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DEVELOPMENT OF ALKALI-ACTIVATED BINDERS UTILIZING RED CERAMIC WASTE: A COMPREHENSIVE LITERATURE REVIEW

DESENVOLVIMENTO DE AGLOMERANTES ATIVADOS ALCALINAMENTE COM USO DE RESÍDUOS DE CERÂMICA VERMELHA: UMA REVISÃO ABRANGENTE DA LITERATURA

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Abstract – The construction industry's material technologies are undergoing transformations related to the growing emphasis on sustainability. This shift has prompted extensive exploration of alternative solutions, with a notable focus on alkali-activated binders as substitutes for high environmental footprint materials like Portland cement. These binders result from a chemical reaction between a silicoaluminous precursor and an alkaline activator, yielding a material with inherent cementitious properties. Beyond this, the innovation holds promise in incorporating by-products and waste materials as constituents, addressing the pressing global challenges of waste management and carbon dioxide emissions. This article presents a thorough literature review, spotlighting the use of red ceramic waste as a precursor material. The analysis extends to comprehensive comparisons based on the results of scientific articles on the subject, establishing a foundation for an examination of this innovative technology's potential in sustainable construction practices.

Keywords: Alkali Activated Binder. Cementitious Composites. Red Ceramic Waste (RCW). Sustainable Management.

Resumo - As tecnologias de materiais na indústria da construção vêm passando por transformações relacionadas à crescente ênfase na sustentabilidade. Essa mudança tem incentivado o desenvolvimento de soluções alternativas, com um foco significativo em ligantes ativados alcalinamente como substitutos para materiais com elevado impacto ambiental, como o cimento Portland. Esses ligantes resultam de uma reação química entre

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um precursor silicoaluminoso e um ativador alcalino, produzindo um material com propriedades cimentícias intrínsecas. Além disso, essa inovação tem o potencial de incorporação de subprodutos e resíduos como constituintes, em encontro aos desafios globais urgentes da gestão de resíduos e emissões de dióxido de carbono. Este artigo apresenta uma revisão abrangente da literatura, destacando o uso de resíduos cerâmicos vermelhos como material precursor. A análise se estende a comparações a partir de resultados de artigos científicos sobre o tema, estabelecendo uma base para a análise do potencial dessa tecnologia inovadora em práticas de construção sustentável.

Keywords: Ligantes de Ativação Alcalina. Compósitos Cimentícios. Resíduos Cerâmicos Vermelhos (RCV). Gestão Sustentável.

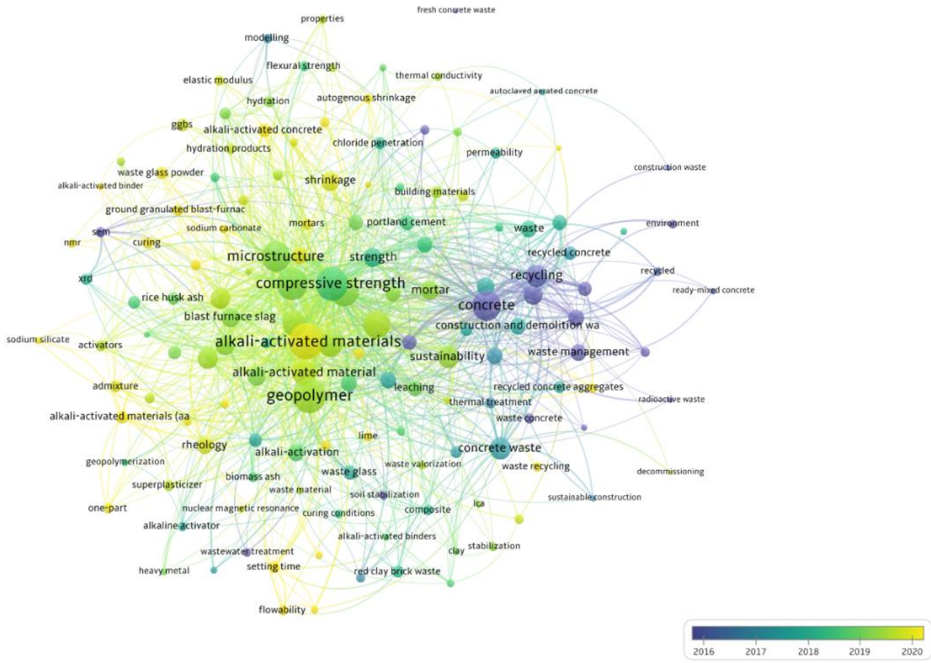
I. INTRODUCTION

Portland Cement (PC) has long dominated the civil construction sector as the primary cementing material, reaching record-bruyeaking production figures each year (MOHAMED *et al*., 2022). This trend is evident in the period from 2015 to 2021, during which annual production increased by a noteworthy 1.5%, as reported by the International Energy Agency (IEA, 2019). In 2020, China, as the largest producer, contributed a staggering 22,489 million tons to these figures (MOHAMED *et al*., 2022). However, the production process of PC entails the release of 0.66 to 0.82 tons of carbon dioxide (CO2) per ton of cement, constituting approximately 5-7% of global CO2 emissions (GARCIA-LODEIRO; PALOMO; FERNÁNDEZ-JIMÉNEZ, 2015). Furthermore, the primary materials, known as clinker, used in PC manufacturing are finite and non-renewable resources (IEA, 2019).

The production of PC, in this regard, exerts a substantial influence on both the economic and environmental fronts. It plays a pivotal role in the global initiative to reduce the emission of polluting gases into the atmosphere, aligning with the objectives set forth in the Paris Agreement of 2015. By reaffirming this landmark agreement at the "27th Annual Meeting of the Conference of The Parties to the Framework Convention (France 2020)"), which was held in Egypt in 2022, we are emphasizing the need to address climate change urgently.

In response to these pressing challenges, the scientific community has embarked on a technological evolution journey. The quest is to develop new materials that can replicate the performance of PC while minimizing environmental impacts. This collective research effort is vividly represented in Figure 1, which utilizes a word cloud generated from research data on the Scopus platform and visualized through VOSviewer software. Notably, the emergence of alkali activation technology has shone brightly in the realm of sustainable cement production. This innovative approach involves a chemical reaction in which an aluminosilicate material, termed a precursor, is combined with an alkaline solution, referred to as an alkaline activator, culminating in the creation of an alkali-activated binder (AAB) with cementitious properties (PACHECO-TORGAL, 2015; PROVIS; PALOMO; CAIJUUN, 2015). The main objective of this study is to provide a throughout analysis, drawing detailed comparisons from scientific articles that elucidate the advancements of alkaline-activated mortars using red ceramic wastes. The aim is to facilitate the practical implementation of this technology in the civil construction industry.

Figure 1 – Word cloud depicting keywords utilized in articles on alkali-activated binders (AAB) from 2016 to 2020



Source: Authors, 2024.

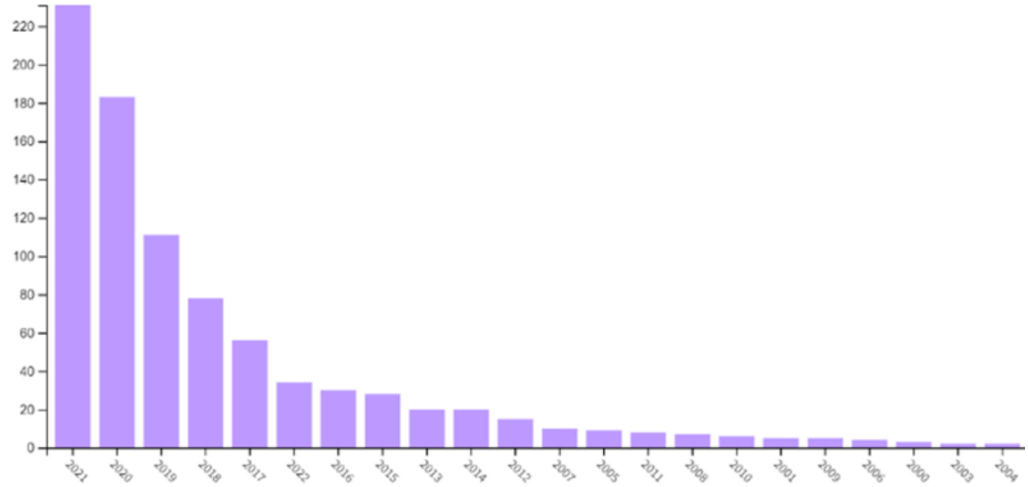
II. AAB PRODUCTION, PROPERTIES, AND PERFORMANCE

Alkaline activation refers to a chemical transformation of solid materials rich in silicon and aluminum, commonly referred to as the "precursor." This process occurs when the precursor interacts with an alkaline solution provided by the "alkaline activator," leading to the formation of a robust binder with cementing properties, resulting in what is known as an alkali-activated binder (AAB) (PROVIS, 2018; PACHECO-TORGAL, 2015).

Historically, the exploration of alkaline activation can be traced back to 1930, marked by the pioneering research conducted by the German engineer Kuhl. Throughout the twentieth century, other notable researchers delved into this subject, including Purdon, who investigated cements produced using blast furnace slag and alkaline caustic soda as substitutes for traditional clinker. Similarly, Davidovits experimented with a blend of alkalinely activated materials such as kaolinite and dolomite (SHI; ROY; KRIVENKO, 2003).

In the twenty-first century, the research focus on this subject matter has experienced consistent growth, contributing significantly to the expansion of knowledge and the potential for broader applications of AABs (PACHECO-TORGAL, 2015). This increasing trend in research activity is substantiated by the escalating number of publications in recent years, as demonstrated in Figure 2, sourced from the Web of Science research platform.

Figure 2 – Graph illustrating the relationship between publication years and the number of publications on the respective topic



Source: Authors, 2024.

The pH of the medium is controlled by the use of alkaline activators or solutions, which induce the dissolution of aluminosilicate particles within the precursor material (PROVIS, 2018). Commonly employed activators include alkaline hydroxide solutions and mixtures of alkaline silicate and alkaline hydroxide solutions (SEVERO *et al.*, 2013). In 1980, Gloukhovsky classified activators into categories such as caustic solutions, weak acid salts, silicates, aluminosilicates, aluminates, and strong acid salts (SHI; ROY; KRIVENKO, 2003). Of these, the first three, which employ Na+ ions for economic reasons, are most prevalent. Additionally, research by Król *et al*. (2018) demonstrated that the dissolution reaction with Na+ ions occur faster compared to other alkaline ions like Li+ and K+. The choice of activator also significantly influences the properties of the final product (PROVIS; BERNAL, 2014).

Precursors are the solid reactants utilized in the alkaline activation process, and they must possess silicon and aluminum in an amorphous state, devoid of spatial ordering. Calcium content, or the lack thereof, enables precursor particles to effectively interact with other materials during the reaction. The amount of calcium oxide available in the system also impacts the outcome. High-calcium systems, such as blast furnace slag, lead to the formation of hydrated calcium aluminosilicate (C-A-S-H), while low-calcium systems, like metakaolin or fly ash, generate hydrated sodium aluminosilicates (N-A-S-H). Intermediate systems can produce both C-A-S-H and N-A-S-H products (PROVIS; PALOMO; SHI, 2015). Precursors extensively studied include fly ash, metakaolin, and blast furnace slag. These materials are already integral to Portland cement production, driving researchers to explore the substitution of alkaline-activated materials with waste or by-products, as waste is frequently discarded with minimal or no utilization (BERNAL *et al*., 2014).

Waste materials such as petroleum industry residue (Fluid catalytic cracking - FCC), agro-industry residue (sugarcane bagasse ash - CBC), glass residue (Vitreous Calcium Aluminosilicate - VCAS), construction and demolition waste (CDW), sewage sludge ash, and mining waste have been frequently employed as precursors in alkaline activation (PROVIS; PALOMO; SHI, 2015). This presents a range of options for precursor materials, all currently being investigated by numerous researchers.

In addition to the use of alkaline precursors and activators in AAB formation, the incorporation of materials as calcium sources has been explored to enhance mechanical performance (BATISTA *et al*., 2023). Studies have shown that the addition of calcium sources, such as calcium aluminate cement (CAC), sodium hydroxide, or calcium hydroxide, significantly improves mechanical properties (PEYNE *et al*., 2017; REIG *et al*., 2016; REIG *et al*., 2014).

Precursor sources provide different methods for preparing AABs, making it impossible to use the same method every time. The characteristics of the resulting mixture are dependent on parameters such as curing time and temperature (PROVIS; PALOMO, CAIJUN, 2015). Various curing conditions have been studied by researchers, with some finding that compressive strength is best at higher temperatures and shorter cuing times (TUYAN; ANDI-AKIR; RAMYAR, 2018). This is based on the acceleration of the chemical reaction.

Durability is a crucial aspect of AABs, particularly in the context of construction. Samples are often exposed to harsh environments, such as seawater or the wetting and drying cycles (KRL; ROEK); CHLEBDA, 2018 - which is commonly used in durability testing. Efflorescence, which is a white "bloom" on the surface of AABs, is frequently encountered as primarily an issue caused by the carbonation of mobile alkalis in the porous solution. Researchers have suggested various mitigation strategies, including the use of healing agents and pores, alumina additives to minimize moisture permeability, or hydrothermal curing (PACHECO-TORGAL *et al,* 2012). The absence of effective rheology control agents poses another obstacle to the feasibility of new AABs (PROVIS, 2018; KANI); ALLAHVERDI and PROVIS in 2012.

Severo *et al*. (2013) highlight the significant potential of ongoing research in the field of alkaline-activated materials. They point out important factors such as the choice of precursors, the nature of the activator used and specific curing conditions that lead to superior results in terms of physical, mechanical and durability properties. Provis (2018) highlights real-life instances where this technology has been utilized to great success. The use of alkaline-activated materials for extensive concreting work was most noticeable at West Wellcamp Airport in Brisbane, Australia during 2013. Featuring the use of non-slip flooring made from various materials such as reinforced concrete, flat cement, precast concrete components, mortars, grouts and all-purpose materials like plaster and lightweight concrete in an ambitious project that highlights the versatility and adaptability of alkaline-activated materials for different construction projects.

III. STANDARDIZATION OF ALKALI-ACTIVATED BINDERS (AABS)

This rigorously tests the properties of a material, and ensures that fairly standardized parameters are used to judge the qualities of this particular material across different samples.).”. In 2023, Batista *et al*. employed the Brazilian standard NBR 13279 (2018), which was designed for "Mortar for laying and covering walls and ceilings," to calculate the tensile strength in bending and compression. The use of NBR 5739 (2005, 2018) by Azevedo and others was also made possible by the Brazilian standard for "Concrete," which is specifically designed for compression testing of cylindrical specimens. These standards are commonly used to test Portland cement.' On the contrary, Reig *et al*. (2014) applied the Spanish standards UNE EN 196-2 (2014) to chemical analysis of cements and utilised the standards for assessing samples strength (resembling a thermometer).

Consequently, the AABs tested in these studies were subjected to performance tests that closely resembled those used for other cement types, such as Portland cement. In their research, Caetano e and al. (2019) pointed out that the absence of specific standards for Portland cement led to the adoption of ABNT standards.

The use of microscopic characterization equipment has been utilized in numerous studies to investigate the connection between materials and molecular structure and performance, as well as compression tests, for studying both reagents and final AAB product. According to Batista *et al.* (2023) and Reig & al." (2014), the main tests include:

- Laser diffraction to determine particle size.
- X-ray Fluorescence (XRF) for assessing chemical composition.
- Scanning Electron Microscopy (SEM) for examining particle morphology.
- X-ray Diffractometer (XRD) for mineralogical determination.

Fourier Transform Infrared Spectrophotometry for qualitative assessment of precursors and alkaline-activated pastes, facilitating the identification of compounds, both organic and inorganic, formed in the reactions.

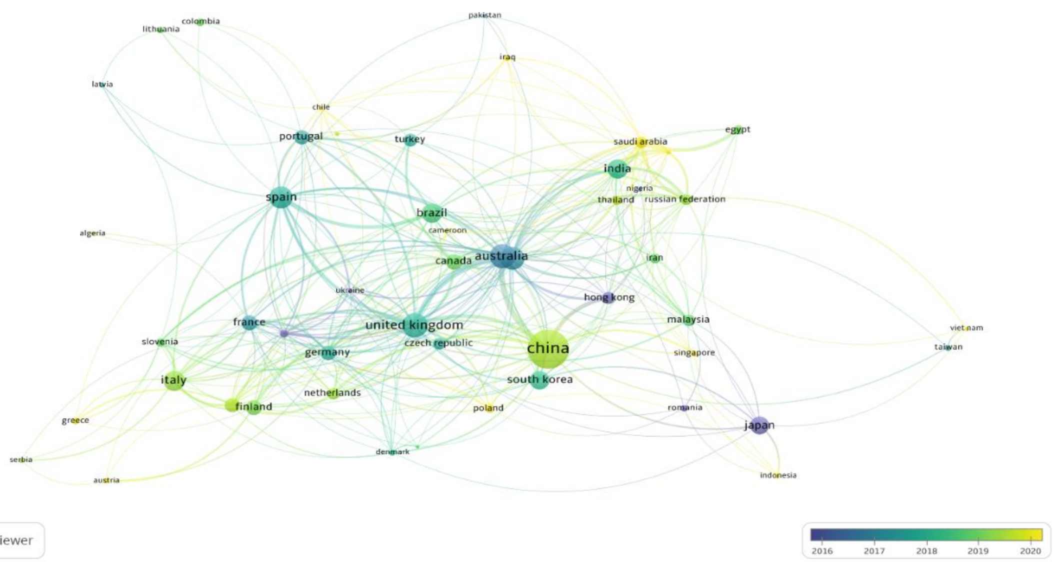
As emphasized by Provis (2018), the endeavour to standardize alkaline-activated materials is progressing at a relatively rapid pace compared to the broader development of standards within the global building materials industry. This standardization effort provides a comprehensive, worldwide perspective on the utilization of these materials, as exemplified in Table 1.

Table 1 – International standards for alkali-activated binders (AABs). (Adapted from Provis, (2018))

Country	**AAB Standardization**
Switzerland	Alkaline-activated slags have been incorporated into national guidelines (SIA, 2014).
United Kingdom	The United Kingdom has introduced the Publicly Available Specification for alkaline-activated concretes and cements (BSI, 2016).
United States of America	In the ASTM standardization regime, alkali-activated materials can be used according to the performance-based standard C1157 (ASTM, 2011), and other specific test standards for these materials are currently under development.
China	China has outlined the utilization of these materials for chemical resistance applications in GB/T 29423. Moreover, there exists an extensive set of prescriptive standards for alkaline-activated cements and slag concretes (SAC, 2012).
Australia	In Australia, VicRoads has taken significant steps by explicitly incorporating alkaline-activated concrete into four standard specifications: Sections 703 (general concrete paving), 701 (drains and pipes), 705 (drainage pits), and 711 (safety barriers). Additional incentives may also be available for the use of these materials under Section 610 (structural concrete) (ANDREWS-PHAEDONOS, 2014).

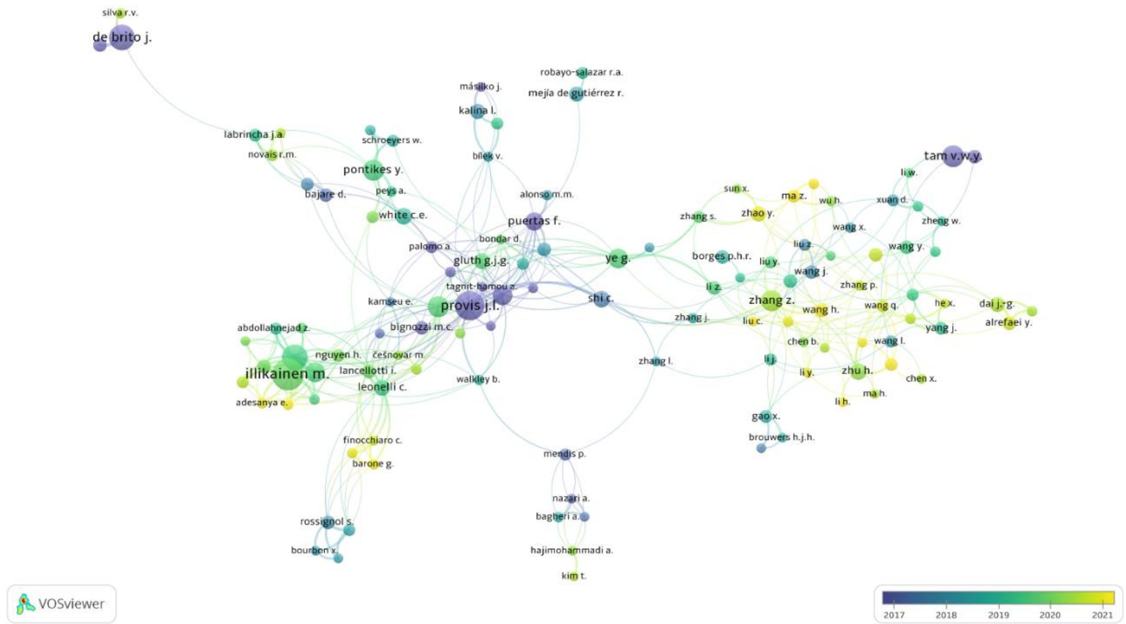
Additionally, Figures 3 and 4 provide valuable insights into the concurrent development of norms and standardizations within this technology and the corresponding research landscape in the country. By analyzing the word cloud derived from publications in different countries from 2016 to 2020, as generated from research data on the Scopus platform and visualized using VOSviewer software, a clear correlation emerges. This word cloud underscores the significance of countries such as China, Australia, and the United Kingdom in the discourse surrounding this field. Notably, China, as previously mentioned, ranks among the world's leading cement producers, with a consistently expanding footprint.

Figure 3 - Word cloud of countries that published articles from 2016 to 2020 with a theme related to AAB



Source: Authors, 2024.

Figure 4: Word cloud depicting authors of articles on alkali-activated binders (AAB) from 2016 to 2020



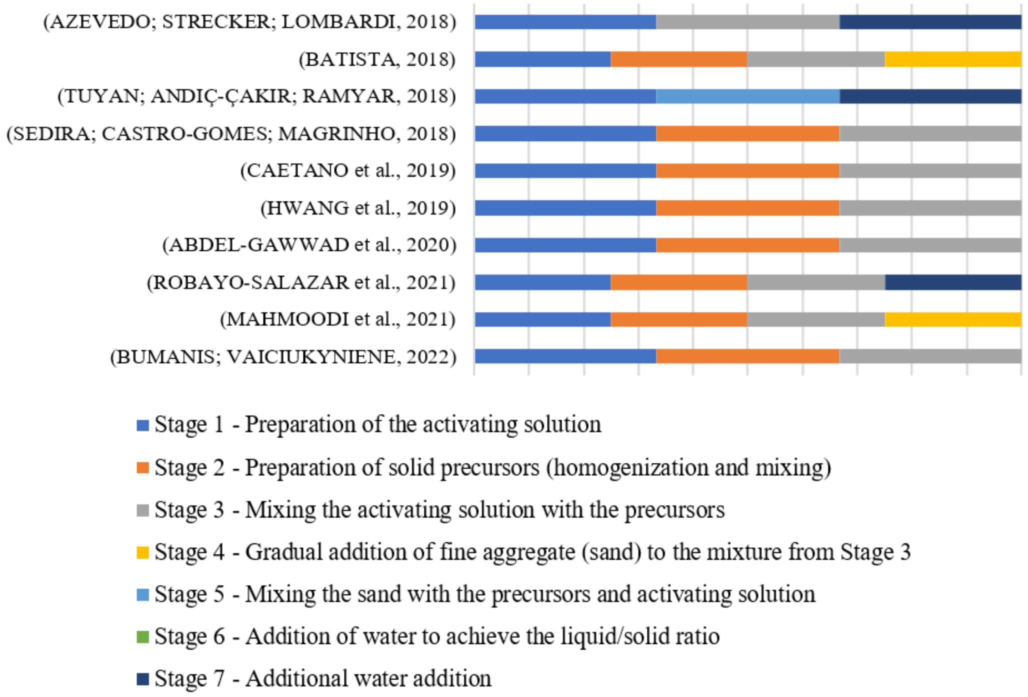
Source: Authors, 2024.

IV. UTILIZING RED CERAMIC WASTE AS A PRECURSOR IN ALKALI-ACTIVATED BINDERS (AAB)

Red ceramic waste can arise during production or post-use, leading to substantial material wastage. According to data from the Brazilian Agency for Industrial Development (ABDI, 2019), the ceramics industry can lose up to 10% of its production during the firing process and an additional 5-20% during post-production, primarily due to broken or flawed components. Brazil holds the second-largest position globally in both ceramics production and consumption. This industry holds significant importance within the country, contributing to approximately 1.0% of the Gross Domestic Product (GDP). In 2016, the non-metallic industry, encompassing ceramics, generated an estimated 386,000 jobs (MME, 2019). This sector alone represents around 1% of the Gross Value of Industrial Production (GVPI), accounting for 4.8% of the construction industry's total turnover. In 2005, the ceramics industry produced an impressive 63.3 billion units, with bricks and blocks constituting 75% of this output (SEBRAE, 2019). As previously mentioned, these materials can serve as precursors in the creation of AAB due to their aluminum and silicon content, essential components for the cementing reaction.

For this research, 13 articles published within the last five years were selected, all sourced from research platforms such as Google Scholar, Web Of Science, and Scopus. The objective was to present the specifics discovered by researchers, facilitate comparisons, and analyse the results. Figure 5 illustrates the common procedures adopted by researchers in preparing their samples, with the exception of three articles that did not provide detailed descriptions of their processes. It is evident that a standard procedure is employed by most researchers for mortar and paste preparation, with the activating solution typically being prepared first ("Step 1") and then mixed with the precursors ("Step 3"). This sequencing is chosen due to the exothermic nature of the activating reaction (AZEVEDO; STRECKER; LOMBARDI, 2018). Additionally, some researchers justify the addition of extra water to the mixture to enhance the workability of the paste and/or mortar.

Figure 5: Graph illustrating the procedure steps in alkali-activated material preparation in various research articles



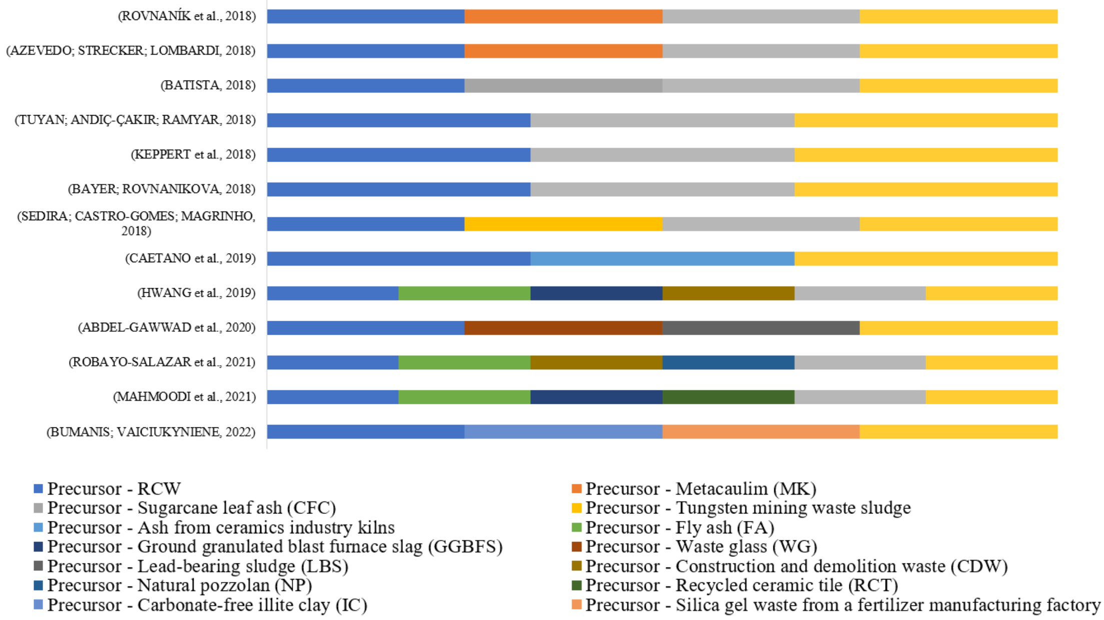
Source: Authors, 2024.

In Figure 6, we observe that the composition of AABs depends on the choice of activators and precursors. Among the 13 articles, all utilized red ceramic waste (RCW) as a precursor. Fly ash was used in three articles (MAHMOODI *et al.*, 2021; ROBAYO-SALAZAR *et al.*, 2021; HWANG *et al.*, 2018), metakaolin in two (AZEVEDO; STRECKER; LOMBARDI, 2018; ROVNANIK *et al.*, 2015), blast furnace slag in two (MAHMOODI *et al.*, 2021; HWANG *et al.*, 2019), and construction and demolition waste in two others (ROBAY-SALAZAR *et al.*, 2021; HWANG *et al.*, 2019). Sodium hydroxide was consistently the activating solution in all 13 articles, and sodium silicate was present in 10 of them (BATISTA *et al.*, 2023; MAHMOODI *et al.*, 2021; ROBAYO-SALAZAR *et al.*, 2021; TUYAN; ANDIÇ-ÇAKIR; RAMYAR, 2018; AZEVEDO; STRECKER; LOMBARDI, 2018; BAYER; ROVNANIKOVA, 2018; HWANG *et al.*, 2018; KEPPERT *et al.*, 2018; SEDIRA; CASTR-GOME; MAGRINHO, 2018; ROVNANIK *et al.*, 2015). It's important to note that the RCW's origin and appearance varied across studies, with some having a specific granulometry for mixing, while others required homogenization and grinding.

Regarding the dosages employed in each study, most researchers chose to vary the percentage of precursors and activator concentrations in the alkaline solution to determine the configuration yielding the highest strength (BATISTA *et al.*, 2023); MAHMOODI *et al.*, 2021; CAETANO *et al.*, 2019; HWANG *et al.*, 2019; SEDIRA; AZEVEDO; STRECKER; LOMBARDI, 2018; CASTRO-GOMES; MAGRINHO, 2018; ROVNANIK *et al*. 2015). This approach aimed to ensure crucial properties such as porosity, absorption, and material durability. The data were processed and summarized to identify the most satisfactory dosage in each study, as presented in Table

2. From the gathered information, it was observed that activator concentrations ranged from 7 to 10 moles, the SiO2/Na2O ratio spanned from 1.4 to 1.6, and the binder-water ratio was typically within the range of 0.25 to 0.50. As for the precursors, except for those exclusively employing RCW, most studies found that a 50% to 60% RCW content led to the highest compressive strength.

Figure 6: Graph depicting the materials utilized and their corresponding research studies



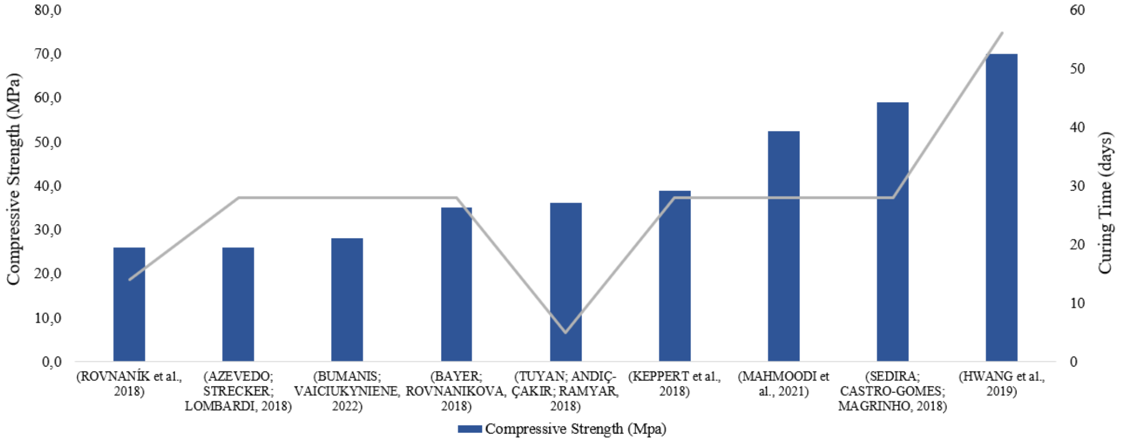
Source: Authors, 2024.

Table 2: Dosage ratios of precursors, activators, and water/binder ratios.

Reference	**Quantity ratio of precursors (%)**	**Concentration of Sodium Hydroxide (NaOH) activator**	**Concentration of Sodium Silicate (Na_2SiO_3) activator**	**w/b**
(ROVNANIK, *et al.*, 2015)	25/75	1.4 (SiO_2/Na_2O) / 7.9 M	1.6 (SiO_2/Na_2O)	0,26
(AZEVEDO; STRECKER; LOMBARDI, 2018)	50/50	8 M	8 M	0,90
(BATISTA *et al.*, 2023)	50/50	1.3 (SiO_2/Na_2O) / 8 M	N/A	0,50
(TUYAN; ANDIÇ-ÇAKIR; RAMYAR, 2018)	100	-	1.6 (SiO_2/Na_2O)	0,46
(KEPPERT *et al.*, 2018)	100	1,4	1.6 (SiO_2/Na_2O)	0,21
(SEDIRA; CASTRO-GOMES; MAGRINHO, 2018)	50/50	10 M	10 M	0,25
(CAETANO *et al.*, 2019)	60/40	N/A	N/A	0,26
(HWANG *et al.*, 2019)	60/30/10	10 M	10 M	0,45
(ROBAYO-SALAZAR *et al.*, 2021)	100	5.6 M	5.6 M	-
(MAHMOODI *et al.*, 2021)	20/80	10 M	10 M	0,30
(BUMANIS; VAIČIUKYNIENĖ, 2022)	100	7MS	-	0,43

Hence, it is evident that the residue holds significant potential for utilization, whether in part or in full, as a precursor in alkali-activated materials. This assertion finds support in the insights gleaned from Figure 7, which showcases the maximum compressive strength data achieved by researchers who have fully or partially integrated this material into their work. Notably, only the compression data from studies involving paste production are presented here to streamline comparisons and facilitate comprehensive analysis. The figure 7 also provides insights into the curing time associated with the recorded compression data, along with details regarding the specimen formats employed.

Figure 7: Graph illustrating compressive strength vs. curing time of paste samples in the mentioned research



Source: Authors, 2024.

In a general assessment, it is evident that all the research endeavours have achieved a compressive strength equal to or greater than 26 MPa, representing commendable outcomes that underscore the potential of this technology. Whether fully or partially incorporating RWC as a precursor, the results demonstrate promise. Among the specimen formats employed, it's notable that 60% of the cubic samples had dimensions of 50 x 50 x 50 mm, while 67% of the prismatic specimens measured 20 x 20 x 100 mm. These dimensions were predominantly chosen due to the convenience of demoulding, particularly in the case of plastic moulds. However, when dissecting each individual research article, it becomes evident that the investigation into the dosage of selected components played a pivotal role in attaining satisfactory mechanical results. Thus, the presented graphs elucidate the relationship between curing time and compressive strength, yet it is important to note that these data cannot be correlated as a sole justification for one research outperforming another. The distinct properties of the materials used (in terms of origin and composition), the specific dosages applied, and the type of curing method employed collectively influence the outcomes.

On the contrary, a notable observation is that studies employing the same materials, albeit from different sources, as conducted by Tuyan; Andiç-çakir; Ramyar (2018), Keppert *et al*. (2018), and Bayer; Rovnanikova (2018), yielded strikingly similar compressive strengths of 36.2 MPa, 38.8 MPa, and 35 MPa, respectively. Of note, the latter two studies achieved this resistance at 28 days of curing, while Tuyan; Andiç-çakir; Ramyar (2018) accomplished the same result in just 5 days of curing. It's worth mentioning that Tuyan; Andiç-çakir; Ramyar (2018) employed the highest curing temperature at 80°C, whereas Keppert *et al*. (2018) and Bayer and Rovnanikova(2018) used 23°C (room temperature) and 60°C, respectively. Therefore, it can be inferred that, although various factors must be considered, these studies achieved comparably excellent results.

Another noteworthy factor concerning strength enhancement was observed in Batista *et al*. (2023), where the addition of 5% (in terms of binder mass) of calcium hydroxide significantly increased the mechanical strength of the mortar produced. The strength increased by approximately 300% (from 4 to 16 MPa). In a similar context, Hwang *et al*. (2019), while using dosages with two different sources of CVR (brick residue and ceramic residue) in their study, found that the sample with almost double the amount of calcium oxide (CaO) in its composition achieved the highest mechanical strength. This factor was found to enhance the alkaline activation reaction. Caetano *et al*. (2019), who compared the achieved strength of specimens with two different dosages (Test 01 - 60/40 with a higher NaOH concentration and Test 02 - 67/33 with a lower NaOH concentration) of the materials mentioned in Table 2, along with conventional PC samples, concluded that the material under study is suitable for use as mortar for construction since they obtained results comparable to conventional cement.

The choice of curing method in this technology is a crucial variable that significantly influences material performance. Among the analyzed research, 46% of them opted for room temperature curing. Batista *et al*. (2023) utilized temperatures of 25°C for curing durations of 3, 7, 28, and 90 days, as well as 65°C for 1, 3, and 7 days. Interestingly, it was observed that the sample subjected to 65°C achieved a resistance level close to that of the sample cured for 90 days. The researchers Tuyan; Andiç-çakir; Ramyar (2018) experimented with temperatures ranging from 50°C to 100° C over different durations of 1, 3, 5, and 7 days, while also considering the effects on sample strength of curing conditions and ambient temperature for 3, 7, 28, and 90 days. The study indicated that the highest compressive strength was 36.2 for the mixture that cured in 5 days. While the MPa subjected to 25°C for 90 days, it only achieved 18.7 degrees. MPa. The first 24 hours after curing, Bumanis and Danut (2022) used temperatures in excess of room temperature, 100°C.Mumoodi *et al*. (2021). Both studies found that this rapid procedure significantly expedited the reaction in the sample, with the former showing a remarkable 77% increase in strength over ten days.

Furthermore, the scrutiny of the attributes of each binder is crucial, particularly in relation to its porosity, which is closely tied to the material's durability and resistance, making it an essential factor in civil construction. Consequently, Table 3 presents the porosity data from three studies, with each sample having the highest compressive strength. Tuyan; Andiç-çakir; Ramyana (2018) had the lowest percentage of apparent porosity. The researchers suggest that the higher $Na2O$ content and $SiO2/Na2OA$ ratio of 1.6 is responsible for this outcome, which results in a denser and stronger structure.

Table 3 – Properties in research on AAB using RCW are shown in Table 3..

Reference	**Water absorption (%)**	**Apparent porosity (%)**	**Density (g/cm³)**
(AZEVEDO; STRECKER; LOMBARDI, 2018)	6,8	47,3	1,9
(KEPPERT *et al*. 2018)	-	36,8	1,6
(SEDIRA; CASTRO-GOMES; MAGRINHO, 2018)	-	28,25	-

The significance of selecting the appropriate materials, setting the correct dosages, curing time interval and temperature for this material is summarized by being emphasized. The various research directions in this domain highlight the potential of this technology. To sum up, Robayo-Salazar *et al*. (2021) present an investigation on the use of MAA in the creation of sustainable housing blocks, following all relevant construction standards and regulations to ensure structural integrity. According to their findings, this technology has the potential to be used to support a circular economy, but it highlights the need for additional research to investigate the thermal performance and durability of the constructed prototypes.

V. CONCLUSION.

Overall, alkaline-activated binders (AABs) are one of the most promising avenues towards more sustainable construction. In the quest for alternatives to high-impact materials like Portland cement, there has been much research on AABs, and this literature review highlights the importance of several factors that affect binder production. The properties of the binder depend on factors such as dosages, temperature, curing time, and activator materials. However, other variables may also play an important role.

Specifically, the use of red ceramic waste (RWC) as a precursor material for AAB production has demonstrated significant potential. Even though comparing results under different experimental conditions is difficult, RWC consistently displays excellent mechanical performance. In addition to being environmentally friendly, this technology also facilitates the reduction of waste and their reuse.

Future research in this area should focus on important factors such as durability and the practical application of AAB across commercially available spaces. These factors are crucial in ensuring the continued progress and efficient utilization of this new construction material.

VI. REFERENCES

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