



DESIGN OF PERVIOUS PAVER BLOCKS INCORPORATING SUGARCANE BAGASSE ASH AND RECYCLED ASPHALT PAVEMENT AGGREGATES

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ABSTRACT

The rapid urbanization and growth in infrastructure development have led to an escalating demand for construction materials, often resulting in the depletion of natural resources. Additionally, the construction industry is one of the significant contributors to landfill waste, which aggravates environmental concerns. Thus, there is an increasing need for sustainable alternatives in construction materials that are both economically viable and environmentally friendly. The study aims to address two significant issues: waste management and sustainable construction. By utilizing sugarcane bagasse ash (SCBA), a by-product of the sugar industry, and Recycled Asphalt Pavement (RAP) aggregates, waste from road renovation or construction. The study aims to reduce landfill waste. Secondly, by developing pervious paver blocks, the study aspires to contribute to the sustainability of urban infrastructure by allowing better water management and utilizing waste materials that are usually considered non-recyclable.

Pervious paver blocks shall be developed by using sugarcane bagasse ash and recycled asphalt pavement aggregates. Important engineering properties of paver blocks shall be evaluated to check the feasibility of paver blocks of different shapes. The successful development of pervious paver blocks using sugarcane

bagasse ash and recycled asphalt pavement aggregates holds significant promise for sustainable urban infrastructure. The findings of this research will contribute to advancing environmentally friendly construction practices and addressing storm water management challenges.

CHAPTER 1 – INTRODUCTION

1.1 GENERAL

The rapid urbanization and growth in infrastructure development have led to an escalating demand for construction materials, often resulting in the depletion of natural resources. Additionally, the construction industry is one of the significant contributors to landfill waste, which aggravates environmental concerns. Thus, there is an increasing need for sustainable alternatives in construction materials that are both economically viable and environmentally friendly. The study aims to address two significant issues: waste management and sustainable construction. By utilizing sugarcane bagasse ash, a by-product of the sugar industry, and Recycled Asphalt Pavement (RAP) aggregates, waste from road renovation or construction. The study aims to reduce landfill waste. Secondly, by developing pervious paver blocks, the study aspires to contribute to the sustainability of urban infrastructure by allowing better water management and utilizing waste materials that are usually considered non-recyclable.

By integrating waste materials into the construction of pervious paver blocks, this study aims to develop a comprehensive solution that addresses both environmental concerns and infrastructural needs. Through rigorous testing and analysis, the study intends to prove the viability of these sustainable construction materials for real-world applications. The present study aims to explore sustainable alternatives in construction materials by developing pervious paver blocks using sugarcane bagasse ash and reclaimed asphalt pavement (RAP) aggregates. Recycling waste pavement materials is a sustainable alternative to road maintenance and rehabilitation. Reusing RAP is an economically attractive option [1]. Sugarcane bagasse ash serves as a partial replacement for cement, while RAP aggregates substitute for traditional aggregates. These blocks are designed to offer efficient water infiltration and thus contribute to groundwater recharge, mitigating surface runoff and reducing the risk of urban flooding. By examining mechanical properties such as compressive strength, water absorption, and permeability, the study evaluates the performance of these sustainable paver blocks against traditional ones. Through this research, we intend to prove the viability of incorporating waste materials into construction, aiming for a comprehensive solution that fulfills both environmental and infrastructural needs.

Paving block is a widely used pavement material due to its long service life, fast and easy production and easily replaced for maintenance purpose. The huge production volume of paving blocks consumes large amount of natural aggregates such as sand and granite.

1.2 PERVIOUS PAVER BLOCKS

Pervious paver blocks, a type of permeable pavement system, have garnered significant attention in recent years due to their ability to mitigate storm water runoff, reduce flooding, improve water quality, and contribute to sustainable urban development. This review explores the existing literature on pervious paver blocks, encompassing their design, materials, construction methods, performance, and environmental impact.

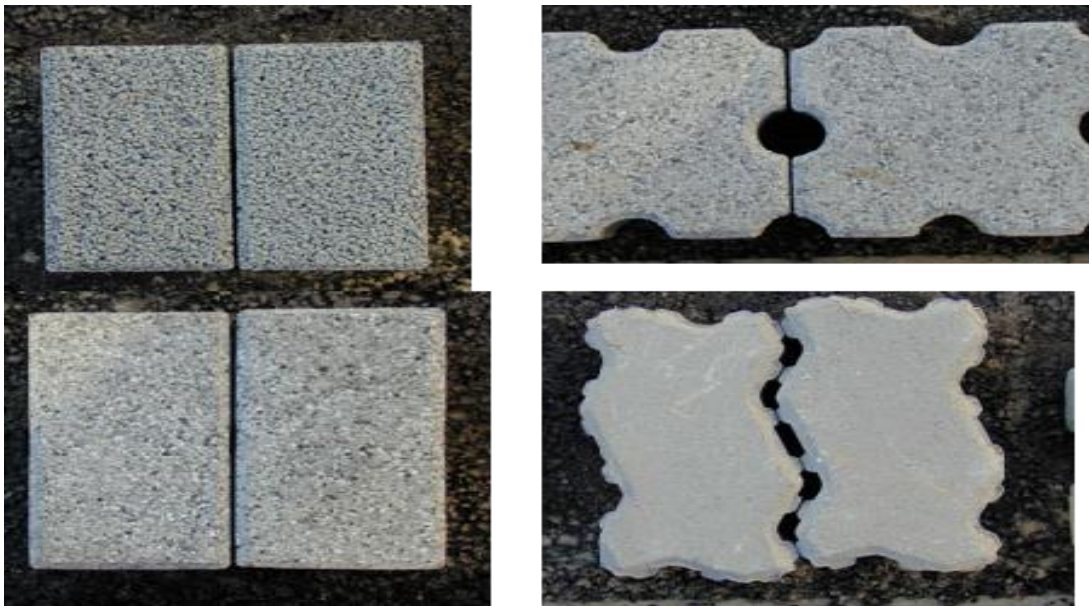


Figure 1.1 Different shape of pervious paver blocks

1.3 OBJECTIVES

- Characterizing the properties of sugarcane bagasse ash and recycled asphalt pavement aggregates.
- Developing optimized mix designs for pervious paver blocks using these sustainable materials.
- Evaluating the structural and hydraulic performance of the designed paver blocks.
- To compare the performance of different shapes of paver blocks.

1.4 SCOPE OF WORK

The scope of the present work includes the study of the following topics:

- To review the utilization of alternative materials as the ingredient for paver block to cut down both the consumption of natural resources and disposal of various waste.

- Investigating the feasibility of bagasse ash as a raw material for paver block.
- Developing pervious paver blocks, the study aspires to contribute to the sustainability of urban infrastructure by allowing better water management and utilizing waste materials that are usually considered non-recyclable

1.5 NEED OF PRESENT STUDY

A large quantity of asphalt pavements are stripped off the surface as part of reconstruction of new pavements. Some percent of asphalt pavements are milled and processed to produce recycled asphalt. Recycled asphalt has applications in bituminous pavement as replacement for virgin aggregates. However, not all the recycled asphalt produced is consumed in bituminous pavement due to various reasons. In the context of sustainability, alternative sources should be identified to utilize recycled asphalt. Past studies have used recycled asphalt in cement concrete but results were found to be inferior narrowing the application areas. In this study, pervious paver blocks (PPBs) shall be produced with recycled asphalt and bagasse ash. PPBs provide a broad application areas ranging from pedestrian walkways to parking lots, which can escalate the consumption of recycled asphalt in addition to bituminous mixtures reducing the consumption of natural aggregates. PPBs will also attract players from local market creating more awareness regarding recycling.

CHAPTER 2 – LITERATURE REVIEW

2.1 GENERAL

A literature review related to paver blocks, pervious paver blocks, and pervious concrete is discussed below:

1. *“Nur Hidayah, A. H., Hasanan, M. N., & Ramadhansyah, P. J. (2015). Physical Properties of Porous Concrete Paving Blocks with Different Sizes of Coarse Aggregate. Advanced Materials Research, 1113, 86-92.”*[2]

- This research studies the properties of Porous Concrete Paving Blocks (PCPB) with different sizes of coarse aggregate.
- Three different sizes of coarse aggregate were used; 1) CA 5 – 10 mm as a control, 2) CA 5– 8 mm and 3) CA 8 – 10 mm.

- It was found that the size of coarse aggregate affects the strength and porosity of the blocks. The strength was reduced approximately in the range 4 % to 12 % from the control blocks. However, it is vice versa with porosity result which porosity of the blocks increased in between 5 % to 10 %.
- This shows that the blocks suitable for use in vehicle area where help in reduce the water ponding on pavement surface and increased the skid resistance between the vehicle tires and pavement.

2. “Singh, S., Shintre, D., Ransinchung RN, G. D., & Kumar, P. (2018). *Performance of fine RAP concrete containing flyash, silica fume, and bagasse ash. Journal of Materials in Civil Engineering, 30(10), 04018233.*”[3]

- In the present study, the adverse effect of dust on the properties of concrete containing 75% fine reclaimed asphalt pavement (RAP) (75F) (obtained using an uncontrolled milling technique) is minimized by using higher doses of superplasticizers (SP) in combination with silica fume (SF), flyash (FA), and bagasse ash (BG).
- It was found that the 75F mix requires at least double the amount of SP to achieve the recommended slump value.
- Moreover, improvement in the fresh state was found to enhance the hardened properties of the 75F mix significantly.
- Inclusion of the considered mineral admixtures was found to further enhance the compressive strength, splitting tensile strength, and abrasion resistance; however, inclusion of BG and FA resulted in comparable flexural strength.
- The determination of water absorption and permeable voids was found to be affected by the asphalt film, suggesting this testing should be conducted at a temperature lower than 50°C.

3. “Yeo, J. S., Koting, S., Onn, C. C., & Mo, K. H. (2020). *An overview on the properties of eco-friendly concrete paving blocks incorporating selected waste materials as aggregate. Environmental Science and Pollution Research, 28, 29009-29036.*”[4]

- This paper thus analyses published works and provides a summary of knowledge on the effect of utilizing selected waste materials such as soda-lime glass, cathode ray tube (CRT) glass, recycled concrete waste, marble waste, crumb rubber (CR) waste and waste foundry sand (WFS) as aggregate replacement in concrete paving blocks fabrication.
- Soda-lime glass, CRT glass, pre-treated RCA and calcined WFS have the potential to be utilized in high quantities (30–100%), normal RCA and marble waste can be incorporated in moderate amount (30%) while CR waste and WFS is limited to low amount (6–10%).
- In overall, the usage of wastematerials as aggregate replacement has good potential for producing eco-friendly concrete paving block towards the sustainable development of construction material.

4. “Saboo, N., Prasad, A. N., Sukhija, M., Chaudhary, M., & Chandrappa, A. K. (2020). *Effect of the use of recycled asphalt pavement (RAP) aggregates on the performance of pervious paver blocks (PPB). Construction and Building Materials, 262, 120581.*”[5]

- This study describes an investigation into the assessment of performance and suitability of pervious paver blocks (PPB) using reclaimed asphalt pavement (RAP) aggregates.
- Virgin aggregates (VA) and RAP were mixed in three different proportions (0–100, 50–50 and 100–0) using two different aggregate gradations (G1-coarser and G2-finer) to fabricate chamfered PPBs using a standard factory method.
- Three different water-cement ratio (w-c ratio) (0.25, 0.30 and 0.35) were used for the production of the specimens.
- The properties of PPBs was characterized by measuring porosity, density, dynamic modulus of elasticity using UPV, compressive strength and abrasion by Cantabro loss.
- Porosity and density measurements had higher variability with no strong inferences on the effect of mix attributes.

- The overall results indicate that up to 50% RAP can be used in pervious concrete paver block with G1 gradation, which will increase the sustainability aspect of pervious concrete.

5. “Mohamad, H. M., Bolong, N., Saad, I., Gungat, L., Tioon, J., Pileh, R., & Delton, M. (2022). *Manufacture of concrete paver block using waste materials and by-products: a review. GEOMATE Journal, 22(93), 9-19.*”[6]

- Henceforth, this research is conducted to study and investigate the potential of using waste materials as a partial substitute for aggregate in producing concrete paving block (CPB).
- The application of various waste materials such as plastic, steel slag, and crumb rubber is excellent.
- Compressive strength of paver blocks with different rates of waste steel aggregates and utilizing elastic cushions shows paver blocks give up to 50% more strength quality than customary paver blocks.
- In terms of the use of industrial waste materials, as a substitute material by reducing the percentage amount of the weight of the cement with the composition ratio varies based on the comparative volume category of the paving block aggregate such as 0%, 5%, 10%, 15%, 20%, and 25% are more applicable.

The overall summary is presented in Table 2.1.

Table 2. 1 Summary of Literature

Author	Material	Test Conducted	Remarks
Hidayah et al., 2015	Coarse aggregate	Density, compressive strength, porosity and skid resistance test	<ul style="list-style-type: none"> • It was found that the size of coarse aggregate affects the strength and porosity of the blocks. The strength was reduced approximately in the range 4 % to 12 % from the control blocks.

			<ul style="list-style-type: none"> • However, it is vice versa with porosity result which porosity of the blocks increased in between 5 % to 10 %.
Singh et al., 2018	RAP, silica fume (SF), flyash (FA), and bagasse ash (BG).	Concrete slump, density, compressive strength, tensile strength, water absorption	<ul style="list-style-type: none"> • Improvement in fresh properties of concrete containing 75% fine RAP aggregates owing to the addition of extra doses of superplasticizers was found to enhance the mechanical properties by approximately 20%. • Moreover, replacement of Portland cement by bagasse ash and flyash up to 10% may also be carried out to further make the concrete cheaper and more durable.
Author	Material	Test Conducted	Remarks
Yeo et al., 2020	Recycled concrete waste, marble waste, crumb rubber waste and waste foundry sand	Aggregate replacement in concrete paving blocks fabrication. Water absorption	<ul style="list-style-type: none"> • The usage of waste materials as aggregate replacement has good potential for producing eco-friendly concrete paving block towards the sustainable development of construction material. • Effect on the water absorption varies, although it was marginal when waste materials were utilized at their optimum contents.

Saboo et al., 2020	Reclaimed asphalt pavement (RAP)	Porosity, density, compressive strength and abrasion	<ul style="list-style-type: none"> The overall results indicate that up to 50% RAP can be used in pervious concrete paver block with G1 gradation (coarser), which will increase the sustainability aspect of pervious concrete.
Mohamad et al., 2022	Plastic, steel slag, and crumb rubber	Compressive strength	<ul style="list-style-type: none"> The mixture design and cement ratio of mix proportions will determine the compressive strength of the paver block itself. The use of Sinabung ash and lime as a cement substitution material can increase the compressive strength of the paving block.

2.2 RESEARCH GAP

- Past studies have used recycled asphalt in cement concrete but results were found to be inferior narrowing the application areas.
- Applications of sugarcane bagasse ash in construction material are very limited. Sugarcane bagasse ash (SCBA) has gained attention as a supplementary cementitious material in construction due to its pozzolanic properties. While its use is less common compared to other supplementary cementitious materials like fly ash or silica fume, SCBA has potential applications in construction materials
- PPBs provide a broad application areas ranging from pedestrian walkways to parking lots, which can escalate the consumption of recycled asphalt in addition to bituminous mixtures reducing the consumption of natural aggregates.

CHAPTER 3 – MATERIALS AND METHODOLOGY**3.1 MATERIALS****3.1.1 Aggregates**

- Natural aggregates (NA) and Recycled Asphalt Pavement Aggregates (RAP)

Natural aggregates, such as crushed stone, gravel, and sand, play a crucial role in the composition of pervious paver blocks. These aggregates provide structural integrity and stability while maintaining the desired porosity essential for effective water permeability.

Reclaimed Asphalt Pavement (RAP) is an innovative and sustainable material for use in pervious paver blocks. RAP is composed of recycled asphalt materials from old road surfaces, offering a practical solution to reduce waste and conserve natural resources. Incorporating RAP into pervious paver blocks can enhance the environmental profile of the pavement system by minimizing the need for new raw materials and lowering carbon emissions associated with asphalt production.

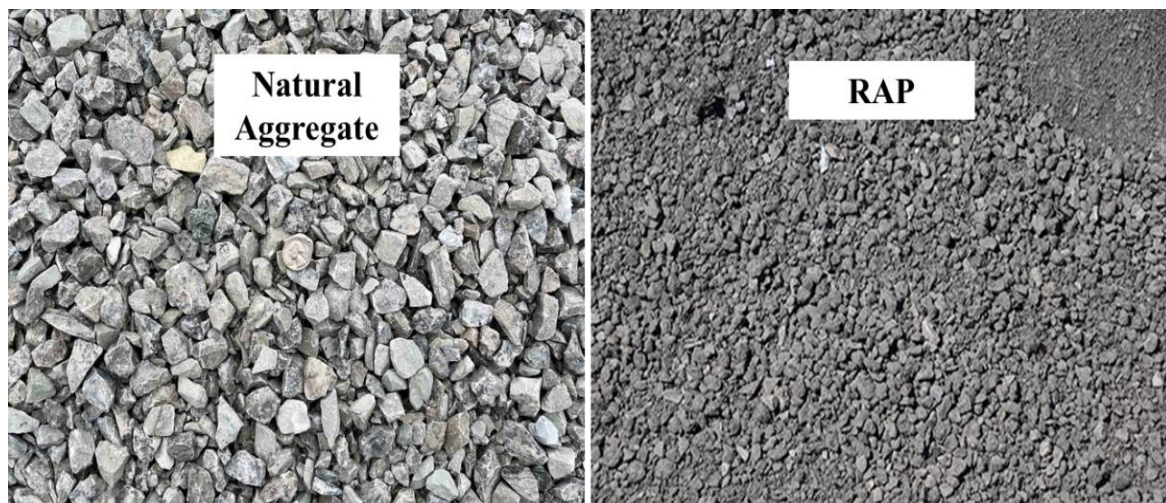


Figure 3. 1 Natural aggregate and RAP

3.1.2 Sugarcane Bagasse Ash

Sugarcane Bagasse Ash (SCBA), a byproduct of the sugar industry, is a valuable supplementary material for pervious paver blocks, promoting sustainability and waste utilization. When used as a partial replacement for Portland cement, SCBA enhances the eco-friendliness of the paver blocks by reducing the carbon footprint associated with cement production. This ash, rich in silica, can improve the pozzolanic activity, contributing to the strength and durability of the concrete mix.



Figure 3. 2 Sugarcane Bagasse Ash (SCBA)

3.1.3 Cement

Cement is a vital component in the production of pervious paver blocks, serving as the key binder that holds the mixture of aggregates together, ensuring the structural integrity and strength of the final product. In pervious paver blocks, cement is mixed with coarse aggregates and minimal fine materials to create a porous matrix that allows water to permeate through the surface.



Figure 3. 3 Cement

3.1.4 Mix Proportion

The selection of specific mix proportions is a critical step in evaluating the performance and suitability of pervious concrete paver blocks (PCPB). By carefully choosing the mix proportions, engineers and researchers can assess various characteristics such as strength, permeability, and durability of the paver blocks under different conditions. This deliberate approach allows for the optimization of the concrete mix to meet the specific requirements of the intended application, whether it be for pedestrian walkways, parking lots, or stormwater management systems. Additionally, studying the performance of PCPBs with different mix proportions provides valuable insights into their behavior over time, aiding in the refinement of design

guidelines and construction practices. Through systematic experimentation and analysis of mix proportions, stakeholders in the construction industry can make informed decisions to enhance the performance and sustainability of pervious concrete paver blocks in diverse applications.

Table 3. 1 Mix Proportions

Sr. No.	Nomenclature	Aggregate		Binder	
		Natural	RAP	SCBA	Cement
1	NA100+RAP0+SCBA0	100	0	0	100
2	NA100+RAP0+SCBA10	100	0	10	90
3	NA100+RAP0+SCBA20	100	0	20	80
4	NA50+RAP50+SCBA0	50	50	0	100
5	NA50+RAP50+SCBA10	50	50	10	90
6	NA50+RAP50+SCBA20	50	50	20	80
7	NA0+RAP100+SCBA0	0	100	0	100
8	NA0+RAP100+SCBA10	0	100	10	90
9	NA0+RAP100+SCBA20	0	100	20	80

3.2 TESTS

3.2.1 Workability of concrete mix:

Workability in concrete refers to its ease of handling, placing, and shaping during construction, influenced by its consistency, cohesion, and ability to flow without segregation or excessive bleeding.

3.2.2 Density of concrete mix:

The density of concrete refers to its mass per unit volume.

3.2.3 Water absorption test:

The water absorption test is a method used to determine the amount of water absorbed by a material, usually expressed as a percentage.

3.2.4 Compressive strength:

Compressive strength of paver blocks is the maximum load per unit area that the block can withstand before undergoing significant deformation or failure when subjected to a compressive force, typically measured in megapascals (MPa).

3.2.5 Porosity:

The porosity of paver blocks refers to the percentage of void space or open pores within the structure of

the block. It indicates the amount of empty space or gaps present in the material compared to its total volume.

Porosity is a crucial characteristic in determining the permeability and drainage capacity of paver blocks, especially in applications like pavements, walkways, and driveways.

3.2.6 Infiltration test:

The infiltration test is a method used to determine the rate at which water can infiltrate, or penetrate, into the soil or other porous media. It is a crucial parameter for various engineering applications, especially in hydrology, agriculture, and civil engineering, where understanding water movement is critical.

CHAPTER 4 – EXPERIMENTAL INVESTIGATION

4.1 BLENDING MIX PROPORTIONS

A comprehensive mix design was employed for this investigation to evaluate the performance of the pervious paver blocks. Typically, precast concrete paver blocks are produced using dry, low-slump mixtures to ensure high strength and durability. For this study, a control mix of concrete of the M30 grade was prepared, adhering to the guidelines and specifications outlined in the Indian Standard (IS) code 10262: 2009, which provides the procedure for concrete mix proportioning. Additionally, the requirements specified in IS code 15658: 2021, which covers the standards for precast concrete blocks for paving applications, were followed to ensure compliance with national standards. This methodical approach ensures that the concrete mix not only meets the necessary strength criteria but also adheres to industry standards for quality and performance in the production of pervious paver blocks.

The mix design for the pervious paver blocks in this investigation follows specific parameters to achieve the desired properties. The grade designation for the concrete mix is M30, ensuring a compressive strength of 30 MPa. The cement used is Ordinary Portland Cement (OPC) with a 43 grade, conforming to the standards outlined in IS 1489 Part (I): 1991. The maximum nominal size of the aggregate is set at 10 mm to maintain appropriate gradation and porosity. A minimum cement content of 400 kg/m³ is required for sufficient binding and strength. The workability of the mix is classified as medium, with a target slump range between 20 and 80 mm to ensure adequate compaction and finishing characteristics. The maximum water-cement ratio is limited to 0.40 to control the water content and ensure optimal strength and durability. The type of aggregate used is crushed and angular, which helps achieve better interlocking and load distribution within the paver

blocks. This detailed mix design ensures that the pervious paver blocks meet the required performance criteria for structural integrity and environmental suitability.

4.2 TARGET STRENGTH

The target strength for the mix proportioning of the pervious paver blocks is determined using the formula

$$F'_{ck} = f_{ck} + t * s_d$$

where F'_{ck} is the target mean strength, f_{ck} is the characteristic strength, t is the factor based on the desired level of quality control, and s_d is the standard deviation. For this investigation, the characteristic strength f_{ck} is 30 N/mm², and the standard deviation s_d is assumed to be 4 N/mm². The quality control factor t is taken as 1.50. Using these values, the target mean strength is calculated as follows:

$$F'_{ck} = 30 + 1.5 * 4$$

$$F'_{ck} = 36$$

Thus, the target strength for the mix proportioning is 36.0 N/mm², ensuring that the concrete mix will achieve the necessary robustness and durability for the production of high-quality pervious paver blocks.

4.3 WATER-CEMENT RATIO

The selection of the water-cement ratio is a critical factor in the mix design for pervious paver blocks, significantly influencing the concrete's strength and durability. For this investigation, the maximum allowable water-cement ratio is set at 0.40. This ratio is chosen to ensure an optimal balance between workability and strength. A water-cement ratio of 0.40 helps to maintain sufficient workability for proper mixing, placing, and compaction of the concrete while minimizing excess water that could weaken the final product. By limiting the water content, the mix achieves a denser and more durable concrete matrix, enhancing the longevity and structural integrity of the pervious paver blocks. This carefully selected water-cement ratio ensures that the concrete mix meets the stringent requirements for both performance and durability in severe exposure conditions.

The selection of water content is a crucial aspect of concrete mix design, and guidelines provided by standards such as IS-10262:2009 play a pivotal role in ensuring optimal concrete performance. These standards outline specific recommendations for determining the appropriate water content based on factors such as the desired workability, aggregate characteristics, and environmental conditions. By adhering to the

guidelines outlined in IS-10262:2009, engineers and concrete practitioners can accurately calculate the water content necessary to achieve the desired consistency and workability of the concrete mix. This meticulous approach helps to prevent issues such as segregation, bleeding, and excessive shrinkage, which can compromise the quality and durability of the final concrete product. Furthermore, by following established standards, construction projects can benefit from improved consistency, reliability, and long-term performance of the concrete structures. Thus, the selection of water content based on IS-10262:2009 guidelines ensures the production of high-quality concrete that meets the stringent requirements of modern construction practices.

4.4 CASTING OF SAMPLES

Preparing and casting concrete paver blocks involves a series of meticulous steps to ensure the quality and durability of the final product. First and foremost, the concrete must be mixed according to the manufacturer's instructions, meticulously combining cement, aggregates, and water to create a homogeneous mixture. Care should be taken to avoid clumps and ensure thorough blending, as the consistency of the mix significantly impacts the strength and uniformity of the paver blocks.

Once the concrete mix is prepared, it is poured into the mold, ensuring that it fills every cavity completely. This step is critical for achieving consistent dimensions and structural integrity in the paver blocks. Care should be taken to prevent any voids or gaps, as these can compromise the integrity of the finished product and lead to potential defects.

After pouring the concrete into the mold, it is essential to consolidate the mixture thoroughly. This is typically done using a vibrating table or similar device to eliminate air pockets and ensure uniform distribution of the concrete. Proper consolidation enhances the density and strength of the paver blocks, reducing the risk of defects and improving long-term performance.

Once the concrete is consolidated, the surface of the paver block is smoothed and leveled using a trowel or suitable tool. It is crucial to ensure that the surface is free from any irregularities, ridges, or lumps, as these can affect both the appearance and functionality of the finished product. A smooth, level surface is essential for safe pedestrian and vehicular traffic.

Following the smoothing process, the freshly poured concrete must be allowed to cure within the mold for the recommended duration, typically between 24 and 48 hours. Proper curing is essential for the development of strength and durability in the paver block. Suitable curing conditions, such as controlled temperature and humidity, should be maintained to promote optimal hydration and concrete maturity.

Once ready for installation in its intended application, contributing to durable and aesthetically pleasing hardscape designs. Each step in the process, from mixing to curing to demolding, requires attention to detail and adherence to best practices to ensure the production of high-quality paver blocks that meet industry standards and performance requirements. By following these steps diligently, manufacturers can produce paver blocks that not only enhance the visual appeal of outdoor spaces but also withstand the rigors of everyday use and environmental exposure. The result is a finished product that offers longevity, functionality, and aesthetic value, making it a desirable choice for a wide range of landscaping and construction projects

I-Block Molds

The "Design of Moulds using I block mould" refers to the process of creating molds for shaping concrete into specific forms, particularly in the shape of an "I" block. This design approach involves the fabrication of molds that are tailored to produce concrete blocks with a particular shape, size, and texture, resembling the letter "I".

Expanding on this process, designing molds for concrete blocks typically begins with conceptualizing the desired shape and dimensions of the final product. Engineers and designers consider factors such as the intended use of the concrete blocks, structural requirements, and aesthetic preferences when developing the mold design.

The "I block" design, in particular, may have specific characteristics such as straight edges, uniform thickness, and a symmetrical profile resembling the letter "I". These features are carefully incorporated into the mold design to ensure consistency and precision during the concrete casting process.

4.5 TOTAL SAMPLES

To conduct a comprehensive analysis of the paver block designs, our team embarked on a meticulous testing process. We began by designing three replica samples for each mix variant, ensuring thorough representation and accurate assessment of each mixture's properties. With nine distinct mixes selected for the

paver block design, this approach allowed us to encompass a wide spectrum of compositional variations, considering factors such as aggregate size, cement content, and water-cement ratio.

Testing intervals were set at 7, 14, and 28 days, reflecting the critical stages of concrete curing and development. This duration enabled us to monitor the evolution of the paver blocks' strength, durability, and other performance indicators over time.

Upon completion of the testing regimen, a total of 81 samples were meticulously crafted for the "I section" paver block design. Each sample underwent rigorous examination to ascertain its mechanical properties, permeability, and overall suitability for real-world applications.

The culmination of this exhaustive testing process yielded invaluable insights into the performance characteristics of the paver block designs. Average values gleaned from the extensive dataset were meticulously documented and analyzed, forming the basis for comprehensive findings presented in the manuscript. These findings offer valuable guidance for optimizing the design and formulation of pervious paver blocks, ultimately contributing to the advancement of sustainable and resilient infrastructure solutions.

4.6 WORKABILITY

Based on the table data, it can be observed that as the amount of SCBA and RAP in the material mix increases, the workability of the mix decreases. The workability of a mix is a measure of how easily it can be mixed, placed, and finished. In this study, the control mix (NA100+RAP0+SCBA0) exhibited the highest workability with a slump value of 86 mm, indicating it was the easiest to work with. Conversely, the mix designated as NA0+RAP100+SCBA20, which had the highest amounts of SCBA and RAP, showed the lowest workability with a slump value of 61 mm. This reduction in workability suggests that the addition of higher quantities of SCBA and RAP increases the internal friction and reduces the fluidity of the mix, making it more challenging to handle and compact.

The decrease in workability with increased amounts of these materials may require additional efforts to achieve the desired consistency for applications such as paver blocks. For instance, more mechanical mixing or the use of vibration during placement might be necessary to ensure proper compaction and finish. Additionally, it is important to consider that other factors can also influence the workability of the concrete mix. The water-cement ratio is a critical factor; higher water content generally improves workability, while lower water content reduces it. Similarly, the use of chemical admixtures, such as superplasticizers, can

enhance workability by increasing fluidity without altering the water-cement ratio.

Therefore, while the increase in SCBA and RAP reduces workability, adjustments in the mix design, such as optimizing the water-cement ratio or incorporating suitable admixtures, can help mitigate these effects and achieve the desired workability for specific applications. This holistic approach ensures that the benefits of using sustainable materials like SCBA and RAP do not compromise the practical aspects of concrete handling and performance.

Table 4. 1 Workability of different mixes

Sr. No.	Nomenclature	Workability
1	NA100+RAP0+SCBA0	86
2	NA50+RAP50+SCBA0	83
3	NA0+RAP100+SCBA0	81
4	NA100+RAP0+SCBA10	79
5	NA50+RAP50+SCBA10	75
6	NA0+RAP100+SCBA10	72
7	NA100+RAP0+SCBA20	69
8	NA50+RAP50+SCBA20	65
9	NA0+RAP100+SCBA20	61

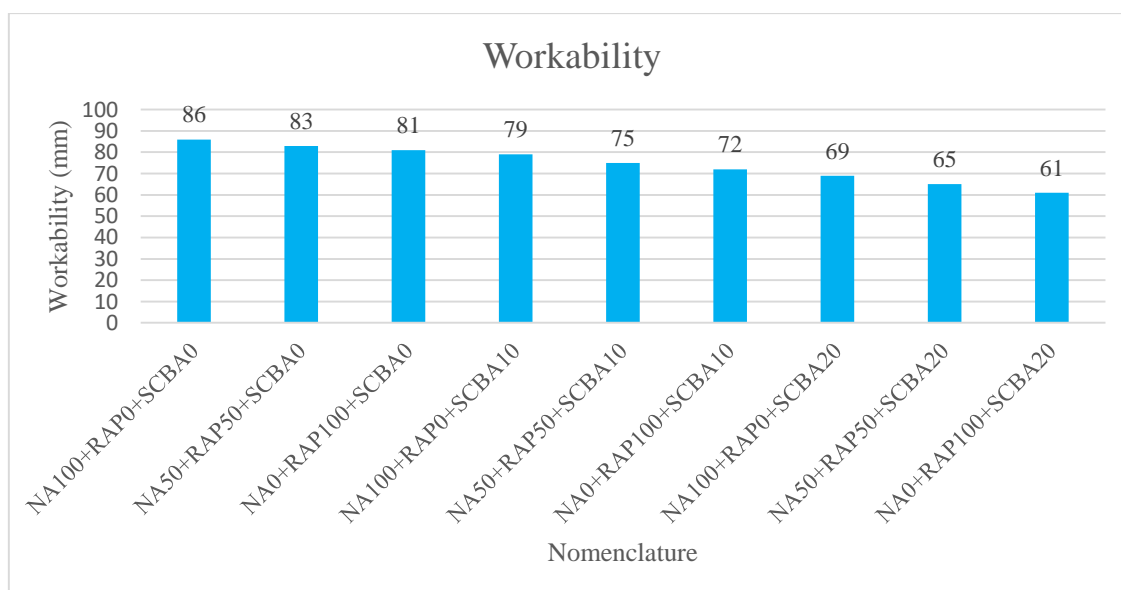


Figure 4. 1 Workability of different mixes

4.7 DENSITY

The density variation observed in the "I section" paver blocks highlights the impact of incorporating SCBA and RAP as a partial replacement material. The control mix, labeled as (NA100+RAP0+SCBA0), which presumably uses conventional materials without RHA, exhibited the highest density at 2066 kg/m³. This serves as a benchmark for evaluating the performance of modified samples.

The other samples, which include varying proportions of SCBA and RAP, demonstrated densities ranging from 1994 kg/m³ to 1830 kg/m³. The decrease in density compared to the control sample indicates that the inclusion of SCBA and RAP significantly influences the density of the paver blocks. This variation in density suggests that the choice and proportion of materials in the mix design play a crucial role in determining the final density of the product.

These findings imply that while SCBA and RAP can be beneficial additives for various properties, their impact on density must be carefully considered. The control sample's higher density serves as a reference point, allowing for a comparative analysis of how different mixes with SCBA and RAP perform in terms of density. Understanding these variations helps in optimizing the mix design to achieve the desired balance between density and other performance attributes such as strength, permeability, and durability in the final paver block product.

Table 4. 2 Densities of different mixes

Sr. No.	Nomenclature	Density (kg/ cubic m)
1	NA100+RAP0+SCBA0	2066
2	NA50+RAP50+SCBA0	1994
3	NA0+RAP100+SCBA0	1969
4	NA100+RAP0+SCBA10	1957
5	NA50+RAP50+SCBA10	1938
6	NA0+RAP100+SCBA10	1931
7	NA100+RAP0+SCBA20	1920
8	NA50+RAP50+SCBA20	1849
9	NA0+RAP100+SCBA20	1830

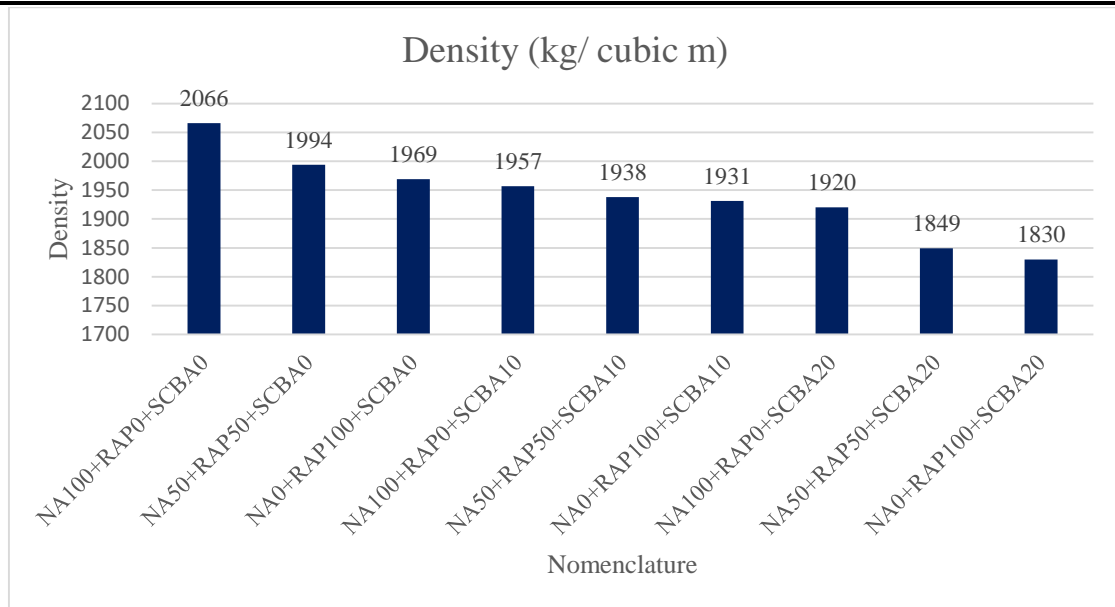


Figure 4. 2 Densities of different mixes

4.8 WATER ABSORPTION

The results of the water absorption test for the paver blocks, detailed in the accompanying table, reveal important insights into how different mix compositions affect this property. According to the data presented, the water absorption of paver blocks increases with the replacement of natural aggregates (NA) and cement with SCBA and RAP.

Specifically, it was observed that higher percentages of NA and cement replacement with SCBA and RAP resulted in the greatest increases in water absorption. This trend indicates that the modified paver blocks absorb more water compared to the control mix. The control mix, which does not incorporate SCBA and RAP, exhibited the lowest water absorption rates, serving as a baseline for comparison.

The water absorption rates among the different samples vary, highlighting the influence of mix modifications on this characteristic. For instance, sample NA0+RAP100+SCBA20 recorded the highest water absorption rate for the I-section paver block at 2.74%. Overall, the water absorption rates for the samples range from 1.64% to 2.74%. Although this range is not extremely wide, it is significant enough to impact applications where water drainage or resistance is a critical factor.

These findings suggest that while the inclusion of SCBA and RAP in the paver block mix does lead to an increase in water absorption, the variations are relatively modest. This implies that the use of SCBA and RAP in paver block production can be considered without dramatically compromising the material's water absorption properties. The slight increase in water absorption might be manageable depending on the specific

requirements of the application, such as in environments where enhanced water drainage is beneficial or where slight increases in permeability are acceptable.

In conclusion, the data indicate that the choice of materials and their proportions in the mix design significantly affect the water absorption characteristics of paver blocks. Understanding these variations is crucial for optimizing mix designs to meet specific performance criteria, particularly in applications where water absorption and drainage properties are of importance.

Table 4. 3 Water absorption for different mixes

Sr. No.	Nomenclature	Water Absorption (%)
1	NA100+RAP0+SCBA0	1.64
2	NA50+RAP50+SCBA0	1.90
3	NA0+RAP100+SCBA0	2.02
4	NA100+RAP0+SCBA10	2.14
5	NA50+RAP50+SCBA10	2.26
6	NA0+RAP100+SCBA10	2.38
7	NA100+RAP0+SCBA20	2.50
8	NA50+RAP50+SCBA20	2.62
9	NA0+RAP100+SCBA20	2.74

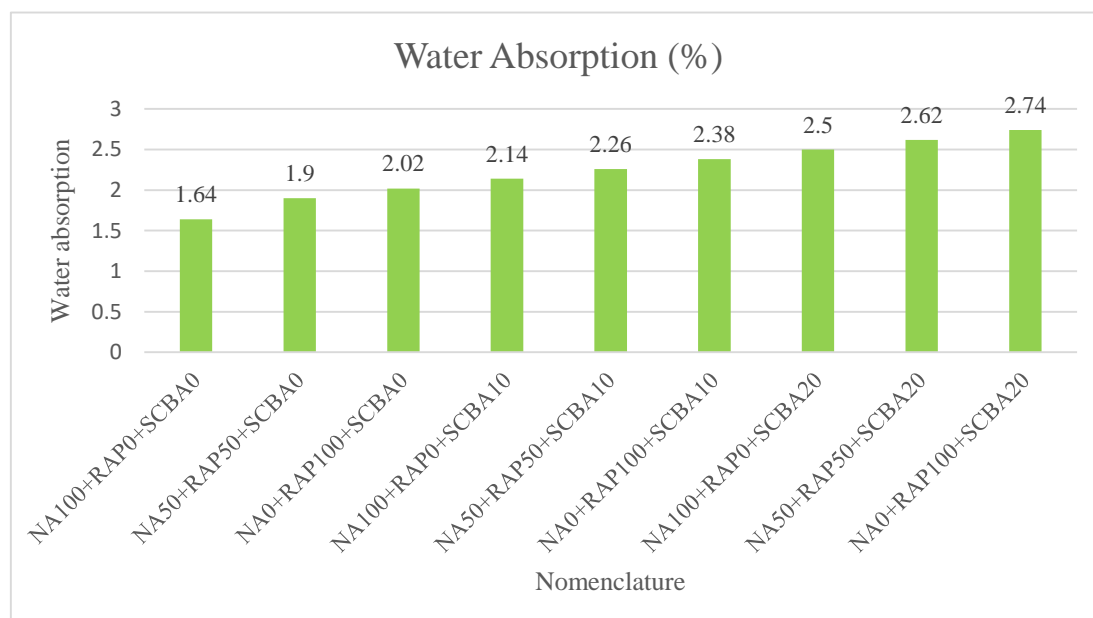


Figure 4. 3 Water absorption for different mixes

4.9 COMPRESSIVE STRENGTH

The table provides a detailed examination of the compressive strength of I-section pervious paver blocks, which were created from various concrete mixes and tested at three different curing intervals: 7, 14, and 28 days. The data demonstrates the performance of these blocks over time, offering insights into their structural integrity and potential applications.

The control sample, denoted as NA100+RAP0+SCBA0, consistently exhibits the highest compressive strength across all tested periods, culminating in an impressive 35.23 MPa after 28 days of curing. This sample serves as the benchmark for high performance, indicating the effectiveness of the conventional materials and mix design used in its creation. The exceptional strength of the as NA100+RAP0+SCBA0 sample sets a standard against which the alternative mixes are evaluated.

As expected with concrete materials, all the mixes show an upward trend in compressive strength as the curing time progresses. This aligns with the typical behavior of concrete, where strength increases as hydration continues over time. However, despite this positive trend, the alternative mixes generally exhibit lower compressive strengths compared to the control mix, indicating a trade-off when substituting traditional materials with alternatives like SCBA and RAP.

For example, Sample NA50+RAP50+SCBA0 demonstrates relatively strong performance among the alternatives, achieving a compressive strength of 32.54 MPa after 28 days. This makes it a viable candidate for certain applications that may not require the maximum strength provided by the control mix but still demand considerable durability. On the other hand, Sample NA0+RAP100+SCBA10 shows a significantly lower compressive strength of 26.7 MPa at the 28-day mark, suggesting its suitability for applications with lower load-bearing requirements.

The consistent increase in compressive strength over the curing period for all samples underscores the uniformity of the curing conditions, which adds credibility to the test results. This uniformity ensures that the variations in strength are attributable to the differences in mix compositions rather than external factors.

Overall, the table highlights that while the control mix (NA100+RAP0+SCBA0) remains the superior choice in terms of compressive strength, some alternative mixes, particularly NA50+RAP50+SCBA0 and NA0+RAP100+SCBA0, offer promising performance. These alternatives could be considered for specific applications where the highest compressive strength is not as critical, or where other factors such as cost,

sustainability, or material availability might influence the choice of mix.

In summary, although the control mix provides the highest compressive strength and is thus the most desirable for applications demanding long-term durability and maximum load-bearing capacity, certain alternative mixes still exhibit considerable potential. The decision to use these alternatives would depend on the specific strength requirements of the project and the timeline in which those strengths need to be achieved. Careful evaluation of the trade-offs in strength against other benefits such as environmental impact or economic considerations would guide the selection of the most appropriate mix for each application.

Table 4. 4 Compressive strength of mixes

Sr. No.	Nomenclature	Compressive Strength		
		7-days	14-days	28-days
1	NA100+RAP0+SCBA0	23.28	30.20	35.23
2	NA50+RAP50+SCBA0	21.54	27.91	32.54
3	NA0+RAP100+SCBA0	19.49	25.21	29.34
4	NA100+RAP0+SCBA10	19.00	24.54	28.54
5	NA50+RAP50+SCBA10	18.15	23.41	27.19
6	NA0+RAP100+SCBA10	18.03	23.23	26.98
7	NA100+RAP0+SCBA20	17.77	22.87	26.54
8	NA50+RAP50+SCBA20	17.26	22.14	25.68
9	NA0+RAP100+SCBA20	16.85	21.61	25.03

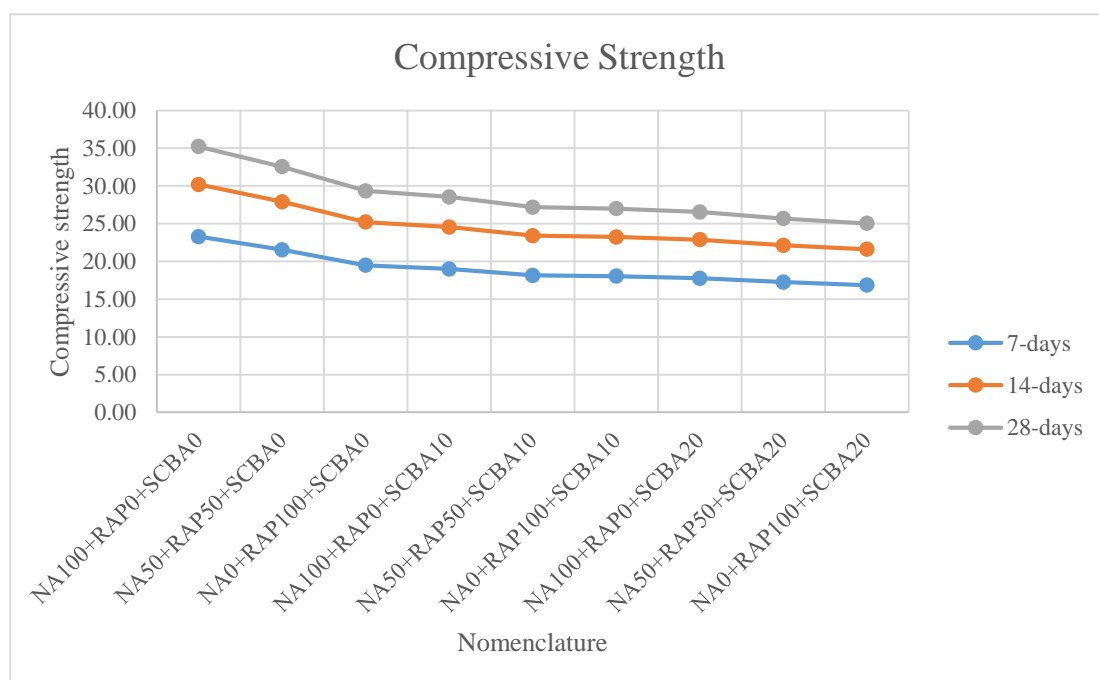


Figure 4. 4 Compressive strength of mixes

4.10 POROSITY RATIO

The control mix (NA100+RAP0+SCBA0) exhibits a porosity ratio of 23.92% for the 'I section,' establishing a baseline for comparing other mixes. Mix NA0+RAP100+SCBA0, with a porosity of 16.12% for the 'I section,' shows a lower porosity than the control mix. This reduction in porosity likely indicates a higher material density or fewer voids, which could lead to decreased water permeability.

Mixes NA100+RAP0+SCBA10, NA100+RAP0+SCBA20 and NA50+RAP50+SCBA0 have porosity ratios that are closer to the control mix, suggesting a more balanced mix of constituents. These mixes maintain permeability characteristics similar to the control, indicating that they may achieve a desirable balance between allowing water to pass through and maintaining structural integrity.

Conversely, mix NA0+RAP100+SCBA20 has the lowest porosity at 16.12% for the 'I section.' This low porosity implies a denser and potentially stronger material, though it comes at the expense of reduced water permeability. Such a mix might be preferable in scenarios where strength is prioritized over drainage capabilities.

In summary, the variations in porosity ratios among the different mixes highlight the trade-offs between permeability and structural strength. Mixes that closely match the control, such as NA100+RAP0+SCBA10, NA100+RAP0+SCBA20 and NA50+RAP50+SCBA0, provide a balanced approach, maintaining similar permeability and structural properties as the control mix.

Table 4. 5 Porosity ratio of different mixes

Sr. No.	Nomenclature	Porosity Ratio (%)
1	NA100+RAP0+SCBA0	23.92
2	NA50+RAP50+SCBA0	19.62
3	NA0+RAP100+SCBA0	18.62
4	NA100+RAP0+SCBA10	21.82
5	NA50+RAP50+SCBA10	19.22
6	NA0+RAP100+SCBA10	17.12
7	NA100+RAP0+SCBA20	20.42
8	NA50+RAP50+SCBA20	18.72
9	NA0+RAP100+SCBA20	16.12

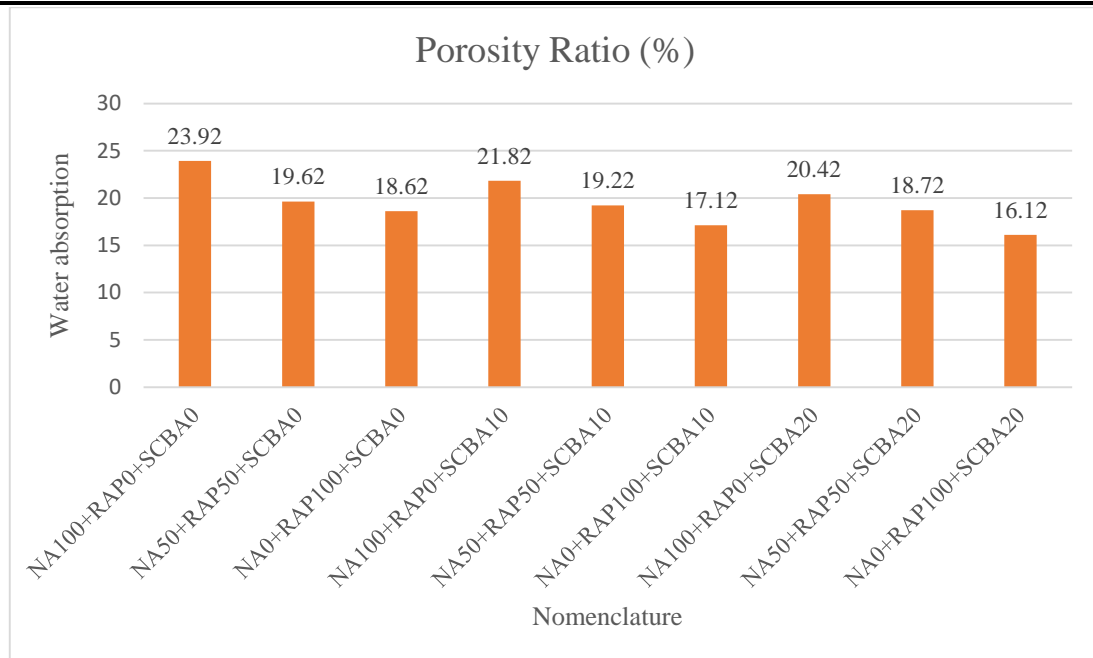


Figure 4. 5 Porosity ratio of different mixes

The correlation matrix provided offers a comprehensive insight into the interrelationships among various variables pertinent to the study, particularly focusing on Recycled Asphalt Pavement (RAP) and Spent Coffee Grounds Biochar Ash (SCBA) alongside characteristics like workability, density, water absorption, and porosity ratio.

Starting with RAP, it's observed that it perfectly correlates with itself, which is expected. However, there's no discernible correlation with other variables in the matrix. This suggests that RAP's properties may be somewhat isolated from those of the other variables under examination.

Similarly, SCBA also displays a perfect correlation with itself but lacks correlations with other variables, indicating a similar degree of isolation in its properties. This indicates that the results obtained are affected by the combinations of the materials rather than one individual material.

Moving to the characteristic of workability, it's notable that it correlates negatively with SCBA and positively with density. This suggests that as SCBA content increases, the workability tends to decrease, possibly indicating challenges in handling or processing. Conversely, the positive correlation with density implies that denser materials may exhibit better workability, likely due to their more compact and stable nature.

The correlation between density and water absorption reveals a negative relationship, indicating that as density increases, the material tends to absorb less water. This is a crucial finding, as materials with lower water absorption are generally more durable and resistant to weathering.

Moreover, the positive correlation between water absorption and workability suggests that materials with higher water absorption may be easier to work with. This could have implications for construction processes, where workability is a critical factor in determining efficiency and quality.

Overall, the correlation matrix provides valuable insights into how different variables interact and influence each other within the scope of the study. These findings can inform decision-making processes in material selection, process optimization, and quality control, ultimately contributing to the advancement of knowledge and practice in relevant fields such as construction and materials science.

Table 4. 6 Correlation matrix

	RAP	SCBA	Workability	Density (kg/ cubic m)	Water Absorption (%)	7-days	14-days	28-days	Porosity Ratio (%)
RAP	1								
SCBA	0	1							
Workability	-0.3401	-0.9354	1						
Density (kg/ cubic m)	-0.4306	-0.8693	0.9601	1					
Water Absorption (%)	0.34835	0.93163	-0.9838	-0.9732	1				
7-days	-0.3874	-0.8479	0.89298	0.92726	-0.9532	1			
14-days	-0.3859	-0.8525	0.89763	0.93052	-0.9562	0.99994	1		
28-days	-0.3853	-0.8539	0.89904	0.93113	-0.957	0.9999	0.99999	1	
Porosity Ratio (%)	-0.8768	-0.4231	0.69049	0.76137	-0.7179	0.72341	0.72309	0.72276	1

CHAPTER 5 – CONCLUSIONS

The research likely delved into an experimental exploration of various mix designs for pervious paver blocks, incorporating a blend of SCBA and RAP aggregates alongside conventional materials. From the obtained results, the conclusion might indicate that the inclusion of SCBA and RAP aggregates influences the permeability of the pervious paver blocks while maintaining satisfactory levels of compressive strength.

This investigation would have entailed a systematic examination of different combinations of SCBA, RAP aggregates, and conventional materials in the fabrication of pervious paver blocks. Through rigorous experimentation, the researchers likely evaluated the permeability performance and compressive strength characteristics of these blocks under various conditions and compositions.

The conclusion drawn from the study's findings is expected to underscore the significant impact of incorporating SCBA and RAP aggregates on the permeability of the pervious paver blocks. By introducing these alternative materials into the mix designs, the researchers likely observed alterations in the pore structure and drainage capabilities of the blocks, potentially leading to enhanced permeability. The following major conclusions can be drawn from the study:

- **Workability:** It's apparent that as the proportion of RAP and SCBA increases in the mix designs, there's a general trend of decreasing workability. This suggests that the inclusion of higher proportions of RAP and SCBA may have a negative impact on workability. However, the workability is near the desired range of 80.
- **Density:** The analysis of density values across various mix designs comprising natural aggregate (NA), reclaimed asphalt pavement (RAP), and sugarcane bagasse ash (SCBA) reveals a clear trend of decreasing density as the proportion of RAP and SCBA increases. This indicates that higher proportions of RAP and SCBA contribute to lower overall density values, suggesting a potential trade-off between incorporating these sustainable materials and achieving desired density levels. Additionally, trials with equal proportions of RAP and SCBA generally exhibit lower density values compared to trials without RAP or SCBA, underscoring the influence of these materials on density. Moreover, increasing SCBA content correlates with decreasing density, highlighting the need for careful consideration and optimization of mix designs to balance sustainability and performance in practical applications.

- **Water absorption:** The observed water absorption percentages across the various mix designs strongly suggest that the results pertain to pervious blocks. Pervious blocks are specifically engineered to allow water to pass through, aiding in stormwater management and groundwater recharge. The increasing water absorption percentages with higher proportions of RAP and SCBA align with expectations for pervious blocks, as they are designed to absorb and facilitate the drainage of water. Additionally, the variations in water absorption percentages based on the composition of RAP and SCBA underscore the importance of selecting appropriate materials to achieve desired permeability and drainage characteristics in pervious block applications.
- **Compressive strength:** The provided compressive strength data, spanning 7, 14, and 28-day periods across various mix designs denoted by different combinations of natural aggregate (NA), reclaimed asphalt pavement (RAP), and sugarcane bagasse ash (SCBA), strongly indicate that the results pertain to pervious blocks. Pervious blocks are engineered to withstand compressive forces while also facilitating water permeability, making compressive strength a crucial parameter in their performance assessment. The observed trends of decreasing compressive strength with increasing proportions of RAP and SCBA align with expectations for pervious blocks, as higher porosity resulting from the inclusion of these materials often correlates with reduced compressive strength. Additionally, the variations in compressive strength across different mix designs highlight the influence of material composition on the structural integrity of pervious blocks.
- **Porosity:** Pervious blocks are specifically engineered to possess a high porosity, allowing for efficient water infiltration and drainage. The observed trends of increasing porosity ratio with higher proportions of RAP and SCBA align with expectations for pervious blocks, as these materials typically introduce additional void spaces within the structure. Additionally, the variations in porosity ratio across different mix designs highlight the significant influence of material composition on the porosity characteristics of pervious blocks.

REFERENCES

REFERENCES

- [1] H. Al Dughaiishi *et al.*, “Encouraging Sustainable Use of RAP Materials for Pavement Construction in Oman: A Review,” *Recycling*, vol. 7, no. 3, p. 35, Jun. 2022, doi: 10.3390/recycling7030035.
- [2] A. H. Nur Hidayah, M. N. Hasanah, and P. J. Ramadhansyah, “Physical Properties of Porous Concrete Paving Blocks with Different Sizes of Coarse Aggregate,” *Adv Mat Res*, vol. 1113, pp. 86–92, Jul. 2015, doi: 10.4028/www.scientific.net/AMR.1113.86.
- [3] S. Singh, D. Shintre, G. D. Ransinchung R.N., and P. Kumar, “Performance of Fine RAP Concrete Containing Flyash, Silica Fume, and Bagasse Ash,” *Journal of Materials in Civil Engineering*, vol. 30, no. 10, Oct. 2018, doi: 10.1061/(ASCE)MT.1943-5533.0002408.
- [4] J. S. Yeo, S. Koting, C. C. Onn, and K. H. Mo, “An overview on the properties of eco-friendly concrete paving blocks incorporating selected waste materials as aggregate,” *Environmental Science and Pollution Research*, vol. 28, no. 23, pp. 29009–29036, Jun. 2021, doi: 10.1007/s11356-021-13836-3.
- [5] N. Saboo, A. Nirmal Prasad, M. Sukhija, M. Chaudhary, and A. K. Chandrappa, “Effect of the use of recycled asphalt pavement (RAP) aggregates on the performance of pervious paver blocks (PPB),” *Constr Build Mater*, vol. 262, p. 120581, Nov. 2020, doi: 10.1016/j.conbuildmat.2020.120581.
- [6] Habib Musa Mohamad *et al.*, “Manufacture of concrete paver block using waste materials and by-products: a review. ,” *INTERNATIONAL JOURNAL OF GEOMATE*, vol. 22, no. 93, pp. 9–19, May 2022.
- [7] A. Mohammadinia, A. Arulrajah, J. Sanjayan, M. M. Disfani, M. Win Bo, and S. Darmawan, “Stabilization of Demolition Materials for Pavement Base/Subbase Applications Using Fly Ash and Slag Geopolymers: Laboratory Investigation,” *Journal of Materials in Civil Engineering*, vol. 28, no. 7, Jul. 2016, doi: 10.1061/(ASCE)MT.1943-5533.0001526.

ANNEXURE

