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doi:10.20944/preprints202210.0137.v1

Review

Steel Slag as a Precursor Material for Alkali-Activated Binders: A Systematic Review.

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Abstract: Steel slag is a co-product of the steelmaking industry, this material is rarely used as a binder due to its low cementitious properties. Thus, it´s believed that the alkaline activation of steel slag can enable its use as a cementitious material. This work has the objective of making a systematic bibliographic review on the theme "slag melt as a precursor in activated alkali binders". To this end, the ProKnow-C method was used for the selection and analysis of relevant research on the topic. The portfolio resulted in 71 texts, mostly journals paper. Bibliometrics showed that the country with the most publications is China and the journal with the most publications is Construction and Building Materials. The critical analysis concluded that the XRD, XRF, and compressive strength tests are the most used for the characterization of the material. It is possible to establish that there are some knowledge gaps on the subject, such as better mechanical characterization and greater production of works with dosing by the one-part method.

Keywords: steel slag; alkali activated; ProKnow-C; review; bibliometric

1. Introduction

In the steelmaking industry are generated two main kinds of slag: blast furnace slag and steel slag. The blast furnace slag, if granulated, is widely used for Portland cement fabrication [1]. Their use by the cement industry is very common in many countries and more than 90% of the worldwide slag production is destinated for this sector. On the other hand, the steel slag is still not used in the same proportion in some countries, like China, India, and Brazil [2]. These countries are among the biggest steel producers and the deposition of this material in landfills can promote many environmental impacts.

The use of steel slag for cement-based materials is very reported by researchers. In a recent article, Martins et al. [3] related a lot of works written by this use, either as a cement substitute or as an aggregate for mortars and concrete. However, the use of steel slag as a precursor in alkali active binder is not very annunciated.

Alkali Activated Binders (AAB) are a possible substitute for Portland cement [4]. This binder is formed by the alkaline activation for aluminum-silicate materials which can be make a workable paste used for mortars, concrete or construction blocks [5]. According to Provis [6], there are many resources that can be used as an AAB, but due to environmental impacts associated with industrial wastes, several research groups have been using preferentially these materials as AAB. This paper aims to make a review literature about the use of steel slag as an alkali activated binder.

2. Methodology

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This work used the ProKnow-C method for search relevant texts about the theme "alkaline activation of steel slag". This method was created in 2007 by Laboratory of Multicriteria Decision Support Methodology (LabMCDA), from Federal University of Santa Catarina, Brazil [7].

The ProKnow-C is a complete method of systematic literature review and aims to provide for authors and researchers an access to a large portfolio of texts on a given topic [8]. The method uses four steps: document select, bibliometric analysis, structured critical analysis and search for knowledge gaps.

2.1. Selection of documents

In first, was used the Brazilian governmental site called *Portal de Periódicos Capes* where is accessed main researcher's platforms. On follow, were chosen the research bases Dimensions, EBSCO, MDPI, Science Direct and Scopus. These five databases were chosen because they provided the most results on the topic.

On these bases, the following key words were hunted: "steel slag", "BOF slag", "EAF slag" combined with "geopolymer", "alkali" and "activation". Preference was given when these words were found in title, abstract or keywords. Furthermore, articles for last ten years were searched. The Figure 1 shown this procedure.

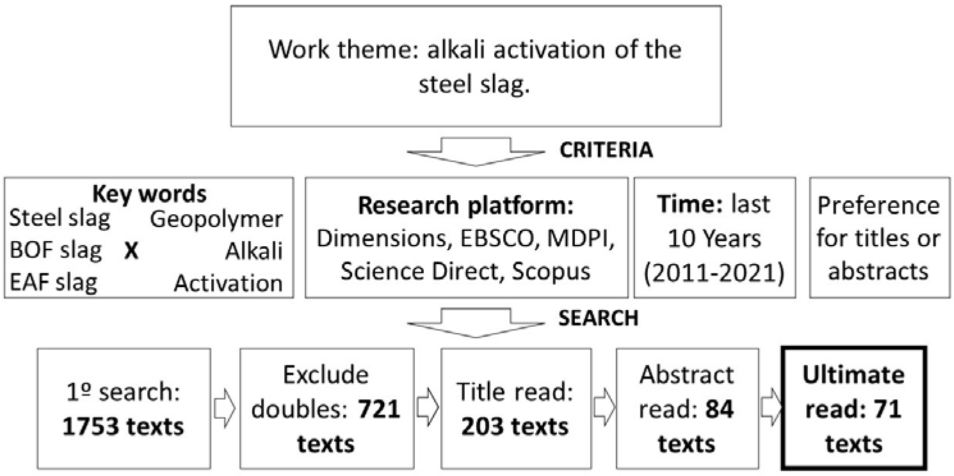

Figure 1. Schematic model of bibliographic research.

The procedure spawn 1753 texts as an initial result and ended in December 2021. Some these texts are repeated, so it was used the Mendeley tool, where is compilated the bibliographic information. Like shown in Figure 1, after deleting the doubled, 721 texts remained.

To establish the familiarity of the texts with the theme, we proceeded with the reading of the titles and abstracts. Then, 203 texts are selectioned. After the read for abstract, it was found that only 84 texts remained. Finally, after reading the full texts, only 63 works persisted. Although, with the full text reading and analysis, more 8 relevant texts were found, which had escaped the filters, totaling 71. These 71 texts form the portfolio on the theme "alkaline activation of steel slag".

2.2. Bibliometric and critical analysis

For bibliometric analysis, the database, the type of text and the number of texts published per year are used. In addition to these, the country of the author of the publication and the journals that published the most were correlated with the number of citations of the works. With the help of VOSviewer Software (version 1.6.16.0), a word cloud was created to correlate the groups of authors who printed works together.

For the structured critical analysis, the type of steel slag used, the use of slag with other precursors, the characterization methods used, activator type method and the

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products obtained were verified. A comparison was made of all the results of chemical and mineralogical composition of the slag, to try to find the main compounds of each material. For the mineralogical composition, the frequency of how many times each mineral phase is found in the articles was calculated. About chemical composition, the mean and the standard deviation for the oxides are determined.

Only for BOF slag, the mechanical behavior of the products was analyzed. Because there are several types of mixtures and activators, this part was done relatively. The reference traces at the age of 28 days were used as a guide and, thus, the influence of the type of activator and the type of precursor combinated was calculated.

Finally, based on the results obtained, gaps in knowledge that studies on alkaline activation of steel slag have not yet studied were proposed.

3. Results and discussion

In general, the texts on portfolio showed publications for 247 authors who are from 24 countries, printed at 31 journals and cited 1421 times. The most cited work is "Bonding and abrasion resistance of geopolymeric repair material made with steel slag" for Hu et al. [9] with 210 citations. All the texts from portfolio are show at Table 1.

Table 1. Texts that made the portfolio about alkaline activation of steel slag (continued).

Citation	Title	Published in
Feng et al. [10]	A comparison between fly ash- and basic oxygen furnace slag-modified gold mine tailings geopolymers	Construction and Building Materials
Feng and Sun [11]	A comparison of the 10-year properties of converter steel slag activated by high temperature and an alkaline activator	Construction and Building Materials
Zhang et al. [12]	A new alkali-activated steel slag-based cementitious material for photocatalytic degradation of organic pollutant from waste water	Journal of Hazardous Materials
Kang et al. [13]	A novel V-doped CeO2 loaded alkali-activated steel slag-based nanocomposite for photocatalytic degradation of malachite green	Integrated Ferroelectrics
Cristelo et al. [14]	Alkali activated composites – An innovative concept using iron and steel slag as both precursor and aggregate	Cement and Concrete Composites
Salman et al. [15]	Alkali Activation of AOD Stainless Steel Slag under Steam Curing Conditions	Journal of the American Ceramic Society
Ozturk et al. [16]	Alkali activation of electric arc furnace slag: Mechanical properties and micro analyzes	Journal of Building Engineering
Lancellotti et al. [17]	Alkali activation of metallurgical slags: Reactivity, chemical behavior, and environmental assessment	Materials
Zhang et al. [18]	Alkali-activated cements for photocatalytic degradation of organic dyes	Handbook of Alkali-Activated Cements, Mortars and Concretes
Rosales et al. [19]	Alkali-Activated Stainless-Steel Slag as a Cementitious Material in the Manufacture of Self-Compacting Concrete	Materials
Kang et al. [20]	Alkali-Activated Steel Slag-Based Mesoporous Material as a New Photocatalyst for Degradation of Dye from Wastewater	Integrated Ferroelectrics
Pinheiro et al. [21]	Application of the response surface method to optimize alkali activated cements based on low-reactivity ladle furnace slag	Construction and Building Materials
Gautier et al. [22]	Basic oxygen furnace (BOF) slag cooling: Laboratory characteristics and prediction calculations	International Journal of Mineral Processing
Hu et al. [9]	Bonding and abrasion resistance of geopolymeric repair material made with steel slag	Cement and Concrete Composites
Salman et al. [23]	Cementitious binders from activated stainless steel refining slag and the effect of alkali solutions	Journal of Hazardous Materials

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Belhadj et al. [24]	Characterization and activation of Basic Oxygen Furnace slag	Cement and Concrete Composites
Zeng et al. [25]	Composite foamed alkali-activated concrete with slag and steel slag	Magazine of Concrete Research
Kuntikana and Singh [26]	Contemporary issues related to utilization of industrial byproducts	Advances in Civil Engineering Materials
Liu et al. [27]	Coupling effect of steel slag in preparation of calcium-containing geopolymers with spent fluid catalytic cracking (FCC) catalyst	Construction and Building Materials
Wang et al. [28]	Development of green binder systems based on flue gas desulfurization gypsum and fly ash incorporating slag or steel slag powders	Construction and Building Materials
Singh et al. [29]	Development of newer composite cement through mechano-chemical activation of steel slag	Construction and Building Materials
Nikolić et al. [30]	Durability of alkali activated slag in a marine environment: Influence of alkali ion	Journal of the Serbian Chemical Society
Salman et al. [31]	Effect of curing temperatures on the alkali activation of crystalline continuous casting stainless steel slag	Construction and Building Materials
Sun and Chen [32]	Effect of silicate modulus of water glass on the hydration of alkali-activated converter steel slag	Journal of Thermal Analysis and Calorimetry
Song et al. [33]	Effect of steel slag on fresh, hardened and microstructural properties of high-calcium fly ash based geopolymers at standard curing condition	Construction and Building Materials
Morone et al. [34]	Effects of Alkali Activation and CO2 Curing on the Hydraulic Reactivity and Carbon Storage Capacity of BOF Slag in View of Its Use in Concrete	Waste and Biomass Valorization
Guo and Pan [35]	Effects of Steel Slag on Mechanical Properties and Mechanism of Fly Ash-Based Geopolymer	Journal of Materials in Civil Engineering
Song et al. [36]	Efficient use of steel slag in alkali-activated fly ash-steel slag-ground granulated blast furnace slag ternary blends	Construction and Building Materials
Du et al. [37]	Efflorescence inhibition of alkali-activated steel slag-slag material by nano SiO2	Ceramics - Silikaty
Wang et al. 2011 [38]	Experimental study on alkali stimulating-steel slag cementitious materials	International Conference CEBM 2011
Mohammed et al. [39]	Geopolymer Steel Slag Brick	Applied Mechanics and Materials
Lee et al. [40]	Geopolymer Technologies for Stabilization of Basic Oxygen Furnace Slags and Sustainable Application as Construction Materials	Sustainability
Morone et al. [41]	Granulation–Carbonation Treatment of Alkali Activated Steel Slag for Secondary Aggregates Production	Waste and Biomass Valorization
Nguyen et al. [42]	High performance cementitious composite from alkali-activated ladle slag reinforced with polypropylene fibers	Cement and Concrete Composites
Kaja et al. [43]	Hydration of potassium citrate-activated BOF slag	Cement and Concrete Research
Sun et al. [44]	Hydration properties and microstructure characteristics of alkali–activated steel slag	Construction and Building Materials
Duda [45]	Hydraulic reactions of LD steelworks slags	Cement & Concrete Research
Khater [46]	Impact of electric arc furnace slag on geopolymer composites exposed to sulphate solution	Journal of Building Materials and Structures
Nikolić et al. [47]	Improved compressive strength of alkali activated slag upon heating	Materials Letters

Zhou et al. [48]	Influence of ground granulated blast furnace slag on the early hydration and microstructure of alkali-activated converter steel slag binder	Journal of Thermal Analysis and Calorimetry
Wang et al. [49]	Influence of initial alkalinity on the hydration of steel slag	Science China Technological Sciences
Kriskova et al. [50]	Influence of mechanical and chemical activation on the hydraulic properties of gamma dicalcium silicate	Cement and Concrete Research
Bai et al. [51]	Influence of steel slag on the mechanical properties and curing time of metakaolin geopolymer	Ceramics International
Guo and Yang [52]	Intrinsic properties and micro-crack characteristics of ultra-high toughness fly ash/steel slag based geopolymer	Construction and Building Materials
Salman et al [53]	Investigating the binding potential of continuous casting stainless steel slag by alkali activation	Advances in Cement Research
Zhang et al. [54]	Investigation on mechanical properties, durability and micro-structural development of steel slag blended cements	Journal of Thermal Analysis & Calorimetry
Nikolić et al. [55]	Kinetics of electric arc furnace slag leaching in alkaline solutions	Construction and Building Materials
Aponte et al. [56]	Ladle steel slag in activated systems for construction use	Minerals
Guo and Pan [57]	Mechanical properties and mechanisms of fiber reinforced fly ash–steel slag based geopolymer mortar	Construction and Building Materials
Liu et al. [58]	Microstructure and phase evolution of alkali-activated steel slag during early age	Construction and Building Materials
Bignozzi et al. [59]	Mix-design and characterization of alkali activated materials based on metakaolin and ladle slag	Applied Clay Science
Niklioć et al. [60]	Modification of mechanical and thermal properties of fly ash-based geopolymer by the incorporation of steel slag	Materials Letters
Kang et al. [61]	Preparation, characterization and photocatalytic activity of novel CeO2 loaded porous alkali-activated steel slag-based binding material	International Journal of Hydrogen Energy
Huang et al. [62]	Properties of waste-based geopolymer building blocks	Applied Mechanics and Materials
Liu et al [63]	Property comparison of alkali-activated carbon steel slag (CSS) and stainless steel slag (SSS) and role of blast furnace slag (BFS) chemical composition	Materials
Nunes and Borges [2]	Recent advances in the reuse of steel slags and future perspectives as binder and aggregate for alkali-activated materials	Construction and Building Materials
Long et al. [64]	Research on mechanism of sodium silicate on gas quenching steel slag cement	International Conference FMRIA 2011
Guo and Xiong [65]	Resistance of fiber-reinforced fly ash-steel slag based geopolymer mortar to sulfate attack and drying-wetting cycles	Construction and Building Materials
Jia and Liu [66]	Simulated Experiment Study of Factors Influencing the Hydration Activity of f-CaO in Basic Oxygen Furnace Slag	Advances in Materials Science & Engineering
Vlcek et al. [67]	Slags from steel production: Properties and their utilization	Metalurgija
Martins et al. [3]	Steel slags in cement-based composites: An ultimate review on characterization, applications and performance	Construction and Building Materials
Pereira et al. [68]	Structural characterization of sustainable geopolymers of steel slag LD and steel slag LF with KOH	Revista Materia
Wang et al. [69]	Study on engineering properties of alkali-activated ladle furnace slag geopolymer	Construction and Building Materials
Chen et al [70]	Synthesis and characterization of geopolymer composites based on gasification coal fly ash and steel slag	Construction and Building Materials

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Furlani et al. [71]	Synthesis and characterization of geopolymers containing blends of unprocessed steel slag and metakaolin: The role of slag particle size	Ceramics International
You et al. [72]	The influence of steel slag and ferronickel slag on the properties of alkali-activated slag mortar	Construction and Building Materials
Apithanyasai et al. [73]	The potential of industrial waste: using foundry sand with fly ash and electric arc furnace slag for geopolymer brick production	Heliyon
Češnovar et al. [74]	The potential of ladle slag and electric arc furnace slag use in Synthesizing alkali activated materials; the influence of curing on mechanical properties	Materials
Lu et al. [75]	Use of basic oxygen furnace slag fines in the production of cementitious mortars and the effects on mortar expansion	Construction and Building Materials
Mastali et al. [76]	Using carbonated BOF slag aggregates in alkali-activated concretes	Materials
Tsai et al. [77]	Using GGBOS as the alkali activators in GGBS and GGBOS blended cements	Construction and Building Materials

3.1. Bibliometric analysis

The author with most publications is Özlem Cizer, from *Katholieke Universiteit Leven*, Belgium. Until December 2021, her articles were cited 168 times. Around her, there is only group of authors found by the analysis of the results (Figure 2). The strongest relationships were with other authors from the same university. However, it was possible to find relationships with other research groups in Italy and Switzerland. This is an indication that there is a working group on the subject at the *Katholieke Universiteit Leven.* Among all the other 247 authors, no relationship between publications was obtained.

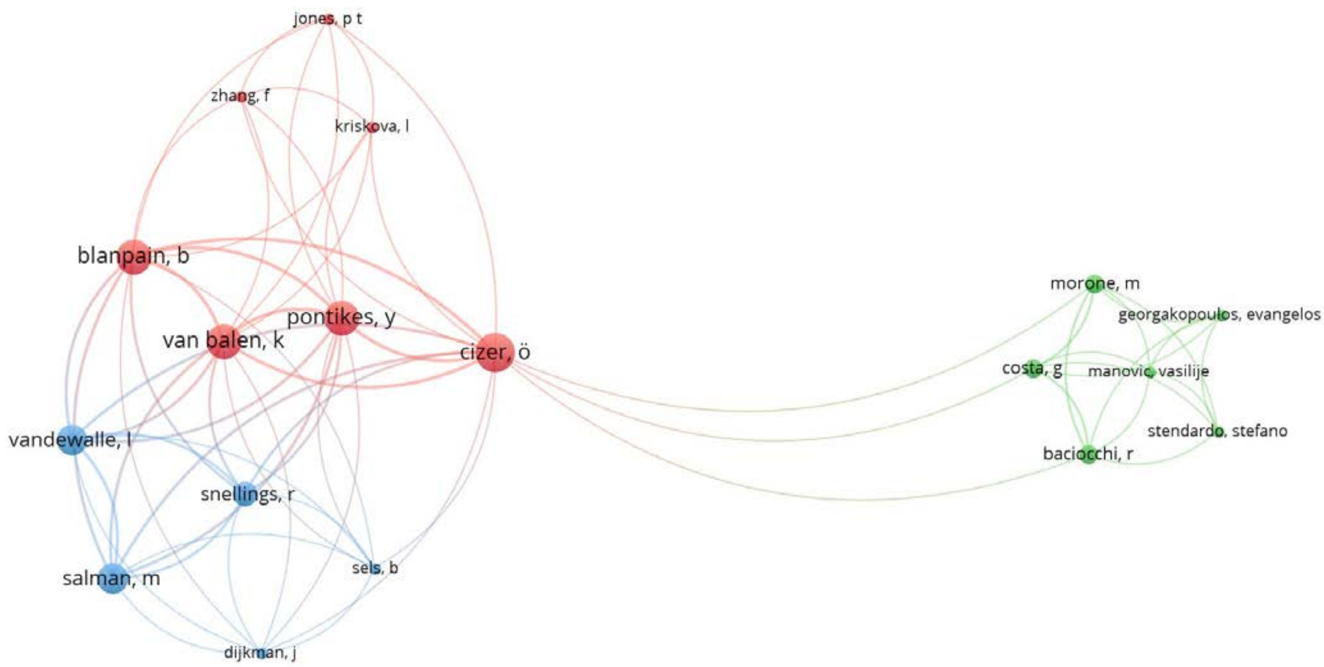

Figure 2. Network connections of the main author.

About the kind of text, was found journal paper, conference paper and book chapter. There are others five conference papers which do not had free access, these papers stayed out from portfolio. Only one manuscript was from book chapter and other three were obtained from conference paper (Figure 3). Theses texts also had few citations, less than five, until December 2021. But the journal papers presented great sum of citation and was majority publication with 67 articles.

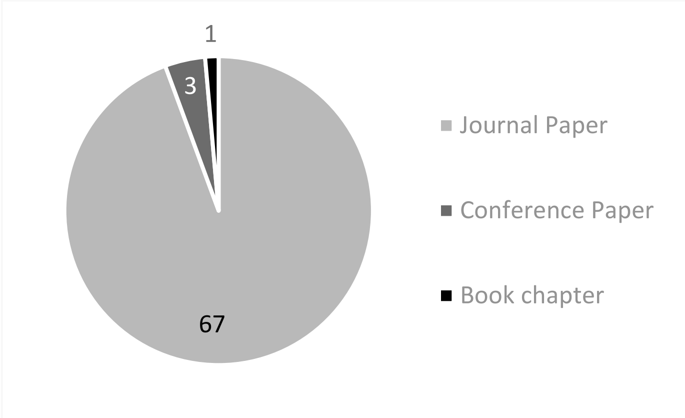

Figure 3. Number of publications for each text type.

Over the Years, few papers were published about the theme. A crescent move started in 2018, but declined in 2021 (Figure 4). This decline can be attributed to pandemic context in past two years. The grow up between 2018 and 2020 can be caused by crescent interesting about theme. Two articles were selected for the portfolio, even though they were outside the 10-year limit amid 2011 and 2021. These were very cited for other works, because of that, they were selected because of their relevance.

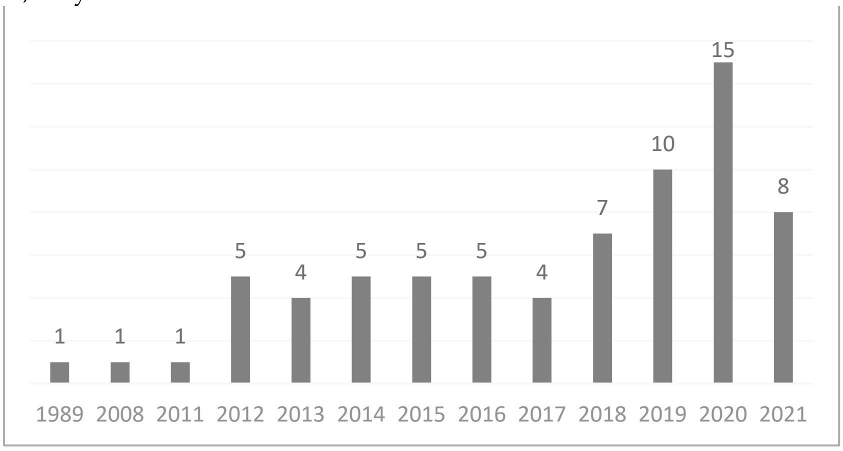

Figure 4. Publications per year with applicated filters.

3.1.1. Publications per country

The Figure 5 shows the country distribution of publications about theme. It is noted that there are works on the subject in four continents, but researchers from China were printed 40% for the texts. China, in addition to being the largest steel producer in the world [78], has low slag utilization rates [2]. That can be explain the interest of the local scientific community. However, other great producers like Japan, United States and Russia do not had write articles about the theme.

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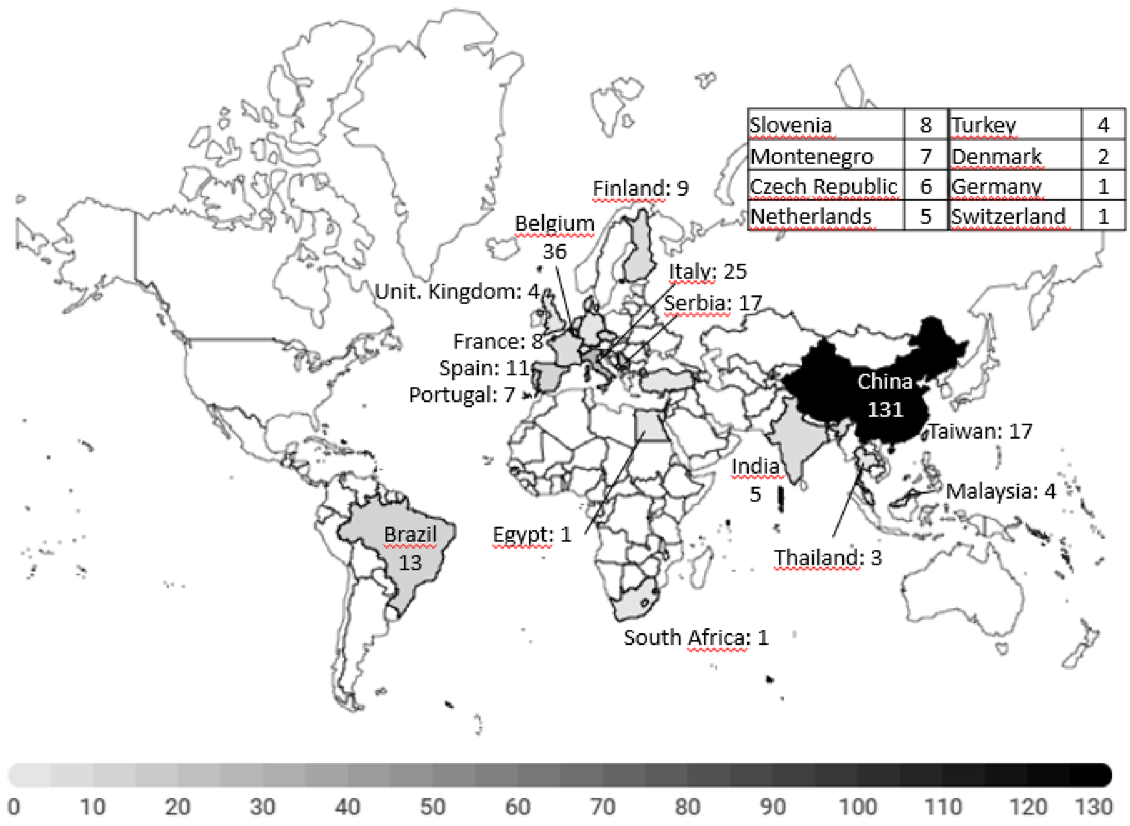

Figure 3. Number of publications per country.

In addition to China, there is a large concentration of articles published by authors in the European Union, with 47% rate. Researchers from Belgium, Italy and Serbia are the continent's greatest writers. Works from Europe tend to be cited more than those from other countries. The Figure 6 show that relation, where the circumference size is the rate between citations and publications. The biggest circle of France, Belgium and Italy tells us that articles produced in these countries are proportionally more cited, in contrast to China which your major number of publications.

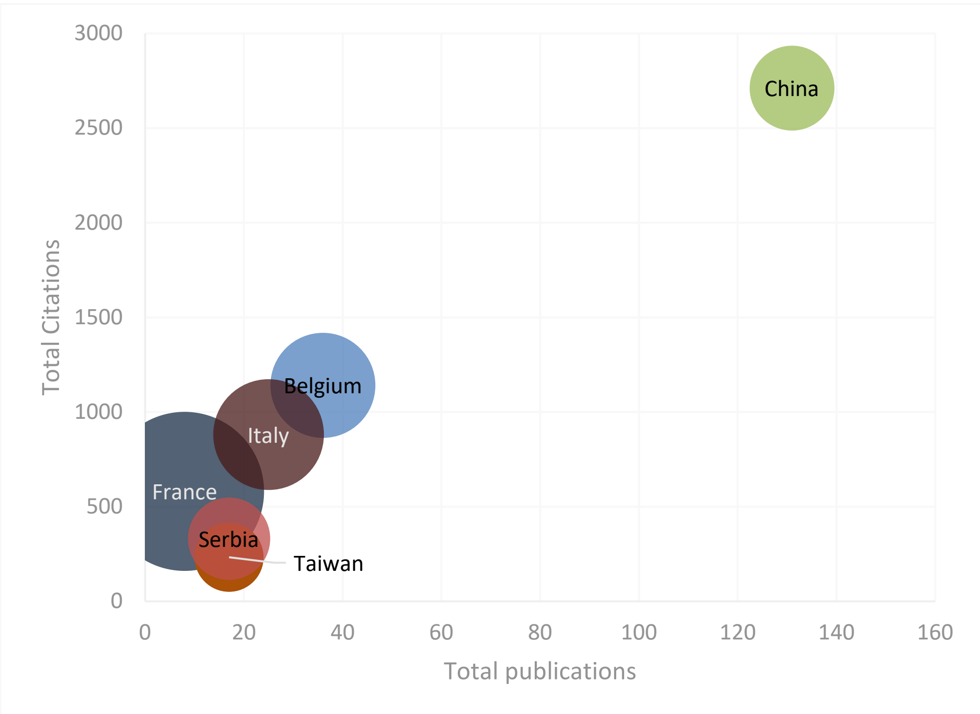

Figure 6. Relationship between number of publications and number of citations per country.

3.1.2. Publications per journal

The portfolio presented 67 journal papers, the main kind of text. These papers were found in 31 periodicals. "Construction and Building Materials" were the most relevant journal about the theme, with 22 publications. This, follow as so far by "Materials". That is an important periodical in civil construction area, its Impact Factor is 6,1 [79], while "Materials" has an Impact Factor of 3,6 [80].

When analyzing the relevance of published article, Figure 7 shows the relationship between the number of publications and citations until December 2021. As well as, "Construction and Building Materials" continue to be to most relevant journal, with major publications and citations. The periodicals "Cement and Concrete Composites" and "Journal of Hazardous Materials" can also be highlighted for presenting a large number of citations, despite few publications on the research object. The first is from civil construction area, with impact factor 7,6, when the other is from Environmental area, with impact factor 10,6 [79].

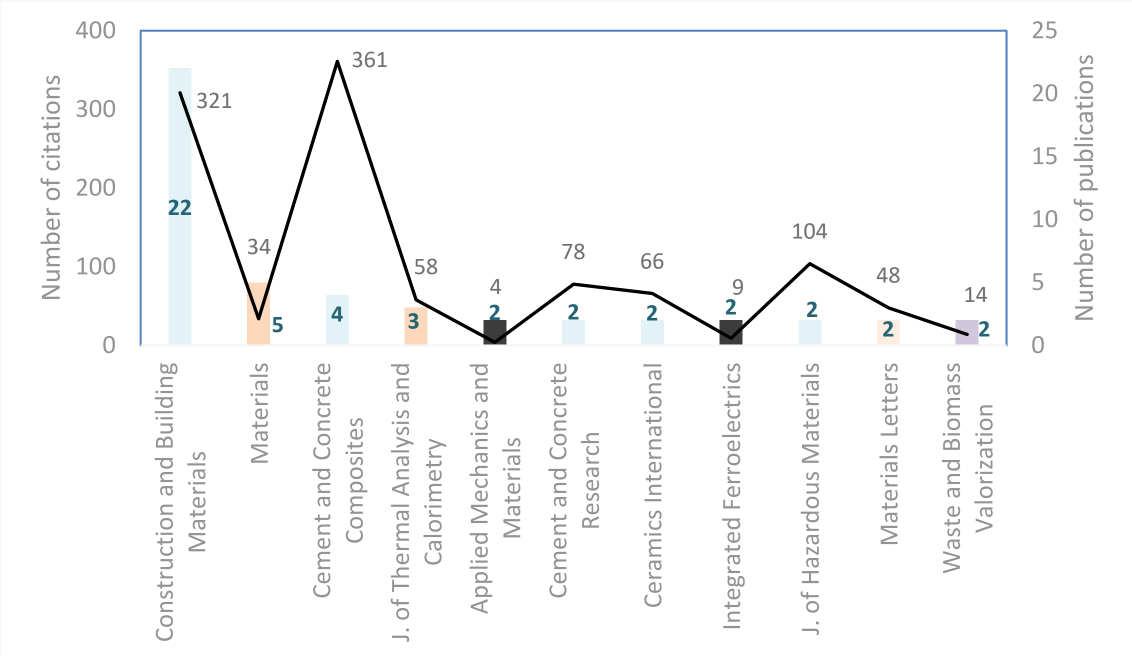

Figure 4. relationship between number of publications and number of citations per journal.

3.2. Bibliometric analysis

There are different types of steel furnace, which spawn steel slag. On the portfolio, four sort of slag were announced: Blast Oxygen Furnace Slag (BOF), Ladle Furnace Slag, Electric Arc Furnaces Slag (EAF) and Stainless-Steel Slag. These slags were used to compose AAB alone or in mixes with other precursors. On the research, 47,7% that articles used steel slag with others precursors. Among these are fly ash (52%), blast furnace slag (38%) and metakaolin (16%) were the main binder utilized on the blends. These materials are so well known in studies about cements and other binders. Other alternative materials like nickel iron slag, gold mine tailings and flue gas desulfurization gypsum had been found. About the Slag, BOF as the main used in texts, present in 61% of them follow by EAF with 18%. According to WSA [78], the oxygen furnace is the most common form of steel production, with a 72% share in the world.

All these slags were used to make some different products: pastes (52% of the texts) and mortars (28%) were produced more times, followed by blocks and concrete with less than 5% each. When analyzing the kind of activator, sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) are the most utilized. Studies were found where these activators were used alone, composing mixtures with each other or mixed with other activators. Beside these, were other ten activators related, like potassium hydroxide (15% of the texts), sodium carbonate, calcium chloride, potassium citrate and cement kiln dust. 86% for the articles utilized the two-part method for mixes the activator. This method uses an alkaline solution and water to hydrate the slag. Any authors consider it more dangerous than one-part method [6, 81]. So, that generate a knowledge gap for one-part method utilization.

3.2.1. Characterization Methods

Table 2 shows the main characterization methods among the works. The majority researches used many physical, mechanical and microstructural tests. Axial compression, X-Ray Fluorescence (XRF), X-Ray Diffraction (XRD) and Scanning Electron Microscope (SEM) were the most utilized method for characterization among all types. On the Physical characterization, Particle Size Distribution (PSD) by Laser Diffraction (LD) and porosity were the most utilized method. These are the tests that must be performed, at least, to characterize the material in future works.

Table 2. Characterization methods used in portfolio.

Physical characterization		Mechanical characterization		Microstructural characterization	
Method	**Quant.**	**Method**	**Quant.**	**Method**	**Quant.**
PSD-LD	25	Axial compression	54	XRF	68
Porosity	20	Bending	20	XRD	54
Calorimetry	14	Tension	4	SEM	47
Density	14	Elastic modulus	2	TG/DTA	21
BET Specific Surface	12	Hardness	2	FTIR	17
Setting time	11	Abrasion	1	UV reflexing	5
Absorption	10	Ductility	1	Rietveld analysis	5
Blaine Spec. Surface	7	Aggregate crush	1	ICP-OES	3
Shrinkage	5	-		TEM	2

Its be possible to note a knowledge gap about these kinds of characterization. On the mechanical characterization, there are few authors utilizing others tests besides axial compression and bending. It be caused by the major utilization of 4x4x16 cm^3 prism molds to mechanical description. Also, on microstructural evaluation, there is room for studies involving Rietveld analysis by XRD and EDS analysis bay SEM. There is demand for articles on a more complete mechanical and microstructural characterization.

A few works used others types of material characterization, like durability, environment tests or fresh state tests. Only twenty-three environmental tests were presented on the texts, the same amount of durability tests. Leaching and pollutant adsorption are the mains tests realized on ambiental characterization, while sulphate resistance is the major utilized for durability studies. About fresh state methods, were only thirteen tests appreciated, mostly spreading. Can be pointed a knowledge gap in these methods for the steel slag as an AAB.

3.2.2. BOF Properties

The chemical composition of the BOF in portfolio is shown in Table 3. The main oxides are calcium oxide (CaO), iron oxide (Fe_2O_3) and silicon oxide (SiO_2), together they account for nearly 80% for the components. Jia and Liu [66] found significant difference in the BOF composition, when varied the slag age or the treatment submitted. The authors collected slag right after leaving the oven, after six months of ripening and after treatment by magnetic separation. In addition to the Fe_2O_3 content, some studies [24, 50, 71] sought to reduce the amount of P_2O_5 or MnO, because these oxides modified the hydraulic properties.

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Table 3. Chemical composition for BOF of the portfolio.

	Mean	Standard Deviation	Maximum	Minimun
CaO	41,2%	5,0%	52,4%	26,5%
Fe2O3	23,5%	6,0%	43,5%	14,9%
SiO2	15,2%	4,0%	26,3%	8,2%
MgO	7,1%	2,6%	13,6%	1,3%
Al2O3	4,3%	2,7%	11,0%	0,8%
MnO	3,1%	1,1%	5,3%	1,1%
P2O5	1,5%	0,9%	4,1%	0,1%
TiO2	1,0%	0,5%	3,1%	0,3%
V205	0,6%	0,3%	1,1%	0,1%
SO3	0,6%	0,4%	1,7%	0,1%
Cr2O3	0,5%	0,4%	1,3%	0,1%
PF	3,5%	3,4%	9,8%	0,0%

About the mineralogical composition, the main phases found in XRD are Larnite ($CaO.2SiO_2$), Wuestite (FeO) and Portlandite ($Ca(OH)_2$). These phases appeared in at least 50% of articles from the portfolio. In addition to these, another 44 minerals were reported as showed in Table 4. As with chemical composition, treatment or age for BOF can be produce changes in mineral composition [22, 29, 58]. Authors reported some phases with hydraulic properties, which can be increased mechanical resistance for Slag's AAB, like Larnite, Portlandite, Alite or Brownmillerite. Also are related components which appear during the hydration, like Hydrated Calcium Silicate, Hydrated Calcium-Aluminate Silicate (CASH), Hydrogarnet or ettringite. These components increase mechanical resistance on the products [32, 43, 53].

Table 4: phases found by XRD for BOF of the portfolio.

Phase	Rate	Phase	Rate	Phase	Rate
Larnite	81,4%	Mayenite	10,0%	CaSO4.H2O	2,9%
Wuestite	64,3%	Tricalcium Aluminate	10,0%	CaSO4	2,9%
Portlandite	50,0%	Zeolite	7,1%	Hydrogrossular	2,9%
Lime	47,1%	Srebrodolskite	5,7%	Calcium Peroxide	2,9%
$CaFeO_2$	42,9%	Rosenhahnite	4,3%	Thaumasite	1,4%
Alite	35,7%	Ussingite	4,3%	Merwinite	1,4%
Calcite	30,0%	Corierite	4,3%	Magnesium Ferrite	1,4%
Magnetite	24,3%	Pirssonite	4,3%	Metahalloysite	1,4%
Brownmillerite	21,4%	Brucite	4,3%	Paligorsquite	1,4%
Quartz	20,0%	Hatrurite	4,3%	Ferrocarfolite	1,4%
Hydrated Calcium Silicate	18,6%	Hematite	4,3%	Meixnerite	1,4%
Amorphous	18,6%	Bredigite	2,9%	Butlerite	1,4%
Ettringite	14,3%	Fayalite	2,9%	Pseudobroquite	1,4%
Hydrogarnet	12,9%	Jennite	2,9%	Grossular	1,4%
CASH	11,4%	Magnesium Silicate Hydroxide	2,9%		
Periclase	10,0%	Vuagnatite	2,9%		

Due to the large number of mixes used in portfolio studies, there are many conclusions about the axial compression resistance. In general, others precursors used withs BOF

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improve the mechanical resistance. Products made with BOF and fly ash have shown that, the greater the amount of fly ash, the greater the compressive strength [52, 65]. Part of the works shows that increasing the proportion of EAF improves resistance, achieving the same strength as cement products in lager ages [63, 72]. Only one paper reported that has a limit to blast furnace addition, beyond which the resistance decreases [77].

However, the kind of activator is the most important factor in increasing mechanical compression. The highest strength was achieved by the KAJA et al. [43] work, reaching 75 MPa at 28 days, using BOF activated with by Potassium Citrate. Small amounts of activator do not cause enough reactions to gain strength, while high levels can cause bond breakage and low strength. There is a need to dose the ideal amount. The combination of Na(OH) and Na_2SiO_3 brings good resistance results, better than either of these activators alone [32, 40]. For levels above 2%, sulphate activators like sodium sulphate (Na_2SO_4) or calcium sulphate ($CaSO_4$) showed better resistance than others activators [28, 29, 38]. On the other hand, calcium chloride and potassium-based activators reached the lowest mechanical resistance [29, 31].

4. Conclusions

For the composition of the portfolio, it started with 1753 texts, which were refined until reaching only 71. These texts were published by 247 authors, who formed little research groups. 95% of the texts are journal papers, with increasing publication between 2017 and 2020. The country with the most authors who published is China, but French, Italian and Belgian articles are more relevant because they are more cited. For the journals, Construction and Building Materials is the one that published the most and also the most relevant within the theme.

In the critical analysis, it was possible to see that four types of slag were used, with BOF being the most common. It was also very common to use slag with other precursor materials, especially materials already known as cement additions. Fly ash and blast furnace slag were the most used in these mixtures. Sodium hydroxide and sodium silicate are the most commonly used activators to make pastes and mortars, using the two-part method.

Regarding the results achieved, the chemical composition showed a slag rich in CaO, Fe_2O_3 and SiO_2, with proportions varying little among themselves. The type of treatment can influence these results. The mineralogical composition showed a BOF rich in larnite, wuestite and portlandite, which explains the low hydraulicity of the material. When analyzing the compressive strength, studies that used other precursors, such as blast furnace slag and fly ash showed better performance. The type of activator, for better mechanical strength, requires an optimal dosage study.

All these results show that there are some knowledge gaps on the subject. First, in mineralogical characterization, few studies use the Rietveld method. Afterwards, few studies were observed on the mechanical properties of hardened pastes or mortars. Finally, there is room for further studies on the durability of these materials, as well as for characterization of the fresh state.

Author Contributions: J. C. B J – conceptualization, writing—original draft preparation, formal analysis. G. J. B. – conceptualization, writing—review and editing, project administration. V. A. A. O. and J. L. C. – methodology, validation, writing—review and editing. E. F. M. – data curation, visualization.

Funding: this research received no external funding.

Acknowledgments: the authors acknowledges the support provided by the Federal University of São João Del-Rei (UFSJ) and Federal University of Ouro Preto (UFOP). Thanks are also due to the Brazilian research groups Ative-CNPq/ UFOP and RECICLOS-CNPq/ UFOP for the infrastructure and collaboration.

Conflicts of Interest: the authors declare no conflict of interest.

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