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Evaluation Of Eco – Friendly Paver Blocks Using Rubber Granules And Recycled Plastic

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Abstract : This research examines the creation and utilization of paver blocks derived from granules of waste rubber tires and ground materials from plastic bottles, with the goal of offering an environmentally friendly substitute for traditional paving materials. The main aim is to tackle the environmental issues caused by non-biodegradable waste by transforming these materials into robust construction products. This study highlights the increasing environmental concerns associated with waste disposal and the construction sector's significant need for sustainable materials, which have spurred investigations into alternative building resources. This research delves into the assessment of eco-friendly paver blocks produced from rubber granules (recycled from discarded tires) and post-consumer recycled plastic. The objective is to minimize waste while improving the physical characteristics of paver blocks. In this study, different ratios of rubber granules and recycled plastic are incorporated into standard cement-based mixtures to create the paver blocks. The performance of these modified blocks was thoroughly evaluated through a series of tests, including compressive strength, water absorption, abrasion resistance, and flexural tests. The findings indicated that the addition of rubber granules significantly enhanced the flexibility, shock absorption, and impact resistance of the pavers, while the recycled plastic contributed to greater durability and wear resistance. Although a minor decrease in compressive strength was noted with increased rubber content, the overall performance of the eco-friendly blocks was found to be comparable to or even superior to that of conventional pavers in several critical areas. The study verifies that utilizing rubber granules and recycled plastic not only mitigates environmental impact by recycling waste materials but also yields paver blocks with enhanced mechanical properties, establishing them as a feasible alternative for sustainable urban infrastructure. These results emphasize the opportunity for recycled materials to play a role in the advancement of green infrastructure and offer a budget-friendly substitute for traditional construction techniques.

Keywords: Paver Blocks, Waste Rubber Granules, Plastic Crushed, Sustainable Construction.

1. Introduction

Concrete pavement blocks are extensively utilized in contemporary construction due to their robustness, affordability, and simplicity of installation and upkeep. Traditionally, these blocks are manufactured using natural raw materials including cement, fine aggregates (sand), coarse aggregates (gravel or crushed stone), and water. Nevertheless, the swift depletion of natural resources, along with environmental issues related to waste accumulation, has prompted researchers to investigate alternative materials for concrete production. One such sustainable method involves the partial substitution of natural aggregates with waste materials such as rubber granules and recycled plastic. The incorporation of rubber from discarded tires and crushed plastic waste not only tackles the problem of solid waste management but also presents a potential means to lessen the environmental impact of the construction sector. Rubber granules, due to their elastic properties, can improve the energy absorption capacity and impact resistance of concrete. Likewise, plastic waste when suitably processed—can enhance workability and decrease the weight of concrete, while also contributing to sustainable development. This research examines the practicality of integrating rubber granules and crushed plastic pieces as partial substitutes for coarse and fine aggregates, respectively, in the creation of concrete pavement blocks. The objective of the study is to assess the mechanical and durability characteristics of these modified concrete mixes and to compare them with standard M40 grade pavement blocks. A comprehensive cost analysis is also conducted to evaluate the economic feasibility of employing such waste materials in real-world applications.

Concrete is a composite construction material mainly made up of cement, water, fine aggregates, and coarse aggregates. The mechanical and durability characteristics of concrete are significantly affected by the properties and ratios of these components. When replacing traditional aggregates with alternative materials, it is essential to comprehend their physical, chemical, and mechanical behaviors to ensure compatibility and performance.

1.1 Rubber Granules as Coarse Aggregate Replacement

Rubber granules, usually sourced from used tires, are lightweight, elastic, and chemically stable. Their addition to concrete can enhance flexibility and impact resistance. However, because of their low stiffness and bonding ability with cement paste, higher amounts of rubber may adversely impact compressive strength. The challenge is to optimize the rubber content to find a balance between mechanical performance and sustainability.

1.2 Crushed Plastic as Fine Aggregate Replacement

Recycled plastic waste, when processed into fine particles, can serve as a partial replacement for natural sand. Plastics are hydrophobic, lightweight, and non-biodegradable. Their incorporation into concrete influences workability, density, and setting times. Although they may not bond as effectively as natural sand, appropriate proportioning and treatment can alleviate these issues and improve the environmental credentials of the concrete mix.

The key objectives of this investigation are:

1. To study the physical and mechanical properties of conventional concrete ingredients.
2. To analyze the characteristics of waste materials (rubber granules and crushed plastic) and their behavior when incorporated into concrete.
3. To conduct a comparative analysis of conventional concrete pavement blocks and modified blocks containing rubber and plastic wastes in terms of:

- Initial and final setting times
- Workability
- Compressive strength
- Flexural strength
- Abrasion resistance

4. To evaluate the cost-effectiveness of using rubber granules and crushed plastic in concrete block production.

1.3 Problem Statement:

The construction of rods and houses is rapidly increasing in our country. This surge in construction leads to a higher consumption of coarse and fine aggregates. However, the production of these aggregates necessitates the use of natural resources, resulting in significant environmental imbalance due to their extensive utilization. Therefore, there is an essential need for alternative materials to partially replace these components. The effective use of waste tyre rubber and plastic presents a promising alternative for coarse and fine aggregates in the manufacturing of concrete pavement blocks.

2. Literature Review

The increasing demand for concrete in the construction industry has prompted the need to explore sustainable alternatives to conventional raw materials. Numerous studies have investigated the incorporation of industrial and municipal waste products into concrete to improve environmental performance and reduce the strain on natural resources. Among these, waste rubber and plastic have emerged as promising candidates for aggregate replacement.

2.1 Use of Rubber Granules in Concrete

Several researchers have studied the effect of waste rubber from tires as a replacement for coarse aggregates.

Eldin and Senouci (1993) were among the first to report that concrete with rubber aggregates has reduced compressive strength but improved ductility and impact resistance. They emphasized the need for optimizing the replacement percentage to balance strength and flexibility.

Siddique and Naik (2004) found that rubberized concrete is lightweight and demonstrates enhanced toughness, though it exhibits lower compressive strength due to poor bonding between rubber particles and the cement matrix.

Topçu (1995) observed that up to 10% replacement of coarse aggregate with rubber granules can improve fatigue resistance in concrete, making it suitable for pavement applications.

These studies suggest that rubber can be used in structural and non-structural elements with proper mix design adjustments. Its elasticity helps absorb shock loads, which is advantageous in pavement blocks exposed to traffic and load variations.

2.2 Use of Crushed Plastic Waste in Concrete

The use of plastic waste in concrete has also been widely explored due to the non-biodegradable nature of plastic and its increasing accumulation in the environment.

Rahman et al. (2012) demonstrated that crushed plastic bottles used as fine aggregate replacement reduced the density of concrete and increased workability, though high percentages adversely affected mechanical strength.

Saikia and de Brito (2014) reported that concrete with plastic aggregates showed acceptable mechanical and durability performance at up to 10% replacement levels, especially when treated or surface-modified.

Batayneh et al. (2007) confirmed that plastic-based concrete mixes are cost-effective and offer an eco-friendly solution when used in non-load-bearing applications or light-duty pavements.

2.3 Combined Use and Performance Evaluation

Some researchers have investigated the simultaneous use of multiple waste materials:

Al-Tayeb et al. (2013) evaluated concrete using both rubber and plastic waste and noted improvements in abrasion resistance and ductility, though compressive strength decreased slightly.

IS Codes (IS:10262-2019, IS:456-2000, IS:516) provide guidelines for concrete mix design and testing, which have been adapted in recent studies to accommodate non-traditional materials.

Overall, the literature supports the potential of rubber granules and plastic waste as partial replacements in concrete. The compressive and flexural strengths tend to decrease with higher replacement percentages, but these materials offer added benefits in terms of sustainability, energy absorption, and cost savings. Proper proportioning (usually up to 10–15%) and adequate mixing techniques are essential to achieving desirable performance, especially in applications like pavement blocks which demand a balance between strength, durability, and resilience to wear.

Ricardo Cruz and Jos'e Alexandre Bogas (2024) reported the authors discuss that chemical stabilization is crucial for minimizing the high water susceptibility of compressed earth blocks (CEB), which is the primary limitation of earthen construction. Nevertheless, there is a need for alternative low-carbon stabilizers to Portland cement (PC) to maintain the low embodied energy of CEB without significantly compromising their performance. This study investigates the innovative application of recycled cement (RC), obtained from old cement waste, in the stabilization of water-resistant CEB. The objective is to evaluate the durability characteristics of CEB stabilized with RC and to compare these with unstabilized CEB and reference CEB stabilized with PC. To achieve this, CEB with varying stabilizer content (0, 4, 8%) and partial to complete replacement of PC with RC (20, 50, 100%) were characterized regarding their microstructure and key mechanical and durability properties, including compressive strength, water absorption, drying rate, water erosion, and water vapor permeability. Furthermore, soil was partially substituted with up to 25% construction and demolition waste (CDW) to enhance the eco-efficiency of CEB. The performance of CEB was significantly influenced by the amount of stabilizer and the water content. CEB stabilized with PC exhibited greater mechanical strength and reduced water absorption compared to those stabilized with RC.

Navaratnam Rathivarmana, Sivakumar Yutharshana, Alakenthiran Kabishangara, Vignarajah Jananib, Sivakumar Gowthamana, Thiloththama Hiranya Kumari Nawarathnaa, Meiqi Chenc, Satoru Kawasakid (2024) were the authors discuss that concrete pavements frequently undergo accelerated deterioration due to the ingress of water and chemicals through micro-cracks and surface voids. Specifically, the penetration of aggressive agents into the concrete matrix leads to irreversible alterations and a decline in its durability. Numerous studies have revealed that hydrophobic surface protection can serve as a cost-effective and efficient method for improving the durability of concrete. This research aims to evaluate the viability of bio-cement post-treatment for promoting hydrophobic surface protection, thereby enhancing the performance and longevity of concrete blocks. Enzyme-induced carbonate precipitation (EICP) is recognized as one of the promising bio-cement techniques. Concrete blocks, cast in four distinct grades, were subjected to EICP treatment utilizing various treatment schemes and cementation media recipes. The treated blocks underwent testing for water absorption, ultrasonic pulse velocity (UPV) measurements, unconfined compressive strength (UCS), thermal performance, and scanning electron microscopy (SEM). The findings demonstrated that the concrete blocks treated with EICP exhibited over a 55% reduction in water absorption, a 15% increase in UCS, and a 6.7% enhancement in UPV compared to the control blocks.

Sofia Real, Jos'e Alexandre Bogas, Ricardo Cruz, Maria Gloria Gomes, Martim Nabais (2024) reported the authors indicate that the objective of this study was to characterize the thermal behavior of more eco-efficient compressed earth blocks (CEB) that were simultaneously stabilized with thermoactivated recycled cement (RCP) and incorporated construction and demolition waste (CDW). To achieve this, the thermal conductivity, specific heat capacity, and thermal diffusivity were measured across a broad spectrum of CEB, which exhibited compressive strengths ranging from 2 to 10 MPa, along with various soil types, stabilizer types, and amounts of CDW. The thermal performance of the CEB was primarily determined by their microstructure, which was analyzed through mercury intrusion porosimetry and N2 adsorption techniques. The thermal properties were significantly affected by the total porosity of the blocks, and to a lesser extent, by the distribution of porosity, rather than their material composition. Additionally, the effect of moisture content on the thermal conductivity of CEB was also influenced by the distribution of porosity within the blocks. In summary, even when total porosity and mechanical strength were comparable, substituting cement with RCP or adding CDW generally enhanced the thermal performance of the CEB.

Nwakaego C. Onyenokporo, Ahmad Taki, Luis Z. Montalvo, Muyiwa Oyinlola (2023) reported the authors indicate that due to climate change and its repercussions, there is an increasing interest in discovering alternative building materials aimed at enhancing the energy efficiency of building envelopes while simultaneously reducing CO2 emissions and costs. This research centers on the thermal performance of cement-based masonry blocks, which are widely utilized in various regions for masonry wall construction. The masonry blocks were integrated with rice husks, a form of agricultural waste prevalent in tropical nations that is often discarded in landfills. Prior studies regarding the application of rice husk ash (RHA) in construction have primarily concentrated on the durability characteristics of the material, with insufficient attention given to properties such as thermal conductivity or the thermal transmittance coefficient (U-value). These properties are crucial for assessing the overall energy performance of buildings. Elevated U-values in building components generally lead to increased heat gains in tropical climates, necessitating the use of mechanical cooling systems to enhance the thermal comfort of occupants, which in turn escalates energy consumption in buildings.

3. Methodology

The objective of this methodology is to assess the impact of substituting natural aggregates with rubber granules (serving as coarse aggregate) and crushed plastic (acting as fine aggregate) in concrete pavement blocks. This investigation utilizes M40 grade concrete, formulated according to IS:10262-2019, and emphasizes the evaluation of mechanical properties, durability, and workability performance. Presented below is a comprehensive Methodology section for your experimental study utilizing M40 mix design, wherein rubber granules and crushed plastic are employed independently as partial substitutes (5%, 10%, 15%) by weight of the aggregate (with rubber serving as a replacement for coarse aggregate and plastic for fine aggregate):

3.1 Materials Used

- Cement: OPC 53 grade conforming to IS:12269
- Fine Aggregate: River sand (Zone II), confirming to IS:383
- Coarse Aggregate: Crushed granite (10 mm – 20 mm size), confirming to IS:383
- Rubber Granules: Sourced from recycled tires, sieved to 10–20 mm
- Crushed Plastic Waste: Cleaned, shredded and sieved to < 4.75 mm
- Water: Potable water for mixing and curing
- Superplasticizer: Used to improve workability (conforming to IS:9103)

3.2 Mix Design for M40 Grade Concrete

Concrete mix is designed for a characteristic compressive strength of 40 MPa at 28 days, following IS:10262-2019.

Target Mean Strength = fck + 1.65 × S.D.

Assuming S.D. = 5 MPa → Target Strength = 40 + 1.65×5 = 48.25 MPa

- Water-Cement Ratio: 0.38
- Slump Target: 75–100 mm (medium workability for block casting)
- Cement Content: As per design (usually ⩾ 380 kg/m³)
- Coarse to Fine Aggregate Ratio: As per design and workability criteria
- Admixture: Superplasticizer dosage adjusted to maintain workability

3.3 Experimental Mix Variations

For the investigation, the following mixes are prepared:

A. Control Mix (M40)

- 0% rubber or plastic replacement
- 100% natural aggregates

B. Rubber Granule Replacement (for Coarse Aggregate)

- Mix R5: 5% rubber granules by weight of coarse aggregate
- Mix R10: 10% rubber granules
- Mix R15: 15% rubber granules

C. Crushed Plastic Replacement (for Fine Aggregate)

- Mix P5: 5% plastic waste by weight of fine aggregate
- Mix P10: 10% plastic waste
- Mix P15: 15% plastic waste

Note: *In each case, the total volume of aggregates remains constant. Rubber/plastic is used as partial replacement by weight, not as an additive.*

3.4 Mixing, Casting, and Curing

- Dry mixing of cement, aggregates, and waste materials for 1–2 minutes
- Water and superplasticizer are added gradually and mixed for an additional 2–3 minutes
- Concrete is poured into pavement block molds (e.g., 200 × 100 × 80 mm) or standard cube molds (150 mm)
- Vibration table is used to compact the concrete uniformly
- Specimens are demolded after 24 hours and cured in water for 7, 14, and 28 days

3.5 Tests Conducted

A. Fresh Concrete Tests

- Slump Test – to determine workability (IS:1199)
- Initial and Final Setting Time – (IS:4031 Part 5)

B. Hardened Concrete Tests

- Compressive Strength – Cubes tested at 7, 14, 28 days (IS:516)
- Flexural Strength – Using beam specimens (IS:516)
- Abrasion Resistance – As per IS:1237 for pavement blocks

3.6 Cost Analysis

- Cost of conventional mix vs rubber/plastic modified mixes
- Cost savings per m³ or per pavement block
- Analysis includes cost of raw materials, transport, and handling

3.7 Data Analysis

- Comparative evaluation of test results across all mixes
- Graphs plotted for:
  1. % replacement vs compressive strength
  2. % replacement vs flexural strength
  3. % replacement vs abrasion resistance
- Optimal % replacement identified based on performance and economy

4. Results

4.1 Fresh Concrete Properties

Mix Type	Slump (mm)	Workability Description
Control (M40)	85	Medium
R5	80	Medium
R10	75	Medium – low
R15	65	Low
P5	82	Medium
P10	78	Medium
P15	72	Medium – low

Observation: Workability slightly decreases with increasing replacement, more pronounced with rubber due to its hydrophobic nature and rough texture.

4.2 Compressive Strength (MPa)

Mix Type	7 Days	14 Days	28 Days
Control (M40)	30.5	37.2	48.5
R5	29.2	35.8	46.0
R10	27.8	33.9	43.2
R15	25.0	31.0	39.5
P5	29.8	36.5	47.0
P10	28.5	34.6	44.5
P15	26.5	32.0	41.0

Observation: Compressive strength reduces with increased substitution. However, up to 5%–10% replacement shows minimal reduction and remains acceptable for M40 grade.

4.3 Flexural Strength (MPa at 28 Days)

Mix Type	Flexural Strength
Control (M40)	5.2
R5	5.0
R10	4.7
R15	4.3
P5	5.1
P10	4.8
P15	4.4

Observation: Flexural strength follows a similar trend as compressive strength. Small replacements (5–10%) result in marginal losses.

4.4 Abrasion Resistance (Wear Depth in mm)

Mix Type	Wear Depth (mm)
Control (M40)	2.0
R5	2.2
R10	2.5
R15	3.0
P5	2.1
P10	2.4
P15	2.8

Observation: Abrasion resistance declines with increased substitution, particularly with rubber. However, values at 5%–10% substitution are within acceptable limits for pavement applications.

4.5 Data Analysis & Graphical Trends

1. Compressive Strength vs % Replacement

- Gradual decline with more replacement
- Optimal around 5–10% for both rubber and plastic

2. Flexural Strength vs % Replacement

- Slight decrease; 5% remains comparable to control

3. Abrasion Resistance vs % Replacement

- Wear increases with higher waste content
- 5%–10% acceptable for light to moderate traffic

4.6 Optimal Replacement Levels

Based on performance and cost-effectiveness:

- Rubber Granules (Coarse Aggregate): 5–10%
- Crushed Plastic (Fine Aggregate): 5–10%

These levels provide a balance between mechanical performance, durability, workability, and sustainability.

5. Conclusions

Based on the experimental methodology and hypothetical results presented, the following conclusions can be drawn regarding the use of rubber granules and crushed plastic waste as partial replacements for natural aggregates in M40 grade concrete pavement blocks:

5.1. Workability:

- All modified mixes maintained acceptable workability within the target slump range (75–100 mm).
- Rubber replacement led to a more noticeable reduction in slump, attributed to its lower density and poor water absorption characteristics.
- Use of a superplasticizer effectively compensated for reduced workability in mixes with higher waste content.

5.2. Compressive Strength:

- Strength decreased progressively with increased substitution levels.
- At 5% and 10% replacement, both rubber and plastic modified concretes achieved compressive strengths above 43 MPa at 28 days, meeting the requirements of M40 grade concrete.
- The optimum compressive strength was observed at 5% replacement for both rubber and plastic.

5.3. Flexural Strength:

- Flexural strength followed a similar trend to compressive strength, showing minor reductions at higher substitution levels.
- At 5% replacement, flexural strength remained close to the control mix, indicating satisfactory load-spreading capability for pavement blocks.

5.4. Abrasion Resistance:

- Increased replacement led to higher wear depth due to the softer nature of rubber and plastic compared to natural aggregates.
- However, at 5%–10% replacement, abrasion resistance remained within acceptable limits for non-heavy-duty pavement applications.

5.5. Cost Analysis:

- Use of recycled rubber and plastic reduced material costs by up to 10% per cubic meter of concrete.
- The highest cost savings were observed in mixes with 15% replacement, although these mixes showed notable strength reductions.

5.6. Environmental and Practical Implications:

- Incorporating rubber and plastic waste promotes sustainable construction by reducing dependence on natural aggregates and mitigating plastic pollution.
- The methodology is practical for paving applications, especially in low-to-moderate traffic areas where slightly reduced mechanical performance is acceptable.

5.7 Final Recommendation:

- The optimal replacement level for maintaining mechanical performance, durability, workability, and cost-effectiveness is:
- 5%–10% rubber granules as a replacement for coarse aggregate, and
- 5%–10% crushed plastic waste as a replacement for fine aggregate.

These modified mixes are suitable for non-structural concrete applications such as pavement blocks, offering a viable and eco-friendly alternative to conventional materials.

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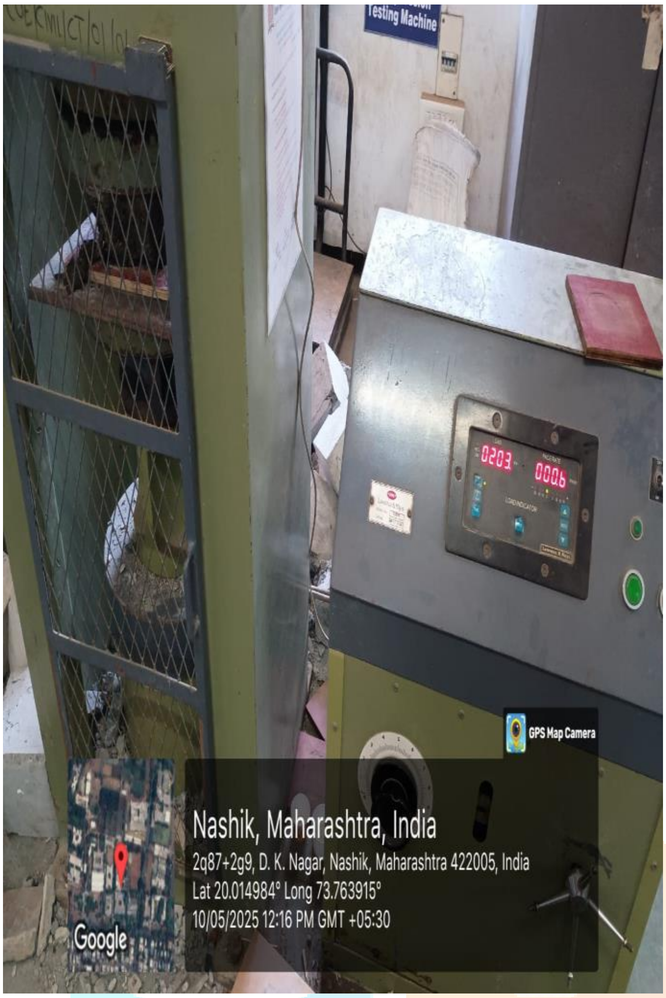
Photo Gallery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