International Journal of
Science and Engineering Investigations vol. 6, issue 65, June 2017

ISSN: 2251-8843

A Review on the Use of Rice Husk Ash as a Mineral Admixture in High Performance Concrete: Research Opportunities

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Abstract- This review presents a structured paper selection process for the composition of a bibliographic set to study the use of an agricultural residue, rice husk ash (HRA), as partial replacement of cement in the production of high performance concrete (HPC). The main objective is to identify knowledge gaps that must be explored by researchers studying the influence of the use of this residue on the concrete final properties. Using the ProKnow-C (Knowledge Development Process-Constructivist), 3994 publications eligible to the desired set were initially identified and, after a continuous selection process, 10 papers were selected. The academic relevance was presented through bibliometric analysis and the content of the papers was submitted to systematic analysis according to five research lenses. These lenses are based on the use and properties of the RHA and the HPC properties.

Keywords- *High Performance Concrete, Rice Husk Ash, Bibliographic Set, Papers*

I. INTRODUCTION

Understood as a technological evolution of conventional concretes, high performance concrete (HPC) is the result of applied research and joint introduction of mineral additions and chemical admixtures in the concrete mix. The use of these materials, especially the dispersing action of the chemical admixtures that allows the reduction of water in relation to the amount of cement material, is directly responsible for the high mechanical strength of concrete [1]. Its dense microstructure and low porosity, which result from these additions, provide concrete with distinguished characteristics, among which we can mention the low water/cement ratio, low permeability and high mechanical strength.

Because it is a composite material, the concrete properties depend directly on the proportion, characteristics and interaction of its components [2]. Among these characteristics, the durability of the concrete is affected directly by the components proportion of the mixture and the quality of these components, since the microstructure of the material is influenced by factors such as the chemical composition of the cements, the water/binder ratio, mineral addition and particle size distribution [3].

Mineral addition is referred to as pozzolanic materials, including natural pozzolans, fly ash, granulated blast furnace slag, rice husk ash (HRA), metakaolin, silica fume, and others. The insertion of these materials into the mixture promotes the need to remove some of the other materials in order to maintain the same volume unit [4].

The RHA is a byproduct obtained by controlled combustion of the rice husk, obtained as agricultural waste. The final percentage of silica in its amorphous form in the RHA can reach 96%. Thus, this product has a very strong pozzolanic characteristic and represents an excellent supplementary cementitious material [5].

Since the 1970s, countries such as India and The United States have been investigating the use of HRA, but only after the development of high performance concrete in the 1980s, there was a concern to obtain the maximum pozzolanic performance of the ash, allowing its use as substitute of silica fume as mineral addition [6].

Recently, many studies have been conducted in order to properly investigate the use of this agricultural residue in HPC and its influence on the concrete properties. However, there is still no consensus on the best way to use this material, especially when we talk about the best cement replacement content. Therefore, this research aims to select a set of papers published in the last 10 years on the subject and analyze them, in order to identify knowledge gaps in the literature that may guide future researches. For this, the methodology known as ProKnow-C (Knowledge Development Process-Constructivist) [7] is used.

In addition to this first introductory section, this paper presents five other sections. The second section presents the methodological framework of this study, the third section presents the entire selection process of the papers that compose the bibliographic portfolio and the fourth section is composed by the bibliometric analysis of the set. The fifth section presents the research opportunities identified through the systematic analysis of the papers and the last section presents the conclusions of this theoretical review.

II. Methodological Framework

The methodological framework of a scientific research can be carried out in various ways and depends mainly on the subject addressed, the objectives of the study and the means that will be used to obtain the data. Thus, the methodological framework of the present research considers the following aspects: nature, approach, objectives, technical procedures and research instrument [8]. Table I presents the methodological framework used in this article, according to the classification presented in [8].

III. Procedures For The Selection of Papers

Basically, the process of selecting the papers to compose the set using ProKnow-C consists in defining the keywords of the search, performing a preliminary investigation and selecting papers for the set [7]. The selection of papers is an ongoing process of filtering until the final portfolio can be assembled.

Two main axes were formulated in order to begin the selection: the main components of the mixture and important concepts. The main material which will be combined with the words of the two axes is the high performance concrete, as shown in Table II.

In order to form the keyword combinations, the words of the two axes were grouped and combined with the main material, totaling six combinations. All the combinations were searched in titles, abstracts and keywords of the papers in the databases.

The search of the databases by area of knowledge (Civil Engineering) showed eighteen bases indexed by the CAPES website [9]. Six databases were chosen because they have complete texts and are more adherent to the research objectives. The databases chosen were:

- American Society of Civil Engineers - ASCE
- Compendex
- ScienceDirect
- Technology Research Database (TRD)
- Web of Science
- SCOPUS

The temporal filter adopted to carry out the search included papers published up to 10 years before the date of the present study (2006 to 2016). In a first search, 3994 papers were found, composing the gross bibliographic set. The number of papers by key-word and database is presented in Table III.

The relevant information of each paper, such as title, authors, year, abstract and etc., were exported to the EndNote application [10], in order to perform the continuous selection process.

TABLE I. Methodological framework

Nature	Basic	Technical Procedures	Bibliographical
	Applied		Documentary
Aproach	Qualitative		Experimental
	Quantitative		Survey
Objectives	Exploratory		Case Study
	Descriptive		Expost-facto
	Explanatory		Action
Instrument	ProKnow-C		Participant

TABLE II. Main material, axes and keywords

Main Material	Main Components	Importants Concepts
High performance concrete	Mineral admixtures Rice husk ash Silica fume Chemical admixture	Mix design Packing density

First, publications that were not journal papers were eliminated from the set, resulting in the exclusion of 643 publications. Afterwards duplicate articles were eliminated, using an Endnote tool, resulting in the exclusion of 1646 publications. After the organization of the papers extracted in alphabetical order of their titles, 253 duplicate papers were identified, which titles had small differences of spelling, but representing the same paper. The duplicity of extracted papers exists because the same article can serve more than one keyword combination and be indexed by more than one database. After a new reading and analysis of the titles, 1360 publications whose titles were not aligned with the research theme were eliminated. After this step, the bibliographic set included 92 papers. In the next selection stage, it was evaluated how many of the 92 papers had texts available, resulting in the exclusion of 24 papers that were unavailable for free download.

The remaining 68 papers were evaluated according to their scientific relevance, obtained through the number of citations that each paper had in Google Scholar. The papers were ordered in descending order according to the number of citations, whose sum resulted in 2283. Adopting the Pareto Postulate, the papers were chosen until the number of citations accumulated reached 1941, which corresponds to 85% of the total 2283 citations. This corresponded to papers with 30 citations. In this step, 22 publications presenting titles aligned with the research theme, available texts and scientific relevance were selected.

In the next stage, the 22 papers in the bibliographic set were assessed to determine whether the abstract was aligned with the research aim. This analysis resulted in the exclusion of 10 papers. After this step, the bibliographic set included 12 papers (gross base papers, not repeated and with the title and abstract aligned with the research aim). A new review process of excluded papers was carried out at the stage of scientific relevance. It was selected seven articles that had less than two years of publication (papers that have not yet had the opportunity to be cited), written by one of the authors al-ready selected. After reading the abstracts of these publications, they were added to the set, which now consists of 19 papers.

Finally, the 19 papers of the set were read in full and were divided according to their main research theme, as shown in Table IV.

TABLE III. NUMBER OF PAPERS BY KEYWORD AND DATABASE

Keywords		Databases						
Search term 1	Search term 2	ASCE	Compendex	ScienceDirect	TRD	Web of science	SCOPUS	Total
High performance concrete	Mineral admixture	12	284	196	82	214	123	911
	Rice husk ash	4	58	18	23	113	21	237
	Silica fume	18	500	152	181	287	246	1384
	Chemical admixture	10	129	18	38	39	54	288
	Mix design	73	500	59	119	126	109	986
	Packing density	2	56	17	20	65	28	188
Total		119	1527	460	463	844	581	3994

TABLE IV. NUMBER OF PAPERS BY THEME

Research Theme	Papers
Assessment of HRA use in HPC	7
Assessment of HRA use in UHPC	3
Assessment of HRA use in conventional concrete or cement paste	5
Production or characterization of HRA	2
Assessment of the use of others mineral additions in HPC	2

The 10 papers dealt with the use of HRA in high and ultra high performance concrete (HPC and UHPC). The final bibliographic set is presented in chronological order of publication, from the most recent to the oldest (Table V).

TABLE V. SELECTED PAPERS FOR THE BIBLIOGRAPHIC SET (CHRONOLOGICAL ORDER)

Papers
Xu, W. et al. (2016) Pozzolanic Reactivity of Silica Fume and Ground Rice Husk Ash as Reac-tive Silica in a Cementitious System: A Comparative Study. Materials, v. 9, p. 146
Le, H. T. and Ludwig, H. M. (2016) Effect of rice husk ash and other mineral admixtures on properties of self-compacting high performance concrete. Materials and Design, 89, n. 4, 156-166.156-166, 2016
Van, V.T.A. et al. (2014) Rice husk ash as both pozzolanic admixture and internal curing agent in ultra-high performance concrete. Cement and Concrete Composites, 53, n. 12, 270-278
Le, H. T., Nguyen, S. T. and Ludwig, H.M. (2014) A Study on High Performance Fi-ne-Grained Concrete Containing Rice Husk Ash. International Journal of Concrete Structures and Materials, 8, n. 7, 301-307, Dec 2014
Van Tuan, N. et al. (2011) Hydration and microstructure of ultra high performance concrete incorporating rice husk ash. **Cement and Concrete Research**, 41, n. 78, 1104-1111
Tuan, N. V. et al. (2011) The study of using rice husk ash to produce ultra high performance concrete. Construction and Building Materials, 25, n. 78, 2030-2035
Sensale, G. R. (2010) Effect of rice-husk ash on durability of cementitious materials. **Cement and Concrete Composites**, 32, n. 54, 718-725, Oct 2010
Salas, A. et al. (2009) Comparison of two processes for treating rice husk ash for use in high performance concrete. Cement and Concrete Research, 39, n. 95, 773-778
Cordeiro, G. C., Filho, R. D. T. and Fairbain, E. D. M. R. (2009) Use of ultrafine rice husk ash with high-carbon content as pozzolan in high performance concrete. Materials and Struc-tures/Materiaux et Constructions, 42, 983-992
Laskar, A. I. and Talukdar, S. (2008) Rheological behavior of high performance concrete with mineral admixtures and their blending. Construction and Building Materials, 22, n. 45, 2345-2354

IV. BIBLIOMETRIC ANALYSIS OF THE BIBLIOGRAPHIC SET

A bibliometric analysis of the bibliographic set of papers is a process that demonstrates quantitatively its statistical data in order to manage the information and scientific knowledge of the subject matter. This analysis is performed by counting the documents and aims to estimate the relevance of journals, the scientific recognition of the papers and the degree of relevance of the authors [7]. To illustrate the bibliometric analysis of this set, it will be demonstrated the degree of relevance of the journals, as well as the scientific recognition of the papers.

The 10 papers selected were published by seven journals, three with two publications each and four with only one publication each (Table VI). The most frequent journals are: "Cement and Concrete Composites", "Cement and Concrete Research" and "Construction and Buildings Materials".

The second analysis was based on the number of times that one of the portfolio journals was referenced by the papers (10 papers) of the portfolio itself. The most cited journal was “Cement and Concrete Research”, as shown in Figure 1.

TABLE VI. RELEVANCE OF JOURNALS

Journal	Number of Papers	SNIP*
Cement and Concrete Composites	2	3,191
Cement and Concrete Research	2	3,577
Construction and Building Materials	2	2,499
Materials	1	1,183
Materials & Design	1	3,391
International Journal of Concrete Structures and Materials	1	-
Materials and Structures	1	1,361

*SNIP (Source Normalized Impact per Paper) www.journalmetrics.com (2014)

The third analysis, which identifies the scientific recognition of the 10 selected papers, was performed by counting the number of citations that each article has received since its publication (Figure 2). It was used the Google Scholar to get these numbers of citation. The paper more cited since its publication is titled "Use of ultrafine rice husk ash with high-carbon content as pozzolan in high performance concrete" [11], with 104 citations. The relevance of the papers that compose the theoretical framework can also be emphasized by considering the rank of the set to which the journals belong, which is pro-vided by CAPES. 8 of the 10 papers (80%) were published by journals with A1 and A2 ranking.

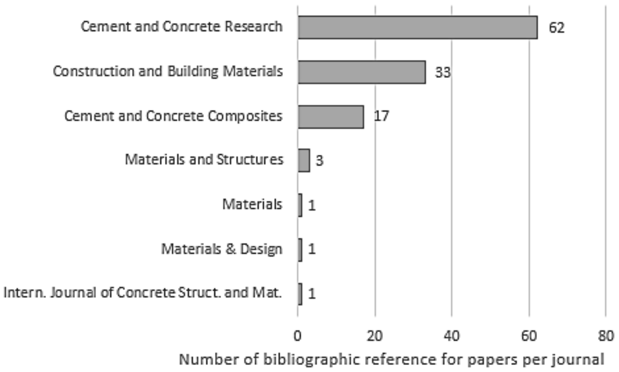

Figure 1. Relevance of the references in the bibliographic set.

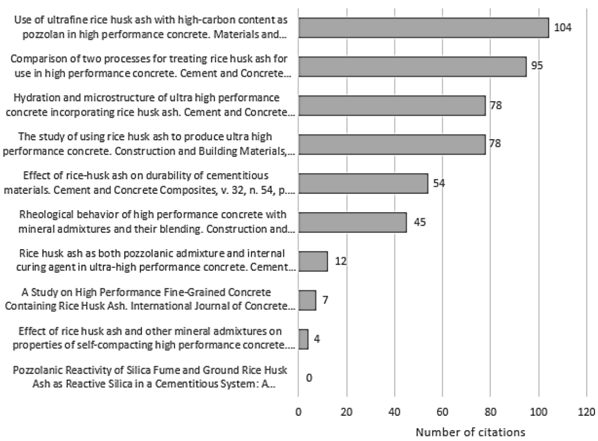

Figure 2. Relevance of papers according to scientific recognition.

V. SYSTEMATIC ANALYSIS OF THE SELECTED PAPERS

The systematic analysis advocated by ProKnow-C [7] aims to analyze each paper of the bibliographic set, from the perspective of research lenses, with the intention of identifying the strengths and opportunities (weaknesses) of the papers. Each research lens addresses a different perspective of the study and together they encompass the knowledge available in the set. Thus, the elaboration of research lenses based on concepts of the studied subject is the first step of this analysis, followed by the analysis stage of the content of the papers and, finally, the analysis phase of the results, in a general way.

The choice of the lenses was made according to criteria to evaluate the use of RHA as mineral addition in high performance concretes: reasons for RHA use, ways of using RHA and HPC Properties evaluated. The research lenses are summarized in Table VII.

The first lens was derived from the reason of the agricultural residue use and was named "Ash characterization". This lens seeks to know if the paper performed physico-chemical characterization of the RHA for its choice as mineral addition.

The second and third lens were formulated from the ways of using the ash and were referred to as "Ash use" and "Replacement content", respectively. These two lenses seek to verify whether the RHA was added to the mixture instead of the cement and what were the cement replacement contents for which the papers used, respectively.

The fourth and fifth lenses were derived from the criterion regarding the properties of HPC evaluated and were named "Properties evaluated" and "Tests carried out", respectively. The formulation of these two lenses aims to investigate whether the papers analyzed the rheological, mechanical and durability properties of the concrete and which tests were carried out for this evaluation.

A. Ash Characterization (Lens 1)

The physical-chemical characterization of the concrete constituents is an essential step to evaluate the influence of them on the high-performance concrete final properties. Therefore, the researchers should perform characterization tests to determine the characteristics of the constituents (RHA), from their geometry to their pozzolanic activity index and chemical composition.

The 10 papers of the set presented the physical-chemical characterization of the RHA, however, using different tests. The main tests were about crystalline analysis, chemical analysis, granulometry, density, surface area, carbon content and pozzolanic activity. No paper used Thermogravimetric (TGA) test for pozzolanic activity and Infrared Fluorescence (FTIR) for chemical analysis. Therefore, future researches should per-form, in addition to the tests used by the papers, the other two tests (TGA and FTIR) that were not used, so that a more complete characterization of the ashes can be obtained.

TABLE VII. RESEARCH LENSES USED IN THE SYSTEMATIC ANALYSIS OF THE LITERATURE.

ID	Lens	What Search?
1	Ash characterization	Did the article perform physico-chemical characterization of the RHA?
2	Ash use	Has the RHA been added to the mixture instead of the cement or in addition to the cement?
3	Replacement content	What were the replacement contents of cement by the RHA that the papers evaluated?
4	Properties evaluated	What were the HPC properties assessed using RHA?
5	Tests carried out	What were the tests used in the papers for the evaluation of these properties?

B. *Ash Use (Lens 2)*

According to the procedures chosen in the dosage, the mineral addition can occur by addition to the cement (with removal of part of the aggregates) or by cement replacement (with removal of part of the cement). When new material is added, others should leave the mixture to maintain the same volume unit [1]. Hence, it is important to know how the ash was used in the concrete mix.

The 10 papers of the set used partial cement replacement by mass. 3 of the 10 papers [12] [13] [14] used traces where RHA was used in combination with other pozzolanic material. As no paper has used volume cement replacement, future researches should investigate this way of using RHA in order to compare with dosage methods that use volume substitution.

C. *Replacement Content (Lens 3)*

Although many researchers have been investigating the RHA use lately, there is still no consensus about the best cement replacement content for this residue that maximizes the benefits. This research is important in relation to the ideal amount of ash in the mixture, from both an economical and technical point of view.

9 of the 10 papers of the set presented the cement replacement contents by the RHA, while only 1 paper [15] did not address this criterion. The levels used were 5%, 10%, 15%, 20%, 25% and 30%, with 10%, 15% and 20% being the most used. No paper has used levels above 30% of cement replacement, which can be investigated in future researches.

D. *Properties Evaluated (Lens 4)*

If, in the past, the compressive strength of the concrete was considered the main criterion of the material performance, over time the durability assumed this prominent position when analyzing the performance of the structural elements [16]. Another important property to be investigated is the rheology of concrete, evaluated in its fresh state. Thus, this lens seeks to evaluate if the papers analyzed the three properties cited: mechanical, rheological and durability.

The 10 papers of the set showed the properties of the concrete evaluated when using the RHA as mineral addition. 7 papers investigated the rheological properties, 8 papers investigated the mechanical properties and 6 papers investigated the durability proper-ties. In addition, only 4 papers [11] [17] [18] [19] investigated the three properties together. Thus, future studies should evaluate the influence of the RHA use on the three properties mentioned.

E. *Tests Carried Out (Lens 5)*

It is necessary to carry out specific tests on the concrete, both in its fresh and hardened states, in order to investigate the properties cited in lens 4. There are numerous trials that can be performed for this purpose, it is up to the researchers to evaluate which are the most interesting and feasible.

The 10 papers of the set presented the tests used to evaluate the concrete properties, however, carrying out different tests for such evaluations. The most used tests were Scanning electron microscopy (SEM), TGA, Mercury intrusion porosimetry (MIP), Rapid chloride permeability test (RCPT), Water absorption, Indirect tensile strength, Modulus of elasticity, compressive strength, Slump test and Plastic viscosity. No paper performed Air content test in the fresh concrete mixture. This test is very important and should be used by future researches because a great air content in the mix can impair the mechanical properties and durability of the concrete.

F. *Research Opportunities*

The systematic analysis of the set facilitated the identification of opportunities for research in the use of the agricultural residue (RHA) as mineral addition in CAD. These opportunities are presented in Table VIII.

As shown in the table 8, the lenses were approached almost entirely by the papers, however, they presented many weaknesses that generated the opportunities identified.

VI. CONCLUSIONS

This paper presented a structured process for the identification of research opportunities regarding the use of rice husk ash as a mineral addition in high performance concrete. It was performed a systematic analysis of a bibliographic set that has gathered papers published in the last 10 years about the subject. Both the selection of papers and the analysis of their contents were performed according to the ProKnow-C method [7], and their main steps were presented in this study.

Among the 3994 publications that made up the gross set of papers, 10 most relevant papers were selected through a continuous process of filtering and selection [11] [12] [13] [14] [15] [17] [18] [19] [20] [21]. The selection procedures allowed the authors to sketch the current state of art of knowledge about the subject, as well as to acquire new knowledge. After the selection of the papers, a bibliometric analysis was carried out in order to investigate the degree of relevance of journals and papers in the set. The most frequent journal in the portfolio, considering the papers and the references, was the "Cement and Concrete Research", classification A1 (CAPES).

The following step was the systematic analysis of the papers content using five re-search lenses, formulated from important criteria: reasons and ways of using RHA and HPC Properties evaluated. This step allowed the identification of research opportunities through the weaknesses of the papers, according to each lens. As a final result of this analysis, a proposal was made for future researches to evaluate how rice husk ash can be used as mineral addition in the production of high performance concrete, taking into account the effects of its use on rheological, mechanical and durability properties of the HPC.

TABLE VIII. RESEARCH OPPORTUNITIES IDENTIFIED IN THE SYSTEMATIC ANALYSIS

ID	Lens	Number of Papers	Opportunity
1	Ash characterization	10	Carry out 10 physical-chemical characterization tests of the RHA (XRD, XRF, FTIR, Laser diffraction, SEM, Density, Specific area, Loss on ignition, TGA and Modified Chapelle.
2	Ash use	10	Use volume partial replacement of the cement by the RHA.
3	Replacement content	9	Use 15%, 25% and 35% replacement levels.
4	Properties evaluated	10	Evaluate the rheological, mechanical and durability properties of HPC.
5	Tests carried out	10	Perform Slump test, Incorporated air content, Compressive strenght, Indirect tensile strenght, Water absorption, RCPT and MIP

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ACKNOWLEDGMENT

This work was supported by CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) and CEFET-MG, Belo Horizonte, Brazil.

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