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# An Evaluation of Geopolymer Cement in Construction Work

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***ABSTRACT :*** *The study investigates the perception of construction experts on geopolymer cement in Nigeria. The research was aimed at evaluating geopolymer cement as a construction material and assessing its potentials as a viable alternative to Portland cement. To carry out the study a questionnaire was formulated to sample the opinions of construction experts and the data collected was analysed and presented in a charts for easy interpretation. The results showed that majority of the experts have no knowledge of geopolymer cement. Despite this fact, it undoubtedly proved that geopolymer cement is more environmentally friendly than Portland cement and that they have better quality as a construction material. The studies however showed that geopolymer cement has some drawbacks that have limited its widespread use and appreciation. Amongst these are lack of standards, risk of handling, cost, and availability.*
***KEYWORDS :*** Geopolymer cement, fly ash, $CO_2$ emission, Portland cement, kaolin.

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## I. INTRODUCTION

Rationalizing an investment in a facility's infrastructure can be a difficult prospect for any plant engineer or technician, often requiring extensive justification.

Geopolymer cement is an innovative material and a real alternative to conventional Portland cement for use in transportation infrastructure, construction and offshore applications. It relies on minimally processed natural materials or industrial by-products to significantly reduce its carbon footprint, while also being very resistant to many of the durability issues that can plague conventional concrete.

Cement is one of the most important building materials in the construction industry. The production of Portland cement is energy intensive and releases a significant volume of carbon dioxide into the atmosphere. The costs associated with these energy requirements are significant. Consequently, there is need for further investigation into cementitious products with decreased environmental impacts and enhanced economic benefits.

Readily-available commercial by-products such as fly ash, blast furnace slag and rock-based materials such as kaolin and metakaolin etc. have been adopted to produce geopolymer cement. It was estimated that the amount of coal ash produced annually worldwide is approximately 600 million tonnes with fly ash constituting 75% - 80% of the composition [1]. The recycled use of this fly ash material in construction will alleviate the cost of disposal elsewhere and invariably reduce the cost of concrete manufacturing in overall.

The term "geopolymer" is used to describe the amorphous to semi-crystalline reaction products from the synthesis of three-dimensional silico-aluminate with alkali reagents/hardener. A geopolymer cement can be used to bind loose aggregates and other inert materials together to form geopolymer cement concrete. Geopolymer cement binders can provide comparable performance to traditional Portland cement binders in a range of applications with the added advantage of significantly mitigating greenhouse gas emissions.

The aim of this study was to evaluate geopolymer cement as a construction material and assess its potentials as viable alternative to traditional Portland cement for industrial use. The objectives of the study were to conduct a field survey on the perception of construction experts on the performance of geopolymer cement; analyze the data using percentage analysis and make recommendations with regards to the data collected. The investigation was carried out in Anambra and River state of Nigeria.

The name geopolymer was formed by a French professor Joseph Davidovits in 1978 to represent a broad range of materials characterized by networks of inorganic molecules [2]. The geopolymers depend on the thermally reactive natural materials like metakaolinite or industrial by-products like fly ash or slag to provide a source of aluminosilicates [3]. These aluminosilicates are dissolved in alkaline reactive medium called alkaline reagent/hardener and subsequently polymerizes into molecular chains and becomes the binder. The term geopolymer cement refers to binders formed as a result of this geopolymerization process [4]. Geopolymerization was also described by Al Bakri et al [5] as the production of a geopolymeric material through inorganic poly-condensation. Several mechanisms of geopolymerization are suggested in the literature [6]. The stages of the process were identified by the geopolymer Alliance [7]. The mixture of this binder with aggregates and water forms geopolymer concrete. Geopolymer cement is regarded as an attractive and greener substitute to ordinary Portland cement binders. This is due to the environmental benefits and performance properties of the material [8][9].

Geopolymer cement typically consists of two components: an aluminosilicates material and a chemical reactor. The aluminosilicate materials are divided into two main categories: industrial by-products and raw rock-based materials [8]. The majority of research has considered the use of industrial bye product such as fly ash, blast furnace slag as potential precursor materials which are pozzolanic material that participates in the chemical reaction that produces geopolymer cement. In addition, consistency of fly ash properties cannot be guaranteed due to presence of contaminants such as calcium and iron. The presence of these impurities can impact upon properties such as strength, setting times, shrinkage and slump [10]. Other precursor sources discussed by Davidovits [8] are rock-based raw materials with high kaolinite content. Kuenzel et al [11] have studied variables which can impact upon the mechanical properties of kaolin-based geopolymer cement. The compressive strength and the workability of geopolymer concrete are influenced by the proportions and properties of the constituent materials that make the geopolymer paste. Experimental works [12] indicate that a higher concentration of sodium hydroxide results in higher strength of geopolymer cement. The addition of naphthalene sulphonate-based superplasticizer can improve the workability of the fresh geopolymer concrete; however, there is degradation in the compressive strength of hardened concrete. The pH level of the alkaline reagents strongly influences the final cement performance. Khale and Chaudhary reported that the strength measured from samples of pH 14 were five times greater than samples formed from pastes of pH 12; and they concluded that a pH range of 13–14 was most suitable for the formation of geopolymers with higher mechanical strengths [13].

One motivator for adopting geopolymer binder is its ability to resist sulfate and other chemical intrusions and maintain excellent thermal loading capacities. However, the question of curing in field applications is a relevant concern limiting the utility of geopolymer as a practical construction material. The tests reported by Sumajouw et al. revealed that geopolymer concrete possess high compressive strength, undergo very little drying shrinkage and exhibit moderately low creep. Their data also indicate that geopolymer concrete possess excellent resistance to sulfate attack, resulting in a promising construction material for some harsh environments [14].

According to Benhelal et al [15], the manufacture of Portland cement is responsible for approximately 6% of global $CO_2$ emissions. Geopolymer cement provides a more environmentally friendly alternative to conventional Portland cement. Depending on the source aluminosilicate, material emissions can be up to 90% lower than Portland cement production [8]. McClellan et al [16] claim that emissions from fly ash based geopolymer concrete can be as low as 90kg of $CO_2$ per ton of cement produced. While this is currently the lowest possible emissions level, fly ash based geopolymer cement production is unlikely to exceed 250kg of $CO_2$ per ton of cement produced [17]. This represents emissions between 70% and 90% less than ordinary Portland cement.

A key aspect of geopolymer cement concrete is its compressive and flexural strength. A Geopolymer Institute review [18] of technical properties of geopolymer cement concrete published 90Mpa compressive strength and 10-15Mpa flexural strength at 28days. A similar rate of strength development was noted by Anuar et al [19]. As such, potential final strength and strength development of geopolymer cement makes it suitable substitute to Portland cement for a long range of applications. Specialist geopolymer cements have also been developed. A fly ash based, rapid-setting geopolymer cement has also been developed [20]. This was followed by the development of ultra-high performance geopolymer cement by Ambily et al [21]. This cement was based on a slag and silica fume mix and a 28days compressive strength of 124Mpa was recorded. A water-to-solid ratio increase causes a decrease in available specimen strength, while geopolymers containing kaolin and/or metakaolin clays were found to be strongest under compressive loads [13]. Geopolymer cements are inherently resistant to chemical attack and thermal loading due to their reduced porosity and thermal conductivity characteristics. Many of the durability problems associated with Portland cement concrete arise from its calcium content in the main phases [22]. It is the low calcium content found within pozzolanic materials that prevents geopolymers from experiencing such negative effects. Under extreme heat loading, geopolymers exhibit a morphological ability to form a new microstructure based on akermanite which possesses superior mechanical and thermal resistance properties making it a prime candidate for fire protection materials and reinforced concrete structures [23].

## II. METHODOLOGY

The study adopted the survey method by using the quantitative method of data collection and analysis. This method describes respondent's perception and acceptability of geopolymer cement.

The study was carried out in Nigeria, and Anambra and River state was chosen as the target area. Since construction processes are the same throughout the country, these two states were used as the representative samples of the study. The targeted participants for this research were Engineers, Architects, Quantity Surveyors and other professionals in the building construction industry. The construction experts were considered appropriate as participants and population of the study because of their years of experience in the construction field. The methods which have been applied in this study are literature review, questionnaires and interview. The main instrument used was a well-structured questionnaire. This was used to solicit respondent's perception on the use of geopolymer cement.

## III. RESULTS AND DISCUSSION

A survey questionnaire consisting of 18 questions was undertaken to obtain data from construction experts on their perception of the usage and adoption of geopolymer cement as a substitute to ordinary Portland cement. There are 115 total respondents to the survey. The data from the retrieved questionnaire are hereby analyzed using simple statistics like bar charts, and percentages for easy interpretation. 145 of the questionnaires were administered to the respondents, 87.60% of the questionnaire was collected and 79.31% was used in the survey analysis. The 12 remaining questionnaires that were not used for the analysis were rejected due to poor completion from the respondents.

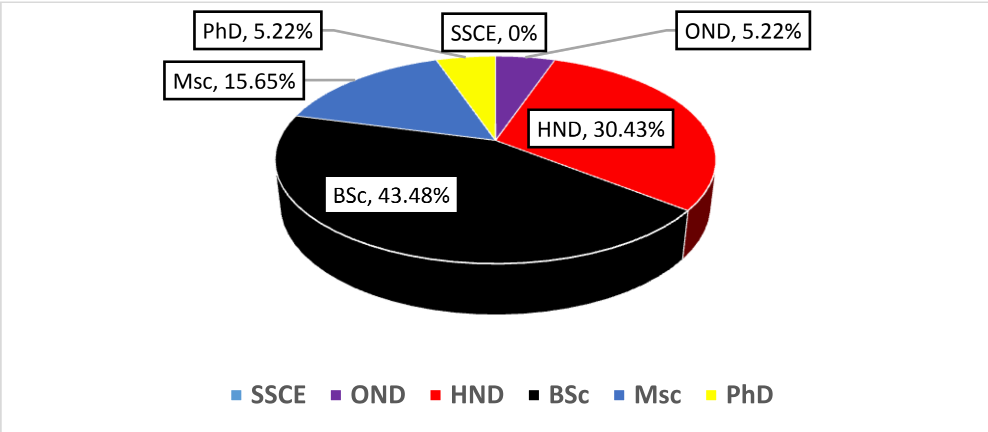


**Fig. 1: Distribution of respondents by academic qualification**

Figure 1 shows that out of the 115 respondents that were surveyed, 43.48% of the respondents had Bachelor of Science degree (BSc), 30.43% of the respondents had Higher Diploma Degree (HND), 15.65% had MSc, 5.22% had Doctorate degrees (Ph.D.), 5.22% had OND and nil% had SSCE.

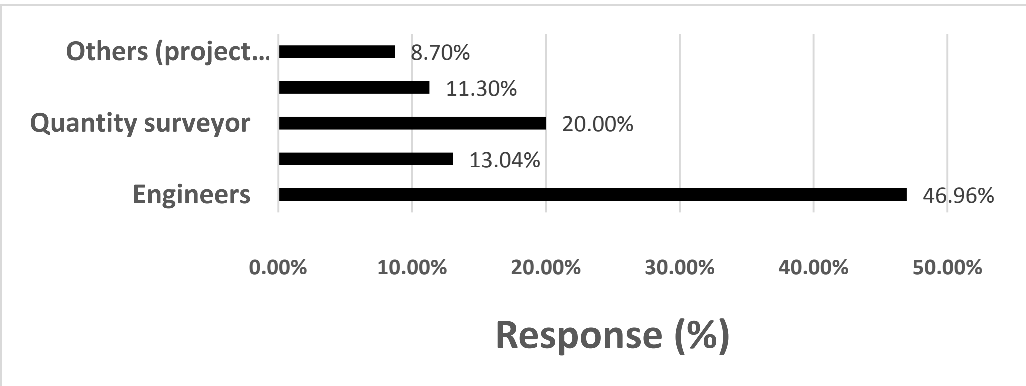


**Fig. 2: Distribution of respondents by occupation**

From figure 2, it can be seen that 46.96% of the respondents were Engineers working in the private sector of the construction industry, 13.04% of the respondents were Architects, while 20% of the respondents were Quantity surveyors whereas 11.30% of the respondent were government employees (all construction experts in ministries and government parastatals), 8.70% of the respondents were in the "other" category.

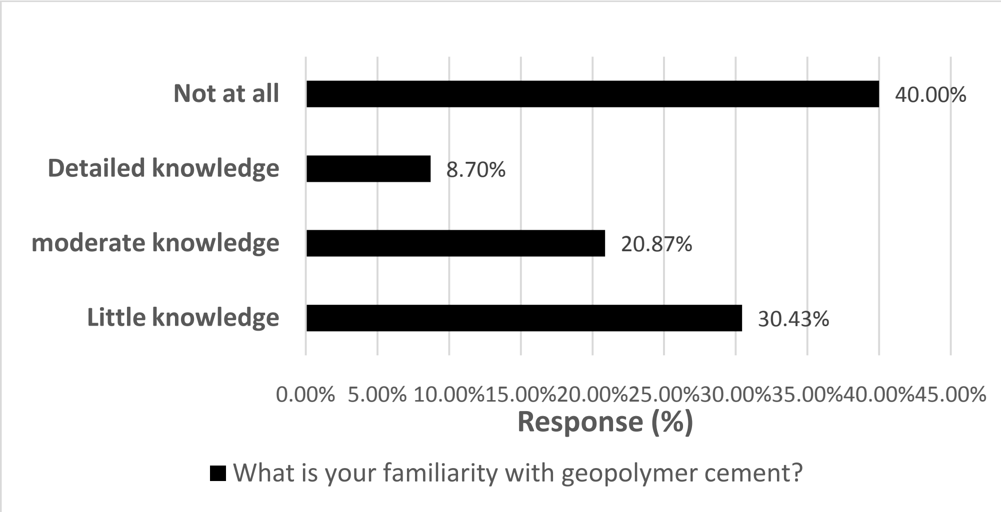


**Fig. 3: Representation of respondent's familiarity with geopolymer cement**

Figure 3 indicates that 40% of the respondents have no knowledge of geopolymer cement, whereas 30.43% of the respondents had little knowledge of geopolymer cement with 20.87% having moderate knowledge of geopolymer cement and 8.70% of the respondents having a detailed knowledge on geopolymer cement.

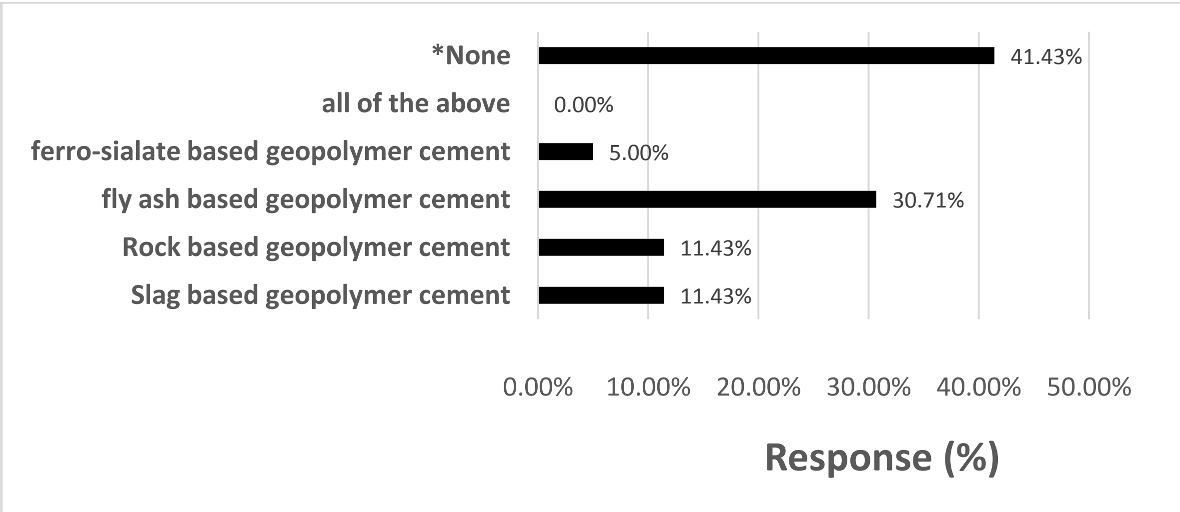


**Fig. 4. The type of geopolymer cement the respondents have used**

Figure 4 shows the type of geopolymer the respondents had used in the course of their practice. 11.43% of the respondents claimed to have used both rock and slag based geopolymer cement, 30.71% of the respondents indicated that they have used fly ash geopolymer cement whereas 5% of the respondents had used Ferro-sialate based geopolymer cement and 41.43% of the "none" category have not used it all. People in this group are those who have no knowledge of geopolymer and have not used geopolymer and those who have knowledge of it but have not used it.

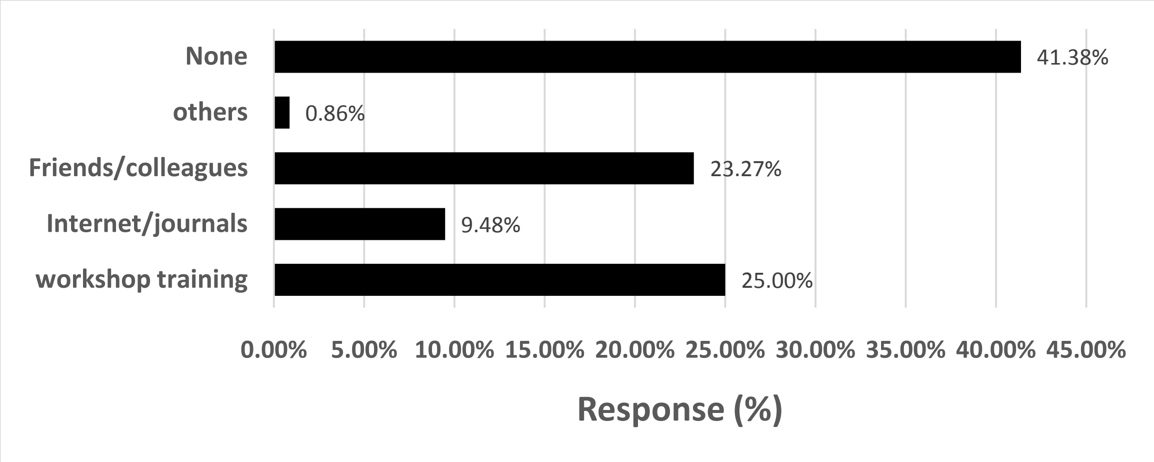


**Fig. 5: Means of getting to know about geopolymer cement**

Figure 5 shows the means by which the respondents came to know about geopolymer cement. 25% claimed that it's through workshop training, 23.27% indicated through friends/colleagues, 9.48% indicates that it's through internet/journals, 0.86% of the respondent reveals that it's through the other category involving television, magazine/newspapers and radio. A whopping of 41.38% indicates the "none" category. People in this category have no knowledge of geopolymer cement.

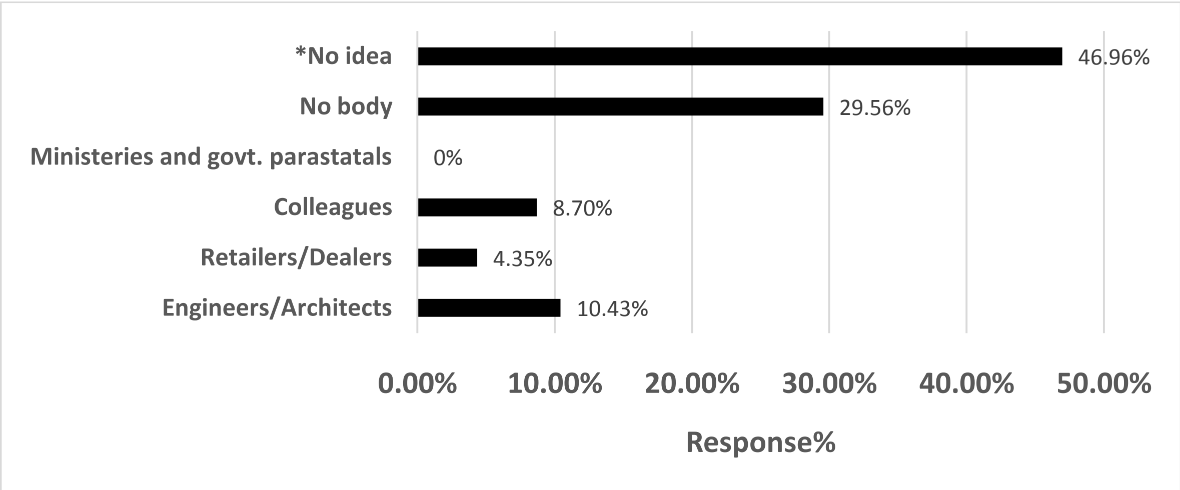


**Fig. 6. Representation of the individual/body the respondents consult before the use of geopolymer cement**

Figure 6 shows that majority of the respondent are in the "no idea" category, with 29.56% attesting to the fact that they don't consult anybody before the use of geopolymer cement, 8.70%, 4.35%, 10.43% indicted colleagues, retailer/dealers and engineers/architects respectively while 0% indicated ministries and government parastatals.

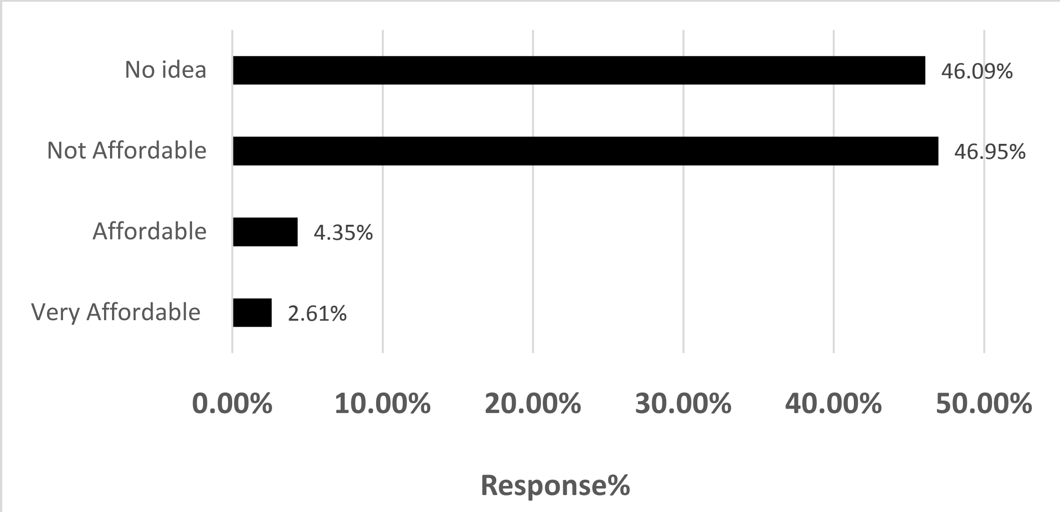


Fig. 7.: Respondents' cost perception of geopolymer cement

Figure 7 represents how the respondents perceived the cost of geopolymer cement. 46.95% of total respondents indicated not affordable, 46.09% affirmed no idea, while 4.35% indicated affordable and 2.61% affirmed very affordable.

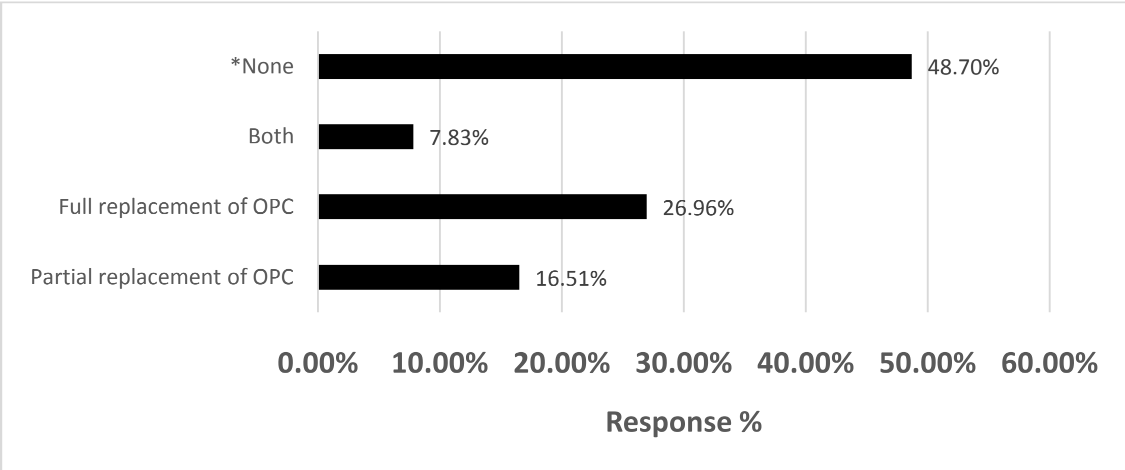


**Fig. 8. Representation of ways by which the respondents use geopolymer cement.**

Figure 8 shows that 26.96% respondents indicated full replacement of OPC, 16.51% affirmed to partial replacement of OPC whereas 7.83% indicated 'Both' and a majority of the respondents affirmed to none.

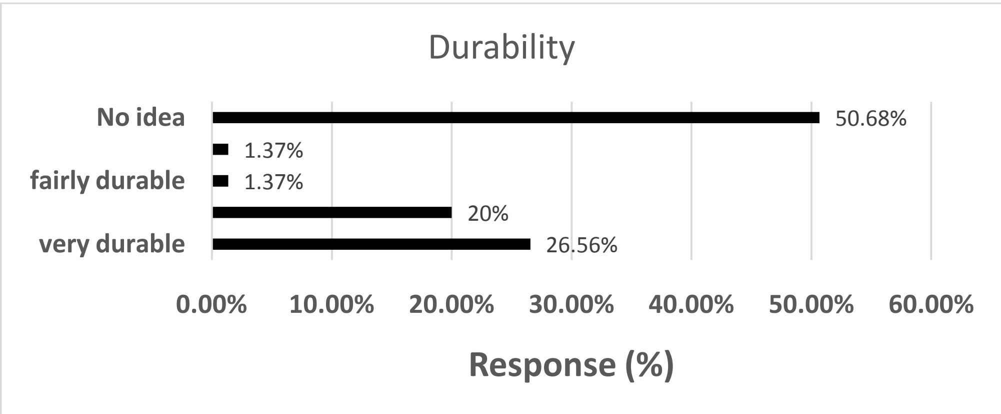


**Fig. 9: Representation of the durability of geopolymer cement based concrete when used as full replacement of Portland cement.**

The result from figure 9 shows that 26.56% of the respondents attested to very durable, with 20%, 1.37%, 1.37% indicated durable, fairly durable, not durable respectively, and 50. 68% of the respondents affirmed to the "no idea" category.

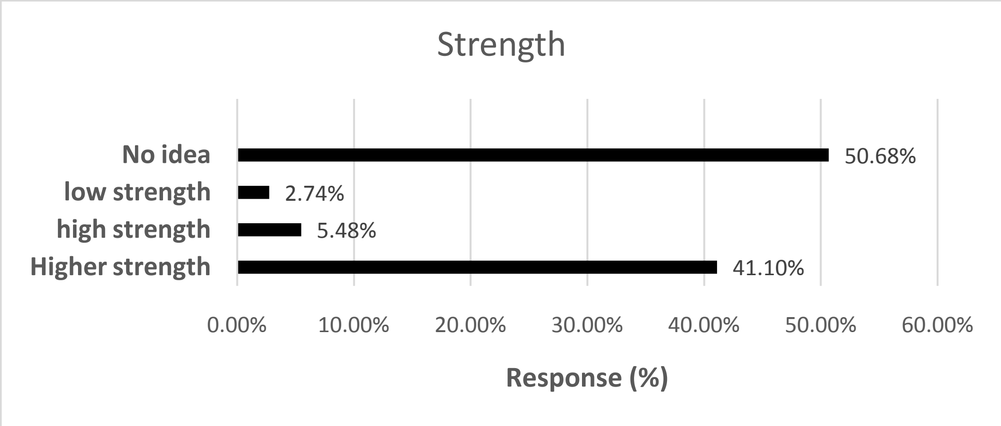


**Fig. 10. Representation of the strength of geopolymer cement based concrete when used as full replacement of Portland cement.**

The result from Figure 10 shows that 41.10% of the respondents attested to higher strength, with 5.48%, 2.74%, indicated high strength, low strength respectively, and 50. 68% of the respondents affirmed to the "no idea" category.

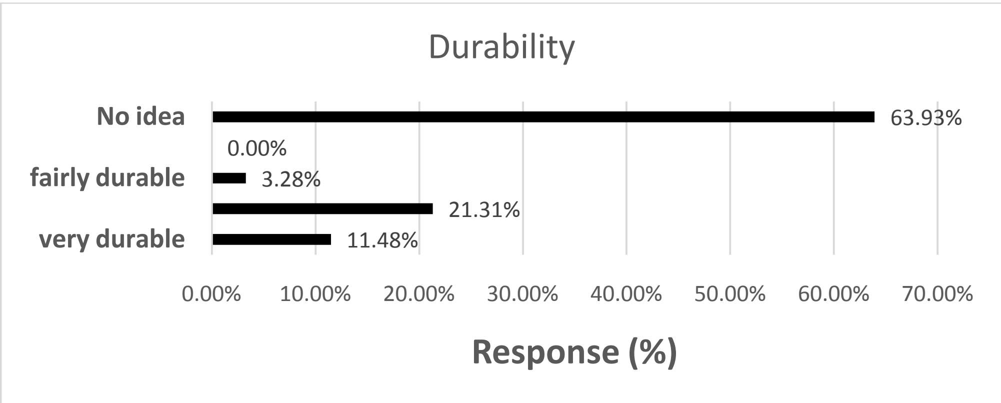


**Fig. 11. Representation of the durability of geopolymer cement based concrete when used as partial replacement of Portland cement.**

The result from figure 11 shows that 11.48% of the respondents attested to very durable, whereas 21.31%, 3.28%, 0% indicated durable, fairly durable, not durable respectively, and 63.93% of the respondents affirmed to the "no idea" category.

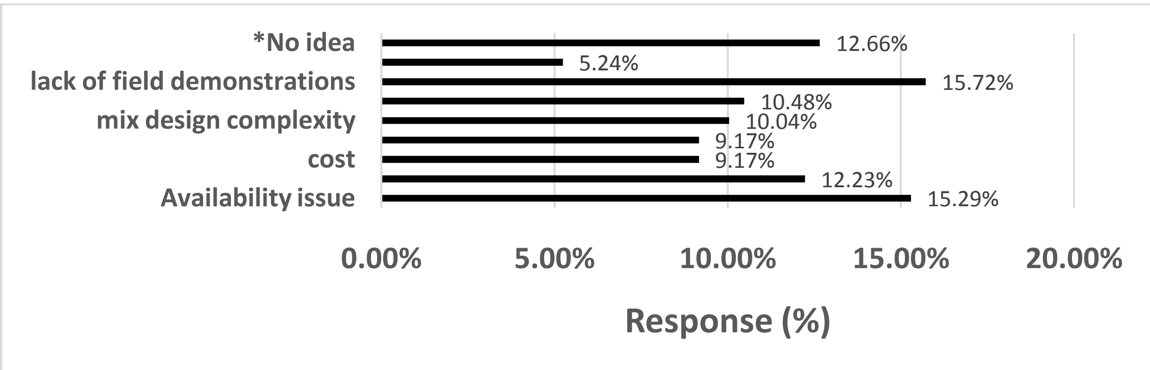


**Fig. 12. Barrier to the widespread implementation of geopolymer cement.**

Respondents clearly identified that lack of inclusion of geopolymer cement in existing British standards (BS codes) and lack of demand, availability issue, cost, mix design complexity, risk of handling, lack of field demonstrations as significant barriers (Figure 12). In particular, 15.72% of respondents rated the lack of field demonstration as the primary obstacle. Availability issue was also significant at 15.29%. Mix design complexity was regarded as problematic to widespread implementation and costs were considered as barriers to a lesser degree. “Other” barriers were related to problems with cement companies, unwillingness of designers to specify geopolymers, and insufficient property data. The responses to the question regarding barriers distinctly demonstrate that there are important issues and concerns that need to be addressed if geopolymer cement is to be realized at large-scale use. Greater percentage of about 12.66% had no knowledge of the question.

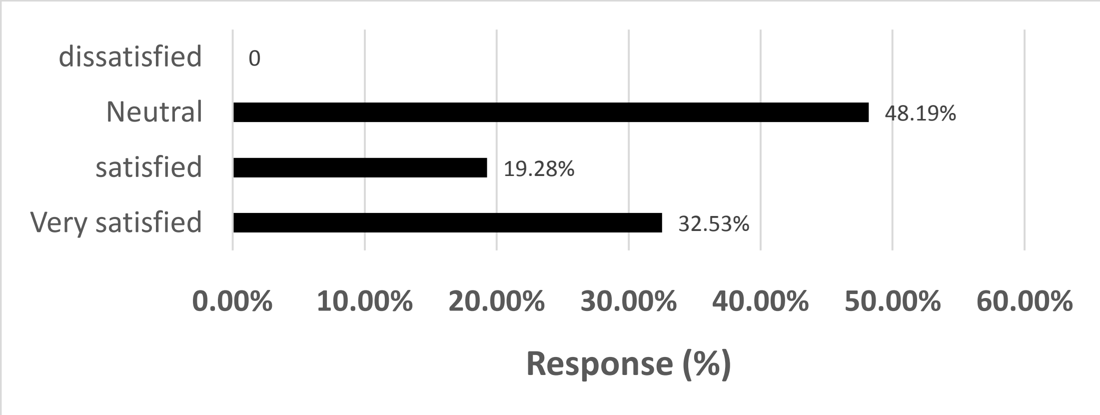


**Fig. 13. Level of satisfaction of respondents with geopolymer cement.**

Figure 13 shows a representation of the satisfaction level of geopolymer cement users. 48.19% of the respondents were neutral, 32.53% affirmed very satisfied and 19.28% attested to satisfied. whilst 0% indicated dissatisfied by the level of performance of geopolymer cement.

From the analysis of data, the following major findings were obtained.

Despite the outstanding qualities and properties, environmental and economic benefits that geopolymer cement offer as stated by Davidovits [6], it was discovered that the level of awareness of geopolymer cement in Nigeria is very low unlike in Australia, India where the degree of awareness is high.

Geopolymer cement was attested to be expensive by majority of the respondents. This contradict the statement made by McDonald et al (2010) that geopolymer cement is of cheaper cost when compared to Portland cement since it makes use of industrial byproduct and rock minerals such as fly ash, blast furnace slag and metakaolin as the source material. It was discovered that the major influencing factors to the use of geopolymer cement are its strength quality, durability and permeability quality confirming the statement made by Sumajouw el at (2004) in his work that geopolymer greatest weapon is its high strength and ability to resist all the durability issues that plague Portland cement. The adoption of a new or a different material in the construction and other industries always face some challenges.

## IV. CONCLUSION

The paper presented a summary of the extensive studies carried out by the researcher. The motivation to find alternative binder systems like the geopolymers comes from the fact that Portland Cement production consumes very large amount of energy and also due to its ill effects on our environment. Geopolymer cement is more environmental friendly than Portland cement and has good qualities and performance characteristics as a construction material based on data from the survey questionnaire. It is quite evident that Geopolymer qualifies to be a veritable alternative binder which could eliminate the usage of Portland cement to a good extent despite been too pricey as suggested by the respondents.

From the survey majority of the respondents do not have knowledge of geopolymer cement, there is a need to engage construction experts in seminars and training to create a high level of awareness of these innovative products. Government can promote geopolymer cement through its addition to the university curricula. It is recommended that geopolymer cement be used frequently in construction activities to help reduced $CO_2$ emissions caused by the production of Portland cement.

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