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COMPARATIVE ANALYSIS OF THE STRENGTH OF CONCRETE MADE FROM SELECTED ADMIXTURES FOR USE IN RIGID PAVEMENTS

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Abstract. This study evaluates the influence of sawdust ash, glass powder and rice husk ash as admixtures for partially replacing fine aggregate in concrete for rigid pavement applications. Compressive strength tests were conducted at 5%, 10%, 15%, and 20% replacement levels. Rice husk ash achieved the highest compressive strength of 10.40 N/mm^2 at 10% replacement after 28 days, closest to the control. However, sawdust ash and glass powder exhibited reduced strengths as replacement levels increased. The maximum compressive strength obtained did not meet the required target for rigid pavement applications.

Keywords: *Fine aggregates, compressive strength, rice husk ash, control, sawdust ash, glass powder*

Rezumat. Prezentul studiu evaluează influența cenușii de rumeguș, a pulberii de sticlă și a cenușii de coajă de orez, folosite ca aditivi pentru înlocuirea parțială a agregatelor fine din beton pentru aplicații de pavaj rigid. Testele de rezistență la compresiune au fost efectuate la niveluri de înlocuire de 5%, 10%, 15% și 20%. Cenușa de coajă de orez a atins cea mai mare rezistență la compresiune de 10,40 N/mm^2 la 10% înlocuire după 28 de zile, cel mai aproape de martor. Cu toate acestea, cenușa de rumeguș și pulberea de sticlă au prezentat rezistențe reduse pe măsură ce nivelurile de înlocuire au crescut. Rezistența maximă la compresiune obținută nu a îndeplinit obiectivul solicitat pentru aplicațiile de pavaj rigid.

Cuvinte cheie: *agregate fine, rezistență la compresiune, cenușă de coajă de orez, control, cenușă de rumeguș, pulbere de sticlă.*

1. Introduction

Transport infrastructure in any economy serves as a foundation to ensure the continuous, smooth movement of people and goods as input and output from all economic sectors. With road transportation, travelling is flexible. It is also possible to provide door to door services by road transport. Transportation by road is the only mode of transportation that provides maximum service to all.

Layering roads with pavement makes them durable, solid and strong enough to withstand the forces of nature and vehicle loads. Several ancient paved roads have been able to withstand the test of time due to their high durability. An example is the Via Appia in Rome which was paved with large stones [1]. Low cost roads such as Macadam and Telford emerged because of the unused stones. In the 18^{th} century, adhesive compounds were applied to roadways to increase their cohesiveness and longevity [2].

A highway/road pavement is a system of treated materials laid one on top of the other through which the traffic load is transmitted to the subgrade [3]. Road pavements contribute to making highway transportation possible and they are categorized into two groups namely asphaltic concrete (flexible) pavements and cement concrete (rigid) pavements.

Rigid pavement is a type of pavement with materials of high stiffness compared to flexible pavement. It functions like an unyielding flat strip by transmitting vehicle loads to the layers beneath by flexure [4]. It is also composed of coarse and fine aggregates, water, Portland cement and commonly reinforced with mesh or steel rod. It is commonly employed in building airports and major highways.

To mitigate early road failure, rigid pavement has been contrived to increase road durability [5]. Rigid pavements provide many advantages in the distant future. Cost-wise, they are oftentimes the most favorable alternative to flexible pavements when life cycle costs are considered. This is because rigid pavement seldom needs regular repair and, when correctly planned, constructed and made using sturdy materials and techniques, causes less disturbance to other road users. Local roads, streets, highways, airport runways, parking lots, industrial buildings and other sorts of infrastructure have all been constructed with rigid pavements. After decades of building and utilizing rigid pavements, it is evident that the environment is more sustainably affected by their longer service life when compared to flexible pavements (asphalt-paved).

Additionally, concrete surfaces reflect more light back from their surface, which enhances nighttime visibility and requires less lighting on the road [6]. The qualities of the concrete used to cast the pavement slabs, as well as the underlying subgrade and base course, determine how the slabs respond to environmental factors and loads. One of the materials that aids in accelerating the curing of concrete cast are admixtures. Hence, this research will compare and analyze the strength of concrete made from selected admixtures for use in rigid pavements.

2. Literature Review

Based on technological, financial, and environmental factors, industrial wastes have been investigated for use in road construction worldwide. This approach is particularly crucial for Nigeria, known for its favorable environment for manufacturing, importing glass materials and engaging in rice production and processing. Sadly, there are environmental problems as a result of Nigerian cities' poor solid waste management system. The increasing rate at which solid waste is generated surpasses the capabilities of the government, resulting in a grave environmental emergency. But by creating and efficiently applying these waste resources in the building of highways, this situation might be lessened [7].

Natural sand, predominantly sourced from riverbeds, traditionally serves as a primary fine aggregate for concrete. However, rampant, non-scientific mining practices in riverbeds have led to the scarcity of river sand. Issues like lowered water tables and compromised bridge piers have become common threats [8]. A growing number of scientists and engineers are investigating novel materials that rely on renewable resources in response to growing worries about resource depletion and global pollution. This entails using waste materials and byproducts in building. Many of these byproducts are used as aggregates in the manufacturing of lightweight concrete [9].

The escalating cost and scarcity of river sand, a vital component in conventional concrete production, necessitate the identification of alternative materials from waste sources. Global research is increasingly exploring the utilization of industrial or agricultural wastes as raw materials for the construction industry. This approach not only offers economic benefits but also contributes to creating a sustainable and environmentally friendly environment. The world currently faces challenges related to the depletion of natural resources for building and construction, making the exploration of alternative materials imperative for present and future sustainability [10].

When planning the building of any structure, structural engineers must take compressive strength into account. The compressive strength of concrete can be influenced by various elements, including the shape, compaction level, aggregate size and water-cement ratio. Achieving the right aggregate gradation is essential for mixing concrete. Poor gradation can cause problems such as internal bleeding, excessive water use, higher cement consumption, mortar segregation from coarse materials and the need for chemical admixtures to restore workability.

Depending on the precise amount utilized, coarse particles usually make up between 50 and 60 percent of the concrete mix. Studies indicate that a greater proportion of coarse particles in the mixture considerably enhances the strength of the concrete [11]. As a composite material, concrete is made up of particles joined by liquid cement that solidifies over time. It finds extensive use in civil engineering construction for creating resilient and enduring structures [11]. Compressive strength is the significant property of concrete which depends on the properties and qualities of the ingredient used to produce it [12].

The workability of fresh concrete and the compressive strength of hardened concrete are influenced by the size and gradation of the aggregate. As aggregate size increases, concrete composed of uniform-sized aggregates becomes less workable and so does the compressive strength of concrete composed of uniform-sized aggregates. When compared to concrete made from uniform size aggregates, the compressive strength of concrete used for rigid pavements is not increased when aggregates are blended utilizing the Cement Treated Aggregate Gradation process [11].

Concrete Admixtures. Admixtures are essential components in the production of concrete, added in small quantities during mixing to enhance specific properties of the concrete. Unlike additives, which are introduced to the cement during its grinding stage at the factory, admixtures play a crucial role in modifying the concrete's characteristics. In the past, there was skepticism surrounding the use of admixtures, stemming from the mistaken belief that they could only improve one aspect of concrete while compromising another. However, advancements in admixture science have revolutionized concrete technology, enabling enhancements across various properties of the material. This progress has led to a remarkable diversity in concrete production and application.

Today, the construction of skyscrapers and lengthy bridges relies heavily on high-strength concrete while achieving improved workability and reducing labor demands through the incorporation of plasticizers. Additionally, the widespread adoption of pumping concrete, alongside the utilization of transit mixers and central batching plants, exemplifies the significant benefits derived from admixtures. Consequently, the study of admixtures has become an integral component of contemporary concrete technology, facilitating the evolution and advancement of construction practices [13].

Any substance added to concrete - other than cement, water, and aggregates - either right before or during the mixing process is referred to as an admixture. Admixtures are essential for improving workability, hardening, and strength among other properties of concrete. The overall cost of concrete production is usually reduced as a result of their integration. Additionally, it has been successfully demonstrated that various types of cement in concrete mixtures can be partially replaced with agricultural by-products like cassava starch, rice husk ash, rice straw ash and wood waste ash. This reduces waste while simultaneously enhancing the strength properties of the concrete. It is noteworthy, however, that over time, the strength of these concrete mixtures may decrease due to microbial activity. Nonetheless, the utilization of such materials represents a sustainable approach to concrete production, aligning with efforts to minimize waste and enhance the performance of construction materials [14].

The role of admixtures in concrete mixtures is of paramount importance, as they contribute significantly to enhancing various aspects of concrete performance. Through mechanisms such as water/cement (w/c) reduction, hydrophobic effects, pore reduction/blocking and increased density, admixtures play a pivotal role in elevating both the compressive strength and durability of concrete. By mitigating water content and altering the microstructure of the concrete mixture, admixtures effectively enhance its overall resilience and longevity. Consequently, their utilization has witnessed a remarkable surge in the construction industry, reflecting their indispensable contribution to modern construction practices. As the demand for durable and high-performance concrete continues to increase, the application of admixtures emerges as an indispensable strategy to meet and exceed stringent performance requirements in various construction projects [15].

Presently, concrete is the most widely used building material. Its popularity is ascribed to concrete's exceptional compressive strength, elasticity and adaptability. Its load tensile strength has been further enhanced by the development of pre-stressing and reinforcing procedures which has cemented its position as the most common building material of our day. However, in contemporary times, the escalating cost of cement poses a challenge, amplified by the substantial waste generated from rapid construction and industrial growth. This waste not only pollutes the environment but also poses risks to living beings. To address these issues, the generated waste can be repurposed as alternative materials, offering a potential solution to the challenges posed by expensive cement and environmental hazards [16].

The global consideration of industrial wastes for road construction has led to this research focusing on partially replacing the constituents of the fine aggregates with specific percentages of various admixtures that would-be used to investigate the strength of the concrete with these different fine aggregates and how they can be applied for the production of concrete and their use in rigid pavements.

3. Materials and Methods

The materials utilized in the study were water, glass powder, sawdust ash, rice husk ash, coarse aggregates (in the form of gravel), ordinary Portland cement (OPC) and fine aggregates in the form of river sand.

The following tests were performed on the materials: tests for the cement's setting time, soundness, and fineness; tests for the fine aggregates' bulk density, silt, and clay content; tests for the coarse aggregate's density, specific gravity, aggregate impact value (AIV), and aggregate crushing value (ACV); tests for the admixtures' natural moisture content and specific gravity.

Fresh concrete samples were subjected to the slump and compaction factor tests to ascertain their consistency and workability, while the hardened or cured concrete (formed into 150×150×150 mm cubes) was subjected to the cube crushing test in a compression testing machine to ascertain its compressive strengths.

4. Results and Discussion

4.1 Compaction factor

The required compaction for rigid pavements ranges from 0.71 – 0.91 [17]. The graph in Figure 1 compares the compaction factors of the concrete cubes made with sawdust, rice husk ash and glass powder replacements at 0 % (control), 5 %, 10 %, 15 % and 20 %. For saw dust ash, the control concrete with 0 % replacement exhibited a compaction factor of 0.966. The compaction factor increased slightly at 5 % replacement to 0.989 and reduced to 0.977 at 15 % and 20 % replacement.

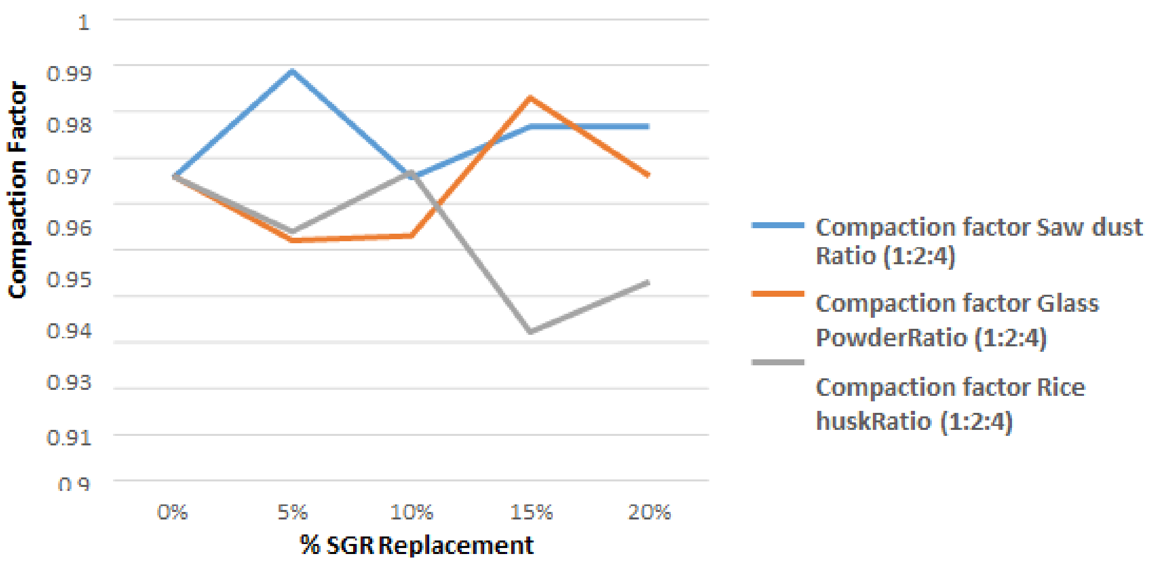


Figure 1. Compaction factor for saw dust ash, glass powder and rice husk ash.

For glass powder, the compaction factor reduces as the replacement level increases. The compaction factor decreased from 0.966 at control and fell within a range of 0.952 to 0.953 at 5 % and 10% replacements respectively. The compaction factor of saw dust got to the peak at 15 % replacement with compaction value of 0.983 after which it decreased to 0.966 at 20 % replacement.

The lowest compaction factor was 0.932 at 15 % replacement of rice husk ash. Overall, the compaction factors of the concrete cubes made with saw dust ash, glass powder and rice husk ash replacements range from 0.932 to 0.989. For rigid pavement applications, the compaction values obtained exceed the required compaction for rigid pavements which ranges from 0.71 – 0.91.

4.2 Slump Test

The results of the slump test on freshly mixed concrete samples depending on the proportion of sharp sand replaced with sawdust ash, glass powder and rice husk for a 1:2:4 mix ratio are displayed in Tables 1, 2, and 3. The control cubes with 0% replacement had a slump of 64 mm. This value falls within the S2 slump class and has a medium degree of workability. At 5 % replacement level, saw dust ash, glass powder and rice husk ash had slump levels of 74 mm, 64 mm and 71 mm respectively. These values also fell under the S2 slump class. At 10 % replacement, the saw dust ash, glass powder and rice husk ash had slump values of 71 mm, 74 mm and 67 mm respectively which are all within the S2 range. The slumps at 15 % replacement were 75 mm, 66mm and 69mm for saw dust ash, glass powder and rice husk ash respectively. At this point, there was also a medium degree of workability. The slump values at 20 % replacement for saw dust ash, glass powder and rice husk ash were 71 mm, 61 mm and 69 mm respectively. Although these values fall within the S2 slump class with a medium degree of workability suitable for use in hard placed pavements, the degree of workability in glass powder was lowest amongst the three admixtures. All things considered, rice husk and saw dust ash were able to retain their workability up to 20 % replacement level. As the amount of replacement increased, glass powder's workability decreased.

The target slump value for rigid pavement is about 50 mm and below as the workability of concrete is normally very low due to operation requirements [17]. This implies that the degree of workability across all replacement levels for the selected admixtures exceeds the slump value required for rigid pavements.

Table 1

Slump value for saw dust ash replacement with mix ratio 1:2:4

% Saw Dust Ash	Slump (mm)	Slump Type	W-C Ratio
Control (0%)	64	TRUE	0.52
Saw Dust Ash 5%	74	TRUE	0.39
Saw Dust 10%	71	TRUE	0.42
Saw Dust 15%	75	TRUE	0.44
Saw Dust 20%	71	TRUE	0.47

Table 2

Slump value for glass powder replacement with mix ratio 1:2:4

% Glass Powder	Slump (mm)	Slump Type	W-C Ratio
Control (0%)	64	TRUE	0.52
Glass powder 5%	64	TRUE	0.58
Glass powder 10%	74	TRUE	0.62
Glass powder 15%	66	TRUE	0.65
Glass powder 20%	61	TRUE	0.69

Table 3

Slump value for rice husk replacement with mix ratio 1:2:4

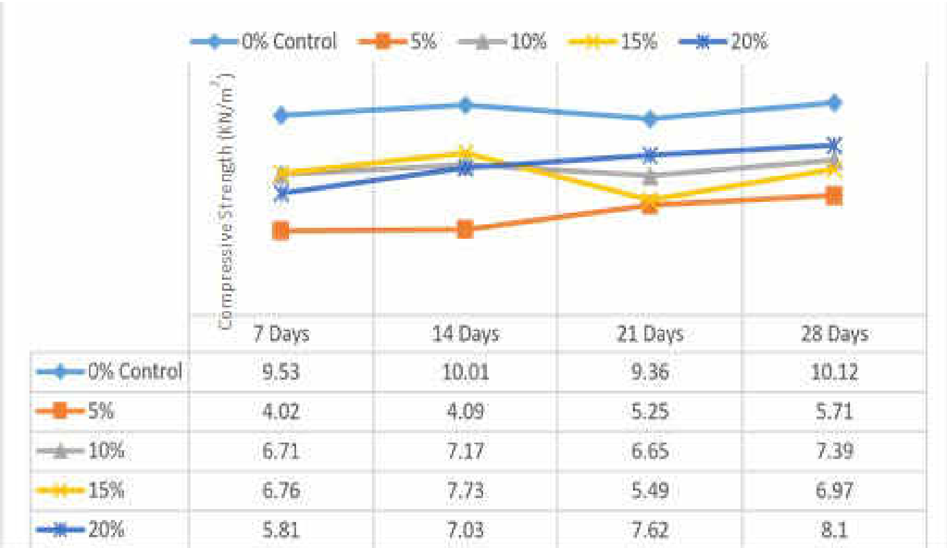
% Rice Husk	Slump (mm)	Slump Type	W-C Ratio
Control (0%)	61	TRUE	0.52
Rice husk 5%	71	TRUE	0.56
Rice husk 10%	67	TRUE	0.59
Rice husk 15%	69	TRUE	0.63
Rice husk 20%	69	TRUE	0.67

4.3 Compressive Strength Test

The results of the compressive strength test of the crushed concrete cubes containing sawdust ash, glass powder and rice husk ash are shown in Figures 2, 3, and 4, respectively. The test results were used to make subsequent deductions.

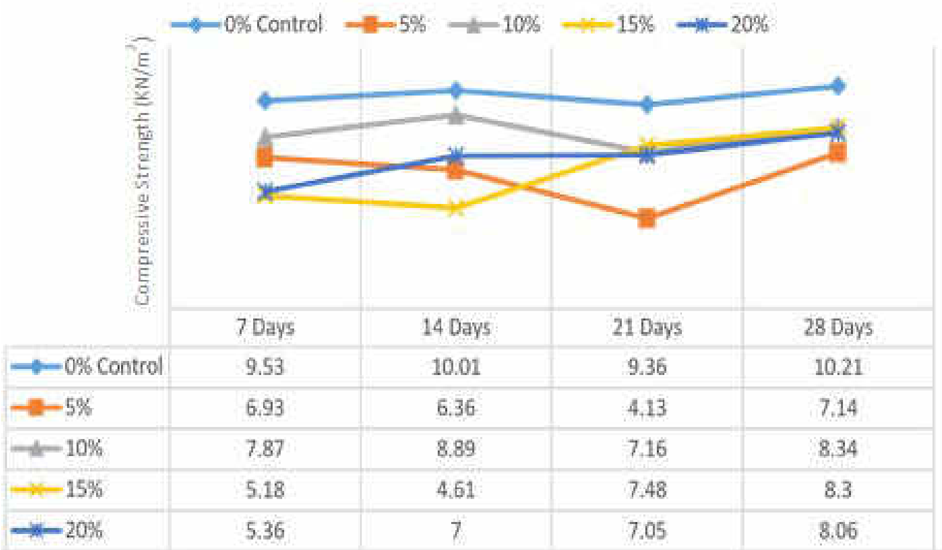
At 28 days, the concrete cubes for saw dust ash, glass powder and rice husk ash achieved a strength of 10.12 N/mm^2. This value was used as the benchmark for comparison in this research. At 20 % replacement, the compressive strength of concrete cubes of saw dust ash was 8.10 N/mm^2 which is 80 % of the control strength. For glass powder, the compressive strength obtained was 8.06 N/mm^2 at 20 % replacement putting it at 79 % of the control strength. Concrete cubes containing rice husk ash attained a compressive strength of 10.40 N/mm^2 at 10 % replacement. This is the closest to the control at 95 %.

Comparing the replacement levels to the control, the compressive strength results indicate that substituting sharp sand with sawdust ash and glass powder up to 20 % reduces the compressive strength as replacement levels rise.



	7 Days	14 Days	21 Days	28 Days
0% Control	9.53	10.01	9.36	10.12
5%	4.02	4.09	5.25	5.71
10%	6.71	7.17	6.65	7.39
15%	6.76	7.73	5.49	6.97
20%	5.81	7.03	7.62	8.1

Figure 2. Compressive strength for % replacement with saw dust ash.

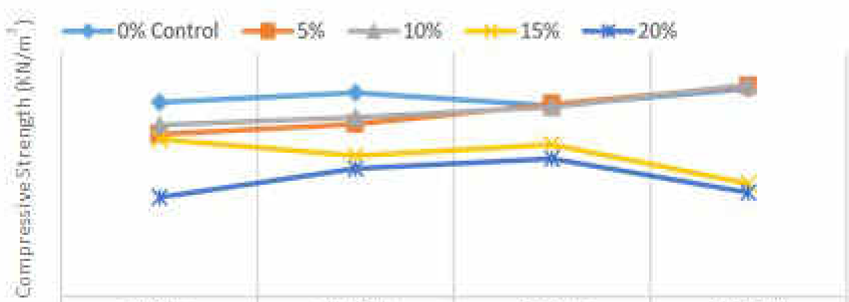


	7 Days	14 Days	21 Days	28 Days
0% Control	9.53	10.01	9.36	10.21
5%	6.93	6.36	4.13	7.14
10%	7.87	8.89	7.16	8.34
15%	5.18	4.61	7.48	8.3
20%	5.36	7	7.05	8.06

Figure 3. Compressive strength for % replacement with glass powder.

The lower specific gravities of the admixtures in comparison to the sharp sand may be the cause of the lower strengths as compared to the control.

Ultimately, rice husk ash seems to be the most promising of the three admixtures chosen, having achieved the strongest result that was closest to the control. After 28 days, rice husk ash reached the maximum compressive strength of 10.40 N/mm^2 at 10 % replacement. All things considered, the obtained compressive strength values do not meet the minimum strength requirements for concrete used in rigid pavements. Road pavements typically have a compressive strength of 20 to 40 N/mm^2.



	7 Days	14 Days	21 Days	28 Days
0% Control	9.53	10.01	9.36	10.21
5%	7.96	8.46	9.44	10.33
10%	8.42	8.79	9.29	10.4
15%	7.72	6.9	7.46	5.53
20%	4.86	6.27	6.76	5.09

Figure 4. Compressive strength for % replacement of rice husk ash.

5. Conclusion and Recommendations

The following conclusion was made based on the results:

- Replacement of sand with rice husk ash up to 10 % shows the greatest potential as an alternative for sand in concrete.
- Saw dust ash and glass powder showed potential as they attained over 70 % of the control strength at 20 % replacement at 28 days of curing.
- The admixtures produced concrete with acceptable workability up to 20 % replacementlevels but not sufficient for use in rigid pavements.
- The compressive strength obtained during this research was not adequate for rigid pavements. This may be due to variations in particle size, mix design and unusual silt content of the river sand.

The following are recommended:

- Rice husk ash is recommended as the most suitable partial replacement for sharp sand asit attained the highest compressive strength.
- Further research could explore rice husk ash replacement beyond 20% to determine the optimal replacement level
- The concrete mix could be optimized to achieve the high strength requirements forrigid pavements using rice husk ash and the other admixtures.
- Further tests such as tensile strength test and flexural strength tests could be carried out.

Conflicts of Interest: The authors declare no conflict of interest.

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