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Sustainable Paver Block by Partial Replacement of Cement with Eggshell Powder and M-Sand with Sawdust

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ABSTRACT
The construction industry faces increasing pressure to minimize its environmental impact, particularly from cement production, which is responsible for a substantial portion of global carbon dioxide emission. In responsible to this, innovative solutions are being explored to reduce the consumption of conventional materials such as cement and sand. This paper investigates the feasibilityof producing sustainable paver blocks by partially replacing cement with eggshell powder and M sand with sawdust, both of which are readily available waste products. The study involves a methodological mix design targetting M40 grade paver blocks with varying percentage of ESP at 0%-15% and sawdust at 0%-15% . The research explores the use of ESP, rich in calcium carbonate, as an alternative to cement, and sawdust as a partial replacement for M sand, a conventional fine aggregate. The study presents the material used, the methodology adopted for mix design, and testing procedures, and discusses the potential for these eco-friendly paver blocks to reduce the carbon footprint of construction and promote circular economy practices.
***Keywords* -** ESP,sawdust,paver blocks,M-Sand, partial replacement,sustainable construcion

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I. INTRODUCTION

Concrete is the most widely used construction material globally, primarily due to its versatility, strength, and relative affordability. It is the backbone of modern infrastructure, including roads, bridges, buildings, and various forms of pavement. Among the different components of concrete, paver blocks serve a vital role in the development of pedestrian pathways, roadways, and landscaping projects. These modular precast units offer considerable aesthetic and functional benefits such as ease of installation, repair, and maintenance. However, despite the widespread application of concrete and its derivatives, the environmental impact of their production remains a major concern. One of the primary contributors to this environmental burden is cement, a key ingredient in concrete. Cement manufacturing is an energy-intensive process, requiring the heating of limestone (calcium carbonate) and other materials to high temperatures in a kiln, resulting in the release of significant quantities of carbon dioxide (CO_2). The cement industry alone contributes approximately 8% of global CO_2 emissions, making it one of the most polluting industries on the planet. Moreover, the production and extraction of natural sand and aggregates further exacerbates environmental degradation through resource depletion, habitat destruction, and increased carbon footprint from transportation. In light of these challenges, there has been a growing focus on the development and use of sustainable construction materials. These are materials that not only meet performance requirements but also reduce environmental impact through the efficient use of resources and energy. One promising approach is the partial replacement of cement and aggregates with alternative materials, particularly those derived from agricultural or industrial waste. This research investigates the possibility of using eggshell powder (ESP) and sawdust as partial replacements for cement and M-sand respectively, in the manufacture of paver blocks.The unsustainable consumption of cement and natural aggregates in construction and improper disposal of waste materials such as eggshells and sawdust. These problems are especially pronounced in developing countries where urbanization is rapid and waste management systems are inadequate. As cities expand and infrastructure demands increase, so does the need for vast quantities of construction materials. Unfortunately, this growth often comes at the expense of environmental sustainability. Traditional concrete relies heavily on virgin raw materials, particularly limestone for cement and river sand for fine aggregates. These materials are non-renewable and their continuous extraction leads to significant ecological disturbances, including riverbank erosion, water table depletion, and biodiversity loss. Simultaneously, waste materials like eggshells, which are generated in large quantities from domestic and industrial food processing units, and sawdust, a by-product of the timber and furniture industries, are often dumped in landfills or open areas, contributing to pollution and health hazards. The dual challenge, therefore, lies in reducing the environmental impact of construction while also addressing waste management issues. The use of ESP and sawdust in paver blocks offers a synergistic solution that not only reduces the carbon footprint of construction activities but also provides an avenue for effective waste utilization.

To investigate the effect of partial replacement of cement with ESP on the mechanical properties of concrete used in paver blocks. This includes assessing the compressive strength, split tensile strength, and water absorption characteristics of the concrete at various replacement levels (5%, 10%, and 15%). To evaluate the influence of sawdust as a partial replacement for M-sand on the workability, compressive strength, and other mechanical properties of paver blocks. Sawdust is a lightweight material, and its inclusion in concrete may provide economic and environmental benefits, such as reducing the overall weight of the paver blocks and utilizing industrial waste. To determine the optimal mix proportion of ESP and sawdust that ensures the highest strength and durability of paver blocks while maintaining cost-effectiveness and sustainability. To assess the environmental impact of replacing conventional materials with waste by-products in terms of carbon footprint reduction and resource conservation. To contribute to the growing body of research on sustainable construction materials by providing experimental data and offering practical recommendations for industry-wide adoption of alternative materials in concrete production.The significance of this research lies in its potential to offer a sustainable alternative to conventional construction practices. By partially replacing cement with ESP and sand with sawdust, this study proposes a circular economy approach in the concrete industry, where waste materials are repurposed as valuable resources. Sustainable paver block production is of great importance for urban construction, particularly in light of the escalating environmental concerns and the rapid pace of urbanization. Paver blocks are commonly used in landscaping, road construction, and various public spaces, making them an essential component of modern infrastructure. The findings of this study could significantly contribute to reducing the environmental impact of paver block production, thus aligning with global sustainability goals, such as reducing carbon emissions, conserving natural resources, and managing waste effectively. Furthermore, the inclusion of agricultural and industrial waste materials such as eggshells and sawdust could stimulate the development of innovative construction materials that are both environmentally friendly and economically viable. Given the growing waste disposal problems and resource depletion globally, the findings of this study could serve as a catalyst for further research and implementation of green building materials in construction, thereby fostering the advancement of sustainable construction technologies.This study focuses on the use of eggshell powder (ESP) and sawdust as partial replacements for cement and fine aggregate (M-sand), respectively, in the production of paver blocks. Specifically, the research is centered on the following key aspects. The selection of ESP and sawdust is based on their availability as waste by-products in various industries. Eggshell powder is derived from discarded eggshells, which are predominantly available in the food industry, while sawdust is a common by-product of the timber and furniture industries. Both materials have been identified as potential alternatives due to their chemical and physical properties that could contribute to the enhancement of concrete's mechanical properties.The study focuses on producing M40 grade concrete paver blocks, which are commonly used for medium traffic applications such as city streets and market roads. The mix proportions are carefully selected to achieve optimal strength and durability while maintaining the environmental benefits of waste material incorporation.The study evaluates the mechanical properties of paver blocks, including compressive strength, split tensile strength, and water absorption. These properties are tested according to standard procedures, such as those outlined by the Indian Standard IS 15658:2021 for concrete paver blocks.

The study also includes an environmental assessment, focusing on the reduction of carbon emissions associated with the production of conventional concrete. By substituting cement with ESP and M-sand with sawdust, the research aims to demonstrate how waste materials can be integrated into concrete to produce a more sustainable and eco-friendly product.The research compares the performance of conventional paver blocks (using only cement and M-sand) with those incorporating various proportions of ESP and sawdust. The results will allow the identification of the optimal mix ratio that balances both strength and sustainability.The methodology employed in this study follows a scientific and experimental approach to investigate the effects of ESP and sawdust on the performance of concrete paver blocks. The study begins with the collection of Ordinary Portland Cement (OPC 53 Grade), M-sand, coarse aggregates, eggshell powder, and sawdust. The ESP is obtained by grinding clean and dried eggshells, while the sawdust is sourced from timber mills and is sieved to ensure consistency in particle size. Concrete mixes are designed to meet the requirements of M40 grade concrete, with the proportioning of cement, aggregates, and water based on established standards. The cement is replaced by 5%, 10%, and 15% ESP, and M-sand is replaced by 5%, 10%, and 15% sawdust, resulting in several test mixes.The materials are mixed in the prescribed proportions using a concrete mixer. The fresh concrete is poured into standard molds for paver blocks (200mm x 100mm x 80mm size), ensuring adequate compaction and uniformity.After casting, the paver blocks are demolded after 24 hours and cured in water for 28 days. Proper curing is essential to ensure the development of the full strength of the concrete and to prevent cracking or shrinkage.The paver blocks are subjected to a range of standard tests to determine their mechanical properties (compressive strength, split tensile strength) and water absorption. The results are compared against conventional paver blocks (without ESP and sawdust) to assess the effects of the replacements on the strength and durability of the blocks.The data obtained from the tests are analyzed statistically to determine the optimal mix ratio of ESP and sawdust that provides the best combination of strength and sustainability. The performance of the paver blocks is compared with industry standards for medium traffic applications.

Eggshell powder (ESP) is emerging as a promising material in sustainable construction due to its high calcium carbonate ($CaCO_3$) content, which is chemically similar to limestone—an essential component in cement production. Typically considered waste, eggshells are generated in large quantities by households, restaurants, food-processing industries, and hatcheries. Unfortunately, much of this waste is discarded into landfills, leading to environmental issues including foul odors, attraction of pests, and methane emissions. By processing these eggshells into a fine powder, their chemical potential can be harnessed for structural applications such as concrete manufacturing. The composition of eggshells includes approximately 94-97% calcium carbonate, along with small amounts of magnesium carbonate and organic matter. Calcium carbonate is a key ingredient in the manufacturing of Ordinary Portland Cement (OPC), where it is thermally decomposed to produce calcium oxide (lime), a principal reactant in cement hydration. When ESP is introduced into concrete mixtures, it not only serves as a filler but also actively participates in hydration reactions, contributing to strength development and microstructural refinement.Sawdust, a lightweight by-product of the woodworking and timber industries, offers a sustainable alternative to natural sand (M-sand) in concrete. It is composed of cellulose, hemicellulose, and lignin, and exhibits a fibrous structure that can potentially enhance the insulating and thermal resistance properties of concrete. It is widely available, inexpensive, and generally considered a waste material. However, if not managed properly, sawdust can contribute to respiratory issues and flammability hazards. Therefore, its valorization in concrete production offers both economic and environmental advantages.

II. MATERIALS AND METHODS

2.1 Cement

Ordinary Portland Cement (OPC) 53 grade was used, known for its high compressive strength and rapid setting properties.Ordinary Portland Cement (OPC) 53 grade is a high-performance cement widely utilized in construction due to its superior strength and durability. It achieves a compressive strength of 53 MPa at 28 days, making it ideal for demanding applications such as high-rise buildings, bridges, and precast concrete products. This grade of cement is known for its rapid setting time, with an initial setting period of approximately 30 minutes and a final setting time of around 600 minutes. The quick strength gain makes it suitable for projects that require early load-bearing capacity. OPC 53 also exhibits excellent workability and low permeability, enhancing the durability of concrete structures and reducing the risk of water ingress and chemical attacks. Its fine particle size contributes to better compaction and surface finish. It meets the requirements of IS 12269:1987 and provides the base binder material for the mix.

2.2 Eggshell Powder

Using eggshell powder as a partial replacement for cement in concrete has gained attention due to its sustainability and potential performance benefits. Eggshells are primarily composed of calcium carbonate, which can enhance the mechanical properties of concrete when properly processed.Incorporating eggshell powder helps recycle agricultural waste, reducing environmental impact and promoting sustainable construction practices. Studies suggest that replacing 5-15% of cement with eggshell powder can improve compressive strength, particularly at later curing stages. The fine texture of eggshell powder can enhance the workability of concrete mixes, making them easier to handle. Eggshells must be thoroughly cleaned, dried, and ground to a fine powder to ensure consistency and effectiveness in the mix. Adjustments may be necessary to account for the water absorption properties of eggshell powder, ensuring optimal performance While initial studies show promise, further research is needed to fully understand the long-term durability and performance characteristics of concrete with eggshell powder.

2.3 Fine Aggregate

Fine aggregate, consisting of particles smaller than 4.75 mm. Common materials used as fine aggregates include natural sand, crushed stone, and gravel. Fine aggregates serve several important functions in concrete production They improve the workability and consistency of the concrete mix, making it easier to handle and place. Fine aggregates contribute to the overall strength and stability of the concrete by filling voids between larger particles, creating a denser structure. They enhance the durability of concrete by reducing permeability and increasing resistance to environmental factors.Often sourced from riverbeds or quarries, natural sand is commonly used due to its availability and suitable grading.Produced by crushing larger stones, this type offers angular particles that improve bonding within the concrete mix. The grading and cleanliness of fine aggregates are crucial, as they can significantly affect the properties of the final concrete product. An optimal blend of fine aggregates ensures a balanced mix, enhancing workability, strength, and durability, making them essential for various construction applications, from pavements to structural elements.

2.4 Sawdust

Using saw dust as a partial replacement for fine aggregate in concrete offers several environmental benefits. It is a sustainable option that helps recycle wood waste, reducing landfill contributions and promoting eco-friendly construction practices. Sawdust is lighter than traditional fine aggregates, which can lower the overall weight of concrete structures, potentially enhancing their design and insulation properties. It can improve workability due to its fine texture, making mixing easier. However, incorporating saw dust requires careful consideration. While studies suggest that replacing 5-20% of fine aggregate with saw dust can yield satisfactory compressive strength, excessive amounts may lead to a reduction in strength and durability. The moisture content of saw dust can also affect the water-cement ratio.using well processed and uniformly sized saw dust is crucial to maintain the concrete's integrity.

2.5 Coarse Aggregate

Coarse aggregate of 6 mm size consists of larger particles ranging from 4.75 mm to 6 mm.It is essential in concrete production, providing bulk, strength, and stability to the mix. Commonly sourced from crushed stone, gravel, or granite, this size is ideal for applications requiring good workability and reduced shrinkage. It enhances the durability and load-bearing capacity of concrete. Using 6mm coarse aggregate in paver blocks offers some advantages but also presents significant challenges, especially in terms of strength. Smaller aggregates like 6mm can provide a smoother surface finish, which is beneficial for certain aesthetic applications. They also improve workability, making it easier to mould the paver blocks, and can enhance compaction by reducing voids, potentially increasing density. 11 The 6mm coarse aggregate enhances the compressive strength of paver blocks. It creates a denser matrix, making the block more durable and resistant to heavy loads.The smaller size of 6mm aggregate helps in better bonding with cement paste, reducing voids and increasing the overall integrity of the block. This helps the block resist wear and tear over time.6mm aggregate improves the workability of the concrete mix for paver blocks. It ensures that the mix is more consistent and easier to compact, leading to fewer defects like cracks or weak spots. Smaller coarse aggregate, such as 6mm, minimizes segregation within the mix. This results in a more uniform distribution of materials within the paver block, improving its durability and resistance to weather conditions.

III. MIX DESIGN AND PROPORTIONING

The concrete mix was designed based on M40 grade, suitable for medium-traffic paver blocks as per IS 15658:2006. The water-cement ratio was maintained at 0.41. The trial mixes involved varying percentages of ESP (0%, 5%, 10%, and 15% by weight of cement) and sawdust (0%, 5%, 10%, and 15% by weight of M-sand).

Standard cube specimens (150 mm x 150 mm x 150 mm) and paver block molds (200 mm x 100 mm x 80 mm) were cast for testing. The prepared samples were subjected to 7-day and 28-day curing in water tanks to simulate standard curing conditions.

IV. EGGSHELL POWDER AS PARTIAL REPLACEMENT FOR CEMENT

4.1 Introduction to Eggshell Powder in Concrete
Eggshell powder (ESP) is emerging as a promising sustainable alternative to cement in the construction industry, particularly in concrete and paver block production. Eggshells, primarily composed of calcium carbonate ($CaCO_3$), are typically discarded as household and industrial waste. However, their chemical composition closely mirrors that of limestone, a principal ingredient in cement manufacturing. This similarity provides ESP the potential to act as a cementitious or supplementary cementing material when processed appropriately.

The use of ESP in concrete contributes significantly to environmental sustainability by addressing two major concerns: reducing the dependency on cement, which is energy-intensive and a significant source of CO_2 emissions, and minimizing landfill waste by repurposing an agricultural by-product. As construction materials continue to evolve with ecological consciousness, the integration of ESP into paver block production marks a notable advancement toward green building practices.

4.2 Processing and Integration of ESP in Paver Blocks

To utilize ESP in cement replacement, the eggshells must first undergo a cleaning and drying process to eliminate organic residues and moisture. After drying, the shells are ground into a fine powder, with particle sizes ideally less than 90 microns to ensure proper dispersion within the mix. This finely ground ESP is then incorporated as a partial replacement for ordinary Portland cement (OPC), usually in incremental proportions of 5%, 10%, and 15% by weight of cement.

In paver block manufacturing, ESP is introduced during the dry mixing phase along with cement and aggregates. This is followed by the addition of water to create a workable concrete mix. Proper mixing ensures homogeneous distribution of ESP and helps achieve the desired consistency and workability, essential for effective molding, compaction, and curing of the paver blocks.

4.3 Chemical and Mineralogical Contribution of ESP
The primary component of ESP—calcium carbonate ($CaCO_3$)—plays multiple roles in the hydration and hardening of concrete. Upon heating during the hydration reaction, $CaCO_3$ decomposes into calcium oxide (CaO), which then reacts with water to form calcium hydroxide ($Ca(OH)_2$):

$$CaCO_3 \rightarrow CaO + CO_2$$

$$CaO + H_2O \rightarrow Ca(OH)_2$$

This $Ca(OH)_2$ participates in pozzolanic reactions with siliceous materials present in the cement or aggregates, forming additional calcium silicate hydrate (C-S-H) gel:

$$Ca(OH)_2 + SiO_2 \rightarrow \text{C-S-H}$$

C-S-H is the primary binder in concrete that imparts strength and durability. The inclusion of ESP thus indirectly contributes to increased formation of C-S-H, which leads to better mechanical performance over time.

4.4 Effect on Workability and Fresh Properties

The introduction of ESP affects the workability of concrete, particularly in paver block applications where compaction and mold filling are critical. Due to its fine particle size and smooth texture, ESP tends to improve the plasticity of the mix. At lower replacement levels, this can lead to easier compaction and finishing without requiring additional water or admixtures. However, at higher percentages, ESP may absorb more mixing water, thereby reducing workability. This is due to its porous nature and increased surface area, which can retain moisture. Therefore, careful monitoring of water-to-cement ratio and potential use of superplasticizers may be required to maintain optimal workability.

4.5 Effect on Mechanical Properties of Paver Blocks

One of the most significant influences of ESP on paver blocks is its effect on mechanical strength, particularly compressive strength, which is a critical parameter for load-bearing performance. At replacement levels up to 5–10%, ESP can enhance or maintain compressive strength, largely due to the micro-filling effect and the pozzolanic activity of its reactive calcium content. The fine particles of ESP fill micro-voids in the concrete matrix, leading to a denser microstructure and improved load distribution. Furthermore, the secondary C-S-H formed through pozzolanic reactions contributes to long-term strength development. However, beyond 10–15% replacement, a dilution effect may occur, reducing the total amount of cementitious binder and thus negatively impacting strength. Hence, identifying the optimal replacement percentage is essential to ensure structural integrity. In addition to compressive strength, the incorporation of ESP can also influence other mechanical properties such as flexural and split tensile strength.

4.6 Effect on Durability and Water Absorption

Durability is another critical factor in evaluating the suitability of ESP in paver blocks. Properly cured concrete with ESP tends to exhibit reduced porosity, which in turn enhances resistance to water ingress, chemical attack, and freeze-thaw cycles. This is particularly important for paver blocks used in external environments where exposure to water and varying weather conditions is inevitable. The presence of calcium carbonate in ESP contributes to a more refined pore structure. Additionally, the C-S-H gel formed through secondary hydration reduces capillary pores, thereby decreasing water absorption. Lower water absorption improves the long-term durability and lifespan of paver blocks by preventing moisture-related deterioration such as efflorescence or scaling. However, this benefit is again subject to the proportion of ESP used. Excessive replacement can lead to an increase in unreacted particles and poor bonding between matrix constituents, resulting in higher porosity and reduced durability.

4.7 Microstructural Enhancement and Filler Effect

The micro-filler effect of ESP is particularly beneficial in paver blocks, which rely on dense packing and minimal void content for strength and abrasion resistance. When ESP is properly ground, its fine particles fill interstitial spaces between larger cement grains and aggregates. This improves the compaction and reduces bleeding and segregation during casting. Scanning electron microscopy (SEM) and X-ray diffraction (XRD) analyses in similar studies have shown that ESP-modified concrete exhibits more uniform matrix structure and fewer microcracks. This microstructural integrity translates into improved overall performance of the paver blocks.

4.8 Sustainability and Cost Benefits

The use of ESP as a partial cement replacement brings substantial sustainability benefits. Cement production is energy-intensive and contributes approximately 8% of global CO_2 emissions. Substituting even a small percentage of cement with waste-derived ESP helps reduce the carbon footprint of construction materials. Moreover, eggshells are freely available as household or food industry waste, making them an economical alternative. Their reuse also alleviates the burden on landfills and promotes circular economy principles in construction. With proper collection, processing, and quality control, ESP can serve as a viable, low-cost additive that improves both performance and environmental profile of paver blocks.

V. SAWDUST AS PARTIAL REPLACEMENT FOR FINE AGGREGATE

Sawdust, a byproduct generated in substantial quantities from woodworking, carpentry, and timber-processing industries, offers an environmentally conscious and economically viable alternative to natural fine aggregates such as M-sand or river sand in concrete production. With growing concerns over the depletion of riverbeds, the environmental degradation caused by sand mining, and the rising costs of construction materials, the integration of waste materials like sawdust into concrete mix design has garnered increasing attention. The reuse of sawdust in paver block manufacturing not only provides a sustainable route for waste management but also reduces the exploitation of non-renewable resources, aligning the construction industry with circular economy principles. Sawdust particles are typically light in weight and fibrous in texture, characteristics that distinguish them from traditional fine aggregates. This makes sawdust an unconventional but interesting replacement material that affects both the fresh and hardened properties of concrete when incorporated in suitable proportions.

5.1 Incorporation of Sawdust

Incorporating sawdust into the concrete mix as a partial replacement for fine aggregate involves a carefully managed process. The sawdust must be sieved to eliminate coarse fibers and debris, ensuring uniform particle size, typically passing through a 1.18 mm sieve to match the gradation profile of M-sand. Clean and dry sawdust is preferred, although in some cases it may be chemically treated to improve compatibility with cementitious systems by reducing its high water absorption tendency. Replacement is typically conducted in progressive increments—such as 5%, 10%, and 15% by weight of the fine aggregate—to determine its influence on workability, density, strength, durability, and water absorption characteristics of the paver blocks. This replacement strategy allows researchers and engineers to evaluate the trade-offs between sustainability and performance in a controlled manner.

5.2 Effect of Sadust on Concrete

Sawdust, being an organic material, presents unique challenges and benefits when used in concrete. One of the most noticeable effects of sawdust inclusion is the reduction in the density of the concrete mix. As sawdust is significantly lighter than sand, it decreases the overall mass of the paver blocks, which can be beneficial in applications where lightweight materials are desired, such as pedestrian pavements, rooftop tiling, and temporary flooring. This reduced density, however, may be accompanied by a reduction in compressive strength, particularly when the replacement percentage exceeds optimal limits. At lower replacement levels—typically around 5%—the mechanical performance of paver blocks can remain satisfactory, with the sawdust acting as a filler that occupies the voids within the mix and thereby contributing to a denser microstructure.

Workability is another parameter significantly affected by the inclusion of sawdust. Sawdust, due to its porous nature and high surface area, tends to absorb water from the concrete mix. This can lead to a dry and stiff mix, especially if additional water is not added to compensate for the absorption. Consequently, concrete mixes with sawdust require careful monitoring of the water-to-cement ratio to prevent poor workability, inadequate compaction, or incomplete hydration. On the other hand, when the water content is properly adjusted, sawdust can contribute to internal curing by slowly releasing absorbed water during the hydration process. This promotes gradual and sustained strength development in the hardened concrete, particularly in its early stages. Additionally, the presence of sawdust can improve thermal insulation and sound absorption properties of paver blocks due to its cellular structure, which traps air and dampens vibration. This makes sawdust-modified paver blocks attractive for use in residential and community areas where comfort and acoustic properties are essential.

Durability is a crucial concern when introducing organic materials like sawdust into concrete. Sawdust is biodegradable and, in its untreated form, may decompose over time, especially in moist environments. However, studies have suggested that encapsulating sawdust within a cementitious matrix can significantly reduce its degradation by limiting exposure to moisture and oxygen. In fact, at low replacement levels, the risk of long-term deterioration is minimal, and the blocks remain structurally sound and reliable. Moreover, the reduction in permeability due to void-filling action of sawdust particles can improve resistance to water ingress, which is particularly advantageous in paver blocks subjected to cycles of wetting and drying. Water absorption, however, generally increases with higher sawdust content, as the organic fibers tend to retain moisture. This necessitates attention to curing and sealing techniques, as proper curing ensures the hydration of cement is completed before the sawdust absorbs moisture that might otherwise compromise strength development. Surface sealing or coating of paver blocks may further enhance their resistance to environmental attack and moisture penetration.

From a microstructural perspective, sawdust functions as both a physical filler and a structural modifier. At optimal replacement levels, it refines the pore structure by reducing large voids and capillaries, which not only improves strength but also enhances dimensional stability. However, excessive replacement may result in poor compaction, increased porosity, and formation of interfacial weak zones between the cement paste and the sawdust particles.

These effects can impair load distribution and lead to premature failure under stress. Therefore, mix design must balance the environmental advantages of sawdust with the mechanical demands of the application.

5.3 Sustainability and Cost Benefits

Economically, the integration of sawdust into paver block production is highly advantageous. Sawdust is an inexpensive, and often freely available, waste product from sawmills and timber factories. By utilizing this material, manufacturers can reduce material costs associated with sand procurement, transportation, and processing. In regions where sand mining is regulated or expensive, sawdust offers an accessible and legal alternative. Moreover, the reuse of sawdust contributes to sustainable construction practices by diverting waste from landfills and lowering the carbon footprint of building materials. It aligns with global goals on sustainable development, waste reduction, and environmental protection by minimizing dependence on virgin resources and maximizing the utility of industrial by-products.

VI. TESTING PROCEDURES

All tests were conducted in accordance with Indian Standard specifications to ensure the reliability and comparability of results.

6.1 Workability

The slump test was performed on fresh concrete to assess the workability of each mix.

6.2 Compressive Strength

Compressive strength tests were conducted on standard cube specimens using a compression testing machine. The values were compared against M40 specifications to assess the structural viability of each mix.

6.3 Split Tensile Strength

Paver blocks were subjected to split tensile strength tests to evaluate their resistance to cracking and tensile stress.

6.4 Water Absorption

Water absorption tests were carried out to determine the porosity and potential durability of the paver blocks in wet conditions. This also reflects their long-term performance in outdoor environments.

6.5 Physical Requirements

Test results were benchmarked against IS 15658:2021 standards for compressive strength, water absorption, and tensile strength for paver blocks intended for medium traffic applications.

VII. DISCUSSION

This study highlights the potential of integrating ESP and sawdust into paver block production, offering an innovative approach to sustainable construction. The use of these waste materials not only addresses the pressing issue of industrial and domestic waste disposal but also mitigates the carbon footprint of conventional concrete production. In regions where eggshell and sawdust waste is abundant, this solution can be scaled for commercial application, fostering both environmental and economic benefits.

Eggshell powder contributes to strength development through pozzolanic reactions and acts as a filler to reduce porosity. Sawdust, on the other hand, enhances workability and thermal insulation. However, excessive use of these materials may lead to reduced mechanical performance, necessitating careful optimization of mix proportions.

VIII. FUTURE RESEARCH DIRECTIONS

The exploration of sustainable alternatives to traditional concrete components in the production of paver blocks has opened up significant avenues for innovation and environmental impact mitigation. This project successfully demonstrated that partial replacement of cement with eggshell powder (ESP) and M-sand with sawdust can produce paver blocks with mechanical properties suitable for medium traffic applications. However, this area of research remains in its infancy, and numerous opportunities exist for further investigation and development. The following future research directions aim to expand upon the current work and contribute to the field of sustainable construction.

8.1. Expanded Material Substitution Studies

One immediate area of future research is exploring additional waste or recycled materials as supplementary cementitious and fine aggregate substitutes. While eggshell powder and sawdust have proven effective, integrating them with other eco-friendly materials like fly ash, rice husk ash (RHA), ground granulated blast furnace slag (GGBS), or silica fume could further enhance the mechanical and durability characteristics of paver blocks. These hybrid combinations could leverage the unique properties of each material to optimize performance.

8.2. Long-Term Durability Studies

Durability is one of the most critical aspects of any construction material. Although this study focused primarily on 28-day strength, long-term performance under various environmental conditions remains unexplored. Future research should include long-term tests such as:
Freeze-thaw resistance,
Chloride penetration,
Acid and sulfate attack resistance,
Carbonation depth over time,
Creep and shrinkage analysis.
These tests would help assess how ESP and sawdust-based paver blocks perform in different climates and exposure conditions over years of use.

8.3. Microstructural and Chemical Analysis

The mechanical improvements observed in ESP-supplemented concrete suggest underlying changes at the microstructural level. Future research should incorporate advanced analytical techniques such as:
Scanning Electron Microscopy (SEM),
X-Ray Diffraction (XRD),
Thermogravimetric Analysis (TGA),
Fourier Transform Infrared Spectroscopy (FTIR).
These analyses can help to better understand the role of calcium carbonate from eggshell powder in the hydration process, the formation of C-S-H (Calcium Silicate Hydrate), and how sawdust particles affect the pore structure of concrete.

8.4. Life Cycle Assessment (LCA) and Carbon Footprint Analysis

Quantifying the environmental benefits of using ESP and sawdust requires a thorough Life Cycle Assessment. Future work should evaluate:
The carbon footprint reduction from decreased cement usage,
The energy savings associated with reduced material processing,
The overall environmental impact, including land use and water consumption.
Such studies would validate the sustainability claims and encourage adoption in green certification programs like LEED or GRIHA.

8.5. Automation and Industrial Scale-Up

Transitioning from laboratory-scale production to industrial-scale manufacturing introduces new challenges. Research should focus on:
Adapting automated mixing and casting techniques for ESP/sawdust-based mixes,
Developing quality control protocols for variable-quality raw waste materials,
Designing production lines to accommodate variable curing and compaction requirements.

IX. CONCLUSION

This project investigated the potential of producing sustainable paver blocks through the partial replacement of traditional cement with eggshell powder (ESP) and M-sand with sawdust. The initiative aligns with the global push toward eco-friendly construction practices, offering an innovative pathway for waste utilization and resource conservation in the civil engineering sector.

The inclusion of eggshell powder and sawdust influenced the workability of the concrete mix. ESP, with its fine particle size and chemical similarity to cement, helped enhance the cohesiveness of the mix, improving workability to some extent. However, sawdust, due to its fibrous and absorptive nature, posed challenges by increasing water demand, thereby slightly reducing the mix's fluidity. This necessitated careful water-to-cement ratio adjustments to achieve a workable consistency.

The compressive strength was observed to be significantly influenced by the replacement levels of ESP and sawdust. While ESP enhanced early and long-term strength due to its calcium-rich composition and pozzolanic activity, excessive sawdust could reduce the matrix density, affecting the compressive resistance. However, at optimum replacement levels, the concrete attained the target strength requirements for M40 grade paver blocks, validating the feasibility of this mix design for structural use.

The split tensile strength of paver blocks with ESP and sawdust showed favorable results. ESP contributed to stronger bonding and a denser microstructure, enhancing tensile resistance. Although sawdust might slightly compromise tensile capacity due to its organic, porous nature, it also imparted minor fibrous reinforcement effects at controlled percentages. Overall, the optimized mix exhibited reliable tensile performance suitable for load-bearing applications.

Water absorption was an important indicator of durability. The incorporation of sawdust, due to its porous nature, tended to increase water absorption if not properly managed. However, in optimized proportions, the mix demonstrated acceptable water absorption values well within the standard limits. ESP, contributing to matrix densification, helped control permeability, thus improving the overall water resistance of the paver blocks.

Advantages:
The approach adopted in this study offers several noteworthy benefits:

Environmental Sustainability: By incorporating eggshell powder and sawdust—two readily available waste materials—the project contributes to reducing construction waste and minimizing reliance on natural, non-renewable resources like limestone and river sand.

Cost Efficiency: The use of industrial and agricultural by-products reduces the consumption of cost-intensive raw materials, potentially lowering the production costs of paver blocks.

Waste Management: Utilizing kitchen and wood industry waste aids in decreasing the burden on landfills and promotes a circular economy.

Lightweight Properties: The fibrous, low-density characteristics of sawdust can reduce the overall weight of the blocks, making transportation and handling more manageable.

Promotes Local Resource Use: The project encourages the use of regionally available waste products, fostering sustainable local construction practices.

Limitations:

While promising, the study also presents certain limitations that warrant further investigation:

Variability in Waste Materials: Differences in eggshell composition or sawdust type may affect consistency in block quality.

Durability Uncertainties: Long-term performance under varying climatic conditions, including freeze-thaw cycles, chemical exposure, and abrasion, remains to be studied in detail.

Scale of Implementation: Transitioning from laboratory testing to industrial-scale production could introduce challenges in uniform mixing, quality control, and logistics.

Limited Performance Scope: The current work primarily focuses on strength-related parameters; comprehensive evaluations on thermal, acoustic, and structural behavior are still pending.

Applications:
The concept developed through this study has a wide array of potential applications, particularly in environments where medium-load-bearing pavements are sufficient. These include:
Urban Footpaths and Sidewalks
Residential Driveways and Courtyards
Low-Volume Internal Roads
Public Parks and Landscaped Areas
Temporary or Semi-Permanent Construction Flooring

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