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Challenges and Prospects of Widespread Adoption of Pozzolans for Building Construction: A Statistical Assessment

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ABSTRACT

Pozzolans are supplementary cementitious materials (SCMs) that many researchers have found suitable for partial replacement of cement in concrete in order to reduce the environmental hazards and energy consumption involved in the production of concrete. However, these materials have been seldomly used in the present day construction industry especially in Nigeria, in spite of notable research efforts on them over the past decade and abundance of evidence to support their tremendous benefits. A question therefore naturally arises: What is responsible for the hesitation in applying pozzolans widely in the construction industry? This paper investigated by means of a research survey the reasons for their low acceptance and adoption by stakeholders in the construction industry. Opinions from 82 respondents of impressive involvement in the construction industry were collated and statistically analyzed using non-parametric tests, namely Cronbach's Alpha Reliability, Kruskal-Wallis H and Mann-Whitney U tests. The results of the analyses affirmed that pozzolans are effective in mitigating the negative environmental effects caused by using conventional cement in concrete. It further revealed that notable factors militating against their adoption in the construction industry include unavailability of relevant mixture design standards for pozzolanic concrete, lack of commercial production of pozzolanic concrete, unavailability of sufficiently skilled professionals on pozzolan application, inadequate public awareness, lack of policies recommending and guiding its use, and fears on results achievable with use of pozzolans. Respondents generally agreed that development of proper guidelines and standards, as well as adequate public awareness will favour wide acceptance and industrial application of pozzolans.

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1. INTRODUCTION

Over the years, the need for production of clean energy resources and building materials has driven several researchers into sourcing for alternatives for cement. Cement constitutes an integral component in the production of concrete, and it has for long been and remains a valuable resource for development of buildings and infrastructure all over the world. However, its production has constituted a menace to the environment that several researchers are battling to solve it today. Production of 1 ton of ordinary Portland cement (OPC) has been found to be accompanied with the release of 1 ton of carbon dioxide (CO_2) into the atmosphere [1]. Furthermore, the cement industry requires close to 1.7 tons of limestone in production of cement and generates approximately 3.2-6.3 GJ amount of energy, amounting to about 11% of the total energy consumption for all industries [2, 3]. These key issues have brought about the need for alternatives for cement. Pozzolans have been identified as supplementary cementitious materials for partial replacement of ordinary Portland cement in concrete, and many research activities on the subject-matter are still ongoing [4-11]. Examples of pozzolans include fly ash, ground granulated blast furnace slag (GGBS), rice husk ash (RHA), palm oil fuel ash (POFA), bamboo leaf ash (BLA) and many more. Indeed, pozzolans have been found effective in production of different types of concrete, including normal strength, high strength, and lightweight concrete. Although the use of fly-ash has already gained ground in application by the construction industry in a number of developed countries,

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other sustainable industrial and/or agro-based supplementary cementitious materials, such as rice husk ash, palm oil fuel ash, sugar-cane bagasse ash are yet to enjoy similar popularity in many countries especially in developing countries typified by Nigeria. Many researches conducted both within and outside Nigeria on utilization of agro-based pozzolans have shown that when used to partially substitute Portland cement in concrete, the resulting concrete exhibits similar strengths as when 100% Portland cement is employed and has the added advantage of enhancing the resistance of concrete to aggressive media and reduces alkali-silica reactions, in addition to being environmentally more friendly [10, 12-14]. Furthermore, in countries such as Nigeria where housing is beyond the reach of many families owing to the high cost of Portland cement component of concrete, preliminary studies have shown that partial replacement of cement with pozzolans obtained from some commonly available agricultural and other waste materials, have the potential to make housing more affordable [9,15]. In spite of the positive results, the use of the research outputs have not been embraced by the construction industry in many countries. This is what motivated the study reported in this paper. This study aimed at examining the reasons pozzolans have not been adopted in the construction industry, and anticipates prospects for the future applications of these materials based on broad-based statistical analyses of a comprehensive survey and recommendations from notable stakeholders in the construction industry. This paper gives an introduction on the research paper, reviewed literature on supplementary cementitious materials, highlights the research method, presents the results from the study and discusses the implications of the results from the study, after which appropriate conclusions are drawn and recommendations made.

2. SUPPLEMENTARY CEMENTITIOUS MATERIALS (POZZOLANS)

There are several types of supplementary cementitious materials (SCMs) that have good prospects of improving the properties of concrete at specific contents. Different researches have shown notable mechanical and chemical properties of SCMs when used in concrete, some of which include reduction in cement required, decreased water absorption, permeability and binder porosity. Pozzolans may be classified into two broad groups; natural pozzolans and artificial pozzolans. Artificial pozzolans can be further subdivided into pozzolans from industrial processes and pozzolans from organic matter [16]. Artificial pozzolans that have been subjects of research by different authors include fly ash, rice husk ash, bamboo leaf ash, palm oil fuel ash, corn cob ash etc. Being by-products of industrial and agricultural sectors, the use of these pozzolans is considered very sustainable and attractive.

2. 1. Fly Ash This is one of the pozzolans that has been widely used in concrete with tremendous results and wide acceptability in several countries today. Fly ash, which generally has a smooth and spherical shape, is a by-product obtained from the combustion of coal in thermal power plants [17]. The annual generation of fly ash in different countries like USA, China and India is in the range of 75 to 120 million tonnes [18-19]. Tremendous benefits offered by fly ash in fresh concrete include improved workability, lower water demand and reduced heat of hydration. Meanwhile in hardened concrete, it improves the ultimate strength and long-term durability, and lowers the permeability. It has also been observed that the use of fly ash in concrete suppresses alkali-silica reaction, and improves resistance to corrosion and sulfate attack [20-21]. According to Dhadse et al. [22], a cut of about 25 MT can be achieved in production of CO_2 when 25MT/year of fly ash is applied to production of Portland Pozzolana Cement (PPC), hence, it is environmentally sustainable. Fly ash has also been discovered as an effective material in production of high performance concrete [23-24]. However, in recent times, market trends have shown that there is a gradual short-fall in the supply of fly-ash due to a gradual retirement of coal-fired power plants, and this trend is likely to continue over the next 20 years [25-26]. Hence there is a need for development of standards and specifications on other supplementary cementitious materials that can be used in place of fly-ash.

2. 2. Metakaolin Metakaolin is another pozzolan with potential application in partial replacement of cement in concrete. It has been known to be effective in producing concrete with very high strength. Metakaolin is produced from the calcination of purified kaolinite, the main mineral present in clay, at a temperature of 700 to 800ºC [27]. At this temperature, the octahedral alumina and tetrahedral silica lamellae structure of kaolinite gets broken down due to de-hydroxylation [16]. This causes the formation of a material possessing very high silica (SiO_2) and alumina (Al_2O_3) content, which could be in the range of 50 to 60% and 40 to 50%, respectively. This in turn enhances the formation of calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) in concrete. Güneyisi et al. [28] showed that the compressive and splitting tensile strengths of metakaolin modified concrete have positive effects on strength with up to 30% higher strength than plain concrete. For the most suitable compressive strength and durability performance, an optimal replacement level of 10% has been recommended [29-31]. Metakaolin is also highly regarded for its durability performance. It has good water absorption properties, improves pore structure of concrete, remarkably resistant to acid and sulphate attack, possesses good thermal properties, good chloride binding capacity, and improved corrosion resistance [27, 31-32]. However, the major drawback to the use of metakaolin is its high cost, which can be attributed to low rate of production, disappointing response from the construction industry, and sometimes environmental legislations against the exploration of kaolinite deposits [12].

2. 3. Ground Granulated Blast Furnace Slag Blast furnace slag is a byproduct generated when pig iron is being produced from a blast furnace, in the presence of iron ore, coke and limestone. When dried and ground into fine particles, this slag is referred to as Ground granulated blast furnace slag (GGBS). GGBS can be used in replacement of cement from a range of 30 to 70%, producing concrete with very high compressive strength and significant gain in strength with time [33]. Gao et al. [34] observed that the microstructural properties of concrete significantly improves with finer GGBS particles, as it results in an increase in surface area and a strengthening of the interfacial transition zone between the aggregate and cement paste. In a study by Lee et al. [35], GGBS was found to possess high bond strength, flexural strength and shear strength values compared to conventional concrete. It was also discovered that it can be used as an admixture in precast concrete without any problem in structural performance. GGBS is also effective in reducing porosity and chloride ion penetration, and improving acid and sulphate resistance [36], as well as decreasing the heat of hydration [6]. The disadvantage of GGBS production is the problem of insufficient steel production industries in Nigeria. Ikpeseni et al. [37] observed that quite a number of steel industries within the country are either moribund or operating below expectation. Hence, the steel industry is still largely dependent on imports. Alberici et al. [38] also noted that the availability of slag in the UK is declining due to the decreasing level of iron and steel production. This is, therefore, a major drawback to the availability of GGBS.

2. 4. Rice Husk Ash Rice husk ash (RHA) is another viable pozzolan which has been used in replacement of OPC and other varied applications. Rice husk is obtained from the milling process of paddy rice. Reports have indicated that approximately 600 million tons of rice paddy is produced annually, which is made up of about 25% rice husks on the average [39]. Hence, rice husk ash is widely available and can be easily produced through burning of rice husk under controlled or uncontrolled conditions [40]. Several researchers have observed that RHA contains high percentage of silica (over 70%) and hence high pozzolanic reactivity. This enables it to form a highly dense calcium silicate hydrate (CSH) gel when the amorphous silica combines with free lime ($Ca(OH)_2$) resulting in tremendous strength gain [41]. RHA generally results in an improvement in compressive strength, split tensile strength, and flexural strength at an optimal percentage addition of 8-10% [8, 42]. Arum *et al.* [10] also observed that RHA increases the setting time of concrete and improves its workability and porosity. The durability properties are very impressive, as it improves concrete corrosion resistance, decreases chloride penetration and reduces the permeability [14]. The relatively low cost of obtaining this material compared to several others makes it a very attractive solution for cement replacement.

2. 5. Palm Oil Fuel Ash Palm oil fuel ash is obtained from the burning of palm oil fibres, bunches and shells under a temperature of about 800 to 1000ºC. In palm oil mill boilers, about 85% fibre, 15% shell and palm fruit bunches are burned, generating the required energy for the extraction of crude palm oil [13]. Several researchers have discovered that palm oil fuel ash (POFA) has promising potentials in producing lightweight concrete with improved compressive strength. Oyejobi et al. [43] in a study observed that partial replacement of cement with 10% POFA in concrete significantly improves the compressive strength and durability of concrete. Rajesh et al. [44] observed a similar trend with optimum at 20% POFA addition. They also found out that POFA improved the flexural quality and split tensile strength of normal concrete. POFA has also been used in making self-consolidating high-strength concrete with encouraging results. Research by Salam et al. [45] revealed that POFA has good filling ability with satisfactory segregation resistance, and in content up to 20% gives improved durability indices such as reduced water absorption and permeable porosity.

2. 6. Bamboo Leaf Ash The significant capabilities of Bamboo Leaf Ash (BLA) as a pozzolanic material have been revealed by several researchers in the past decade and is yet undergoing exploration. In order to obtain this ash, dried bamboo leaves are heated and burnt in a furnace at 600ºC for 2 hours. The ash produced has been found to possess pozzolanic properties. Singh et al. [46] studied the mechanism of BLA during hydration of OPC, and observed that BLA reacts with calcium hydroxide ($Ca(OH)_2$) to form calcium silicate hydrate (C-S-H), with progression of pozzolanic activity as temperature increases. Considering the strength properties of concrete produced from BLA, [47-48], among others found out that cement could be replaced with BLA up to 15%, although with some compromise in the desirable strength. They also observed that they have tremendous durability properties such as improved acid and chloride resistance, reduced porosity and improved permeability properties. Umoh and Ujene [49] also observed that the splitting tensile strength values obtained using BLA can be up to 75% of that of the OPC concrete.

As reported from these researches, pozzolans have great potentials to be used in concrete. However, they are yet to be widely adopted in the construction industry. The reason for this has been scarcely looked into by researchers. Botchway and Masoperh [50] investigated the reason for low application of pozzolana cement in the Ghanian construction industry. Results from the study revealed that inadequte awareness, lack of commercial availability of pozzolans, limited market and absence of active support from the government are major factors mitigating against the patronage of pozzolanic cement. Adisa [15] examined the effect of partially substituting RHA in cement for a low-cost housing unit. Results revealed that cement is responsible for up to 42% of the total construction cost, and when partially replaced with 15% RHA, about 7% of the total building cost can be saved. Anigbogu [51] studied the means of developing and efficiently applying pozzolan cement in Nigeria, and suggested strategies for establishing a viable basis for their application. Some of the strategies advanced include development of national standards for production and use of Pozzolanic cements in Nigeria, creation of data bank on available pozzolans in Nigeria, encouragement of further research into effective local pozzolans and academia-industry cooperation on its production. Some of these researches and the research gaps are summarized in Table 1.

TABLE **1.** Summary of literature review

S/N	Author	Research focus	Research gap
1.	Reddy and Rao [6]	Used fly ash and GGBS in replacement of cement	Application of this in industrial context is not known
2.	Shafabakhsh and Ahmadi [8]	Evaluated performance of coal waste ash and rice husk ash in improving properties of pervious concrete pavement	Application of this in industrial context is not known
3.	Ikumapayi [11]	Examined effect of Bamboo Leaf Ash and Locust Bean Pod Ash on crystal and microstructure properties of concrete	Application of this in industrial context is not known
4.	Kanthe et al. [13]	Fly ash and rice husk ash were blended with cement to improve shrinkage properties of concrete	Application of this in industrial context is not known
5.	Sudha [14]	Evaluated the effect of lime sludge and fly ash in partially replacing fine aggregate in concrete	Application of this in industrial context is not known
6.	Botchway and Masoperh [50]	Examined low utilization of pozzolans in Ghanian construction industry	The Nigerian context has not been studied
	and so on.		

Seeing the great possibilities achieveable with the use of pozzolans when applied in concrete and the variety of researches that have delved into proving its value, it has been a matter of concern that pozzolans have not been in use in the construction industry in Nigeria. From Table 1, it is clear that none of the research works investigated why pozzolans are not widely in use across the world and not in use almost totally in countries such as Nigeria. This has created a knowledge gap, hence, the present study was conducted in order to ascertain what is responsible for this seeming apathy to the use of pozzolans. This general objective was achieved by gathering information from different stakeholders in the construction industry on the subject matter. The information obtained were subsequently analyzed using appropriate statistical tools to obtain insightful revelations.

3. RESEARCH METHODOLOGY

An online survey was conducted and responses were gathered from eighty-two (82) different respondents who are quite visible in the civil engineering and construction industry. This was done through the use of Google forms. In the questionnaire, general data was first collected about the respondents, their areas of specialization and number of years of practice. Opinions of the respondents were then gathered based on the use of ordinary Portland cement concrete, its benefits, and challenges involved with its use. Thereafter, information was collected on the availability of pozzolans, their use, merits and demerits, and reasons for their non-applicability in the present day construction industry in many developing countries including Nigeria. Statistical analysis of the results of the survey was done using SPSS Statistical Analysis software package. The questions asked on the opinions of respondents on the use of concrete and pozzolans were coded as presented in Table 2.

Cronbach's Alpha Reliability test was done to ascertain the level of reliability of the results obtained from the collected data. The Cronbach's Alpha is a tool used to evaluate the internal consistency of a test or scale, and is usually expressed as a number between 0 and 1. The internal consistency explains the inter-relationship between items within a test, or the extent to which the items in a test evaluate a particular concept. It therefore assists in ensuring that a test is valid and reliable for research purposes. When items in a test are well correlated to each other, the alpha value increases. Acceptable values of alpha range between 0.7 to 0.95 [52]. The formula for Cronbach's alpha is given by Glen [53]:

TABLE **2.** Survey Questions and their respective codes

What is your opinion on the following advantages and disadvantages of concrete	C1	Concrete is a very good material for construction?
	C2	In terms of ease of construction, concrete is more preferred than other construction materials
	C3	In terms of accessibility as a construction material, concrete is more readily available than other construction materials (e.g. Steel, timber)
	C4	Use of concrete is more economical compared to other types of materials
	C5	Concrete is more effective in handling complex designs
	C6	More skilled professionals are available in the construction industry involved with concrete
	C7	Concrete contributes largely to the problem of global warming
	C8	Production of ordinary portland cement (opc) incessantly poses a serious environmental threat
	C9	Alternative materials for cement for use in tackling the issue of environmental sustainability caused by cement productions have not been discovered
What are your opinions on the use of pozzolans in concrete?	P1	Pozzolans have been widely accepted and applicable in the construction industry
	P2	Pozzolans have been found comparatively effective in concrete production when used in replacement of cement
	P3	Pozzolans are easily obtainable and available
	P4	Use of pozzolans brings an overall improvement in environmental sustainability by curbing cement production
	P5	The use of pozzolans from local materials offers an effective means of managing waste
	P6	Use of pozzolans can bring an overall reduction in the cost of using cement as a binder in concrete production
	P7	The unavailability of relevant design mix standards places a limitation on the use of pozzolans in the current day industry
	P8	Lack of commercial production of pozzolans for use in the industry has limited its applicability to the construction industry
	P9	Lack of professionals involved with the use of pozzolans presents another limitation to its use
	P10	Inadequate public awareness on the effectiveness of pozzolanic cement concrete has limited its wide-spread acceptance
	P11	Fears on the results achievable with the use of pozzolans prevents designers and contractors from considering the option of pozzolans for use
	P12	Lack of policies and standards on the use of pozzolans has limited its acceptability in the construction industry
	P13	With proper guidelines on use of pozzolans and public awareness, they can effectively be applied to the modern day construction industry

$$\alpha = \frac{N\cdot\bar{c}}{\bar{v}+(N-1)\cdot\bar{c}} \quad (1)$$

where N is the number of items, $\bar{c}$ represents average covariance between item-pairs, $\bar{v}$ represents average variance.

A Kruskal-Wallis H test was performed to see if there was a significant difference between the opinions of the respondents on concrete and pozzolans based on the number of years of practice, central area of practice and which branch of construction industry the repondent is mostly involved in. Kruskal-Wallis test is a non-parametric test that checks if samples are originated from the same distribution. In other words, we are able to ascertain by this test if the differences between more than two groups are so large and unlikely to have occurred accidentally [54]. In this case, consideration is given to the number of years of practice. The null hypothesis of the Kruskal-Wallis test supposes that the groups have the same mean ranks. It is the non-parametric equivalent of one-way ANOVA, in which data are jointly ranked from low to high or vice-versa. It also assumes that the underlying data is not normally distributed. The H statistic is mathematically represented by Kothari and Garg stated below [55]:

$$H = \left[\frac{12}{N(N+1)}\sum_{i=1}^{k}\frac{{R_i}^2}{n_i}\right] - 3(N+1) \quad (2)$$

where N is the total number of participants in all groups combined, R_i is the total rank for the i-th group and n_i is the number of participants in the i-th group. The value of H is tested in comparison with the chi-square distribution for k-1 degrees of freedom, where k is the number of groups.

A Mann-Whitney U test was also conducted to see if there was a difference in the opinions on the use of concrete as well as pozzolans between respondents in Nigeria and those in other countries. It was also conducted to check if familiarity of respondents with pozzolans affect their opinions. Mann-Whitney U test is the non-parametric equivalent of the independent *t*-test, which is used in testing for differences between the dependent variable for two independent groups.

The *U* statistic, which measures the difference between the ranked observations of the two groups is mathematically expressed by the following exptession [55]:

$$U = n_1 \cdot n_2 + \frac{n_1(n_1+1)}{2} - R_1 \quad (3)$$

where n_1 and n_2 are the group sizes and R_1 is the sum of ranks assigned to values of the first group.

The flow chart of the adopted methodology is presented in Figure 1. The results of the statistical analyses are presented and discussed in the next section.

4. RESULTS AND DISCUSSION

4. 1. General Information on Respondents Majority of the respondents are resident in Nigeria (69.5%) while other respondents are from sixteen (17) other different countries as shown in Figure 2. Eighty-three per cent (83%) of the respondents recorded that they were in the civil engineering profession and among the remaining; only 2 of the respondents were not in a field related to civil engineering and/or building construction. Figure 3 shows that most of the respondents had their central area of practice in the academia, construction and consultancy, with 24% having more than one central area of practice. Considering the branches of civil engineering with higher concentration of respondents, it was observed that majority of the respondents were involved in structural engineering, civil engineering and construction engineering and management or combinations of these. Some other respondents are based in geotechnical engineering, environmental engineering, water resources and waste-water engineering. This can be observed in Figure 4. Furthermore, Figure 5 shows that many of the respondents were in the practice of civil engineering between 0 to 5 years. However, majority (over 50%) of the respondents had practiced the profession for over 6 years. This indicates a quite experienced set of respondents.

Majority (84%) of the respondents were involved in the use of concrete in construction, with several of them also involved in use of alternative materials such as steel and timber. This is presented in Figure 6. Other materials

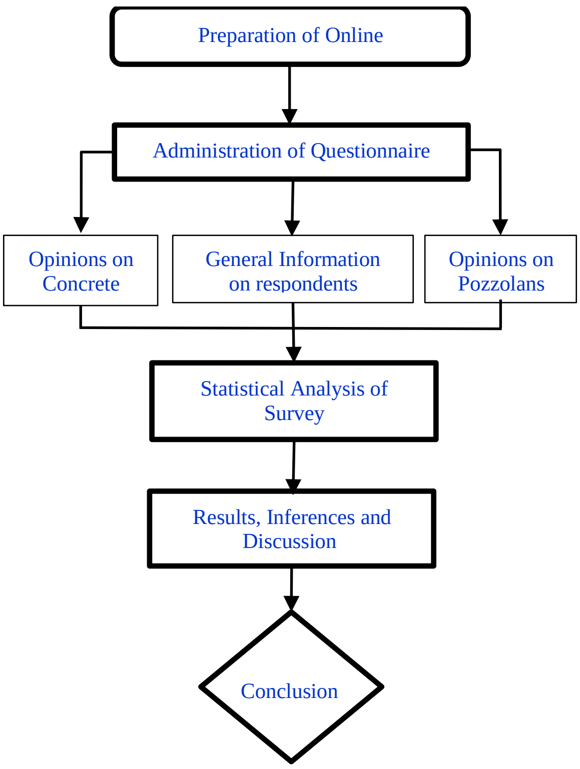

Figure 1. Flow chart showing methodology

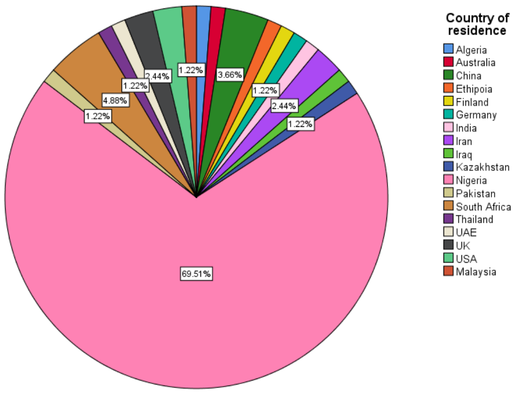

Figure 2. Country of residence

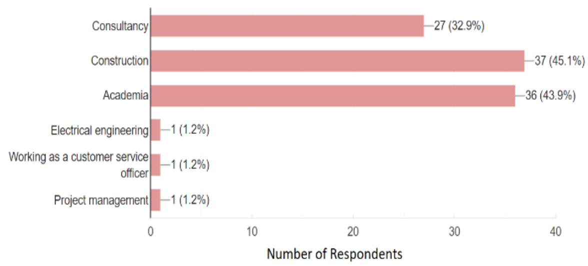

Figure 3. Central Area of Practice in the Industry

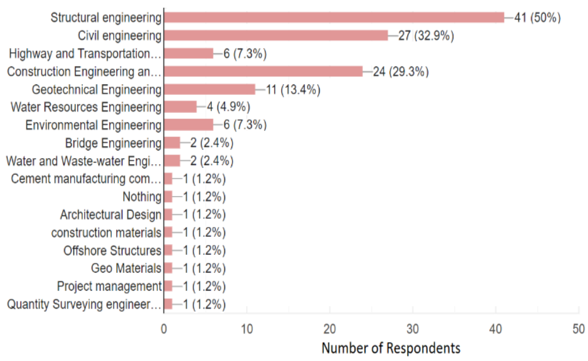

Figure 4. Branch of Civil engineering/construction mostly involved in

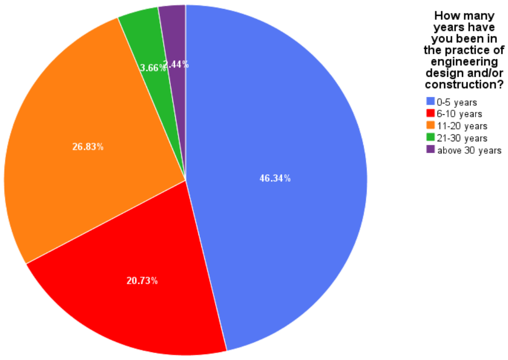

Figure 5. Years of Practice of respondents

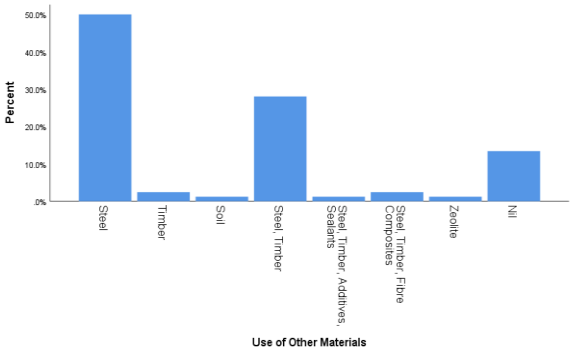

Figure 6. Use of other materials

used include soil, fibre-reinforced polymer (FRP) composites, unplasticized polyvinyl chloride (UPVC). It can be inferred that majority of the respondents are involved in the use of concrete due to its availability, economy compared with other materials, and its ease of construction, as seen from the opinions gathered on the use of concrete.

4. 2. Opinions on the Use of Concrete The responses from the survey alluded to the fact that concrete is a good construction material. Majority (84%) of the respondents also agreed that concrete is preferred to other construction materials. Similarly, the responses from the survey indicate that concrete is more readily available than other construction materials (e.g. steel, timber etc.). It was also noted that most respondents (69%) believe that the use of concrete is more economical compared to other types of materials, and is more effective in handling complex designs. In addition, majority (83%) of the respondents alluded to the fact that there are more skilled professionals working with concrete than other materials in the construction industry. However, a large number of respondents also supported the fact that concrete contributes largely to the problem of global warming, and poses a serious environmental threat to the environment. One crucial issue discovered from the responses is that quite a number of stakeholders were not aware of alternative materials for cement. However, some noted that they were aware of the use of pozzolans (such as Ground granulated blast furnace slag (GGBS), fly ash, volcanic ash etc.) and biopolymers (such as Xanthan gum). These foregoing questions led to a further enquiry on the general knowledge of the stakeholders about pozzolans and their application in the construction industry.

4. 3. Opinions on the Use of Pozzolans Upon introducing the concept of pozzolans, it became clearer that only a few were not really familiar with pozzolanic materials (10%). Results of the survey, however, showed that the pozzolans have only been fairly applicable in the construction industry. Most of the respondents (65%) agreed that pozzolans are comparatively effective in concrete production when used in replacement of cement. It was also agreed that pozzolans generally bring an overall improvement in environmental sustainability by reducing the environmental effects involved in cement production. There were relatively indistinct opinions about the availability and obtainability of pozzolans (with only 45% consenting to their availability). The fact that the use of pozzolans brings an overall improvement in environmental sustainability was largely admitted by most of the respondents (78%). It was also the popular view of majority of the respondents (93%) that using pozzolans in concrete is an effective waste management approach. The survey shows that in spite of these tremendous qualities of pozzolans, the application of pozzolans to the construction industries has been limited due to lack of commercial production, with many respondents (73%) consenting to this fact. Another observed limitation is that the level of available skilled professionals within the construction industry presently applying pozzolans in their construction activities is low, 75.6% consenting to this fact. Majority (87.6%) of the respondents also believe that inadequate public awareness on the effectiveness of pozzolanic cement concrete has not allowed them to be widely accepted. The fears and doubts largely exercised by designers and contractors on the results achievable with the use of pozzolans, and lack of adequate policies and standards on pozzolan use are also factors limiting their use in the industry. As seen from the survey, most of the respondents (approximately 75.7%) allude to these opinions. Generally, it was observed by majority of the respondents (89%) that the applicability of pozzolans to the industry can be improved upon by adequate public awareness and development of proper guidelines on their use.

4. 4. Statistical Analyses

4. 4. 1. Cronbach's Alpha Reliability Analysis In order to ascertain the reliability of the test results obtained from all respondents, statistical analyses were performed based on the collected data. The results of Cronbach's Alpha Reliability test are presented in Tables 3 and 4. The Cronbach's alpha value for the opinions on the use of concrete and the use of pozzolans were 0.736 and 0.779, respectively. This shows that the results from this survey are very reliable and well correlated, since these values fall between the acceptable range of 0.70 to 0.95, as recommended by Tavakol and Dennick [52].

4. 4. 2. Kruskal-Wallis H Test The Kruskal-Wallis H test results of opinions on concrete and pozzolans based on number of years of practice, central area of pracice and branch of involvement in civil engineering are presented in Tables 5-8. The null hypothesis was that there is no significant difference in the opinions of respondents based on their number of years in practice, central area of practice or branch of civil engineering they are involved in.

TABLE 3. Reliability results on the Opinions concerning the Use of Concrete

Reliability Statistics		
Cronbach's Alpha	**Cronbach's Alpha Based on Standardized Items**	**N of Items**
0.723	0.736	9

TABLE 4. Reliability results on the Opinions concerning the Use of Pozzolans

Reliability Statistics			
Cronbach's Alpha	**Cronbach's Alpha Based on Standardized Items**	**N of Items**	**Cronbach's Alpha**
0.767	0.779	13	0.767

TABLE 5. Kruskal-Wallis H Test on opinions concerning Use of Concrete Based on Number of Years of Practice

Test Statistics[a,b]									
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
Kruskal-Wallis H	1.591	8.290	5.678	4.189	6.065	3.487	2.431	2.716	2.672
Df	4	4	4	4	4	4	4	4	4
Asymp. Sig.	0.810	0.082	0.225	0.381	0.194	0.480	0.657	0.606	0.614

a. Kruskal Wallis Test

b. Grouping Variable: How many years have you been in the practice of engineering design and/or construction?

TABLE 6. Kruskal-Wallis H Test on opinions concerning Use of Pozzolans Based on Number of Years of Practice

Test Statistics[a,b]													
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**P11**	**P12**	**P13**
Kruskal-Wallis H	2.174	2.735	3.625	4.907	7.658	2.572	4.323	1.285	1.031	2.135	5.389	2.858	6.664
Df	4	4	4	4	4	4	4	4	4	4	4	4	4
Asymp. Sig.	0.704	0.603	0.459	0.297	0.105	0.632	0.364	0.864	0.905	0.711	0.250	0.582	0.155

a. Kruskal Wallis Test

b. Grouping Variable: How many years have you been in the practice of engineering design and/or construction?

TABLE 7. Kruskal-Wallis H Test on opinions concerning Use of Pozzolans Based on Central Area of Practice

Test Statistics[a,b]													
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**P11**	**P12**	**P13**
Kruskal-Wallis H	3.247	6.032	3.759	4.663	0.752	1.363	6.274	5.922	6.397	5.551	7.736	2.603	3.545
Df	4	4	4	4	4	4	4	4	4	4	4	4	4
Asymp. Sig.	0.517	0.197	0.440	0.324	0.945	0.851	0.180	0.205	0.171	0.235	0.102	0.626	0.471

a. Kruskal Wallis Test

b. Grouping Variable: Which of this is your central area of practice in the industry?

TABLE 8. Kruskal-Wallis H Test on opinions on Use of Pozzolans Based on Branch of Civil Engineering involved in

Test Statistics[a,b]	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
Kruskal-Wallis H	0.797	6.108	2.657	4.881	3.034	4.174	2.466	3.040	5.141	2.861	4.695	4.174	3.454
Df	4	4	4	4	4	4	4	4	4	4	4	4	4
Asymp. Sig.	0.939	0.191	0.617	0.300	0.552	0.383	0.651	0.551	0.273	0.581	0.320	0.383	0.485

a. Kruskal Wallis Test

b. Grouping Variable: In which of these branches of civil engineering and/or construction are you mostly involved?

TABLE 9. Mann-Whitney U test on the Use of concrete based on Country of residence

Test Statistics[a]	C1	C2	C3	C4	C5	C6	C7	C8	C9
Mann-Whitney U	595.500	689.000	694.000	610.000	651.000	543.000	533.000	604.500	662.000
Wilcoxon W	895.500	2400.000	2405.000	2321.000	2362.000	843.000	2244.000	2315.500	962.000
Z	-1.332	-.077	-.022	-.919	-.482	-1.687	-1.731	-.994	-.356
Asymp. Sig. (2-tailed)	0.183	0.938	0.982	0.358	0.630	0.092	0.083	0.320	0.722

a. Grouping Variable: Country of residence

TABLE 10. Mann-Whitney U test on the Use of Pozzolans based on Country of residence

Test Statistics[a]	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
Mann-Whitney U	590.0	621.0	620.0	689.5	686.0	610.0	485.5	442.0	472.5	480.0	451.5	456.0	596.0
Wilcoxon W	2301.0	921.0	2331.0	989.5	986.0	910.0	785.5	742.0	772.5	780.0	751.5	756.0	896.0
Z	-1.124	-0.825	-0.806	-0.073	-.114	-.967	-2.316	-2.781	-2.528	-2.483	-2.684	-2.685	-1.124
Asymp. Sig. (2-tailed)	0.261	0.410	0.420	0.942	0.909	0.333	0.021	0.005	0.011	0.013	0.007	0.007	0.261

a. Grouping Variable: Country of residence

TABLE 11. Mann-Whitney U test on the Use of Pozzolans based on Familiarity with Pozzolans

Test Statistics[a]	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
Mann-Whitney U	258.0	286.5	293.0	165.0	80.0	196.0	278.0	218.0	154.5	194.5	169.0	130.0	154.5
Wilcoxon W	3033.0	322.5	329.0	201.0	116.0	232.0	314.0	254.0	190.5	230.5	205.0	166.0	190.5
Z	-0.618	-0.160	-0.049	-2.251	-3.773	-1.725	-0.304	-1.309	-2.455	-1.789	-2.138	-2.848	-2.438
Asymp. Sig. (2-tailed)	0.537	0.873	0.961	0.024	0.000	0.085	0.761	0.190	0.014	0.074	0.033	0.004	0.015

a. Grouping Variable: Are you familiar with the word pozzolans?

The Kruskal-Wallis H test results showed that the number of years of practice of respondents did not cause any significant difference in their opinions on concrete and pozzolans, $H(4) = 1.59$ to 8.29, all $p_s > 0.05$ (Mean ranks for all groups range from 19.75 to 65.5), hence we accept the null hypothesis. This suggests that there was a universal agreement in the opinions of the respondents on the use of concrete and pozzolans considering their experience in the construction industry. The respondents were classified according to their central area of practice into 5 broad groups which include “academia”, “construction”, “consultancy”, “combined” (where respondents are involved in 2 or more areas), and “others”. It was also discovered that there was no significant difference between these groups, H(4) = 0.754 to 7.736, all $p_s > 0.05$ (Mean ranks for all groups range from 20.17 to 55.33). Another classification of the respondents was into the major branches of civil engineering and construction they were involved in. Five (5) broad groups were identified “Civil & Structural Engineering”, “Construction Engineering & Project management”, “Geotechnical, Highway & Transportation Engineering”, “Water & Environmental Engineering” and “Others”. The test showed similar trend as in the other two tests above, H(4) = 0.797 to 5.141, all $p_s > 0.05$), hence we accept the null hypothesis.

4. 4. 3. Mann-Whitney U Test The results of the Mann-Whitney U test are presented in Tables 9-11. The null hypothesis was that no significant difference exists between the opinions of respondents in Nigeria and outside the country on concrete and pozzolans. The results interestingly reveal that the general opinions on concrete (C1 - C9) and on the ability of pozzolans (P1 – P6) were the same, that is there was no significant difference (U = 533.0 to 694.0, all $p_s > 0.05$). However, the opinions on the challenges preventing the adoption of pozzolans (P7 – P12) were significantly different (U = 442.0 to 485.5, all $p_s < 0.05$). In other words, it can be inferred that respondents from Nigeria differed in opinions from respondents outside Nigeria on the reasons for poor adoption of pozzolans in the construction industry. The factors represented by these codes (P7 to P12) include “use of pozzolans can bring an overall reduction in the cost”, “the unavailability of relevant design mix standards places a limitation on the use of pozzolans”, “lack of commercial production of pozzolans”, “lack of professionals involved with the use of pozzolans”, “inadequate public awareness”, and “fears on the results achievable with the use of pozzolans”. This difference in opinions can be explained by the fact that unlike Nigeria, several developed countries are already putting pozzolans into industrial application. Hence, the issues perceived as major factors inhibiting pozzolan application in Nigeria may not be the same as in some other countries. One critical factor generally agreed upon, however, is that provision of proper guidelines, standards and adequate public awareness improves the adoption of pozzolans for industrial applications. Another U-test was conducted based on the null hypothesis that no significant difference exists between the opinions of those familiar with pozzolans (74) and those that are not (8). The results of the test showed that there was significant difference in some opinions, represented by codes P4, P5, P6, P9, P11, P12 (U = 80 to 169, $p_s < 0.05$). This suggests that there needs to be improved awareness on the potential benefits of pozzolans and means of application will significantly improve its acceptance within the construction industry. The major factors responsible for the low level of adoption of pozzolans proven by this research are similar to those reported by Botchway and Masoperh [50] and Anigbogu [51].

5. SUMMARY AND CONCLUSION

This research sought to examine the probable reasons behind the low level of adoption of these SCMs in the Nigerian construction industry. It has explored the different potentials of some supplementary cementitious materials (SCMs) in concrete as well as their effectiveness. In order to understand the reason behind the low level of their acceptance in the construction industry, an online survey was carried out, which revealed that although concrete is a very good material for construction, its adverse environmental impacts require the partial replacement of its ordinary Portland cement fraction with supplementary cementitious materials in order to mitigate the negative environmental effects and in some cases, to also reduce cost. The study also confirmed that pozzolans have been comparatively effective in concrete production when used in partial replacement of cement. However, the research revealed that the most significant factors mitigating against their widespread adoption, especially in the Nigerian construction industry include: unavailability of relevant design mix standards for pozzolanic concrete, lack of commercial production of pozzolanic concrete, unavailability of sufficiently skilled professionals involved with the use of pozzolans, inadequate public awareness, lack of policies recommending and guiding its use, and fears on results achievable with use of pozzolans. It was generally agreed that the provision of guidelines and adequate public awareness on the use of pozzolans will improve their acceptance and adoption in the contemporary construction industry.

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Persian Abstract

چکیده

پوزولان ها مواد سیمانی تکمیلی (SCM) هستند که بسیاری از محققان آن را برای جایگزینی جزئی سیمان در بتن به منظور کاهش خطرات زیست محیطی و مصرف انرژی در تولید بتن مناسب می دانند. با این حال، علیرغم تلاش های تحقیقاتی قابل توجه در دهه گذشته و شواهد فراوان برای حمایت از مزایای فوق العاده آنها، این مواد به ندرت در صنعت ساخت و ساز امروزی به ویژه در نیجریه استفاده می شود. بنابراین به طور طبیعی یک سؤال مطرح می شود: چه چیزی باعث تردید در کاربرد گسترده پوزولان ها در صنعت ساختمان می شود؟ این مقاله با استفاده از یک بررسی تحقیقاتی به بررسی دلایل پذیرش و پذیرش کم آنها توسط ذینفعان صنعت ساختمان پرداخته است. نظرات ۸۲ پاسخ دهنده در مورد مشارکت چشمگیر در صنعت ساخت و ساز با استفاده از آزمون های ناپارامتریک، یعنی قابلیت اطمینان آلفای کرونباخ، آزمون Kruskal-Wallis H و Mann-Whitney U، گردآوری و مورد تجزیه و تحلیل آماری قرار گرفت. نتایج آنالیزها تایید کرد که پوزولان ها در کاهش اثرات منفی محیطی ناشی از استفاده از سیمان معمولی در بتن موثر هستند. علاوه بر این، فاکتورهای قابل توجهی که مخالف پذیرش آنها در صنعت ساختمان است عبارتند از: در دسترس نبودن استانداردهای طراحی مخلوط مربوطه برای بتن پوزولانی، عدم تولید تجاری بتن پوزولانی، در دسترس نبودن متخصصان با مهارت کافی در کاربرد پوزولان، آگاهی ناکافی عمومی، فقدان سیاست های توصیه کننده. و راهنمایی استفاده از آن و ترس از نتایج قابل دستیابی با استفاده از پوزولان ها. پاسخ دهندگان به طور کلی موافق بودند که توسعه دستورالعمل ها و استانداردهای مناسب و همچنین آگاهی عمومی کافی به پذیرش گسترده و کاربرد صنعتی پوزولان ها کمک می کند.