

## RESEARCH ARTICLE

# GREEN PAVEMENT: ASSESSMENT OF THE USE OF WASTE MATERIALS IN PAVEMENT BLOCK MANUFACTURING

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## ABSTRACT

Pavement blocks are increasingly popular in construction due to their durability, versatility, and aesthetics. However, their conventional production process heavily relies on natural resources like sand, cement, and aggregates, raising sustainability concerns. The construction industry faces growing pressure to adopt eco-friendly practices that minimize environmental harm and conserve resources. This study explored using waste materials in making interlocking pavement blocks. It found that replacing some cement with bagasse ash, fly ash, and brick kiln dust improved compressive strength compared to traditional blocks after 28 days. Substituting some aggregate with crushed waste plastic slightly reduced tensile strength, particularly at 7 and 28 days, with lower replacement ratios performing better. Overall, using waste materials in pavement block production has the potential to promote sustainable construction by reducing environmental impact and costs, aligning with sustainable development principles and resource efficiency.

## KEYWORDS

Eco-Friendly, Interlocking Paving Units, Waste Materials, Plastic Waste, Sustainability.

## 1. INTRODUCTION

In recent years, there has been growing concern about the environmental impact of construction, driving the need for sustainable practices. Sustainable construction aims to reduce environmental harm by using eco-friendly materials and minimizing waste. One promising approach is utilizing waste materials like fly ash, sugarcane bagasse ash, brick kiln dust, and plastic waste in making interlocking pavement blocks. These blocks are popular due to durability, low maintenance, and easy installation. Incorporating waste materials can cut waste generation and support sustainability. This study explores using these waste materials to partially replace cement and aggregate in block production.

Our overarching vision is to advance sustainable infrastructure by exploring waste materials in interlocking pavement block manufacturing. We aim to assess these blocks' performance as alternatives to traditional materials. By investigating fly ash, sugarcane bagasse ash, brick kiln dust, and plastic waste, we strive to provide innovative solutions for waste reduction and sustainable development. Our goal aligns with UN Sustainable Development Goals, especially SDG 9 (Industry, Innovation, and Infrastructure) and SDG 11 (Sustainable Cities and Communities), by offering sustainable, cost-effective, and resilient infrastructure materials. Our findings can inform policies, guide sustainable development, and contribute to a circular economy transition.

## 1.1 Research Significance

The research's significance lies in several key areas:

- **Environmental Impact:** By using waste materials in pavement block production, it reduces carbon emissions and waste disposal, promoting a cleaner environment.

- **Cost Efficiency:** Incorporating waste materials can cut raw material costs, making pavement construction more economical.
- **Performance Assessment:** The research evaluates pavement block performance through tests like compressive strength and water absorption to assess their suitability for construction.
- **Sustainable Development:** Using waste materials aligns with sustainable development principles by reducing resource use and environmental impact.
- **Innovation Potential:** The research opens doors for innovative approaches in pavement block manufacturing by integrating waste materials.
- **Conclusively,** this research offers substantial potential to support sustainability, address environmental concerns, and provide cost-effective and innovative solutions for pavement construction.

## 2. LITERATURE REVIEW

Interlocking Concrete Pavement Blocks (ICPBs) have gained significant traction in recent years due to their resilience, ease of installation, and aesthetic appeal. They find widespread use across residential, commercial, and industrial settings, serving as the foundation for driveways, parking lots, walkways, patios, and public spaces. The key feature of these blocks is their interlocking design, which allows them to tightly fit together without the need for mortar, resulting in a robust and stable surface. ICPBs are typically crafted from a blend of aggregates, cement, and water, a mixture that is molded into various shapes and sizes tailored to the intended use of the pavement blocks. Notably, there's a growing interest in integrating waste materials as partial replacements for cement in the concrete mix. This initiative aims to reduce the carbon footprint of the

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manufacturing process and promote sustainability within the construction industry. According to a study, ICPs consist of three essential layers: a base layer, a bedding layer, and a surface layer (Di Mascio et al, 2019). The base layer forms the pavement's foundation and is typically composed of compacted crushed stone or gravel. Directly above it, the bedding layer is placed, creating a level surface upon which the ICP blocks are installed. This layer is usually comprised of sand or stone dust. Lastly, the surface layer houses the interlocking blocks and is responsible for providing the final appearance of the pavement. In addition to their functional benefits, ICPs also offer environmental advantages. They are permeable, enabling rainwater to seep into the ground, thereby reducing stormwater runoff and preventing erosion. Furthermore, they possess the ability to reflect heat, effectively mitigating the urban heat island effect. Extensive research has been conducted to understand the properties and performance of ICPs. Khanal, Tighe, and Bowers (2013) delved into the impact of various factors, including material properties and interlocking patterns, on the mechanical behavior of ICPs. Their findings revealed that the compressive strength and interlocking force of ICPs are profoundly influenced by the material properties of the blocks and the joint width between them (Khanal, Tighe, and Bowers, 2013). Another study explored the influence of different types of bedding materials on the load-bearing capacity of ICPs. They concluded that the choice of bedding material significantly affects the structural behavior of ICPs, recommending well-graded sand for optimal performance (Rathan, Sunitha, and Anusudha, 2022).

Furthermore, there has been a surge in studies investigating the utilization of waste materials in the manufacturing of ICPBs. A study explored the incorporation of waste glass powder as a partial replacement for cement in ICPBs, resulting in improved compressive strength compared to conventional blocks (Marathe, Mithanthaya, and Susmitha, 2021). Similarly to other study, they examined the use of waste marble dust as a partial cement replacement, revealing enhanced durability and wear resistance in the resulting blocks (Sharma, Mishra, and Gupta, 2019). The literature also underscores the pivotal role of proper mix design and manufacturing practices in achieving optimal ICPB performance. As highlighted in previous research, mix design plays a critical role in determining the durability and load-bearing capacity of ICPBs. Additionally, the appropriate curing and handling of the blocks throughout the manufacturing process are essential prerequisites for achieving the desired strength and durability (Arjun and Sunitha, 2021).

In summary, the integration of waste materials in ICPB manufacturing holds immense potential for promoting sustainability and reducing the environmental impact of the construction industry. However, it is imperative to conduct thorough evaluations of the properties of the resulting blocks to ensure they meet the necessary performance requirements for their intended use. As sustainability becomes an increasingly pressing concern, the construction industry must continue to explore innovative and eco-friendly approaches, such as the incorporation of waste materials, to strike a balance between functionality and environmental responsibility.

### 3. RESEARCH METHODOLOGY

#### 3.1 Parameters and Process

- **Cement:** We utilized cement from Lucky Cement Limited, a prominent manufacturer in Pakistan. It underwent ASTM-standard testing, meeting ASTM C150 Type I Portland cement requirements.
- **Fine Aggregate (Sand):** Sourced locally in Bahawalpur, Pakistan, the sand was washed, dried, and met ASTM C33 zone-II grading standards.
- **Crushed Stone:** Compliant with ASTM C33, the 7 mm stone chips met size, shape, and cleanliness specifications.
- **Water:** Local water supply in Pakistan, tested to ASTM C1602 mixing water standards.

**Fly Ash:** Class F fly ash from "D.G Cement Company Ltd" in Punjab, conforming to ASTM C618 standards. Used in varying proportions (10%, 20%, 30%) as a cement replacement.

**Sugar Cane Bagasse Ash:** Obtained locally in Pakistan, classified as Type F. Used as a partial cement replacement (10%, 20%, 30%), guided by ASTM C618 properties.

**Brick Kiln Dust:** Sourced locally, specifically from clay brick manufacturing, chosen for better pozzolanic properties. Used in proportions of 10%, 20%, 30%.

**Plastic as Aggregate:** Local plastic waste, including Polyethylene Terephthalate (PET) and Low-Density Polyethylene (LDPE), shredded and used as aggregate.

#### Collection and Mixing Process:

Followed ASTM C1602/C1602M-18 for water-cement ratio (0.35 to 0.45) and ASTM C936/C936M-17 for cement, fine aggregates, and coarse aggregates ratio, using a dry mixing process for uniform distribution.

#### Pouring of Mixture into Interlocking Pavement Machine:

Complied with ASTM C936/C936M-17, adjusting the hopper to ensure uniform block size, shape, and quality.

#### Shape of Mold:

Utilized Unipaver/Zigzag mold as per ASTM C936/C936M-17, with dimensions conforming to ASTM C140/C140M-20 (200mm x 100mm x 60mm) for interlocking capability and ease of installation.

#### Air Drying Process:

- Allowed the molded blocks to air dry for 24 hours in low-humidity, well-ventilated conditions to prevent cracking, following ASTM C140/C140M-20.

#### Curing of Samples:

- Cured the air-dried blocks in a water tub for 28 days, following ASTM C140/C140M-20.

### 3.2 Experimental Methods

#### 3.2.1 Compressive Strength Test

Compression testing was conducted following ASTM C936-13 on 16 samples per set (1 from batch 1, 3 each from batches 2-6, representing 10%, 20%, and 30% partial replacements). Used a compression testing machine to record maximum load at failure.

#### 3.2.2 Water Absorption Test

Water absorption test performed as per ASTM D570 on 16 samples (same composition as compressive strength test) subjected to drying, saturation, and weight measurements.

#### 3.2.3 Fire Resistance Test

- Complied with ASTM E119 standard on 16 samples (same composition) exposed to 800°C temperature. Conducted a mechanical strength test after cooling.

#### 3.2.4 Skid/Slip Resistance Test

- Conducted according to ASTM E303 standard using the British pendulum tester on 16 samples (same composition). Steps included preparation, calibration, testing, and result recording.

#### 3.2.5 Tensile Strength Test

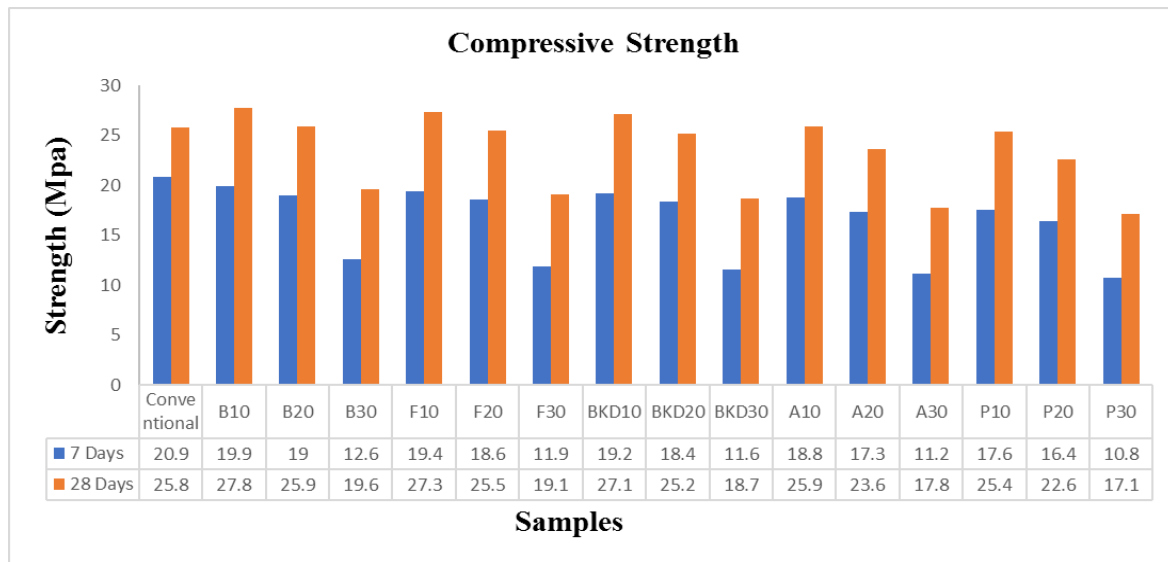
- Performed in line with ASTM C1583 standard on 16 samples per set (same composition as compressive strength test).

## 4. RESULTS AND DISCUSSION

### 4.1 Compressive Strength Test

The study highlights the importance of curing time and choice of replacement materials in determining interlocking pavement block compressive strength. Substituting some cement with other materials can enhance block performance. Longer curing periods are also vital for maximizing compressive strength, ensuring blocks endure heavy loads without harm.

Results indicate that longer curing periods generally lead to higher compressive strength. After 7 days, the conventional sample had a strength of 20.9 MPa, while samples with partial cement replacement ranged from 10.8 MPa to 19.9 MPa. At 28 days, the conventional sample reached 25.8 MPa, while replacements varied from 17.1 MPa to 27.8 MPa. These findings emphasize the significant impact of curing time and replacement materials on interlocking pavement block compressive strength as shown in Figure 1.



**Figure 1:** Compressive Strength of different Samples of Interlocking Pavement Blocks

**Table 1:** Compressive Strength of different Samples of Interlocking Pavement Blocks

| Sample            | Average Compressive Strength |                   |                |                              |                   |                |
|-------------------|------------------------------|-------------------|----------------|------------------------------|-------------------|----------------|
|                   | 7 Days                       |                   |                | 28 Days                      |                   |                |
|                   | Density (kg/m <sup>3</sup> ) | Failure Load (KN) | Strength (Mpa) | Density (kg/m <sup>3</sup> ) | Failure Load (KN) | Strength (Mpa) |
| Conventional      | 2583                         | 388.78            | 20.9           | 2647.08                      | 431.32            | 25.8           |
| B <sub>10</sub>   | 2509.58                      | 349.41            | 19.9           | 2570.53                      | 458.45            | 27.8           |
| B <sub>20</sub>   | 2497.08                      | 338.91            | 19.0           | 2556.66                      | 429.18            | 25.9           |
| B <sub>30</sub>   | 2473.33                      | 280.16            | 12.6           | 2530.37                      | 346.51            | 19.6           |
| F <sub>10</sub>   | 2593.75                      | 342.25            | 19.4           | 2648.74                      | 447.54            | 27.3           |
| F <sub>20</sub>   | 2637.5                       | 331.77            | 18.6           | 2690.41                      | 427.44            | 25.5           |
| F <sub>30</sub>   | 2661.25                      | 273.55            | 11.9           | 2713.33                      | 339.76            | 19.1           |
| BKD <sub>10</sub> | 2588.75                      | 340.13            | 19.2           | 2655.83                      | 449.35            | 27.1           |
| BKD <sub>20</sub> | 2590.83                      | 329.98            | 18.4           | 2660                         | 428.55            | 25.2           |
| BKD <sub>30</sub> | 2592.91                      | 267.73            | 11.6           | 2664.16                      | 332.16            | 18.7           |
| A <sub>10</sub>   | 2581.25                      | 332.34            | 18.8           | 2644.17                      | 430.12            | 25.9           |
| A <sub>20</sub>   | 2577.5                       | 316.23            | 17.3           | 2639.13                      | 418.57            | 23.6           |
| A <sub>30</sub>   | 2572.92                      | 270.13            | 11.2           | 2634.83                      | 319.45            | 17.8           |
| P <sub>10</sub>   | 2517.61                      | 318.44            | 17.6           | 2559.15                      | 423.47            | 25.4           |
| P <sub>20</sub>   | 2507.87                      | 304.65            | 16.4           | 2544.82                      | 410.88            | 22.6           |
| P <sub>30</sub>   | 2489.16                      | 246.87            | 10.8           | 2524.84                      | 312.34            | 17.1           |

## 4.2 Water Absorption Test

All samples underwent a standardized process by drying them at 110°C for 24 hours according to the specified standard code. Following drying, the samples were weighed and immersed in water for 24 hours to saturate them. After removing excess surface water, the saturated samples were

reweighed. Water absorption percentage was determined by calculating the weight difference between the dried and saturated conditions. Results of the test indicated varying water absorption characteristics in interlocking pavement blocks with different percentages of cement or material replacement. The results are shown in following Table 2.

**Table 2:** Water Absorption of different Samples of Interlocking Pavement Blocks

| Sample Number     | Weight Before Curing (grams) | Weight After Curing (grams) | Difference (%) |
|-------------------|------------------------------|-----------------------------|----------------|
| Conventional      | 3100.0                       | 3176.5                      | 2.4            |
| B <sub>10</sub>   | 3011.5                       | 3084.5                      | 2.42           |
| B <sub>20</sub>   | 2996.5                       | 3068.0                      | 2.38           |
| B <sub>30</sub>   | 2968.0                       | 3036.5                      | 2.3            |
| F <sub>10</sub>   | 3112.5                       | 3177.5                      | 2.0            |
| F <sub>20</sub>   | 3165.0                       | 3228.5                      | 2.0            |
| F <sub>30</sub>   | 3193.5                       | 3256.0                      | 1.97           |
| BKD <sub>10</sub> | 3106.5                       | 3187.0                      | 2.59           |
| BKD <sub>20</sub> | 3109.0                       | 3192.0                      | 2.67           |
| BKD <sub>30</sub> | 3111.5                       | 3197.0                      | 2.74           |
| A <sub>10</sub>   | 3097.5                       | 3173.0                      | 2.43           |
| A <sub>20</sub>   | 3093.0                       | 3167.5                      | 2.4            |
| A <sub>30</sub>   | 3087.5                       | 3161.5                      | 2.39           |
| P <sub>10</sub>   | 3021.5                       | 3071.0                      | 1.6            |
| P <sub>20</sub>   | 3009.5                       | 3053.5                      | 1.4            |
| P <sub>30</sub>   | 2987.0                       | 3029.5                      | 1.4            |

### 4.3 Fire Resistance Test

Results of the fire resistance test as shown in table 4.3 revealed that interlocking pavement blocks with higher replacement percentages (B30, F30, BKD30, A30, and P30) generally exhibited reduced compressive strength after fire exposure compared to their pre-fire strength. For instance, post-fire average compressive strengths for B30, F30, BKD30,

A30, and P30 samples were 20.8, 22.1, 21.2, 16.7, and 20.4 MPa, respectively, indicating decreased fire resistance. Conversely, samples with lower replacement percentages (B10, F10, BKD10, A10, and P10) showed minimal or no change in compressive strength after fire exposure, suggesting better fire resistance. For example, post-fire average compressive strengths for these samples were 22.9, 24.6, 23.4, 18.4, and 22.6 MPa, respectively.

**Table 3:** Fire resistance test of different Samples of Interlocking Pavement Blocks

| Sample            | Fire Resistance Test |                |
|-------------------|----------------------|----------------|
|                   | Before fire          | After fire     |
|                   | Strength (MPa)       | Strength (MPa) |
| Conventional      | 25.8                 | 22.1           |
| B <sub>10</sub>   | 27.8                 | 24.7           |
| B <sub>20</sub>   | 25.9                 | 23.5           |
| B <sub>30</sub>   | 19.6                 | 18.2           |
| F <sub>10</sub>   | 27.3                 | 24.6           |
| F <sub>20</sub>   | 25.5                 | 22.9           |
| F <sub>30</sub>   | 19.1                 | 17.5           |
| BKD <sub>10</sub> | 27.1                 | 25.3           |
| BKD <sub>20</sub> | 25.2                 | 23.8           |
| BKD <sub>30</sub> | 18.7                 | 17.1           |
| A <sub>10</sub>   | 25.9                 | 22.4           |
| A <sub>20</sub>   | 23.6                 | 20.7           |
| A <sub>30</sub>   | 17.8                 | 16.2           |
| P <sub>10</sub>   | 25.4                 | 24.9           |
| P <sub>20</sub>   | 22.6                 | 22.1           |
| P <sub>30</sub>   | 17.1                 | 16.7           |

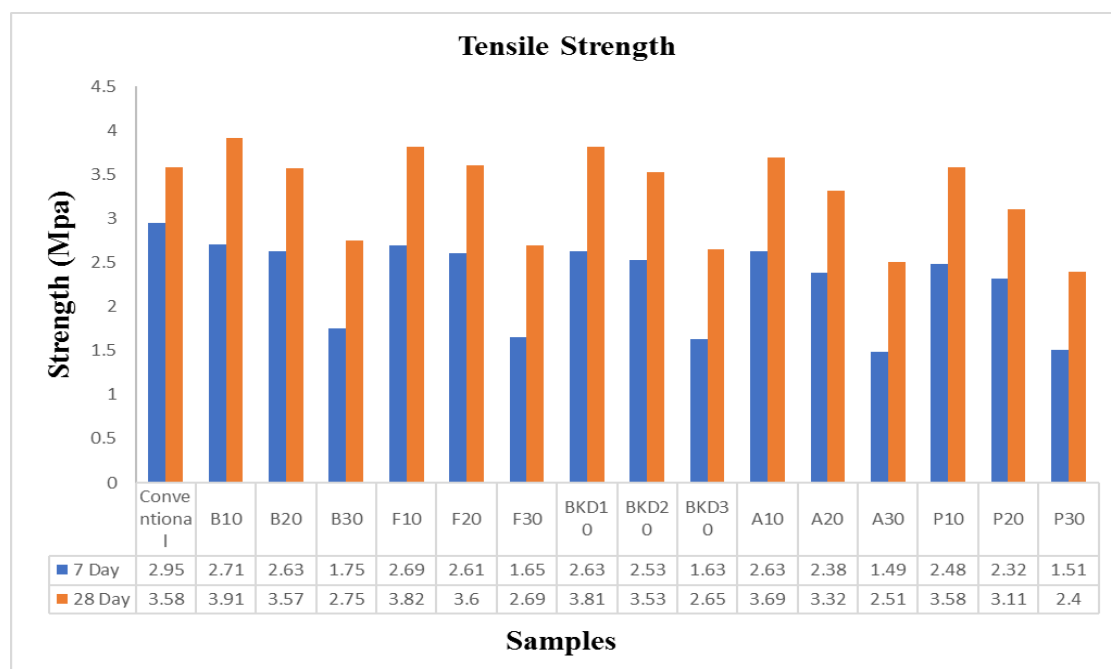
### 4.4 Tensile Strength Test

Tensile strength data, including maximum load and deformation, were recorded using the ASTM C1583 standard formula for each sample, along with batch number and material replacement percentage. The results

were analyzed to assess tensile strength characteristics of interlocking pavement blocks from different batches with varying material replacements, evaluating their performance against typical tensile stresses in real-world applications. The results are shown in Table 4.

**Table 4:** Tensile Strength of different Samples of Interlocking Pavement Blocks

| Sample            | Average Tensile Strength     |                   |                |                              |                   |                |
|-------------------|------------------------------|-------------------|----------------|------------------------------|-------------------|----------------|
|                   | 7 Days                       |                   |                | 28 Days                      |                   |                |
|                   | Density (kg/m <sup>3</sup> ) | Failure Load (KN) | Strength (Mpa) | Density (kg/m <sup>3</sup> ) | Failure Load (KN) | Strength (Mpa) |
| Conventional      | 2583                         | 388.78            | 2.95           | 2647.08                      | 431.32            | 3.58           |
| B <sub>10</sub>   | 2509.58                      | 349.41            | 2.71           | 2570.53                      | 458.45            | 3.91           |
| B <sub>20</sub>   | 2497.08                      | 338.91            | 2.63           | 2556.66                      | 429.18            | 3.57           |
| B <sub>30</sub>   | 2473.33                      | 280.16            | 1.75           | 2530.37                      | 346.51            | 2.75           |
| F <sub>10</sub>   | 2593.75                      | 342.25            | 2.69           | 2648.74                      | 447.54            | 3.82           |
| F <sub>20</sub>   | 2637.5                       | 331.77            | 2.61           | 2690.41                      | 427.44            | 3.60           |
| F <sub>30</sub>   | 2661.25                      | 273.55            | 1.65           | 2713.33                      | 339.76            | 2.69           |
| BKD <sub>10</sub> | 2588.75                      | 340.13            | 2.63           | 2655.83                      | 449.35            | 3.81           |
| BKD <sub>20</sub> | 2590.83                      | 329.98            | 2.53           | 2660                         | 428.55            | 3.53           |
| BKD <sub>30</sub> | 2592.91                      | 267.73            | 1.63           | 2664.16                      | 332.16            | 2.65           |
| A <sub>10</sub>   | 2581.25                      | 332.34            | 2.63           | 2644.17                      | 430.12            | 3.69           |
| A <sub>20</sub>   | 2577.5                       | 316.23            | 2.38           | 2639.13                      | 418.57            | 3.32           |
| A <sub>30</sub>   | 2572.92                      | 270.13            | 1.49           | 2634.83                      | 319.45            | 2.51           |
| P <sub>10</sub>   | 2517.61                      | 318.44            | 2.48           | 2559.15                      | 423.47            | 3.58           |
| P <sub>20</sub>   | 2507.87                      | 304.65            | 2.32           | 2544.82                      | 410.88            | 3.11           |
| P <sub>30</sub>   | 2489.16                      | 246.87            | 1.51           | 2524.84                      | 312.34            | 2.40           |



**Figure 2:** Tensile Strength of different Samples of Interlocking Pavement Blocks Graph showing Tensile Strength of different samples

#### 4.5 Skid/Slip Resistance Test

Skid resistance tests were conducted using the British pendulum tester, measuring the British Pendulum Number (BPN) on a clean, dry surface. Each sample underwent three repetitions, and the average BPN value was recorded as the final skid resistance value. Results are indicated in Table 5.

**Table 5:** Skid Resistance of different Samples of Interlocking Pavement Blocks

| Sample Number     | Pendulum Number |
|-------------------|-----------------|
| Conventional      | 47.3            |
| B <sub>10</sub>   | 45.2            |
| B <sub>20</sub>   | 43.7            |
| B <sub>30</sub>   | 42.5            |
| F <sub>10</sub>   | 46.5            |
| F <sub>20</sub>   | 44.8            |
| F <sub>30</sub>   | 42.3            |
| BKD <sub>10</sub> | 48.0            |
| BKD <sub>20</sub> | 49.2            |
| BKD <sub>30</sub> | 49.7            |
| A <sub>10</sub>   | 45.7            |
| A <sub>20</sub>   | 43.5            |
| A <sub>30</sub>   | 42.0            |
| P <sub>10</sub>   | 46.3            |
| P <sub>20</sub>   | 44.5            |
| P <sub>30</sub>   | 43.2            |

#### 5. CONCLUSION

This research explored the feasibility of producing eco-friendly, lightweight, and strong interlocking paving units by replacing cement and aggregates with waste materials such as fly ash, bagasse ash, brick kiln dust, and plastic waste. The results showed that certain ratios (10%) of cement replacements led to higher compressive strengths at 28 days, while aggregate replacements with crushed waste plastic had a minor effect on tensile strength. Brick kiln dust (BKD) at a 30% ratio (BKD30) proved to be the best material due to its superior strength after fire and skid resistance performance. Utilizing these waste materials in pavement block manufacturing can contribute to waste reduction and environmentally sustainable construction. However, this study has limitations, including the use of a limited range of waste materials and testing under specific conditions. Future research should focus on long-

term durability, explore other waste materials, investigate large-scale construction applications, inform industry stakeholders about eco-friendly materials, and conduct cost-benefit analyses. Utilizing waste materials as replacements can lead to cost savings and reduced environmental impact, making them a viable option for sustainable construction practices.

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