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ARTICLE

Prospects of Partial Substitution of Cement with Rice Husk Ash for Road Concrete Works

Chidozie Maduabuchukwu Nwakaire* **Chukwurah Henry Aginam** **Chinenye Alfred Chidolue**

Department of Civil Engineering, Nnamdi Azikiwe University, P.M.B. 5025, Awka, Anambra State, Nigeria

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ABSTRACT

Rice Husk Ash (RHA) has been found as a potential partial replacement for cement in concrete. This study attempts to make an evidence based evaluation of the sustainability and benefits of RHA utilisation as partial replacement of cement in road concrete works within Anambra State of Nigeria. The ashes of the rice husks collected from different locations were characterised. Direct interviews were conducted among the rice mill personnel and experts in the construction companies. The values of SiO2 + Fe2O3 + Al2O3 for the four analysed RHA samples ranged from 78.9% to 80.3% as revealed by the X-ray fluorescence analysis. This confirms that they are pozzolanic. The highest observed 28th day compressive strength of concrete was 41.8 N/mm2 for the concrete containing 10% RHA. Beyond the 10% replacement level, the compressive strength dropped below the control values. The result of the Analytical Hierarchy Process (AHP) analysis displayed the highest option preference of 40.3% for utilising RHA in road construction. These show that utilising RHA for road concrete works would be a sustainable option. 10% replacement of cement with RHA was recommended for optimum performance based on the compressive strengths of the tested RHA based concretes.

1. Introduction

Road transport is the dominant mode of transport in Nigeria which is Africa's most populous country. Most freight and passengers are predominantly transported by road. This has resulted in frequent failure of existing pavements due to high volume of heavy goods vehicles [1]. The parlous state of the road transport infrastructures, especially the pavements, is an evidence for this. This situation has resulted in frequent need for road maintenance and location of new roads across the country.

There are two types of pavements; rigid and flexible pavements. The rigid pavement is surfaced with concrete whereas the flexible pavement is surfaced with asphalt [2]. Cement is the binding material in concrete but bitumen is the binding material in asphalt. These two types of pavements are widely constructed in Nigeria. However, concerns have been expressed over the years about the environmental impacts associated with increasing use of both materials [3]. Cement is of major concern because it accounts for up to 8% of man-made CO_2 globally [4]. Moreover, the use of cement is almost inevitable at present. Even for flexible pavement constructions, concrete is still used for side drains, kerb stones, footpaths, and verges. The solution to reduction of the environmen-

**Corresponding Author:*
Chidozie Maduabuchukwu Nwakaire,
Department of Civil Engineering, Nnamdi Azikiwe University, P.M.B. 5025, Awka, Anambra State, Nigeria;
Email: cm.nwakaire@unizik.edu.ng

tal impact from cement production lies in reduction of cement utilisation [5]. This can only be possible when sustainable alternatives have been discovered, either for total replacement or partial substitution of the cement. The later has been found to be feasible as material for complete replacement of cement is yet to be discovered [6]. However, many materials which have cementitious properties have been found to perform satisfactorily as partial replacement of cement in concrete. Utilisation of such materials will be a very sustainable attempt to improve the sustainability of pavement construction, preserving natural resources, and enhancing present and future societal interests [7,8].

The ash from rice husk promises to be a good option for partial replacement of cement in concrete [6]. Rice husk is an agricultural waste. About 300 million tons of rice paddy is produced yearly across the world and rice husk constitutes 22% [9]. The RHA is produced when the husk is burnt in a kiln or furnace at a high temperature of about 700ºC. According to Habeeb and Mahmud [10], the particles of RHA are very fine and amorphous in nature. Their study which mainly focused on the morphology of RHA showed that RHA has very high silica content. This enhanced its reaction with $Ca(OH)_2$ resulting in the production of more calcium-silicate-hydrate. The compressive strength of the concrete mixtures tested in their study revealed that inclusion of RHA can improve the compressive strength of concrete. Anupam et al. [11] incorporated a couple of such pozzolanic materials as a stabilizer for low strength residual soils. They concluded that RHA improved the California Bearing Ratio (CBR) value of the soil more than bagasse ash, fly ash, and rice straw ash. Another example of weak soil is black cotton soil. Whenever it is encountered, it always poses some challenges in construction. Shrivastava et al. [12] investigated into the effectiveness of improving the engineering properties of black cotton soil using RHA. They found that inclusion of 20% of RHA increased the CBR of the black cotton soil by 30%. There was also a significant improvement of the shrinkage and swell indices of the soil up to 87%. Hence, inclusion of RHA can improve the engineering properties of weak earth materials. This is a pointer to its ability to act as a sustainable alternative to cement in soil stabilisation applications [13].

RHA is an eco-friendly material. Studies have shown that it can enhance the strength and durability of concrete when it is used as a supplement [14]. Mishra and Deodhar [15] also confirmed that RHA can improve the strength of concrete. Nevertheless, they added that other factors like cement quality, aggregate gradation, water cement ratio, curing, and degree of compaction can also influence the strength and durability of concrete. Ismail and Waliuddin [16] reported that the strength of concrete was improved with RHA inclusion, but suggested that the proportion should not be above 20% by weight of cement. This was because the mixture with 20% RHA has the best compressive strength in their study. RHA can be utilised for concrete of different grades, but strength loss is expected when it is added beyond a reasonable optimum amount [14].

The Ayamelum area of Anambra State, Nigeria, is known for its large volume of rice production and consequently of rice husk output. The use of RHA in concrete for road construction within Anambra State would lead to sustainable and environmentally friendly construction. Despite this possibility, RHA is not being used in any aspect of road construction in Anambra State at present. This paper attempts to study the challenges and deterrents to utilization of RHA for road works. The chemical compositions of RHA from Ayamelum rice husks was studied and Characterised based on the X-Ray fluorescence analysis. Having confirmed that it is pozzolanic, its effect on the compressive strength of concrete grade 30 was investigated to confirm its structural performance. Sustainability options assessment was conducted using Analytical Hierachy Process (AHP). These offered research based evidences on which the feasibility and viability of RHA utilisation for road works was established and encouraged. Together with presentation of information from direct interview conducted at rice mills and construction companies, this paper makes a unique contribution to existing knowledge on this subject matter. Such holistic evidence based analysis is lacking in most existing literatures. In addition, studies on waste recycling remains a relevant one at present time when sustainability is enshrined in all proposals and strategies. Utilization of RHA is a reasonable sustainability strategy as it would minimise overdependence on cement, reduce the amount of agricultural waste disposal, conserve natural resources, and save energy consumption associated with cement production.

2. Methodology

2.1 Collection and Characterisation of RHA

Rice husk wastes were collected from rice mills located at Omor, Umumbo, Anaku, and Ifite-Ogwari towns within Ayamelum Local Government Area (LGA) of Anambra State, Nigeria. They were burnt into ashes under a controlled temperature of 700 ºC in an electric furnace. The ash obtained was left to cool before it was sieved through the 75μm sieve. The fraction passing through the sieve were used for the characterisation analysis and laboratory

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experiments. The specific gravity of the fine ash particles was determined in accordance with ASTM D 854-00. The X-ray fluorescence analysis was performed in order to reveal the chemical composition of the RHA samples. The characterisation of the ash was done in accordance with ASTM C618 which specifies that a fine material containing a minimum of 70% silica, alumina, and iron oxide ($SiO_2 + Fe_2O_3 + Al_2O_3 \geq 70\%$) can be a supplementary cementitious material (SCM). Such materials are referred to as pozzolanic materials.

2.2 Concrete Testing

The materials used for the concrete making include; cement, coarse aggregates, fine aggregates, water, and the rice husk ash. Ordinary Portland Cement (OPC), crushed granite, and river sand were used in this study. These were used to prepare concrete cubes with different proportions of RHA as cement substitute. These were subjected to compressive strength tests to confirm their performance as partial replacement of cement. The mix design comprising to concrete grade 30 was conducted on the concrete mixtures without RHA. The resulting concrete mix proportion was 1:1.5:3 with water/cement ratio of 0.45. For uniformity, this was adopted for all the mixtures containing RHA. Concrete cubes of 150x150x150 mm were made and subjected to compressive strength test. The maximum load recorded from the compression machine before the cubes were crushed was recorded and the compressive strengths were calculated based on equation 1.

$$\text{Compressive Strength} = \frac{Maximum\,Load\ (N)}{Cross\,sectional\ Area\ (mm^2)} \quad (1)$$

2.3 Qualitative Surveys and Reuse Options Analysis

According to Becker et al. [17], a very effective qualitative research can be done using direct interviews. It is widely employed for many informative studies. A series of semi-structured interviews were conducted in this study to glean the information documented in this paper. Key workers at rice mills located within Ayamelum were interviewed face-to-face by two researchers at twenty mills. This was considered enough as it represents up to 35% of the rice mills within that locality. No statistical analysis was intended, hence the sample size was not a strict consideration. Representatives from construction companies handling road projects within Anambra State, Nigeria, were also interviewed. This interviews complemented the one conducted at the rice mills. The facts gattered from the surveys have been summarised in this paper. The information from these interviews were useful in revealing the prospects and highlighting the possible challenges of utilizing RHA as an SCM in Anambra State road projects. Identification of other reuse options of rice husk in the Ayamelum area was also made possible through these direct interviews.

The sustainability gains of the current rice husk reuse options were evaluated based on Analitical Hierarchy Process (AHP). This is a multifactor assessment method developed by Thomas Saaty in 1980 [18]. It has been an effective tool for making evidence based decision on seemingly complex scenarios. The approach allows for a pairwise comparison between alternatives. The output is used to synthesize and optimize the benefits of any decision made. The process makes use of a set of evaluation criteria (see Table 1) and iterative options to optimise for the criterion which achieves the best trade-off among different criteria. Coyle [19] gives an elaborate detail AHP and the indices based on which the consistency of the scores were checked.

Table 1. Weight Selection Criteria for AHP [19]

Intensity of Importance	Definition	Explanation
1	Equal importance	There is equal contribution of the two factors to the objective.
3	A little more important	Experience slightly favour one option over the other.
5	More important	This shows that there is clear experience based judgement to favour an option over another.
7	Very much more important	This shows that there is a very strong evidence favouring one option over the other.
9	Absolutely more important	This shows highest possible validity of the evidence favouring one option over the other.
2,4,6,8	Intermediate values	Based on the discretion of the assessor.

3. Results and Discussions

3.1 Characterisation of the Rice Husk Ash (RHA)

The X-ray fluorescence gave a spectrum of the constituent elements in the RHA and OPC. The predominant element in RHA is silicon (Si) whereas the predominant element in OPC is Calcium (Ca). The oxide compositions were deduced based on the elemental compositions of the different samples of RHA tested. Table 2 shows the oxide compositions and physical properties of RHA samples produced from rice husks collected at four different locations in Ayamelum.

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Table 2. The oxide concentrations of rice husk ash and cement

Oxides	Concentration (%)				
	Ifite-Ogwari RHA	Umumbo RHA	Omor RHA	Anaku RHA	OPC
SiO_2	77.64	72.26	75.73	77.80	20.90
P_2O_5	9.78	7.90	11.30	5.80	-
K_2O	1.50	0.76	3.97	2.53	0.58
Fe_2O_3	3.23	2.34	3.06	2.13	4.23
MgO	1.70	1.79	2.93	3.83	0.23
Al_2O_3	1.40	4.30	1.51	2.40	5.87
CaO	0.47	1.63	0.69	0.93	65.96
MnO	0.08	2.34	0.22	0.09	-
Rb_2O	-	-	0.06	-	-
TiO_2	0.28	0.65	0.43	1.32	-
ZnO	0.03	0.50	0.06	0.10	-
ZrO_2	-	-	0.01	-	-
SO_3	-	0.07	0.02	-	-
LOI	3.87	5.45		2.50	1.73
Specific gravity	2.25	2.25	2.31	2.18	2.96
Colour	Greyish White	Greyish White	Greyish white	Greyish White	Grey

The chemical properties of the tested RHA samples are very similar. This show that they can be used together without any significant difference in performance as a result of location differences. The RHA is very rich with SiO_2. OPC is very rich with CaO which is only available in very minute proportions in RHA. In the presence of water, both materials can react to form Calcium silicate hydrate and Calcium aluminate silicate as much as there remains Ca^+ ion in the mixture. The specific gravities of the RHA samples are less than that of OPC. However they are all comparable. This shows that the RHA can substitute cement by weight, without any significant reduction in density of the resulting concrete. The sum of the proportion of silica, alumina, and iron oxides are presented in Figure 1. The RHA is pozzolanic and can be used as SCM.

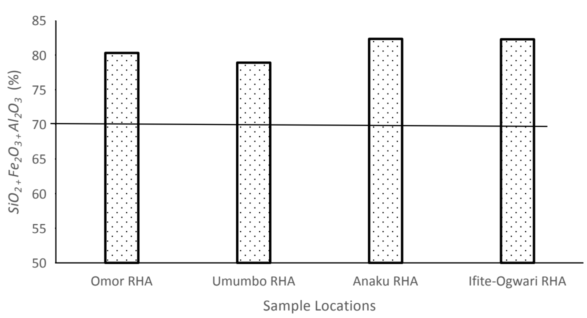

Figure 1. All Samples Significantly Pozzolanic

These results indicate that the RHA, produced from rice husks gotten from Ayamelum, is a pozzolanic material. It meets the specification of ASTM C618. The 70% criterion is indicated by the horizontal line across the chats. This makes the RHA suitable for utilisation in concrete mixtures. In line with other studies, improvement of the concrete compressive strength was anticipated.

3.2 Compressive Strength of RHA Based Concrete

The RHA was used as a cement substitute in the conventional mix design that was made. The proportion of RHA in the mixtures was varied from 0% to 20% at intervals of 5%. Since the RHA from the four locations have similar properties, there was no need for distinction between concrete made with RHA from different locations. The ashes were combined and measured out by weight for each replacement level. The compressive strength of the concrete cubes were tested after 7days, 14days, and 28days of curing. Figure 2 shows the results of the compressive strength tests.

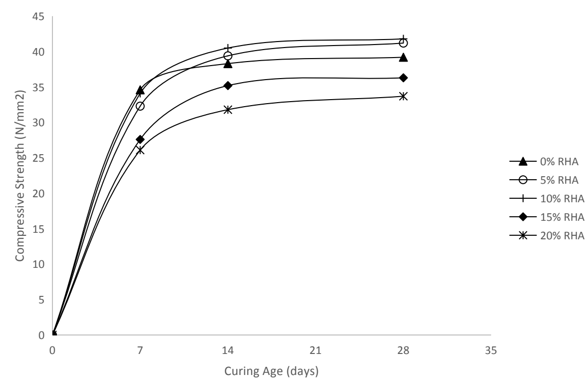

Figure 2. Effect of Rice Husk Ash (RHA) on the compressive strength of concrete

As expected, the strength of all the concrete samples increased with increase in curing age. There was a rapid strength gain within the first 7 days that all the samples achieved above 25 N/mm^2 compressive strength. This shows a strength gain above 80% of the target compressive strength of 30 N/mm^2. With longer curing age, the concrete samples gained higher strength. The 28th day compressive strength is taken for compressive strength analysis of concrete. The compressive strength of the control mixture is 39.2 N/mm^2 which is satisfactory above the design compressive strength. As the RHA was added, the 28^{th} day compressive strength of the concrete increased to as much as 41.8 N/mm^2 for the concrete containing 10% RHA. Beyond the 10% replacement level, the compressive strength dropped to 36.3 N/mm^2 and 33.7 N/mm^2 for 15% and 20% replacement levels respectively. These val-

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ues are less than the control compressive strength but are yet above the target compressive strength. The implication is that further addition of RHA would result in more drops in the strength of the concrete. The reason for this is the absence of sufficient Ca^+ for the hydration reaction necessary for concrete hardening. This has been illustrated by the characterisation analysis presented in section 3.1 of this paper. Hence based on this analyses, the optimum proportion of RCA: OPC in concrete is 1:9 which implies that up to10% of cement by weight can be substituted with RHA for improved strength. This further shows that RHA is a pozzolanic material and can be utilised for concrete works in road constructions works.

3.3 Facts from the Surveys

3.3.1 Availability of Rice Husks in Ayamelum

The rice husks are produced after separation of the rice grains from the paddy. Among the Ayamelum farmers and rice mill workers, the rice husks are popularly known as rice dusts. This is because the rice grain separation process results in the crushing of the rice husk. Large quantities of rice paddy is being processed at the rice mills. There was no data for quantitative evaluation of the amounts of rice husks produced daily because the rice mills keep no record of such since they treat the rice dusts as wastes.

Currently, rice husk produced at Ayamelum is being disposed by open burning. Some proportion of it is being utilized locally for making fire for cooking, adding to poultry feed, and stabilizing clay for mud houses. These are the predominant reuse options. A few respondents also reported that the husks can be reused for mulching in the farms. The fact that the local communities use this rice husk as a soil stabilizer in raiding mud houses shows that it has some properties with engineering relevance. However, as the area become increasingly assessable, most recent building constructions are being done with sandcrete blocks and cement mortar. With these facts, it was clear why the rice husks are yet seen as wastes. They are not being commercialized or marketed because no viable commercial need have been identified. Utilization of RHA in road concrete works would offer such opportunity.

3.3.2 The Utilisation Level of Pozzolans for Anambra State projects

The use of pozzolanic materials generally is not popular amount contractors within Anambra State. Concrete works are strictly done with cement as binder. Earthworks are also done without any form of stabilization. The responders reported that instead of embarking on soil stabilisation, which they considered encumbering, the usual practice is to remove the weak soils and replace with a stronger one from a different location. With the abundance of rice husk in the state, it can be argued that stabilising the weak soils with RHA may be of much cost reduction benefit. However, no analyses or investigation was made to support this because the interest of this study is on reduction in the amount of cement used in concrete making. This is very expedient in order to reduce the environmental impact associated with cement production.

All road projects in Anambra State involves concrete works. In order words, cement must be utilised at some points of the road constructions. Apart from using the concrete for rigid pavement surfacing, it is mainly used for other parts of the pavement such as drainages, verges, curbs, and central reserves. Hence, both flexible and rigid types of pavement involves the use of cement. This shows that concrete works are not limited to rigid pavements. The need to substitute cement is a quest for environmental friendly and economically viable constructions. The following information from the construction personnel summarise why RHA is not yet being utilised in Anambra State.

(1) Motivation; There is not yet strict regulation and implementation of sustainable waste management strategies in Anamabra State. As a result, waste reuse and recycling has not been taken seriously. The responses from the survey show that the construction companies can accept to implement the use of pozzolans in their concrete works if there were government motivation or regulations in line with that.

(2) Confidence; There is concern as to whether the use of pozzolans can feasibly achieve the required concrete strength and the desired structural durability. This motivated the need for the compressive strength test performed in this study as reported in section 3.2. This gave the basic evidence based analyses to support the reliability of utilisation of RHA as a cement substitute in concrete mixtures.

(3) Packaging; The ash of the rice husk is what is needed for concrete applications. This ash is not yet portably available. For effective implementation of this strategy, the construction companies are of the opinion that the RHA should first be processed and commercialised.

(4) Information; Above all, dearth of information on the possibility and prospects of utilisation of RHA in concrete happens to be very characteristic of many contractors. This idea that has been promoted for decades is yet alien to most of the respondents. This study would offer an eye opener. The Nigerian Industrial Standard (NIS) would be instrumental towards incorporating this strategy to existing standards and communicate the same to relevant stakeholders.

RHA utilization will offer several benefits to different stakeholders. The government would save some cost of production from savings in cement cost. This would make possible the commissioning and execution of more construction projects. The contractors would improve their credibility since the RHA improves the strength of concrete. In the long run, the rice mills and rice farmers could have additional revenues when rice husks become a marketed commodity. Obviously, reduction in cement consumption will significantly result in reduced dependence on natural resources and improved carbon footprint of concrete works.

3.4 The Reuse Options Analyses Using Analytical Hierarchy Process

As outlined in section 3.3.1, rice husks are currently being utilised in small quantities at Ayamelum, whereas the remnants are disposed of. Mostly, the local communities use these rice husks to make fire for cooking, some add it to poultry feed, and others use it to stabilize mud for small buildings. Since these reuse options already exist, it was considered a better approach to enhance these reuse options and maximize the benefits from them. However, making such a decision is better supported by analytical evidences. The benefits from these three predominant reuse options were compared with the potential benefits of utilizing them for road construction concrete works. The AHP is a very suitable analytical tool for this option based analysis. The guidelines for the scoring has been detailed by Coyle [19].

3.4.1 Indicators to Sustainable Reuse of RHA

The assessment of sustainability of a system can only be done with respect to a set of performance factors or sustainability indicators. Generally, indicators are parameters used to explain the state of a system with a significance above the direct values of the parameter [20,21]. Indicators are often used to make full or partial judgement of a particular scenario or phenomenon. They are necessary in sustainability analysis because they reduce the amount of data required to evaluate a condition or system. This helps to facilitate communication with the interested audience.

In this study, four indicators were adopted. Community hygiene, savings in cost, reduction in greenhouse gas emissions, and transportation cost are the factors considered most important for ascertaining sustainable waste management. The relative importance of these factors was first evaluated as shown in Table 3. The pairwise comparison of the factors was made to describe which of them is of more importance in sustainability assessment.

Table 3. The scores of the pairwise comparison of the sustainability factors

Factors	Community Hygiene	Cost Savings	Reduction in Emissions	Transport Distance	Nth root	Eigenvector	Dot product	Division (x)
Community Hygiene	1	3	1/3	6	1.565	0.274	1.096	3.994
Cost Savings	1/3	1	1/5	3	0.669	0.117	0.462	3.943
Emissions reduction	3	5	1	7	3.201	0.561	2.300	4.099
Transport cost	1/6	1/4	1/8	1	0.269	0.047	0.192	4.083

Note: Consistency index = 0.010; Critical Value = 0.9; Consistency ratio = 0.011 < 0.1

The consistency ratio of 0.011 is very satisfactory as it is below the 0.1 limit. The result shows emission reduction with eigenevector of 0.561 is of utmost importance in sustainability assessment. This is because it has impact on the immediate surrounding and also the global atmosphere. Transportation cost is also very important because it indirectly relates to distance of transportation which is also associated with greenhouse gas emissions. The hygiene and cleanliness of the environment is ranked next to these whereas savings in production cost as a result of waste utilization was considered of least importance because it only accounts for economic costs. The four reuse options were evaluated based on their potentials and ability to achieve these factors.

3.4.2 The Options Performance Assessment

At the stage of the analysis, the reuse options were assessed to determine the most viable and reasonable alternative. Being the greenhouse gas reduction has been rated the most important consideration factor, the option that gives the most possible opportunity of achieving this would likely be the most viable option, provided it does not found critically lacking in other indicators for the assessment. Considering the case study at hand, it was not trivial to decide such an option. The AHP procedure was completed as presented in Table 4.

The consistency ratios in this analysis ranges from 0.008 to 0.029. All are less than 0.1 and are very satisfactory. Based on the eigenevectors, utilization of rice husk for road concrete works would be the best option to achieve community hygiene, save more cost, and reduce greenhouse gas emissions. However, considering the transportation distances involved in transporting rice husk from the rice mills to the places of reuse, it was opined that road works would require longer transport distances. Generally, the analysis supports the use of RHA for concrete works in road construction. It offers more viable sustainability

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Table 4. The analytical scores for the relative impacts of the reuse alternatives

Sustainability Factor	Pairwise Comparison	Cooking Fuel	Poultry Feed	Mud Stabilisation	Road Construction	Nth root	Eigenvector	Dot product	Division (x)
Community Hygiene	Cooking Fuel	1	2	1/4	1/7	0.517	0.085	0.347	4.065
	Poultry Feed	1/2	1	1/5	1/4	0.334	0.055	0.225	4.080
	Mud Stabilisation	4	5	1	1/3	1.607	0.265	1.081	4.074
	Road Construction	7	8	3	1	3.600	0.594	2.429	4.087
	Consistency index = 0.026; Critical Value = 0.9; Consistency ratio = 0.028 < 0.1								
Cost Savings	Cooking Fuel	1	1/3	1/2	0.2	0.427	0.084	0.339	4.058
	Poultry Feed	3	1	2	1/3	1.189	0.233	0.942	4.047
	Mud Stabilisation	2	1/2	1	1/4	0.707	0.138	0.558	4.033
	Road Construction	5	3	4	1	2.783	0.545	2.216	4.066
	Consistency index = 0.017; Critical Value = 0.9; Consistency ratio = 0.019 < 0.1								
Greenhouse gas emissions	Cooking Fuel	1	1/3	1/6	1/8	0.289	0.053	0.213	4.032
	Poultry Feed	3	1	1/2	1/4	0.783	0.143	0.574	4.010
	Mud Stabilisation	6	2	1	1/2	1.565	0.286	1.149	4.010
	Road Construction	8	4	2	1	2.828	0.518	2.086	4.030
	Consistency index = 0.007; Critical Value = 0.9; Consistency ratio = 0.008 < 0.1								
Transport cost	Cooking Fuel	1	5	4	8	3.557	0.613	2.510	4.097
	Poultry Feed	1/5	1	1/2	3	0.740	0.127	0.518	4.060
	Mud Stabilisation	1/4	2	1	4	1.189	0.205	0.833	4.067
	Road Construction	1/8	1/3	1/4	1	0.319	0.055	0.225	4.094
	Consistency index = 0.026; Critical Value = 0.9; Consistency ratio = 0.029 < 0.1								

benefits above the other reuse options considered. The final step of the AHP is to calculate the options value for money. This is actually a function of the cumulative AHP parameters. Based on this, the extent of sustainability benefits for the four options was gotten as percentages.

3.4.3 The Preferred Reuse Option

The most preferred reuse option is determined based on the Relative Value Vector (RVV) and Value for Money (VFM) computed from the AHP analysis. These are presented in Table 5. The options with lower RVV will have higher VVM. The option with the highest VVM is considered the most reasonable and beneficial option. When the VFM is normalised, the percentages of the options utilities were gotten and is presented in Figure 3.

Table 5. The relative utility for the reuse options

Options	Community Hygiene	Cost Savings	Emissions reduction	Transport cost	RVV	VFM
Cooking Fuel	0.085	0.084	0.053	0.613	0.274	0.383
Poultry Feed	0.055	0.233	0.143	0.127	0.117	0.129
Mud Stabilisation	0.265	0.138	0.286	0.205	0.561	0.259
Road Construction	0.594	0.545	0.518	0.055	0.047	0.520

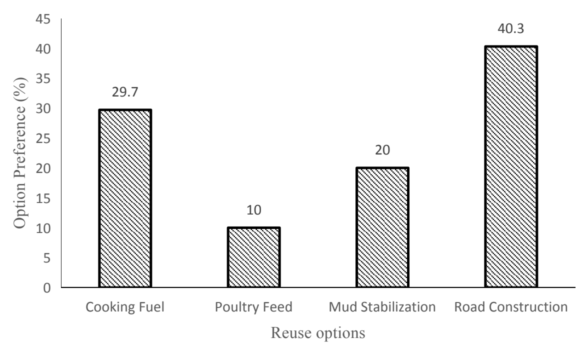

Figure 3. Best benefits from application of RHA in pavement concrete works

The foregone analysis has shown that rice husk recycling would be more beneficial and sustainable if applied in road construction concrete works. It offers higher utility for the interest of the different stakeholders. This is much more viable, as RHA could be a suitable SCM available within Anambra State. By implementing this strategy, the carbon footprint of the construction projects would be reduced due to lesser quantity of cement used.

4. Conclusion

This paper assesses the prospects of RHA utilisation in road construction concrete works. The need for this is cogent as the high level of greenhouse gas emissions from cement productions increases much higher. Given the environmental concerns about high dependence on cement for the ever growing global infrastructural provisions, partial inclusion of pozzolanic materials would reduce the amount of cement needed and improve the environmental friendliness of concrete works, especially in developing countries. RHA is one of such materials which has been found as a potential partial replacement for cement. This study shows that despite its abundance, RHA is not being utilised currently for road projects in Anambra State, Nigeria.

The X-Ray florescence analyses show that RHA samples produced from Ayamelum rice husk are similarly pozzolanic. Their values of their specific gravities are similar but less than that of cement. Inclusion of RHA increases the 28^{th} day compressive strength of the concrete to 41.8 N/mm^2 for the concrete containing 10% RHA. Beyond the 10% replacement level, the compressive strength dropped to 36.3 N/mm^2 and 33.7 N/mm^2 for 15% and 20% replacement levels respectively. Substitution of cement with RHA had optimum Compressive strength at 10% substitution level. Dearth of technical information and packaged RHA products were found to be the main deterrents for the utilization of RHA for Anambra road projects. Currently, the rice husk produced at Ayamelum is mainly used as cooking fuel, poultry feed, and mud stabilization. The AHP analysis displayed the highest option preference of 40.3% for utilising RHA in road construction. This showed that utilising RHA for road concrete works would be more sustainable and beneficial than the current reuse methods.

Based on these research outcomes, it is recommended that the Anambra State ministry of environment will discourage indiscriminate disposal of solid wastes and enforce recycling of the same. In the case of rice husks, it is recommended that they be converted into the very pozzolanic RHA for inclusion into concrete mixes used for road construction as partial replacement of cement. Industrial production and packaging of RHA would be a very reasonable attempt towards encouraging the implementation of this sustainable strategy.

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