replacement of cement or even as a fine aggregate. Table 4 shows the classification of 22 titles. There were works focused on evaluating the effects caused by the presence of ash in only one characteristic, such as porosity by Moretti *et al.* (2018), durability by Jiménez-Quero, Ortiz-Guzmán and Montes-García (2019), and hydration by Moura *et al.* (2019) or even with a broader look at the various properties of mortars as in Maldonado-García *et al.* (2018), Kusbiantoro, Embong and Aziz (2018), Macedo *et al.* (2014) among others. The majority of studies within this cluster reported positive outcomes regarding the incorporation of SCBA in mortars, based on the evaluated physical-chemical attributes.

Author (year)	Title
Balapour, Zhao and Joshaghani (2020)	Empirical correlation between mortars mechanical and durability tests with different cementitious materials replacements
Praveenkumar, Sankarasubramanian and Sindhu (2020)	Selecting Optimized Mix Proportion of Bagasse Ash Blended Cement Mortar Using Analytic Hierarchy Process (AHP)
Moura *et al.* (2019)	The influence of calcium-rich environments in siliceous industrial residues on the hydration reaction of cementitious mixtures
Jiménez-Quero, Ortiz-Guzmán and Montes-García (2019)	Durability of mortars containing sugarcane bagasse ash
Jagadesh *et al.* (2019)	Adaptability of Sugar Cane Bagasse Ash in Mortar
Maldonado-García *et al.* (2019)	Long-term corrosion risk of thin cement composites containing untreated sugarcane bagasse ash
Martins Filho *et al.* (2019)	The use of residues of civil construction and ashes from sugar cane bagasse for the production of finishing mortar
Joshaghani and Moeini (2018)	Evaluating the effects of sugarcane-bagasse ash and rice-husk ash on the mechanical and durability properties of mortar
Moretti *et al.* (2018)	Pore size distribution of mortars produced with agroindustrial waste
Maldonado-García *et al.* (2018)	The influence of untreated sugarcane bagasse ash on the microstructural and mechanical properties of mortars
Kusbiantoro, Embong and Abd Aziz (2018)	Strength and microstructural properties of mortar containing soluble silica from sugarcane bagasse ash
Joshaghani and Moeini (2017)	Evaluating the effects of sugar cane bagasse ash (SCBA) and nanosilica on the mechanical and durability properties of mortar
Bezerra *et al.* (2017)	Effect of partial replacement with thermally processed sugar cane bagasse on the properties of mortars
Maldonado-García, Montes-García and Valdez-Tamez (2016)	Effect of the addition of sugar-cane bagasse ash on the corrosion risk of uncured mortars
Berenguer *et al.* (2016)	Effect of sugarcane bagasse ash as partial replacement of cement on mortar mechanical properties

Almeida *et al.* (2015)	Sugarcane bagasse ash sand (SBAS): Brazilian agroindustrial by-product for use in mortar
Canova, Miotto and de Mori (2015)	Evaluation of plastering composite mortar with replacement of natural sand in sugarcane bagasse ash
Macedo *et al.* (2014)	Performance of mortars produced with the incorporation of sugar cane bagasse ash
Muangtong *et al.* (2013)	Effects of fine bagasse ash on the workability and compressive strength of Mortars piyanut muangtong
Jiménez-Quero *et al.* (2013)	Influence of sugar-cane bagasse ash and fly ash on the rheological behavior of cement pastes and mortars
Valencia *et al.* (2012)	Durability and corrosion study of reinforced blended mortars with tuff and sugar cane bagasse ash [Estudio de Durabilidad y Corrosión en Morteros Armados Adicionados con Toba Volcánica y Ceniza de Bagazo de Caña de Azúcar]
Paula *et al.* (2010)	Sugarcane bagasse ash as a partial-port-land-cement-replacement material [Ceniza de bagazo de caña de azúcar como material de sustitución parcial del cemento portland]

Table 4 - Publications included in the blue cluster: evaluation of mechanical and physical properties
Source: Own Author.

Among the 12 studies classified in the yellow cluster, these were not included in the systematic analysis because they dealt with the use of SCBA in concrete. It also classified the works that distanced themselves from the proposal addressed in this research but covered sugarcane bagasse, such as Pellegrin, Acordi and Montedo (2019), who evaluated the use of sugarcane bagasse fibers in mortars or even Abraham and Ransinchung (2020), who analyzed the potential of using SCBA in paving applications. Krishna and Reddy (2019) developed sustainable pavers utilizing gray use techniques.

The publications presents various approaches to using SCBA. Table 5 provides a quantitative classification of the different methods employed in the studies considered relevant to this research.

Scba application method	Number of publications
Partial replacement of cement	35
Partial replacement of sand	4
Replacement of BFS	6
With other additions/waste	6

Table 5 - Forms of application of the SCBA studied
Source: Own Author.

It is important to note that most of the studies aim to evaluate the behavior of SCBA as a binder, whether in partial replacement of cement or conjunction with BFS in obtaining alkali-activated binders. Some authors also analyzed the action of ash in conjunction with other types of additions from different sources, such as Akbar *et al.* (2021), who added propylene fibers to the mortar, Braz *et al.* (2019), who evaluated the effect that aluminum recycling residues would have on the pozzolanic activity of SCBA, and Martins Filho *et al.* (2019) which completely replaced fine aggregate with combinations of ash and construction waste. The cement types used in the investigated mortar compositions were identified. These details can be found in Table 6, with the aim of discerning the influence they would have on the final results.

Cement type used	Number of publications
Portland Common	38
Portland high initial strength	11
Portland compound with pozzolana	1
Portland composite with slag	1

Table 6 - Cement types used in the studied publications
Source: Own Author.

The researchers assessed the method of obtaining ash as described in 43 publications. This process may involve either controlled or uncontrolled burning of bagasse by the researchers, or direct collection of ash after combustion in power plant boilers. The researchers described the raised numbers in Table 7.

Obtaining ash means	Number of publications
Controlled burning of bagasse/ash	6
Self-combustion of bagasse	4
Ash collected in power plant	41

Table 7 - Methods for obtaining SCBA
Source: Own Author.

Discussions

Pozzolanic Activity

The existing knowledge about the behavior of pozzolanic materials has guided various studies to standardize the assessmentof the pozzolanicity of the SCBA according to national and international standards. After demonstrating the existence of this characteristic in SCBA in initial studies, subsequent publications aimed to explore ways to enhance its sought effectiveness. The goal was to ensure that the application of SCBA leads to improvements in the properties of mortar (Cordeiro, 2006; Frías *et al.*, 2017; Mehrotra; Masood, 1992).

Different methods have been adopted to ensure that the particles of pozzolanic materials are fine and homogeneous enough to be reactive. This is an important characteristic that requires evaluating the fineness of their particles in the SCBA. According to Chusilp, Jaturapitakkul and Kiattikomol (2009), closely monitoring and regulating the firing temperature is crucial in ensuring the thorough removal of organic matter. This is necessary to decrease the high carbon levels in the ashes since they can adversely affect the properties of the hardened mortar. This theory is supported by the work of Frías *et al.* (2017), who compared the pozzolanic reactions of two different ashes. One ash was obtained directly from a sugar and alcohol mill where it was burned in a boiler at temperatures between 700 °C and 800 °C, without any burning control. The other ash was produced in a laboratory setting, where bagasse was burned with temperature control at 700 °C. Both ashes were ground and sieved for the comparison. The authors concluded that although all samples met the physical requirements established by the pozzolanicity standard, the mortar made with ash without burning control had a water demand of 12.7% more than the mortars with controlled burning ash. The study by Torres *et al.* (2020) supports the theory, highlighting that while calcination effectively removes organic matter, it should not be the only method used to improve the pozzolanic properties of SCBA. Grinding the material to the appropriate fineness is necessary to achieve significant reactivity.

Embong *et al.* (2016) verified the reactivity of SCBA with firing control at different times and temperatures. The controlled incineration of sugarcane bagasse at 800 ºC for 1 hour and subsequent milling and sieving prevented the transformation of ash from amorphous to the crystalline phase, which increased its pozzolanic reactivity. The particle scans and the higher consumption of portlandite in the Chapelle test provided proof of this. Joshaghani and Moeini (2018) discovered a similar result.

Arif, Clark and Lake (2016) studied the reactivity of SCBA when used untreated after collection at the mill, without re-burning, milling, and screening. The scans revealed that samples with a cement-to-ash replacement exceeding 5% exhibited minimal to no pozzolanic activity. However, in durability tests in the immersion of specimens in sulfuric acid solution (aggressive medium), mortars with higher SCBA content (20% substitution) showed the lowest mass loss, demonstrating a significant increase in durability. The authors attributed this success to the increased durability of the mortar due to the filler capacity of the ash to fill the pores.

Mechanical and physical properties

Publications centered on the assessment of mechanical and physical characteristics of mortars highlighted studies employing diverse materials and methodologies. The main tests carried out were resistance to compression, porosity and durability of mortars with SCBA, the latter being through tests of electrical resistivity or accelerated corrosion.

In their study, Almeida *et al.* (2015) observed the impact of using SCBA obtained without firing control as a replacement for fine sand on the applied mortars. After collecting the ash at the plant. The material was sifted and used to replace 30% and 50% of the original substance. The mortar with 30% replacement of sand reached compressive strength greater than that obtained in the control mortar, and the result of resistance of 50% replacement was equivalent to that of only fine sand. By microscopically observing the pores of the mortars, the author concludes that due to the fineness of the SCBA, it can fill smaller pores, giving a filler effect. This characteristic can justify the increase in the compressive strength obtained and improve the durability of the mortar. Moretti *et al.* (2018) used a similar methodology to evaluate the distribution of pores in the mortar with SCBA and obtained similar results, replacing 0%, 10%, 20%, 30% and 40% of fine sand with SCBA. The authors also identified the capacity of the ash to fill the macropores (> 0.1μm) of the mortar. However, they point out that the samples with a value above 30% of SCBA had a loss of workability.

The evaluation conducted by Berenguer et al. (2016) used laboratory tests, specifically X-ray diffraction and X-ray fluorescence, to determine the chemical and mineralogical composition of the ash, which was only sieved after being collected from the plant. The results indicated that the percentage of amorphous silica in the ash suggests that using 15% of siliceous coal bottom ash (SCBA) as a replacement for cement leads to improved performance in compressive strength tests. This mixture demonstrated higher strength compared to the control mortar. Maldonado-Garcia *et al.* (2018) showed similar strength results. Joshaghani and Moeini (2018) achieved an enhancement in this percentage to as much as 20% substitution while ensuring a greater compressive strength by conducting controlled combustion of the bagasse at a temperature of 800 ºC for a minimum duration of 30 minutes, followed by sieving.

Some authors have evaluated the action of sugarcane in combination with other materials; Akbar *et al.* (2021) prepared mortars based on SCBA reinforced with propylene fibers. They used SCBA burned at 900°C for 2 hours, and with an addition of 3% fiber, achieved a 58% increase in tensile strength compared to plain cement mortar. Martins Filho et al. (2019) conducted a comparison of the mechanical properties of standard cement mortar with variants incorporating sugarcane bagasse ash (SCBA) and construction waste as a total replacement for fine aggregates. Among the various proportions tested, the mix containing 75% construction waste and 25% SCBA demonstrated the best tensile and compressive strength. Additionally, this mix exhibited reduced air content and high water retention, which contribute to improved workability, mechanical strength, and durability. Alkali-activated binders

The great interest generated in the sustainable advantages of using BFS as a binder aroused the interest in studying how to use SCBA in conjunction with this material. Moraes *et al.* (2015) used the burnt ash without control, only with subsequent sieving in the production of alkaline activated mortars using an activator solution of sodium hydroxide (NaOH), the ratios of BFS / SCBA evaluated were: AA0 (100 BFS / 0 SCBA), AA25 (75 BFS / 25 SCBA), and AA50 (50 BFS / 50 SCBA). The authors concluded that after 7 and 28 days of curing, both AA25 (75 BFS / 25 SCBA) and AA50 (50 BFS / 50 SCBA) showed higher compressive strength compared to AA0. The increase after 28 days of curing from AA0 to AA25 is 148.5%, and from AA0 to AA50 is 49.1%. Researchers attributed the observed phenomenon to the presence of active silica in the SCBA: the presence of soluble silica under highly alkaline conditions plays a crucial role in the generation of the C(N)-A-S-H gel and thus significantly contributes to the attained strength.

Moraes *et al.* (2017) evaluated this time the influence that an activation solution composed of sodium hydroxide and sodium silicate would have in different proportions of BFS and SCBA on its properties. The ratios evaluated of BFS / SCBA were 100/0, 85/15, 75/25, 67/33, and 50/50. The proportion of BFS / SCBA considered ideal was again 75/25 due to its better compressive strength developed early in the curing time relative to other substitutions tested. The high C(N)-A-S-H compacted gel formation highlights the critical reduction in the volume of capillary pores in mortars containing SCBA, which is directly linked to their durability and explains the increase in compressive strength.

Final considerations

This systematic literature review has reached the proposed objectives of analyzing the works related to the applicability of SCBA in mortars to facilitate and encourage future works on the subject in question. By addressing only published papers, researchers obtained relevant results. The key conclusions of the critical review are as follows.

The optimal proportions for replacing Portland cement with sugarcane bagasse ash (SCBA) to maintain or enhance compressive strength are typically between 10% and 20%. This effectiveness depends on the treatment applied to the ash, which may involve processes such as controlled burning, sieving, or grinding. These treatments help create finer particles, resulting in a more homogeneous structure and reduced grain size. Although the controlled burning of sugarcane bagasse at a temperature of 800 °C shows the greater formation of amorphous silica than crystalline silica, an essential factor to ensure good pozzolanic reactivity, satisfactory reactivity results were found only with sieving and/or grinding after the collection of ash directly from the mill, ensuring a cheaper and more sustainable production process.

For the case of use as alkali-activated material, the proportion of 75% BFS and 25% of SCBA showed satisfactory results with all activator solutions used, increasing the compressive strength by up to 148% compared to the control mortar without the use of ash.

The filler effect given by the fineness of the particles analyzed microscopically is a factor for the increase in durability of the mortars analyzed, which guarantees a reduction in mass in greater exposure to aggressive media when compared to the control samples, whether by using ash as a substitute for cement or sand.

Despite the several advantages, the use of SCBA diminishes the workability of mortars, and it is advisable to substitute up to 30% of the fine aggregate to prevent substantial alterations in consistency.

No studies have demonstrated the behavior of mortars with the use of SBA under real conditions, outside of laboratory production control and when handled directly by site labor, to evaluate the application under different conditions of the base and exposure of the coating and the ash to common environments.

In general, the SCBA presents good applicability in mortars by improving their durability without compromising the compressive strength, and with specific treatments such as grinding or sieving, besides guaranteeing the sustainable use of a residue produced on a large scale in the national territory and reducing the emission of CO_2 with the reduction of Portland cement production.

Based on the research conducted on the influence of SCBA, future work should focus on evaluating the following aspects:

- Evaluate the mortars with SCBA produced outside laboratories against the real conditions of the construction site;
- Perform cost analysis of the mortar production process using SCBA;
- Perform tests to verify the mortar's tensile bond strength in the rough casting;
- Evaluate the behavior of mortar in the laying of ceramic blocks and concrete blocks.

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