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Innovative Uses of Industrial By-Products in Construction: Evaluating Performance and Environmental Impact using MOORA Method

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Abstract*: By incorporating materials such as bauxite residues, phosphogypsum, fly ash, and various slogs, researchers have developed methods to synthesize alternatives like C4A3S and improve concrete's mechanical properties. This process not only addresses the disposal issues of industrial waste but also optimizes construction materials, such as aggregates for highway construction, asphalt, and concrete. Furthermore, multi-objective optimization techniques like the MOORA method have been applied to enhance decision-making in manufacturing and material selection, contributing to improved efficiency in construction and waste management processes. By combining these techniques with recycled waste materials, cost-effective and sustainable construction solutions are achieved, reducing the environmental risks associated with improper waste disposal. Incorporation of industrial by-products such as fly ash, slag and quarry dust into concrete and pavements has demonstrated significant potential to improve strength, durability and density. This approach not only reduces the environmental impacts of waste disposal, but also improves the mechanical properties of construction materials such as compressive and tensile strength, providing a sustainable alternative to conventional materials. Moreover, using these by-products can lead to more economical and sustainable construction methods, particularly in highway construction and hard pavement applications. Alternative: Fly Ash Concrete, Slag Cement, Recycled Aggregates, Rice Husk Ash Bricks, Silica Fume Concrete, Rubberized Concrete. Evaluation Preference: Compressive Strength (MPa), Durability (years), Thermal Insulation (R-value), Cost per Unit ($), Carbon Emission (kg CO_2/unit), Water Consumption (L/unit). The results indicate that Rice Husk Ash Bricks achieved the highest rank, while Silica Fume Concrete had the lowest rank being attained. The value of the dataset for Utilization of industrial waste in construction materials, according to the MOORA method, Rice Husk Ash Bricks achieves the highest ranking.”*

Key words: *MOORA method, Phosphonyls, Geopolymer concrete, Fly ash, Slag waste.*

1. INTRODUCTION

Considerable research has been conducted into the incorporation of industrial by-products into synthetic composites to determine which types of waste can be successfully recycled into construction materials. [1] In addition to natural or commercial products, industrial byproducts from various processes can be used as raw materials to synthesize C4A3S. For example, bauxite residues ("fines") can provide the alumina required for this synthesis. Also, impurities found in bauxite fines can enhance the synthesis of C4A3S due to their fluxing properties. [2] The calcium content of phosphonyls (PG) affects its physical properties and the mechanisms by which it is studied. The goal is to create a product that matches or exceeds existing options for shaft repair or replacement, while making optimal use of locally sourced aggregates. This method can reduce the cost of hard pavement construction. Additionally, industrial waste is used for highway construction, crushed base and asphalt aggregate. Cement, fly ash (FA), industrial waste (PG), and quicklime are added to stabilization processes to improve their efficiency. [3] Tran Viet Hung et al. A study was conducted to evaluate the mechanical properties of geopolymer concrete prepared from industrial waste. Strength performance evaluation of fly ash-based geopolymer concrete involves analyzing its elastic modulus, tensile strength, and response to compressive and flexural stresses. The flexural strength and tensile properties of geopolymer concrete were compared with traditional cement concrete. [4] Research is being conducted to investigate the use of slag waste from stone quarries in the manufacture of terrazzo floor tiles to reduce waste and tackle environmental issues. The findings indicate that the slag generated from the stone cutting process can be successfully used as a raw material for the production of terrazzo tiles. Four samples, named T1, T2, T3 and T4, were made by incorporating varying concentrations of sludge into a fixed mixture of 100%, 75%, 50% and 25%, respectively. Sludge-free reference samples are denoted by the symbol TR. [5] The study demonstrated that the addition of industrial waste materials such as copper slag, steel slag and ISF slag increases the density of concrete. However, the density of concrete made with F-class fly ash and waste foundry sand was comparable to that of control concrete. In contrast, using bottom ash and palm oil clinker instead of sand reduces the density of concrete. Although various industrial wastes were used instead of natural sand, all concrete samples had densities between 2000 and 2600 kg/m³, which are suitable for normal concrete classifications. [6] Exploring other industrial waste alternatives to fly ash bricks is key to improving waste management and developing fly ash brick aggregates, especially in our increasingly energy- and resource-intensive lifestyles Industrial waste materials such as ground granulated blast furnace slag (GGPS), granite powder, foundry sand, fly ash, bag ash, steel slag, quarry dust and rice husk ash can partially replace fly ash in brick production. These materials show great potential as they have been researched for use in brick production or as a substitute for fly ash in various industries. [7] The waste materials are processed into the desired shape and size and exhibit properties similar to natural aggregates, with minimal impact on the original concrete quality. Nevertheless, these recycled aggregates generally show low specific gravity and high porosity. As a result, concrete made from recycled admixtures loses workability quickly due to their fineness and requires more water to achieve the same level of workability. High quality recycled aggregates perform well in crush and impact tests and Los Angeles abrasion tests. [9] In contrast to other industrial waste materials investigated in this study, lime dust shows unique behavior when used as a substitute for fine aggregate in concrete. On the other hand, the shrinkage factor test showed that using slag filler as the best aggregate substitute reduced the shrinkage factor value in all alternative scenarios compared to C30 concrete. [12] The studies mentioned above illustrate that the incorporation of industrial The use of waste in the production of concrete, a major construction material, presents a promising opportunity to mitigate the environmental impact of these waste products. This study aims to investigate the carbon powder produced by aluminium factories, focusing on Its chemical composition, structure and particle size distribution. [13] In addition to physical, chemical, thermal, and biological treatment methods, traditional approaches to solid and hazardous waste management include strength reduction, volume reduction, and waste detoxification or immobilization. [14] Also, many waste products are in powder form, which are prone to becoming airborne and contributing to air pollution. When these wastes are disposed near agricultural areas, they negatively affect the soil used for agriculture. As concrete is increasingly used in construction, adding waste materials to it provides a more sustainable solution. [16] Despite extensive research on inorganic polymer binders incorporating alkali-activated materials and industrial waste or by-products, little attention has been paid to recycling waste concrete from construction and demolition activities. Since waste concrete does not have significant aluminosilicate content, co-evaluation in which the different by-products are considered together provides a better approach. This method allows the addition of aluminosilicate content from other sources, and enables more effective and integrated management of solid waste. [18] Energy can be generated from sugarcane biomass through a variety of methods, including combustion and fermentation. While there is research on separate clean energy production techniques from biogases, there are few studies that integrate and evaluate these different processes and their practical applications. A comparative study of these processes, including their advantages and limitations, is necessary to fully understand the methods. [21]

2. MATERIALS AND METHOD

Alternative: Fly Ash Concrete, Slag Cement, Recycled Aggregates, Rice Husk Ash Bricks, Silica Fume Concrete, Rubberized Concrete.

Fly Ash Concrete: Fly ash is an excellent admixture produced by burning pulverized coal, which increases the durability and workability of concrete, while reducing its permeability. Fly ash is widely used in Commercial and Industrial Sectors and its primary use is to improve concrete mixes by improving durability and workability. Additionally, it acts as filler in paints, adhesives and metal or plastic composites. Fly ash is often used as structural filler in road construction, and is also used in the manufacture of bricks, ceramic tiles, plaster, Portland cement and ready-mix cement.

Slag Cement: Slag cement, also known as ground granulated blast-furnace slag (GGPFS), is a by-product of the steel industry that results from the rapid cooling of molten iron slag to form a glassy, granular material. It is usually mixed with Portland cement to increase the durability, strength and durability of concrete. Slag cement offers many advantages, including better resistance to chemical attacks, low permeability, improved workability and reduced heat of hydration, making it ideal for large-scale construction projects such as bridges, dams and foundations.

Recycled Aggregates: The recycled aggregates are refined to remove impurities and then crushed into various sizes for use in new construction. They act as an environmentally friendly alternative to natural accumulations, reducing the need for virgin materials and reducing land waste. Frequently used in road surfaces, pavements, drainage systems and concrete production, recycled aggregates offer benefits such as environmental protection, cost savings and promoting the circular economy in construction.

Rice Husk Ash Bricks: Paddy husk ash, rich in silica, increases the strength and durability of bricks. These bricks are made by mixing rice husk ash with clay or cement, then shaping and firing or curing. Paddy husk ash bricks come with many advantages such as improved insulation; lighter weight compared to conventional bricks and lower carbon footprint due to the use of recycled agricultural waste. Working mostly in sustainable construction, they offer a cost-effective option for eco-friendly bricks.
Silica Fume Concrete: Silica fume concrete offers many advantages, including improved compressive strength, better resistance to abrasion and chemical exposure, and reduced risk of corrosion in reinforced structures. It is often used in projects that require superior strength and durability, such as bridges, marine constructions, high-rise buildings and industrial facilities.

Rubberized Concrete: The addition of rubber increases the material's flexibility and crack resistance make it suitable for a variety of applications., including pavements, sidewalks and other infrastructure projects. A major advantage of rubberized concrete is its ability to reduce noise and absorb sound in urban settings. Also, rubber particles can increase the thermal properties of concrete, resulting in energy savings for buildings.

Evaluation Preference: Compressive Strength (Map), Durability (years), Thermal Insulation (R-value), Cost per Unit ($), Carbon Emission (kg CO_2/unit), Water Consumption (L/unit).

Compressive Strength (Map): Many factors affect the compressive strength of concrete, including water-cement ratio, aggregate type, and curing conditions. High-strength concrete, typically greater than 40 Map, is often used in high-rise buildings and infrastructure projects where load-bearing capacity is important. In comparison, standard concrete typically has a compressive strength of 20 to 30 Map. Testing for compressive strength follows standardized procedures, which include casting concrete specimens in melds and applying a controlled load Until failure occurs. Compressive strength is calculated by dividing the maximum load at failure by the cross-sectional area of the specimen.

Durability (years): The longevity of concrete is affected by several key factors, including its composition, environmental exposure, and maintenance practices. For example, concrete made with high-quality aggregates, low water-cement ratios, and appropriate admixtures exhibits high durability. Also, the use of protective coatings and sealants increases resistance to moisture, chemicals and freeze-thaw cycles. Environmental factors such as temperature changes, humidity and aggressive substances such as chlorides and sulphates can greatly affect the life of concrete structures.

Thermal Insulation (R-value): R-values vary significantly between materials. For example, common insulation materials such as fiberglass, foam board, and cellulose typically have R-values of 2 to 6 per inch of thickness. In contrast, concrete has relatively low R-values, typically between 0.1 and 0.5, indicating that it is a less effective insulator unless improved with additional insulation layers. Efficient thermal insulation contributes to reduced energy consumption for heating and cooling, resulting in lower utility costs and smaller carbon footprint.
Cost per Unit ($): In construction, different materials have unique cost per unit values that are influenced by factors such as material type, quality and market demand. For example, common building materials such as concrete and steel often have lower unit costs than specialty options such as high-performance insulation or decorative coatings. Additionally, regional price differences and changes in supply chain costs can affect these values.

Carbon Emission (kg CO_2/unit): Carbon emissions related to a product can vary greatly depending on factors such as manufacturing methods, raw material extraction and transportation. For example, conventional concrete production is recognized for its energy-intensive processes, resulting in significant CO_2 emissions, estimated at around 0.5 to 0.9 kg of CO_2 per kg of concrete produced. In contrast, sustainable alternatives such as recycled materials or low-carbon concrete mixes can significantly reduce these emissions.

Water Consumption (L/unit): Reducing water use is increasingly important in light of global water scarcity. Strategies to achieve this include improving material manufacturing processes, using recycled water and adopting efficient construction practices. Additionally, estimating water consumption allows builders and developers to make informed choices that align with sustainable practices.

3. MOORA METHOD

Alti-objective optimization, often referred to as multi-criteria or multi-attribute optimization, involves optimizing two or more competing objectives simultaneously while conforming to specific constraints. The MOORA method, originally developed by Brazier, is A technique for multi-objective optimization is very useful for dealing with complex decision-making challenges in manufacturing. It It starts with a result matrix showing the performance of various alternatives. on several attributes. [4] Except for the NTM process selection problem, most problems include significant amounts of cardinal data in their decision matrices, which improves the stability of the MOORA method's analysis. In addition, since the referenced research is fairly recent, it is reasonable to assume that the MOORA method is based on the most up-to-date data for its primary outcome metrics. Based on the above discussions, the MOORA method meets all criteria established by Braziers and Zavatskas for six decision problems, demonstrating its robustness in various manufacturing environments. [1] The MOORA method, which uses dimensionless measures, has two components: a rate system and a reference point approach. Each component acts as a barrier to the other. The methodology was used to evaluate and select 15 leading housing contractors to meet the needs of homeowners in Vilnius, the capital city of Lithuania. [3] The MOORA method, like the SAW and COPRAS methods, can be classified as a performance-based approach within the ratio structure framework. Unlike the SAW method, MOORA does not require conversion of minimum objectives into maximum objectives. Additionally, like COPRAS, MOORA handles up scaling and downscaling objectives differently in the aggregation phase. While other MCDM methods address these types of objectives in different ways, the integration procedures in COPRAS and MOORA are relatively straightforward. [6] The MOORA method is used in a decision support system for selecting students for scholarships aimed at improving academic performance. This method helps to address various challenges, making decision making more efficient. By implementing this decision support system at the college, decision makers can quickly identify scholarship recipients based on the merits of students in need, thereby promoting academic achievement. [7] Similarly, the literature indicates that systems of care can be evaluated using multi-criteria decision analysis. Ultimately, the goal of this paper is to assist maintenance managers in making informed decisions to assess machine maintenance and develop effective strategies aimed at reducing failures and operating costs. [9] In each instance, the best alternative is precisely consistent with the findings of previous researchers. The MOORA method takes into account all attributes and their relative importance, leading to an accurate evaluation of alternatives. It is easy to understand and easy to use. As a versatile approach, the proposed method can handle both quantitative and qualitative attributes simultaneously, and provides an objective and straightforward decision-making process. Additionally, it can be adapted to different types of selection problems. [10] With objective results serving as a basis for comparing choices and ultimately selecting the best option, the alternative outcomes of each decision can be measured. Therefore, the MOORA method is an effective tool for ranking and selecting alternatives from a range of available options. [11] Taking advantage of the MOORA method and Pythagorean fuzzy (PF) sets, this paper introduces two multi-criteria decision-making (MCDM) algorithms that adapt MOORA to PF sets. It also faces the last two challenges mentioned earlier. The distinctive features and contributions of this paper can be outlined as follows: First, we demonstrate the use of MOORA in PF environments to address its limitations in managing data beyond smooth values, thereby expanding its potential applications. Second, our method enables the simultaneous handling of both quantitative (definitive) and qualitative (implicit) information, which is often encountered in MCDM problems. The aim of this paper is to extend the Moore method into a Pythagorean fuzzy set (PFS) framework for the multi-criteria decision-making (MCTM) domain. [12] In the MOORA approach, rankings can be determined with or without attribute weights. The MOORA method provides three ranking techniques: ratio approach, reference point method, and full multiplication approach, all of which provide the same ranking results. In addition, the PSI method is used to rank factors without assigning relative importance to attributes. The rankings produced by both MOORA and PSI are consistent, placing productivity at the top, flexibility in the middle and quality at the bottom. [14] This paper presents a practical case study to demonstrate the proposed method. The main goal is to develop a straightforward and effective approach to solving current multi-response optimization problems. Additionally, the paper aims to clearly explain each step, making it easier for professionals to apply similar methods within their own organizations. [15] The MOORA method is used to assess the elasticity and clarity of the bias in decision making and the value of weighting criteria relative to various alternatives. In this context, MOORA serves the same purpose as execution, efficiency and flexibility in decision making within a production environment. This method is highly selective because it effectively determines outcomes based on useful or costly criteria. [16]

4. ANALYSIS AND DISSECTION

TABLE 1. Utilization of industrial waste in construction materials

	Compressive Strength (MPa)	Durability (years)	Thermal Insulation (R-value)	Cost per Unit ($)	Carbon Emission (kg CO_2/unit)	Water Consumption (L/unit)
Fly Ash Concrete	40	50	2.5	50	200	100
Slag Cement	45	55	2.7	60	180	90
Recycled Aggregates	38	45	2.8	55	220	110
Rice Husk Ash Bricks	35	40	3	45	250	130
Silica Fume Concrete	50	60	2.6	70	190	95
Rubberized Concrete	42	48	2.4	65	210	105

Fly ash concrete offers a moderate compressive strength of 40 MPa and a lifespan of 50 years. It has a relatively low thermal insulation (R-value 2.5) and costs $50 per unit, emitting 200 kg CO_2 and consuming 100 liters of water per unit. Slag cement is stronger at 45 MPa, lasts 55 years, and provides slightly better insulation (R-value 2.7), costing more at $60 per unit, with lower emissions (180 kg CO_2) and water use (90 liters).Recycled aggregates provide similar strength to fly ash (38 MPa) but with higher durability (45 years) and better insulation (R-value 2.8), though it's more expensive at $55 per unit and has the highest carbon emissions (220 kg CO_2) and water use (110 liters).

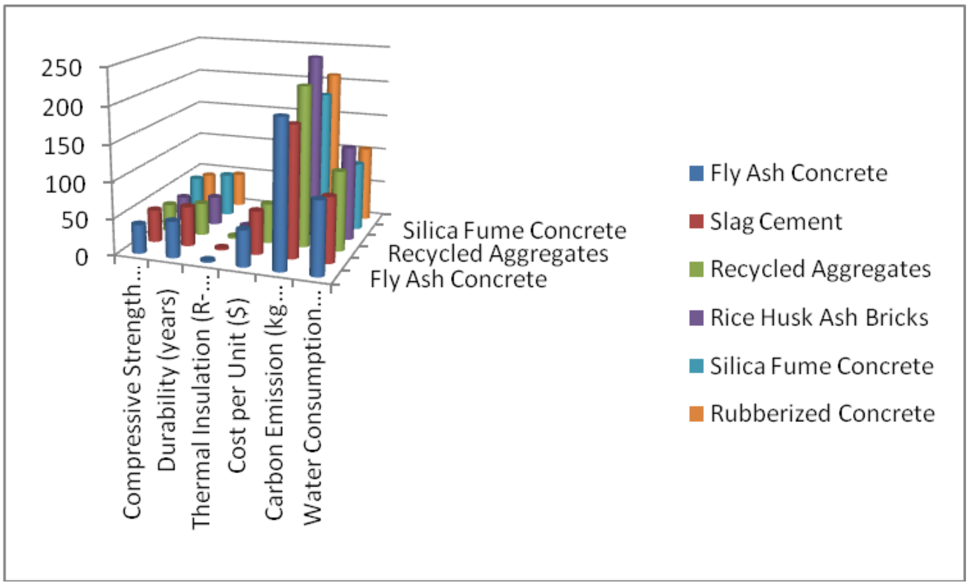

FIGURE 1. Utilization of industrial waste in construction materials

In terms of **compressive strength** and **durability,** Silica Fume Concrete (in blue) and Slag Cement (in red) stand out as the strongest and longest-lasting materials, followed closely by Rubberized Concrete (orange) and Fly Ash Concrete (green). These materials are well-suited for projects prioritizing strength and longevity. **Thermal insulation** is relatively low across all materials, with only small variations between them. **Cost per unit,** however, shows a wider range, with Rice Husk Ash Bricks (purple) being the most affordable, while Silica Fume Concrete is the most expensive. In the environmental metrics, **carbon emissions** and **water consumption,** Rice Husk Ash Bricks have the highest values, suggesting that while they are cost-effective, they come with significant environmental trade-offs. On the other hand, Slag Cement and Fly Ash Concrete show more moderate environmental impact, making them better options for sustainability-conscious projects.

TABLE 2. Normalized Data

Normalized Data					
Compressive Strength (MPa)	Durability (years)	Thermal Insulation (R-value)	Cost per Unit ($)	Carbon Emission (kg CO_2/unit)	Water Consumption (L/unit)
0.389286338	0.486607923	0.02	7.6338	1.4046	0.1948
0.43794713	0.535268715	0.02	9.1606	1.2641	0.1753
0.369822021	0.43794713	0.02	8.3972	1.545	0.2143
0.340625546	0.389286338	0.02	6.8704	1.7557	0.2533

0.486607923	0.583929507	0.02	10.687	1.3344	0.1851
0.408750655	0.467143606	0.02	9.924	1.4748	0.2045

Durability shows a similar range from 0.39 to 0.58, with silica fume concrete again being the most durable. Interestingly, thermal insulation (R-value) remains constant across materials, with a normalized value of 0.02, reflecting little variation in insulation properties. In terms of cost, the normalized values range from 6.87 to 10.69, suggesting that rice husk ash bricks are the cheapest and silica fume concrete the most expensive. Carbon emissions are significantly varied, with values ranging from 1.26 to 1.76, showing that rice husk ash bricks have the highest environmental impact in this regard. Water consumption also varies, from 0.17 to 0.25, with rice husk ash bricks consuming the most water and slag cement being more water-efficient.

TABLE 3. Weight

Weight					
0.25	0.25	0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25	0.25	0.25

This indicates that in evaluating the construction materials, no single factor is prioritized over the others. Each property is considered equally important when assessing the overall performance and sustainability of the materials. This equal weighting suggests that decision-makers aim for a balanced evaluation, where strength, longevity, environmental impact, cost, and efficiency hold the same significance. In practical terms, this approach implies that materials offering better durability or strength would not be favored at the expense of environmental or cost factors. Instead, any material performing poorly in one area would need to compensate with equally high performance in other categories to be considered optimal. This method of equal weighting can simplify comparisons but may not account for specific project requirements where certain attributes, like environmental sustainability or cost-effectiveness, might need to be prioritized.

TABLE 4. Weighted normalized DM

Weighted normalized DM					
0.0973	0.1217	0.0050939	1.9085	0.3511	0.049
0.1095	0.1338	0.0055015	2.2901	0.316	0.044
0.0925	0.1095	0.0057052	2.0993	0.3863	0.054
0.0852	0.0973	0.0061127	1.7176	0.4389	0.063
0.1217	0.146	0.0052977	2.6718	0.3336	0.046
0.1022	0.1168	0.0048902	2.481	0.3687	0.051

The compressive strength values (e.g., 0.0973 to 0.1217) and durability values (0.0973 to 0.146) reflect moderate differences among the materials. Silica fume concrete shows the highest values in both strength and durability, indicating superior performance in these aspects. In contrast, rice husk ash bricks have the lowest scores in strength and durability, implying they are less robust over time. The thermal insulation values are very small, ranging from 0.0049 to 0.0061, reflecting minimal differences in insulation properties across all materials. Cost per unit has a substantial impact, with values ranging from 1.71 to 2.67. Silica fume concrete is the most expensive material, while rice husk ash bricks are the cheapest. Carbon emissions and water consumption also vary, with rice husk ash bricks having the highest environmental costs (0.4389 for carbon emissions and 0.063 for water consumption).

TABLE 5. Assessment value

Assessment value	
Fly Ash Concrete	-2.1
Slag Cement	-2.4
Recycled Aggregates	-2.3
Rice Husk Ash Bricks	-2
Silica Fume Concrete	-2.8
Rubberized Concrete	-2.7

Slag cement and recycled aggregates score -2.4 and -2.3, respectively, indicating they are less desirable choices than fly ash concrete and rice husk ash bricks. Slag cement's higher strength and durability do not seem to compensate for its cost and environmental impact in this evaluation, while recycled aggregates, despite their sustainability appeal, may be underperforming in other key areas such as strength or cost. Silica fume concrete and rubberized concrete, with scores of -2.8 and -2.7, respectively, are the least favorable materials. Although silica fume concrete has strong durability and strength, its higher cost and moderate environmental impact might have led to this lower rating. Rubberized concrete, despite its innovative design, appears to suffer from similar trade-offs.

TABLE 6. Rank

Rank	
Fly Ash Concrete	2
Slag Cement	4
Recycled Aggregates	3
Rice Husk Ash Bricks	1
Silica Fume Concrete	6
Rubberized Concrete	5

Fly ash concrete comes in second place, meaning it is considered a strong contender. Its moderate strength, durability, and relatively balanced environmental impact make it a reliable option for construction, likely appealing due to its balance of performance and cost. Recycled aggregates rank third, reflecting their good performance in strength and durability, combined with a sustainable approach, despite slightly higher emissions and water usage. Slag cement, in fourth place, performs similarly to recycled aggregates but may be less favored due to its higher cost and moderate environmental footprint. Rubberized concrete and silica fume concrete rank fifth and sixth, respectively. While both materials offer innovative solutions and good performance in strength and durability, their lower rankings are likely due to their higher costs and significant environmental impact, making them less attractive compared to other options.

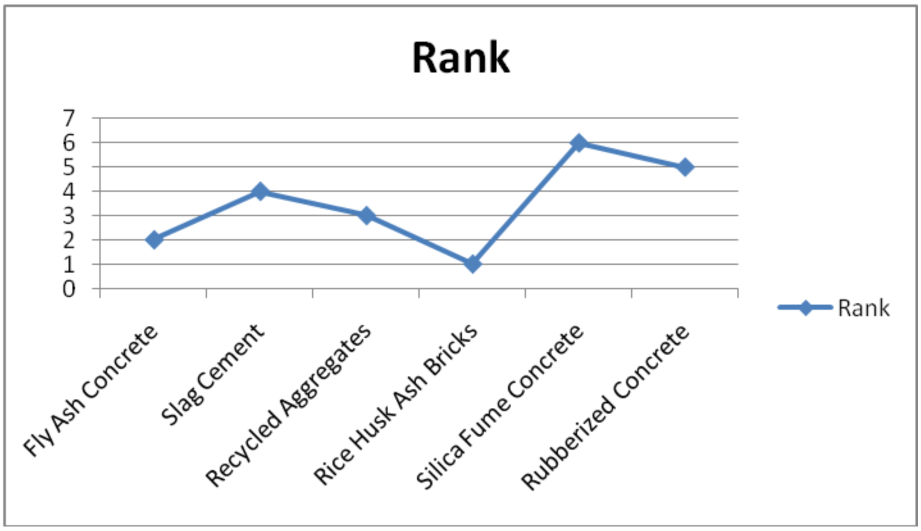

FIGURE 2. Rank

The line chart titled "Rank" displays the comparative ranking of various construction materials: Fly Ash Concrete, Slag Cement, Recycled Aggregates, Rice Husk Ash Bricks, Silica Fume Concrete, and Rubberized Concrete. The vertical axis represents the rank, with 1 being the highest and 7 being the lowest. Fly Ash Concrete has a rank of 2, indicating that it performs well compared to the other materials. Slag Cement follows with a rank of 4, showing slightly lower performance. Recycled Aggregates are ranked similarly to Slag Cement but slightly lower at 3, reflecting its moderate performance. Rice Husk Ash Bricks have the lowest rank of 1, suggesting that this material excels compared to the others in the given criteria. Silica Fume Concrete, with a rank of 6, seems to perform the lowest out of all the materials. Rubberized Concrete ranks 5, indicating better performance than Silica Fume Concrete but still lower than Fly Ash Concrete and Recycled Aggregates.

5. CONCLUSION

These by-products can substitute for natural or commercial materials in the synthesis of compounds like C4A3S, which are critical for high-performance concrete and other building materials. Additionally, waste such as phosphonyls, which is rich in calcium sulphate, can replace gypsum, while impurities in bauxite can enhance the synthesis process due to their fluxing properties. This method not only provides a cost-effective alternative to traditional construction materials, but also reduces the environmental impact associated with waste disposal. Inclusion of industrial waste materials such as fly ash, fly ash and palm oil clinker in geopolymer concrete and other construction applications has demonstrated various effects on mechanical properties. For instance, while the use of slag waste in terrazzo floor tiles and geopolymer concrete results in increased density and improved strength, other materials like bottom ash and palm oil clinker may reduce concrete density. Fly ash-based geopolymer concrete has demonstrated comparable performance to conventional cement-based concrete in terms of compressive, flexural and tensile strength, highlighting its potential for use in the construction industry. However, challenges persist, particularly regarding the workability of concrete made from recycled admixtures. Recycled materials generally have lower specific gravity and higher porosity than natural aggregates, requiring more water to achieve the desired workability. Lime dust, when substituted for fine aggregate, can improve slump values but reduce compaction, while materials like quarry dust result in only slight reductions in compaction factor. Nevertheless, recycled aggregates perform well in tests for crushing, impact resistance, and abrasion. In addition to construction applications, industrial by-products have also been explored in the context of energy production and waste management. For instance, sugarcane biomass can be utilized in various processes to produce clean energy, though research on the comparative efficiency of these methods is still limited. Furthermore, hazardous waste materials, if not properly treated, pose significant environmental and health risks. Solid waste management practices must include methods to reduce strength, volume, and toxicity, ensuring that waste disposal does not harm agricultural lands or contribute to atmospheric pollution.

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