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Contents

Article

4 Effectiveness of Urban Farming Program in Providing Multiple Benefits to the Urban Community in Malaysia

Nazanin Nafisi Osman Mohd Tahir Sara Nafisi Nazri Ishak

- Tensegrities and Tensioned StructuresMa Dolores Álvarez Elipe
- 17 Prospects of Partial Substitution of Cement with Rice Husk Ash for Road Concrete Works
 Chidozie Maduabuchukwu Nwakaire Chukwurah Henry Aginam Chinenye Alfred Chidolue
- 26 Construction Technology and Quality Control of Double Layer Continuous Paving of Cement Stabilized Macadam Base
 Jin Ma

Review

1 Valuation of Laterite in Low-cost Building in West Africa

Ibrahima Sow Ibrahima Khalil Cisse Souleymane Mbingue

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REVIEW

Valuation of Laterite in Low-cost Building in West Africa

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ABSTRACT

The study of the performance of raw clay bricks has made it possible to develop laterite in Eco village construction projects. Identification tests (particle size analysis, Atterberg limits, Proctor, shrinkage limit, and sand equivalent) made it possible to characterize the laterite, the sand, and the E1 mixture (70% laterite and 30% sand). By adding binders to E1, three other types of mixtures E2, E3, and E4 have been proposed. The improved E1 sample:(1) At 2.5% of cement gives E2; (2) At 10% of lime gives E3; (3) with 0.8% lignosulfonates. After making the bricks using the samples E1, E2, E3, and E4, we perform uniform compression test at 3, 7, and 21 days. All samples have simple compressive strengths greater than 0.5 MPa (in accordance with standard NF EN 771-1) after 3 days. Their evolution from 0.5 to 2.5 MPa, between 3 and 7 days, shows a jump of 1.5. From 7 to 21 days the evolution curve of the Rc shows a slight ascension then a plateau pace (2.5, 2.51, 2.56 MPa). From these results, we concluded that they were used according to the area and the type of climate. The use of the sample E1 is proposed in arid zones or with low rainfall, the sample E2, and E3 in the rainy zones without risk of capillary rise and the sample E4 in the rainy zones with the risk of capillary rise.

1. Introduction

aced with the current environmental challenges linked to climate change and the depletion of resources (United Nations Environment Program, 2016), the building sector must renew its design practices and methods while taking into account economic and health criteria and comfort. UN-Habitat estimates that 3 billion human beings will be poorly housed by 2030. Given its availability, raw earth constitutes a viable alternative in the construction sector in order to meet the needs of the world population [1]. However, scientific studies must be carried out on this material in order to define manu-

facturing conditions within the reach of the target population. Indeed, despite its many ecological, thermal, and economic advantages, raw earth has the disadvantage of deteriorating under the effect of climatic conditions. It is therefore essential to take precautions in order to increase its durability [1]. In this study, it will be a question of improving the laterite with sand, lime, cement, or lignosulfonates.

The objective is to contribute to the improvement and development of local building materials made from laterite blocks. Specifically, this study aims to:

(1) Define the properties of lateritic and clay materials;

1

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(2) Improve performance by adding lime, cement, and lignosulfonates.

2. Characterization of Materials

2.1 Laterite and Sand

Laterite is a residual rock. Its composition is rich in iron hydroxide and aluminum hydroxide. They appear in the form of red earth mainly due to oxidized iron and which contain nodules (an abnormal size of generally rounded shape) harder due to the recrystallization and the dissolution of the oxides of iron and alumina ^[2]. When this phenomenon occurs in superficial horizons, it generates the birth of what is called the "lateritic breastplate".

Laterite is taken from the Bambey area.

The whitish-colored sand is extracted from the bottom of the dry water points. The following tests were carried out: particle size, determination of the dry density, Atterberg limits, and shrinkage limit.

2.2 Manufacture of Earth Bricks

Analysis of the laterite results shows that it has a clay fraction. In order to keep the plasticity index lower than 25, we added 30% of sand to make an E1 sample of raw earth. The sample shows the granular skeleton shown in the figure 1.

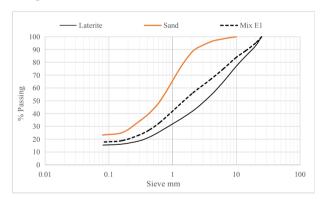


Figure 1. grading of laterite-sand-mix E1

The characteristics of the materials are summarized in Table 1.

Table 1. Results of laterite and sand identification test

Materials	rials Mdd (g/ Liquid Plasticity S cm³) limit index		Shrinkage limit	Sand equivalent	
Laterite	1.982	42	12 26 8		NC
Sand	1.892	21	10	NC	89
E1 (70% laterite+30% sand	1.99	39	23	5	NC

From E1 we prepared three other samples (E2, E3 and E4) whose composition is defined in Table 2.

Table 2. Composition of study's samples

Materials	Laterite	Sand	Additive
E1	70%	30%	NC
E2	70%	30%	2.5% cement
E3	70%	30%	10% lime
E4	70%	30%	0.8% Lignosulfonates

E1 and E3 are wetted to the optimum water content and compacted @ 90% of the modified Proctor optimum.

E2 and E4 are lateritic concrete. The molding is done with a sag of 60 cm.

Eighteen samples were made from each mixture, which will be overwritten in groups of six at 3, 7 and 21 days.

Figure 2 shows the illustration of earth brick construction.



Figure 2. Earth brick construction

Sample E1 is burned over a wood fire to give it hardening and thermal insulation properties. Traditional bricks are classified in type (a) and (b) insulating masonry. A traditional brick with an R> 1m^2 .K / W is more than four times more insulating than a common aggregate concrete block (R = 0.23 m².K / w) ^[3,4]. The thermal performance of traditional bricks and their accessories gives them a strong ability to correct thermal bridges.

The compressive strength results are shown in Table 2.

Table 2. Compressive Strength of E1, E2, E3 and E4

Materials	Additive	3 days (MPa)	7 days (MPa)	21 days (MPa)
E1	NC	0.50	2.00	2.01
E2	2,5% cement	0.60	2.50	2.54
E3	10% lime	0.65	2.51	2.51
E4	0.8% Lignosul- fonates	0.61	2.52	2.56

2.3 Analysis and Interpretation

Analysis of the results shows a first trend from the first

three days: E1, E2, E3, E4 have Rc \geq 0.5 MPa (requirement of standard NF EN 771-1) [4].

Sample E1, without additive, burned at 285° c has the following Rc: 0.5 MPa @ 3 days, 2.0 MPa @ 7 days and 2.01 MPa @ 21 days. The increase in resistance took place between three and seven days with a jump of 1.5 MPa. Between 7 and 21 days we observed a slight increase which presents a plateau-like appearance on the evolution curve.

Sample E2, E3 and E4 show the same trend in the evolution of compressive strength. This trend is illustrated in Figure 3.

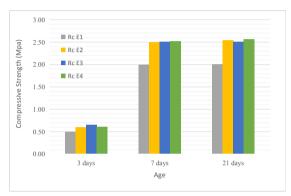


Figure 3. Evolution of Rc according to ages

All of the samples studied present the minimum specifications for their use in construction.

- (1) The firing of raw clay bricks has increased the compressive strength and given its thermal insulation properties
- (2) In sample E2, the cement served as a binder, thus improving the stability of the brick, and will help prevent rising damp.
- (3) In sample E3, lime replaces cement and plays the same role.
- (4) Various hypotheses have been proposed to explain the interaction of lignosulfonates with clay fractions VAN OLPHEN (1963) envisages the adsorption of organic molecules on the lateral surfaces of clay crystallites at the level of the surface cations of the octahedral and tetrahedral layers of the sheets ^[5,6]. On sample E4 we observed that lignosulfonates would have the property of adsorbing on any surface having chemical carboxylic or hydroxyl groups capable of giving rise to hydrogen bonds; which hardens the brick and increases its compressive strength.

3. Conclusion and Recommendations

The objective of this study is the development of laterite

in Eco village construction projects. The standardized geotechnical tests were carried out at the laboratory of Compagnie Sahélienne d' Entreprises.

The results obtained to meet the technical specifications of standard NF EN771-1. The evolution of resistance to compression shows a first phase of maturity between 3 and 7 days and stabilization between 7 and 2 days, from where we propose a period of cleaning of 14 days of earth bricks before the implementation of the buildings.

Depending on the area and the type of climate, we make the following recommendations:

- (1) Use sample E1 in arid areas or with low rainfall
- (2) Use the sample E2 and E3 in rainy areas without risk of capillary rise
- (3) Use the E4 sample in rainy areas with the risk of capillary rise.

So we can say that in the face of current environmental concerns, raw earth returns to the spotlight thanks to its many advantages. Raw earth can be used in new construction, renovation, and rehabilitation both in traditional and contemporary ways. Raw earth has many qualities and is a material for the future.

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ARTICLE

Effectiveness of Urban Farming Program in Providing Multiple Benefits to the Urban Community in Malaysia

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ABSTRACT

Residents have chosen to be living in urban regions in recent years largely due to the accessibility of job opportunities and public services. These led to a fast increase in the amount of people live in urban regions and cities. As a result, a large amount of the property used for agricultural activities was transformed into factories, housing units, and highways. This also resulted in a decrease in food production, growth in food prices and food import bills as the country now relies on food imports especially rice, fruits and vegetables, that can prevent the fostering of urban farming activities and then provide beneficial information essential to form it into a more consumer friendly program. Moreover, studies on urban farming are somewhat few in Malaysia and this study can become helpful for future research. The study focused on small-scale agriculture projects, such as community gardens, and community-level programs such as community supported agriculture and farmers markets. The study found that how urban agriculture enhances community resilience and wellbeing. This is the necessity for the Malaysian urban authorities to provide more proper identification and support to city residents and promote them to develop the practice of urban farming.

1. Introduction

Trban agriculture is a creative solution for improving access to healthy foods, revitalizing communities' economies, and social health, especially in developing cities [1]. Such practices of urban farming take place in different parts of the cities, such as the backyards, rooftops, and others. Urban agriculture is increasingly growing in Malaysia. Urban agriculture plays a significant role, in improving nutrition and safety, urban food security, generating job opportunities and contributing to increase the recycling of nutrients and community development [2].

Urban agriculture contributes to addressing urban issues such as environmental issues and is being widely adopted and used as an instrument for sustainable urban growth around the world. Urban agriculture is not a new phenomenon, it just transforms the face of agriculture into a different style in urban condition as one of the latest techniques to challenge the traditional farming method. Complex structure of urban farming can be described in many ways and needs to be adapted to the local context ^[3]. Urban agriculture is described as the expanding, processing, and supply of food and other products via intensive plant farming and animal farming in and across towns ^[4].

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In addition, urban agriculture also involves agricultural production activities as well as associated processing and distribution by specialized microenterprises or NGOs of inputs and service supply. Therefore, the long-term activity of urban agriculture supports the urban dwellers, local authorities, and the general community. Urban agriculture, according to Pearson [5]. is not a single entity. It includes residual, mostly peri-urban, large acre farmland, small community gardens, self-managed allotments, home gardens, and parts of parks that had previously been entirely planted with facilities, fruit tree along roadside reserves, greenhouse, green roofs and green walls. Beside crops, urban agriculture also includes the cultivation of livestock within cities. It can be anything from small vegetable gardens in the backyard to an organization or neighbourhood group's activities like livestock on community lands, in which the production typically geared to household consumption (FAO, 2010). Food grown at the city or town's daily pace, developed directly for the marketplace, and mainly processed and sold by the farmers or their near associates [6]. Urban farming is a wide and expanding sector using wastewater and solids waste as input that closes ecological loops when extracted on idle land and water bodies [6]. Urban and peri-urban agriculture provide food products from different crop types and urban livestock farming.

1.1 Definition of Urban Agriculture

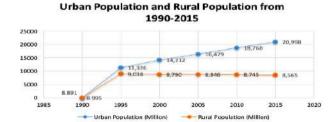
Urban agriculture consists of a variety of things to do worried with elevating vegetation or raising animals. Private gardens in backyards, neighbourhood gardens and city farms are some of the greater typically referenced developing activities. Chickens, bees, fish, and farm animals are also involved. Other activities that are incidental to these encompass composting animal waste or vegetative and putting in constructions such as hoop and greenhouses homes to prolong the growing season of plant life. Retail and marketing and attempt like farmers markets, food vehicles and produce stands are also captured in this classification [7]. Beyond the manufacture of foods is the variety of benefits attributed to urban agriculture. Urban farming is a comprehensive system covering a range of interests, from a usual core of activities linked with the production, advertising distribution, processing, and consumption, to a variety of different benefits and services that are much less generally known and documented. These involve leisure, endeavour and, financial vitality and well-being; neighbourhood health and well-being, environmental restoration and landscape beautification and remediation [8]. These social advantages are regularly recognized to urban farming regardless of the true affects the use might have.

Several advocates and practitioners of urban farming cite these advantages as inherent to the usage. Urban farming advocates frequently champion farms and gardens to "bring back" nature into towns ^[9].

1.2 Urbanization in Malaysia and the Rise of Urban Agriculture

About 30 per cent of the world's population is supposed to stay in urban regions in 2025 (Department of Statistical Malaysia, 2015). This pattern is expected to continue with the country witnessing population growth and rapid urbanization. This situation would arise because of the increasing migration of rural people to the city due to the improved economic conditions in urban areas. Rural-urban migration would make urban areas more heavily populated, which resulted in competing for access to food sources, education, accommodation, and food security.

Table.1 Urban and Rural Population in Malaysia (1990-2015).



Sources: Department of Statistic Malaysia, 2016



Figure 1. PANa (Urban Area Needed Percentage) to meet the actual consumption of vegetables by urban residents in UA

Source: [10]

The community garden is not new to Malaysia, as the "Bumi Hijau" program has existed since 2008, Putrajaya Corporation launched "Kebun Komuniti Programme", a community gardens project involving the citizens of Putrajaya. The initiative has positive outcomes and enhances interaction through community engagement. The community garden used traditional beds and irrigation for farming at the beginning of the program. Two greenhouses built at the Community Garden by the end of 2013, an initiative to enhance Community Garden in Putrajaya in

collaboration with MARDI (Putrajaya Corporation, 2014).

1.3 Implications of Urban Agriculture and Well Being

Public and educational lands dedicated to food production promote contribution in the vigour of a positive urban environment. Working collaboratively to "green" a neighbourhood creates secure and enjoyable neighbourhoods that reduce air pollution, decrease crime, and improve public life [11] Social meeting is positively linked with individual attention to wellness and health care. Urban neighbourhood farms and gardens improve the health of the environment as well as that of social dwellers. Farming enhances air quality and rises biodiversity [12]. Rooted shrubs stabilize the ground and decrease soil ablation. Working with plants and being in the outside cause disease prevention and recovery responses. Health specialists use gardening and plants resources to help patients of diverse ages with mental illness enhance social abilities, self-esteem, and use of relaxation time. Gardening therapy promotes plant-human relations to encourage relaxation and to decrease stress, blood pressure, fear and anger, and muscle tension [13].

1.3.1 Personal Norms

According to Ajzen [14] the subjective norm shows perceived social stress to do or not accomplish the behaviour. Subjective norms that is relevant to be related with urban agriculture activities are like family, friends, neighbour, and government. Studies from Weiss [15] identified elements such as perceptions of friends or family or about urban agriculture activities, campaign from school or university and neighbourhood characteristics are influencing youth to participate in urban agriculture activities in their vicinity. Another studies from Herren et al [16] found that students in one school at Texas, believed that the agriculture teacher had an impact on their decision to participate and register in agricultural activities.

1.3.2 Identified Behavioural Control

The perceived behavioural control is the extent to which the person understands the behaviour to be under control. It shows whether people simply join or vice versa. According to Vermeir and Verbeke, [17] people will not have intention to perform the behaviour when they feel they are lacking the opportunities or resources to accomplish a behaviour. In this case, people might have intention to perform urban agricultural activities if they have time, knowledge, and suitable equipment for such activity. Besides, Sparks et al, [18] have indicated that perceived be-

havioural control shows both external perceived problem aspects such as perceived obstacles and inner control factors such as self-efficacy.

2. Urban Farming Program

The impact of the urban farming system can be seen by various elements such as availability and quality of food, cost-effective food supply and revenue production through sales [19].

Table 2. Urban farming systems

Farming system description	Expected products	Place location / tech- nique
Aquaculture	Vegetables, fish, seafood, and fodder	Ponds, cages, streams, lagoons and wetlands
Horticulture	Fruits, vegetables, and compost	Homesteads, wetlands, parks, containers, rooftops, hydroponics, and greenhouses
Livestock farm- ing	Milk, eggs, meat, hides and manure	Hillsides, zero grazing, peri-urban areas
Agro-forestry	Fruits, wood fuel, building posts and fodder	Street trees, home- steads, forest parks, steep slopes wetlands and orchards.
Other systems	Household plants, flowers, and medicinal herbs.	Ornamental horticul- ture, roof tops and container farming

Source: [20]

3. Profitability of Urban Farming

Urban agriculture has been shown to offer many environmental benefits that assist local people support local environmentalism. Furthermore, the social, cultural and health effects of urban farming are generally positive and has benefits to a variety of community organizations and groups. An urban farmer requires an effective infrastructure, a competitive marketplace and a group engaged community, careful crop selection, and many other factors to reach success.

Economic Impacts

Urban farming can build economic progress within the communities. Urban green infrastructure will boost real estate values within their areas ^[21]. Enhanced green infrastructure by urban farms and gardens will help decrease urban vandalism ^[21]. Such improvements to the neighbourhood lead to a more active market for real estate in the region. Nevertheless, by establishing food production within urban regions, farmers can deliver fresh, healthy food at relatively low costs ^[22]. The direct relations between customer and producer make these low costs and comparatively easy but profitable paradigms possible ^[23].

Since urban farms are established within the neighbour-hoods they manage, these businesses can attach directly with the users of their supplies and cut certain costs associated with the distribution and sale of items. The direct link makes commodities produced by urban agriculture not only to be competitive but also reasonable to the customer ^[22]. Regional food production also creates competition with traditional rural agriculture and mark down overall food costs in the area, making healthy economic competition ^[24].

4. Methodology

The study reviewed linked lectures which had been peer-reviewed and sought the answer to how urban farming be able to solve the profitability, food security, and wellbeing issues in the urban region? The corpus was taken from Science Direct, Scopus, Web of Science, Google Scholar and ProQuest. These databases given access to the publications that were needed. The following key terms were explored for Urban Farming, wellbeing, farming in urban regions profitability, and food security. The abstracts, keywords and titles were searched for the key terms. The year was set from 2015 to 2020 from various resource categories such as thesis, journals, books, conference papers and reports. After That, the documents were checked to make sure for the applicability and determine the final outcomes. Additional sources were announced in the reference list of each paper. Hence, the sample collection was followed in this stage. The papers found were reviewed, contrasted, and compared. The process of study is shown in Figure 2.

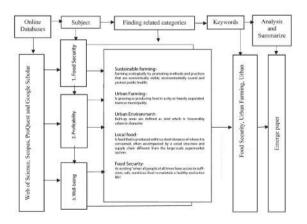


Figure 2. Research process

5. Discussion and Conclusion

Considering the ever-rising urbanization and increase of residents, designers and planner's universal have started to view towns as places for food production to meet public and ecological demands. Town zones requires the most serious efforts but at the same point have the advantage of merging local food making facilities in planning. It is mostly because of the high focus of customers and huge amounts of the sparse residents with limited gain access to farm areas and fresh food. The limitation of nature resources led to the execution of accuracy cultivation. In this system, just the needs of the farm are supplied. Therefore, it can reduce on wastewater, nutrients, natural light, energy, and the damage of products is stayed to a bare lowest too. There are other essential features of urban agriculture than just regional products. How it gets it path in the economic and social. In urban agriculture, urban supplies are employed with the workforces, organic waste material, land, and water. So, each the input it requires is urban and is observed by city laws and policies, conditions, the goal market, and land competition. It is affected by other factors as the cost, decreased life conditions, impacts of food security, health issues and the ecological conditions [25]. Urban agriculture can deal with the unstable production of food in towns that is still expanding alongside with the transformation of residential high population or poverty in developing regions. Finally, the structure that have been proposed could boost the overall value of the town landscape and inspire rules modified to the weather change. Farming performs an important position in the cities. It affects many of lands of jungles to be ploughed which would set a stop to many lands. It seems that the idea of an urban farm in the town regions could solve many actual problems linked to production of food and degradation of environmental [26]. Urban farming is a valid indicator of cities ecosystem. It implements an integrating approach. It does not transform environment to suited in with social demands. It can utilize several areas by getting them appropriate for cultivation. Urban farming is a transforming point of the millennium in urban planning but not bounded to that [27]. In faraway towns that are extremely dense, aids to increase production and reduce effect of farming. The main feature of urban farming is close connection to the ecological, economic, social, and state of towns. The notion necessitates the creation of a diversity of plants in inhabited areas, that hold the world-wide residents far away from the country. Since the goods are traded in the local marketplace in the same location they are cultivated, there is minimal need for transportation that is engaged in the traditional methods of agriculture. Therefore, no crop would damage by climate happening like hurricanes, floods, droughts etc. Thus, what urban farming delivers for a town ecosystem helps citizens to live there for a secure and healthful ecosystem, safe drinking water, safe use of public water waste, cleaner air, new occupation opportunities, and fewer empty lots and construction. Not only make urban farms play as hospitals for food stuff but they similarly act environmentally to the town which deeply needs innovations in structures such as the management of hydrological facilities and waste, water management method.

6. Conclusions

The concept of urban farming is not new, however more research is required in the field of "going green architecture" as these phenomena is of global importance in the existing trends of climate change and inevitable development. There are several laboratories which are doing research on urban farming, but in the case of research is needed to gain public help for the landscape. Urban farming could be energy efficient and cost-effective and way to help and solve some of human health issues and urban environmental and food product with no concern of dead end. World is facing environmental problems, but the technologies of green landscapes are brand new for whole world equally. The bigger industrial towns should be the trend-setters in approval of urban farming construction. The developing countries have more capacity to adopt it as they are suffering from the effects of food shortage and global warming at higher ratio. To evaluate the logic and form of government support for urban farming in Malaysia, the following strategic framework should be followed: Creating national action plans and policies to have an integrated change of landscapes. Projects should be announced and should be awarded on competition basis to boost the public awareness and involvement. Removal of current barriers in constructing and zoning codes. A sustainable method to develop urban farming technology can possibly address multiple human health problem and environmental problems in cities including the urban heat island effect, global climate change, and food security and storm water runoff.

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ARTICLE

Tensegrities and Tensioned Structures

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ABSTRACT

"Push-and-pull" efficient structures have been inconceivable between XVIII centuries. It is because of the incapacity of obtain an efficient behaviour of tensioned material. Since XVIII centuries, architecture developed some structural knowledge generating novel structural forms in the architecture and engineering that were not known before. Tensegrities and tensioned structures were studied due to the knowledge of geometry and tension. Some investigations about tensegrities and tensioned structures have been developed since that moment. Tensegrities are bar and cable structures that work only in compression or tension efforts. Bars and cables are balanced, but in appearance the growth is disorderly. Most of deployable structures are based on tensegrity systems. The research is focused in presenting a summary of tensegrities and tensioned architectures that have been used in the structural design of novel patterns. The research of adequate materials to tension efforts will be crucial in this study. The investigation presents an important state of the art that provides technical solutions to apply on novel architectures based on tensegrities and tensioned structures. The research is useful to produce the current constructive solutions based on these constructive systems.

1. Introduction

he research is focused in presenting a summary of tensegrities and tensioned architectures that have been used in the structural design of novel patterns. The research of adequate materials to tension efforts will be crucial in this study.

The goal is to know any current tensegrities and tensioned architectures to know this configuration and the advantages and disadvantages of them. It is collected for the knowledge of tensegrities and tensioned structures to the artists, architects, engineers and all type of people. Relations with architecture and arts will be shown to generate the lines of work of this type of structures.

Some examples of researches of this type of structures

are Shookhov, Passera, Manterola, Kenneth D. Snelson, Philip Powell and Hidalgo Moya, Francis, Nowicki, Frei Otto, Jörg Schlaich, Geiger, Motro, A.M. Watt, Levy and Weidlinger Associates, Y. Kono, Buckminster Fuller, Pugh, Kenner, Robert Burkhardt, D. Williamson, Ariel Hanaor, Nestorovic, Connelly, Back, S. Pellegrino, A.G. Tibert, W.O. Williams, R.E. Skelton, David Georges Emmerich, M. Pedretti.

Solutions for the creation of tensegrities and tensioned structures will be looked for. These solutions are characterized by their elements, which are only compressed and tensioned. These structures are not based on thrust and weight strategies. Tensegrities are focused on tensioned and equilibrate configurations. External forces as gravity

*Corresponding Author: Ma Dolores Álvarez Elipe, CEIPSO Salvador Dalí, Spain; Email: mdolores 500@hotmail.com or weight not influence this type of structures.

The research is supported by geometrical and mathematical basic criteria. The questions of form are in the first topic geometric and mathematic questions. The growth questions are physic problems, because the matter reflects physic principles. Therefore, the apparition of ordered designs is a result of physicochemical processes, and as many of the principles that govern these processes are expressed in mathematical expressions, then, in the final study, the underlying mechanisms which explain the appearance of developments are based on maths.

2. Evolution of Tensegrities and Tensioned Structures

The evolution of tensegrities and tensioned constructions will be studied to generate a synthesis of the novelties than have been developed in this area. All of this is possible because of the study of some authors and some existing patents.

"Push-and-pull" efficient structures have been inconceivable between XVIII centuries. It is because of the incapacity of obtain an efficient behaviour of tensioned material. Edmonson [1] in 1987 states that until that time only the tensile strength of wood had been exploited (mainly in the construction of ships). But its tension was not comparable with the compression of the stone masonry.

But in 1851 the massive steel generation modified this criteria a lot. Steel could achieve strengths similar to masonry stone, both in compression and in tension, leading to a lot of novel situations. Edmonson [1] said that a new time of tension design was opened with the construction of the Brooklyn Bridge. According to Edmonson [1] Fuller said: "Tension is something very novel".

The development of steels and other alloys led to unpredictable results in terms of strength, weight and material performance. This allowed architects and engineers to develop novel structural designs. These novel materials decrease the cross section of the materials and, consequently, their weight. They also served to increase the strength of the elements.

But the behaviour of components when they are loaded is different depending of the type of the load. When a lineal element is compressed along this principal axe it generally increases its cross section (by Poisson ratio effect). This element also warps, losing its straight shape. In the other hand, the component tends to thin and it also "firms" its straight axis, if it is tensioned in its principal axe. By this reason, the innovation in materials is essential to the future of pre-stressed structures, in which their tensioned elements must resist better the tensile efforts.

Some constructions were designed to take advantage of the latest studies and adopt their most useful characteristics, specially their tension resistance. As Tibert said ^[2], the first wire roof structures were developed in 1896 by the Russian engineer V. G. Shookhov. He constructed four suspended ceilings pavilions in the Nizjny-Novgorod exposition (Russia). Along the 1930 decade many other designs were proved after this first attempt, but they did not suppose relevant examples.

Aside from suspension bridges, a few other patterns of bridges raised the value of stress to the same importance that compression had had in previous centuries. For example the cable-stayed bridges were used in the tensioned wires that maintain the cover in compression. By this way, the cover is pre-tensioned and put in equilibrium. A great example is the bridge of the Barrios of Luna in Asturias (Spain), of Javier Manterola, that works in its two towers and in the principal section of 440 m this principle.

The South Bank Exhibition Festival in Britain was in London three years after the discovery of the tensegrity, in 1951. With the festival, a concourse was organized to build a "Vertical Feature", a basic element in international expositions. Philip Powell and Hidalgo Moya (inspired and helped by their trainer Felix Samuely) developed the Skylon that was chosen like the winning project and was erected close to the Discovery Dome.

Many authors like Burstow^[3] and Cruickshank^[4] claim that this vertical construction was a sculpture without functional proposes. However, this needle was converted in the attractive of the festival. It was a beacon of social and technological potential and a reference to future engineers and architects. The needle of 300 foots of higher was a body coated of aluminium shaped like a cigar suspended by just three almost invisible cables. It seems float up 40 foots upon the floor. The structure was constructed with a series of pre-stressed steel cables and three lowered poles.

As Moya said, "By an amazing stroke of genius (Felix Samuely) organized a hydraulic jacks system under the three smaller needles. When all the construction was assembled, he pumped these hydraulic jacks and raised the pylons. This one put tensions or tractions in all cables and did that all became a stressed structure. It reduced the number of necessary wires to anchor the Skylon and it halved the amount of oscillation in the structure. This lack of support made the structure look tremendously dangerous. It seems not have enough cables to hold it, which became enormously exciting" [4]. The cause of the sensation of not having enough cables to hold the element in the same form that a dirigible was because of the stable equilibrium obtain by this special configuration.

Francis [5] presented a diagram that explains the stability condition of a post sustained by tensioned wires. When one cable is joined to the floor, the point in which the other cable be kept will influence the equilibrium of the strut. If it is fixed in a point under the level of the strut, it will collapse. If it does it at the same level, the pole is in an unstable balance (any displacement will cause it to fall). Conversely, if it is held at a point above ground level, the set is in stable equilibrium. In other words, when there is any movement to this situation, it tends to return to the vertical position. The diagram of the Skylon is similar. In fact, the conditioning factors for the balance of a strut in a three-dimensional structure influence the place of application of the ends of the cables that fix it.

In 1950 years, the use of wires in tension was perfected, but also that of other parts such as materials, membranes and fabrics. In 1950, the State Fair Arena, in Raleigh (North Carolina) was design by Matthew Nowicki following its basic ideas of suspended ceilings. That same year, a German architecture student had a brief look at the drawings and plans during an exchange trip to the US, and he was completely fascinated by the novel idea. As a result, he started a systematic research that was defended as his doctoral thesis in 1952. His name was Frei Otto and it was the first complete documentation about suspended ceilings ^[2,6].

The Development Centre for Light Construction was founded by him five years later in Berlin and, in 1964; it was included in the Light Surface Structures Institute at the University of Stuttgart, to further increase research in tensioned architecture. Therefore, some important works that exploit the tension characteristics of the materials (principally steel, but also polyurethane, PVC, fibreglass, cotton-polyester blend, polyester, acrylic panels...) were developed. Within these works was a four-prop tent such as the Bundesgartenschau Music Pavilion, Kassel (Germany) in 1955, the first large cloth-covered wire mesh, the German pavilion at the 1967 Montreal World's Fair and the known 1972 Munich Olympic Stadium, the structure of which was calculated by Jörg Schlaich.

For example, Pugh in 1976 [7] built a dome done with wood struts and plastic skin. The plastic skin was the component in tension that supports the compressed elements of the structure.

W. O. Williams [8] said that the term "tensegrity" was being used to some type of pin-connected construction in which some of the strut components are tensioned cables or compression-only bars. The "Cable domes" or the "Bicycle wheel domes", designed by David Geiger [9], are examples of this type of structures. Since this moment, some domes have been erected with this principle. They have a group of radial tensegrity girders attached by an outer ring in com-

pression, and converge to an inner ring to fix all of them.

Although some engineers and architects include these cover constructions within the tensegrities, Motro [10] say that they are false tensegrities, as they have a compressed limb member. In fact, although Geiger did not point out directly to Buckminster Fuller, it must be remembered that Fuller in 1964 [11] patented an alike type of construction that was called later "Aspension" by him.

The first wire domes were design by Geiger to the Seúl Olympic Games (1986), followed by the Redbird Arena in Illinois, the first oval wire dome (1988), the Florida Suncoast Dome in Saint Petersburg (1988), and The Tayouan Arena in Taiwan (1993). In fact, the biggest dome in the world until today, that is a one of this family, is the Atlanta Georgia Dome (1992) of Levy and Weidlinger Associates.

It should be pointed out about the "tensegrity" definition, essential to consider any structures like real or false tensegrities. Gómez [12] in his thesis published in 2004 defined the tensegrities as a structural principle based on the use of isolated components under compression inside a continuous tension set. The members that work under compression (generally struts or bars) don't touch each other, and the tensioned members (usually cables or tendons) draw the spatial configuration.

According to Gómez [12], the inventors of the tensegrities have been three men: Richard Buckminster Fuller, David Georges Emmerich and Kenneth D. Snelson¹. Emmerich reported the first system of proto-tensegrity, said "Elemental equilibrium" o "Simplex", with three bars and nine cables. Fuller and K. D. Snelson, independently of David Georges Emmerich, studied different types of geometric models considered tensegrity structures.

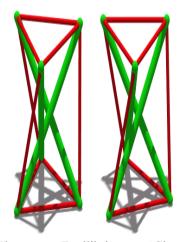


Figure 1. "Elementary Equilibrium" or "Simplex", David Georges Emmerich

¹ As note, they are mentioned chronologically according their conceived patents: Fuller-13 Nov 1962; Emmerich-28 Sep 1964; Snelson-16 Feb 1965.

The aesthetic and sculptural aspect is chosen by Snelson to focus his work. He did not want lot complications with physics and mathematics. He knew the difficulty applying tensegritical principles by his artistic background. This development facilitated him the development of a lot of diverse asymmetric and not typical configurations¹. The construction of tensegritical systems requires a slim and delicate technical that he has been improved during years, too. The actual process which Snelson erect his works is a science and an art by itself. Actually, as Fox established [13], he is the only people able to engineer these constructions.

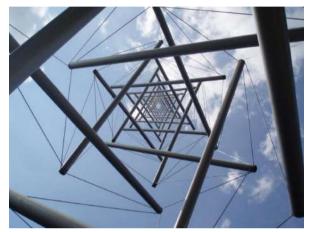


Figure 2. Needle Tower II in the Kröller-Müller Museum in Holland. Kenneth Snelson (1969)

With another perspective, Emmerich and Fuller chose alternative paths, investigating the alternative tensegrity typologies, specially one-dimensional and spherical types like needles. The principal work tools of them were the empiric experiments and the used models. They wanted the application in engineering and architecture in contrast with Snelson.

Right after, looking at the Snelson sculpture, the Massachusetts researcher investigated some simple developments and generated a classification for tensegritic needles, characterized by vertical surfaces of three, four, five and six sides respectively [14]. He developed the "six isolated bars icosahedron" (expanded octahedron)² too. Consequently, his investigation was studied by others developing types of tensegrity like the "balance vector" (cuboctahedron), the "tensegritical sphere of 30 isolated bars" (icosahedron), the "isolated six bar tetrahedron" (truncated tetrahedron) and the "octa-tensegrity of three isolated bars". Consequently, a hierarchy of the first tensegrity models was developed, and the principles of compression of the universal tensegrity structures were close.

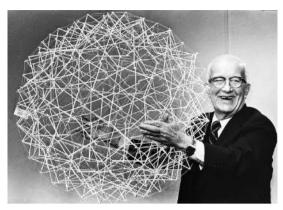


Figure 3. Buckminster Fuller holding a geodesic tensegrity sphere

Thus, Buckminster Fuller was investigating for novel developments, applications, and construction methodologies. He realized some proves of designing tensegrity geodesic domes (figure 3) (although since they were not triangulated they were not stable), and he patented³ many of his studies in relation with this area ^[15,16]. But the last enforcement of the tensegrities was not as satisfying as it was believed to be. He never produced the tensegrity dome that was able of coat a great city, as he had supposed. He also had to construct the Expo Montreal Bubble in 1967 like a geodesic dome, but without use tensegrity knowledge by budget and time causes.

From now on, many researches interested in the work of Fuller began to study his novel constructive system, trying to find some uses for engineering and architecture. In 1973, René Motro, for sure a very good expert in tensegrities actually, started to publish his research in this area: Topologie des structures discrètes. Incidence sur leur comportement mécanique. Autotendant icosaédrique [12]. It was an internal archive to the Civil Engineering Laboratory of the Montpellier University (France) about the mechanical behaviour of this type of structures. Henceforth, this laboratory and engineering became the reference in investigation on tensegrities.

Many years after, Pugh and Kenner (1976), both of the California University (Berkeley), continued their investigation by diverse paths. In one hand, Pugh wrote "An Introduction to Tensegrity" [7] that is important because of the diversity of types that it explains and its strict typology and classification. In the other hand, Kenner wrote "Geodesic Math and How to Use It" [17] that explains the calculus "for any degree of accuracy", the relevant aspects of the geometry of the geodesic and tensegritic structures (angles and lengths of the bar pattern) and investigates

¹ See web page of Kenneth Snelson (www.kennethsnelson.net)

² In quotation marks, denomination of Fuller

³ Casually, while Fuller was patenting his "geodesic domes" in 1954 (US 2,682,235), Emmerich patented the "stereometric domes" in 1967 (US 3,341,989).

their potential. Although this last research focuses more in geometry and mathematics, it doesn't focus in the loaded tensegrity behaviour.

Along 1980 years, many researches strove in developing the open investigation of their ancestors. Robert Burkhardt (figure 4) developed an exhaustive research and he corresponded with Fuller [18] to know more about the geometrical and mathematical principles of the tensegrities. The final goal 20 years after is a useful, complete and continuously reviewed "practical guide to tensegrity design" [19]. The researcher Ariel Hanaor [20] developed the principal two-dimensional sets of self-balancing elemental cells. Nestorovic [21] proposed a metallic dome of integrated tension. Recently, some works have been added to this field of knowledge.

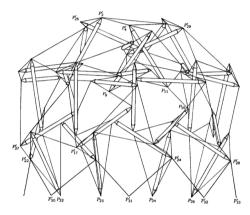


Figure 4. T-Octahedron Dome (lateral view), Burkhardt

Connelly and Back ^[22,23] have looked for finding an adequate generalized three-dimensional relationship for tensegrities. They have produced a detailed classification according to symmetry and stability typology rules of tensegrities, with many tensegrities that not had been seen before. They did it by the use of tools based on representation theory, mathematics of group theory and computer capacities.

Other authors (A.G. Tibert, S. Pellegrino, A.M. Watt, D. Williamson, W.O. Williams, R.E. Skelton, Passera, Y. Kono, M. Pedretti...) have also developed the physic, mathematics (since a geometric, topologic and algebraic point) and mechanisms of the tensegrity constructions. But apart from the mentioned authors, and Motro and his group in Montpellier, there are not a lot of investigations looking for the application of this novel knowledge to any area particularly.

Recently Peter Testa has developed the Carbon Tower (figure 5), first carbon fiber tower based on the concept of tensegrity: it is an interesting development with tensioned and compressed elements, but the concept of skein is applied in order to do more resistant the structure getting a

pre-compression.

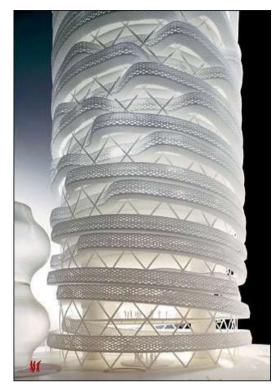


Figure 5. Carbon Tower, Testa

The Arena stadium (figure 6) also changes the structural concept, when putting a bicycle wheel frame as cover, in which the external edge is compressed, and the central ring and the radios are tensioned.

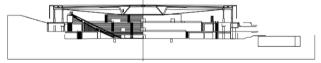


Figure 6. Madrid Arena stadium, Cano Lasso studio

Note: Roof structure design by Julio Martínez Calzón

In bar structures, apart from the forces, we have to pay attention to deformations: the solution of angular deformation that has the Berlin Bank of Ghery (figure 7) consist in a tensioned bar system.



Figure 7. DZ Bank, Pariser Platz, Berlin, Frank O Gehry

Landolf Rhode-Barbarigos, Nicolas Veuve, Nizar Bel Hadj Ali, René Motro and Ian F. C. Smith develop a tensegrity system of pedestrian bridge (figure 8), which deployment requires employing active cables to adjust simultaneously the degrees of freedom of the structure.

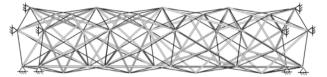


Figure 8. Boundary conditions of the limit of the tensegrity bridge, Landolf Rhode-Barbarigos, Nicolas Veuve, Nizar Bel Hadj Ali, René Motro and Ian F. C.

Josep Llorens, V. Gómez-Jauregui, C. Manchado y C. Otero, Paolo Beccarelli, Guglielmo Carra y Roberto Maffei, Carolina M. Stevenson Rodríguez, Ana Cocho-Bermejo, InA Sin and SeungDeog Kim are researches interested actually in tensegrity structures. All of them realize theoretical researches in an academic context.

3. Discussion

A tensegrity is a structural set in which three or more components are compressed by tensioned elements. Tensile components create space between compression components and it creates a triangulate pattern that maintains the forces in perfect equilibrium. This means that tensegrity not depends of thrust and weight strategies. Tensegrity depends of patterns with tensions in equilibrium. They are not based on external forces as a gravity and weight.

Tensegrity constructions are capable of generating a general behaviour like something global. All concrete loads are equally distributed and received for the global set. When the load is increased, its stiffness is increased too.

The principal structural property of the tensegrities is their lightweight when they are compared with designs of approximately the same resistance. They possess great carrying capacity in comparison with other designs of similar weight.

The tensegrities have self-balance. They do not require anchoring or fixing to conserve their geometry and shape. They have stability in all positions.

When the pre-stressing of a tensegrity configuration is higher, its resistant capacity and bearing capacity will be higher.

As the compression components are no continuous, they act locally. They also are resistant to torsion and buckling because of the small section of their elements.

The synergy is a property of the tensegrities. From the behaviour of their separate elements is not supposed the behaviour of the set.

The links and the materiality influence the rigidity of the design.

Natural principles influence the tensegrities designs. One example of this is the cell, which cytoskeleton has the same behaviour that wires and bars in tensegrities design. The cell receives stiffness and shape of the cytoskeleton, which balances the stresses.

To finish, it should be noted that some of the presented deployable constructions base their principles on tensegrity configurations.

4. Conclusion

A tensegrity is a wires and bars design that only generates forces of tension and compression. Equilibrium between wires and bars is produced. Apparently the design has a disordered growth.

The advantages and disadvantages of the tensegrity designs are:

Advantages:

- (1) There are no local weak points..
- (2) Materials can be used economically and cost-effectively.
- (3) Tensegrities usually have no buckling or torsion stresses.
- (4) It is possible to generate more complex sets by the assembly simpler systems.
- (5) For big-scale designs, the building process can be carried out without scaffolding. The construction works as a scaffold by itself.
- (6) To change the configuration in folding designs, very little energy is required.

Disadvantages:

- (1) The tensegrities have yet to solve the bar congestion problem. When the size grows, their components begin to interfere with each other.
- (2) Compared to traditional geometrically rigid designs a relatively low material efficiency and high degree of deformations are observed.
- (3) The complex manufacture of these structures is an impediment to their development.
- (4) To maintain the self-tensioning state, it is necessary to submit them to a pre-stressed state which would need big efforts for their stability, especially for those of big size.

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ARTICLE

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

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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 CO₂ 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-

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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 700°C. 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 Hierarhy 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 $^{\circ}$ C in an electric furnace. The ash obtained was left to cool before it was sieved through the 75 μ m sieve. The fraction passing through the sieve were used for the characterisation analysis and laboratory

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 (SiO₂₊Fe₂O₃₊Al₂O₃ \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.

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

2.3 Qualitative Surveys and Reuse Options Analvsis

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 in-

formation 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.

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

	Concentration (%)									
Oxides	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 ₂ O	1.50	0.76	3.97	2.53	0.58					
Fe ₂ O 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 ₂ O	-	-	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 SiO₂. 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.

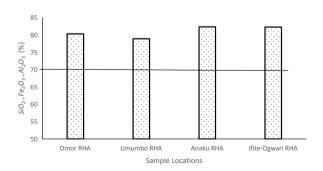


Figure 1. All Samples Significantly Pozzolanic

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.

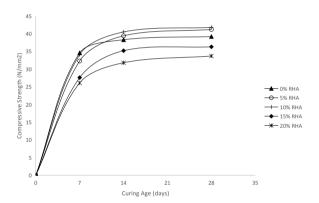


Figure 2. Effect of Rice Husk Ash (RHA) on the compressive strength of concrete

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/mm² compressive strength. This shows a strength gain above 80% of the target compressive strength of 30 N/mm². 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/mm² which is satisfactory above the design compressive strength. As the RHA was added, the 28th day compressive strength of the concrete increased to as much as 41.8 N/mm² for the concrete containing 10% RHA. Beyond the 10% replacement level, the compressive strength dropped to 36.3 N/mm² and 33.7 N/mm² for 15% and 20% replacement levels respectively. These values 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	Commu- nity Hygiene	Cost Sav- ings	Reduc- tion in Emis- sions	Trans- port Dis- tance	Nth root	Eigen- vector	Dot prod- uct	Division (x)
Commu- nity 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

Sustainability Factor	Pairwise Comparison	Cooking Fuel	Poultry Feed	Mud Stabilisa- tion	Road Construc- tion	Nth root	Eigenvector	Dot product	Division (x)		
Community Hy-	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		
giene	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		
		(onsistency	index = 0.026; Cri	tical Value = 0.9; C	onsistency	ratio = 0.028 < 0.1				
	Cooking Fuel	1	1/3	1/2	0.2	0.427	0.084	0.339	4.058		
6 . 6 .	Poultry Feed	3	1	2	1/3	1.189	0.233	0.942	4.047		
Cost Savings	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										
	Cooking Fuel	1	1/3	1/6	1/8	0.289	0.053	0.213	4.032		
Greenhouse gas	Poultry Feed	3	1	1/2	1/4	0.783	0.143	0.574	4.010		
emissions	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 = $0.029 < 0.1$									

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

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 Con- struction	0.594	0.545	0.518	0.055	0.047	0.520

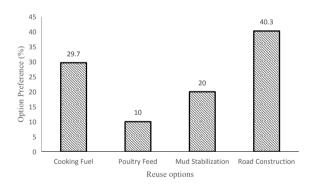


Figure 3. Best benefits from application of RHA in pavement concrete works

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 28th day compressive strength of the concrete to 41.8 N/mm² for the concrete containing 10% RHA. Beyond the 10% replacement level, the compressive strength dropped to 36.3 N/mm² and 33.7 N/mm² 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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ARTICLE

Construction Technology and Quality Control of Double Layer Continuous Paving of Cement Stabilized Macadam Base

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ABSTRACT

The construction method of continuous paving of the upper and lower base of the water stable macadam base can improve the construction efficiency, overcome the quality problems of the traditional layered paving of the upper and lower base, such as untimely curing, slow construction, poor interlayer bonding, contraction joint and interlayer, so as to ensure the construction quality of the water stable macadam. It is also the promotion and application of new technology.

1. Introduction

ouble layer continuous paving of cement stabilized macadam base is a new type of paving method. Under the condition of strict control of mixture and arrangement of construction organization, it is feasible to continuously pave the upper and lower base. On the premise of ensuring the quality, it not only speeds up the construction progress, but also improves the economic benefits.

2. Mixing of Mixture

The mixture shall be mixed in the mixing station. Before mixing the mixture formally, the cement stabilized soil mixer must be debugged to make the particle composition and moisture content of the mixture meet the specified requirements. The bin of the mixer shall be labeled and

numbered, and different aggregates shall correspond to the corresponding silo. Before loading, the aggregate in the bin shall be mixed to ensure the uniformity of aggregate. The test personnel must stay at the mixing station and calibrate the cement consumption regularly, that is, carry out the cement titration test and establish the account to control the cement consumption. The moisture content of the mixture shall be detected every 2 hours, and the moisture content shall be detected once an hour when the temperature is high, and timely adjust according to the test data [1].

3. Mixture Transportation

The mixture is transported to the site by dump truck from the mixing plant. In order to prevent the mixture from segregation, the front part shall be loaded first, then the rear part, and finally the middle part; in order to prevent moisture loss, tarpaulin must be covered during the trans-

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portation process, and the covering shall be "no outcrop at the front and no leakage at the rear". After the transport vehicles arrive at the site, it is strictly forbidden to uncover the tarpaulin in advance, that is to say, the whole process of the tarpaulin covering should be from loading and leaving the station, transportation to the end of paving. After arriving at the paving site, the transport vehicles should turn around at the opening. It is strictly forbidden to turn around on the paved water stable base to avoid the damage of the lower bearing layer. A special person shall be assigned to direct the dump truck to unload materials. The dump truck shall not impact the paver. When the distance between the dump truck and the paver is 10-30cm, the dump truck shall stop and shift to the neutral gear to let the paver take the initiative to meet the dump truck. The dump truck shall be pushed forward by the paver [2].

4. Formwork Support

The national standard channel steel (size: length × width \times height = 600cm \times 7cm \times 18cm) with the same thickness as the base course is used as the side formwork at the middle line of the lower base course, and the channel steel is reinforced and supported: one triangular support is set per meter, and the steel drill rod (diameter: 25mm) is used to fix the channel steel end. The joint of channel steel end is supported by inclined ground anchor, and each adjacent joint is welded with a sleeve. After alignment, the end reinforcement of inclined ground anchor is embedded After entering, the formwork shall be inlaid tightly to ensure that the formwork joint is flat, the position is stable, and the alignment is straight and smooth, so as to avoid the influence on the longitudinal joint caused by the edge rolling due to the instability of channel steel, and special personnel shall be arranged to check the stability of the support steel drill rod. Considering the longitudinal joints, the channel steel in the middle of the lower base course shall be offset by 25cm from the middle pile position for fixing, so that the upper and lower base layers form a step shape. Shoulder soil is used as retaining structure at the edge [3].

The national standard channel steel (size: length \times width \times height = $600 \, \mathrm{cm} \times 7 \, \mathrm{cm} \times 18 \, \mathrm{cm}$) with the same thickness as the base course is used as the side formwork at the middle line of the upper base course, and the channel steel is reinforced with the same support method as the lower base course. Considering the longitudinal joints, the inner side of the channel steel is fixed along the middle pile position during the installation of the middle channel steel of the upper base course, that is, the lower base course is 25 cm wider than the upper base course, forming a step shape.

The edge of the upper base course adopts the square timber with the same thickness as the base course (size: length \times width \times height = 300cm \times 20cm \times 18cm) as the side formwork, and strengthen the support for the square timber: each two square timber is fixed with a steel drill rod (diameter of 25mm) at 40cm from the joint position to ensure that the square wood joint is flat, the position is stable, and the alignment is straight and smooth, so as to avoid the side rolling compaction caused by the channel steel instability and affect the longitudinal joint Arrange special personnel to check the stability of supporting steel drill rod. In consideration of the shift of square timber and formwork during the rolling process of the roller, and the convenience and reduction of workload in the later construction and installation of curbstone, the distance between the inner side of square timber and the inner side of channel steel is determined as 5.15 M. After rolling, the width of upper base is 5.2m, which achieves the expected effect.

5. Spreading of Mixture

5.1 Determine the Appropriate Paving Section

According to the mixing, transportation, paving and rolling time of mixture (the length of each rolling area is about 50m, the paving time of each section is about 30 minutes, the rolling time of each section is about 30 minutes, and the paving and rolling time of 100-200m water stable mixture is about 120-180 minutes), and the initial setting time of cement in the mixture is 3-4 hours, the final determination is that the lower base course is paved after 100-200m, When the upper base has enough working surface, the upper base course shall be paved [4].

5.2 Paving Control Points

Before the paver runs, the elevation and cross slope of the screed shall be adjusted, and the sensor shall be placed on the fixed wire line. Then, the paver's feeding bearing shall be fully rotated to feed, and the screed shall walk when the blanking is fully saturated. Note that after the hopper of the paver is close to the chute of the unloading truck, command the dump truck to lift the truck and lift the chute for unloading. Do not lift it all at once, but gradually lift it with the paver moving forward to prevent the lifting too fast.

Special personnel shall be assigned to monitor the sensors on both sides of the paver to prevent the sensor from breaking away from the reference line during the operation of the paver, which may lead to the control failure of the paving thickness, flatness, cross slope and other indi-

cators. Secondly, the computer indicator light of the paver shall be controlled so as not to make the sensor and other paving performance lose their functions. If problems are found, timely report and stop the machine for inspection immediately, so as to avoid damage to the paving quality of the base course.

In order to prevent the mixture from falling to the ground from both sides of the hopper of the paver and entering into the paver track, thus affecting the construction smoothness, special personnel must be arranged on site to remove the dropped mixture in time to prevent it from entering under the paver track.

During the paving process, a special person shall be assigned to monitor the paving thickness and cross slope at any time, and two persons shall be set behind the paver to deal with segregation and pits, so as to eliminate the segregation of coarse and fine aggregate and local unevenness in time. During the layered construction of cement stabilized macadam base, when paving the upper base course, the lower base course shall be spread with cement paste

6. Epilogue

Due to the cement and other cementing materials contained in the water stability, the whole construction process should be completed before the final setting of cement, and the quality standard should be met at one time,

otherwise it is not easy to repair. Therefore, it is necessary to determine the length of the construction section, speed up the construction progress, and select the appropriate construction machinery to ensure that the upper and lower layers form a whole. The construction method of double layer continuous paving is also in line with the development direction of modern large-scale mechanization. Therefore, the application of double layer continuous paving in pavement engineering should be popularized and developed.

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