Experimental Investigation on Paver Block with Waste Plastic Chips and Sugarcane Bagasse Ash

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Abstract. India is the top producer of sugarcane in the world, making sugarcane bagasse 91 million tonnes annually from more than 500 sugar mills. Besides, the country is grappling with plastic waste management as it produces 3.4 million tonnes of plastic waste every year out of which only 30% is recycled. Therefore, solving these problems requires a new, eco-friendly approach that can efficiently use both agricultural and plastic wastes. This research is about the possibility of producing eco-friendly paver blocks by using sugarcane bagasse ash and waste plastic chips as partial substitutes for natural materials. We experimented with various percentages of bagasse ash and plastic chips to evaluate the main mechanical properties such as compressive strength and water absorption. The experimental results indicate that a mix containing 15% SBA and 5% waste plastic chips attained compressive strength values comparable to conventional paver blocks, with acceptable water absorption characteristics. Based on experimental outcomes, the developed paver blocks are suitable for footpaths and low-load paving applications, contributing to sustainable construction and effective waste utilization.

1 Introduction

Sustainable practices have shifted from a small interest to the mainstream trend within the global construction industry, owing to the critical need to reduce the impact on the environment through the reduction of carbon emissions and efficient use of resources. The infrastructure industry is witnessing tremendous growth in the country, given the massive investment by the government for construction and infrastructure development in the fields of housing, roads and ports, thereby increasing the growth of traditional construction materials on the nation's resources [1, 2, 3]. This is a critical juncture for combating two of the biggest issues affecting the environment globally: plastic and agricultural waste.

Agricultural residues like sugarcane bagasse ash (SBA) and waste plastics are readily available, cost-effective and environmentally compatible replacements for conventional cements and aggregate materials [1, 4, 5]. The sugarcane bagasse ash, being a by-product of

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the sugar industry, has been found to be high in its content of amorphous silica, thus making it efficient as a pozzolanic binder component, particularly for enhancing the mechanical properties and durability of concrete-based construction materials [6, 7, 8, 9]. Meanwhile, the inclusion of waste plastic chips in the matrix has been found to be viable for the recycle and potential improvement of the ductility and water-resistive properties of the matrix [4, 10, 11].

Recent research pinpointed the efficiency of computational and innovative approaches towards waste incorporation within construction. For example, the environmental use of red mud in concrete has been analysed by checking the mechanical strength and durability with machine learning models [12]. On similar lines ANN-PSO modeling has been utilized effectively to predict buckling in self-compacting concrete column having properties of Rice Husk Ash (RHA) [13]. Further, on the experimental investigation of flexural strength of RC beams, by using the laminates of polymer infiltrated steel fiber, represents the diversification of composite materials in structural engineering [14].

In terms of infrastructure, paver blocks are integral parts of pathways and driveways in urban areas. The added benefit of considering SBA and plastic chips in the paver blocks will improve their strength, allowing them to withstand larger weights without compromising their beauty. However, despite the benefits associated with the usage of each of these products individually, a significant research need exists, particularly in terms of investigating the synergistic effects of the materials during the creation of paver blocks.

The present paper has identified this research gap and critically examines the effects of sugarcane bagasse ash and waste plastic chips in terms of water absorption, compressive strength and performance of paver blocks. By optimizing the mixture proportion using optimized mixture proportion using advanced techniques in modeling such as Response Surface Methodology [7], the scientific contribution of this research is the development of sustainable and high-performance paver blocks for circular economy and sustainable construction practices [11, 15].

2 Materials

2.1 Sugarcane bagasse ash

Sugarcane bagasse ash (SBA), the byproduct of burning sugarcane bagasse, is the waste left behind after crushing the sugarcane stalks to extract the juice in sugar mills. SBA has pozzolanic properties, thus making it a potential substitute for cement. The use of SBA in place of cement is ecologically sound and minimizes the environmental impacts due to the disposal of sugarcane bagasse.

Table 1. Physical Properties of Sugarcane Bagasse Ash

Property	**Value**
Specific gravity	2.35

2.2 Waste plastic chips

Waste plastic originates from the post-consumer or industrial plastic materials, such as PE, PP and PET were crushed and converted into chips. It is utilized as a partial replacement for coarse aggregate in concrete mixtures. The use of these plastic chips could enhance sustainability and mechanical performance. Polyethylene (PE) is the major constituent in the plastic chips.

Table 2. Properties of Waste Plastic Chips

Property	**Value**
Specific Gravity	0.96
Thermal Coefficient of Expansion	200×10^{-6} /°C
Density	0.965 g/cm³

3 Methodology and Specimen Preparation

The experimental program was designed to evaluate the mechanical and physical properties of paver blocks incorporating Sugarcane Bagasse Ash (SBA) and waste plastic chips as partial replacements for cement and coarse aggregates, respectively. The methodology followed a systematic approach consisting of mix design, specimen casting and standardized testing.

3.1 Mix Design and Proportions

Concrete mix proportioning was designed in accordance with IS 10262:2019 guidelines. A control mix, designated as M20, was designed, and cement was replaced by SBA in varying proportions, such as 5%, 10%, 15%, 20%, 25%, and 30%. The proportion of waste plastic chips was kept constant at 5% by weight of coarse aggregate. The water-binder ratio (w/b) was kept at 0.50.

Table 3. Mix calculation

S.No	**Material**	**Unit volume**
1	Cement	384.0 kg/m^3
2	Water	192.6 kg/m^3
3	Sand	726 kg/m^3
4	Coarse aggregate	1105 kg/m^3
5	Water to binder ratio	0.50

3.2 Specimen Preparation

Preparation of the specimens was done through a standardized casting method, which was as follows:

- **Mixing:** Initially, a dry mix of cement, SBA, sand, and coarse aggregates, including plastic chips, was prepared. Water was then gradually added to the mixture to attain uniform consistency.
- **Molding:** Concrete cubes of 150 mm x 150 mm x 150 mm dimensions were prepared for compressive strength and absorption tests. Concrete beams were prepared for flexural strength tests. Standardized molds were used to produce paver blocks at 0%, 15%, and 25% replacement levels.
- **Compaction and Curing:** Compaction of the prepared concrete was done using a vibrating table. After 24 hours, the specimens were removed from the molds and placed in a curing tank. This was done to allow the development of strength in the concrete.

3.3 Materials Required

Table 4. Material Required for Cube

Material / Proportion	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Plastic Chips (kg)	Sugarcane Bagasse ash
0%	1.292	0.646	2.453	3.7226	-	-
5%	1.2274	0.646	2.453	3.546	0.176	0.0646
10%	1.1628	0.646	2.453	3.546	0.176	0.1292
15%	1.0982	0.646	2.453	3.546	0.176	0.1938
20%	1.0336	0.646	2.453	3.546	0.176	0.258
25%	0.969	0.646	2.453	3.546	0.176	0.323
30%	0.9044	0.646	2.453	3.546	0.176	0.3876

Table 5. Material Required for beam

Material / Proportion	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Plastic Chips (kg)	Sugarcane Bagasse ash
0%	1.915	0.958	3.635	5.515	-	-
5%	1.915	0.958	3.635	5.245	0.275	0.019
10%	1.723	0.958	3.635	5.245	0.275	0.195
15%	1.627	0.958	3.635	5.245	0.275	0.287
20%	1.532	0.958	3.635	5.245	0.275	0.383
25%	1.436	0.958	3.635	5.245	0.275	0.478
30%	1.340	0.958	3.635	5.245	0.275	0.578

Table 6. Material required for Paver Block

Material / Proportion	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Plastic Chips (kg)	Sugarcane Bagasse ash
0%	1.008	0.504	1.913	2.903	-	-
15%	0.856	0.504	1.913	2.469	0.43	0.151
25%	0.756	0.504	1.913	2.469	0.43	0.252

3.4 Test Methods

To evaluate the performance of concrete mixtures, the following tests were carried out:

- **Compressive Strength Test:** This test was carried out on concrete cubes and paver blocks using a Compression Testing Machine (CTM) at 7 and 28 days of curing. The maximum load at which each sample failed was recorded and used to calculate compressive strength in N/mm^2.
- **Flexural Strength Test:** This test was carried out on beam specimens to find out the modulus of rupture, which is a measure of resistance of concrete to bending.
- **Water Absorption Test:** Specimens were weighed in a dry state and weighed again after immersed in water for 24 hours to determine the percentage of water absorbed, serving as an indicator of porosity and moisture resistance.

4 Results and discussions

4.1 Compressive strength test

The compressive strength tests were performed according to IS 516 specifications. The compressive strength values for the concrete were determined at 7 days and 28 days with sugar cane bagasse ash mixes at various proportions, viz., 0%, 5%, 10%, 15%, 20%, 25%, and 30%. For each proportion, three tests were performed, and the compressive strength values for each proportion are listed in Table 7 and Fig. 1 for both curing periods.

Table 7. Compressive strength – 7 & 28 days

S. No.	Sugarcane Bagasse ash	7 days Strength N/mm^2	28 days Strength N/mm^2
1	0%	15.07	20.2
2	5%	14.36	18.91
3	10%	10.25	15.4
4	15%	13.33	19.34
5	20%	10.76	13.39
6	25%	14.07	14.44
7	30%	4.90	8.05

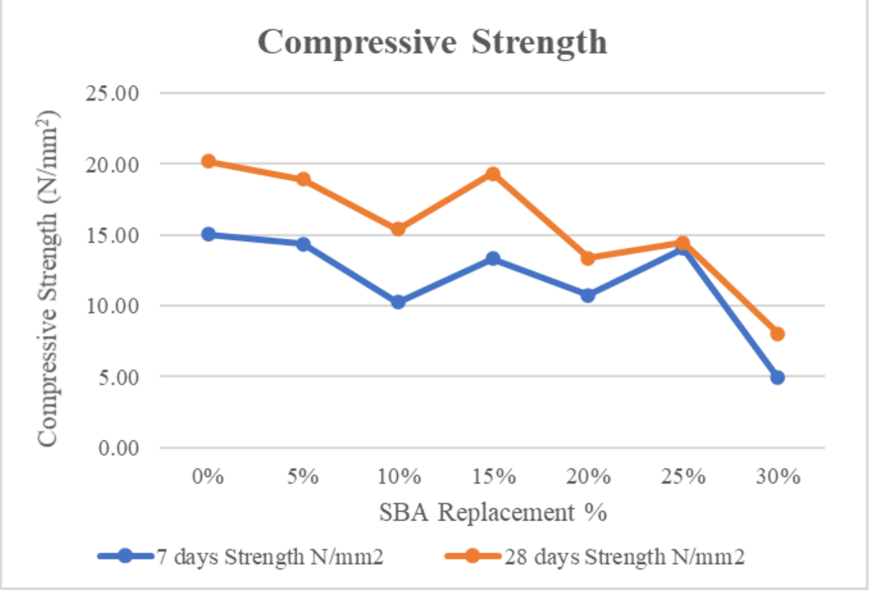

Fig. 1. Compressive strength

From the graph it is evident that as the percentage of the Sugarcane Bagasse Ash (SBA) increases from 0 to 30, the compressive strength decreases in the material, but slight changes are noticed in the progress. It is evident that the compressive strength is greater after 28 days compared to that after 7 days in the entire range of the Sugarcane Bagasse Ash, showing that the strength increases as the days pass in the mixture. It is evident that the mixture, which contains 15% Sugarcane Bagasse, possesses an outstanding balance of strength, as the proportion is closer to the normal mix after 28 days. In the mix, it was noted that after the replacement of greater than 20% of the Sugarcane Bagasse, the strength in the mixture was reduced to a considerable extent.

4.2 Water absorption test

The water absorption test for concrete was evaluated on 7 and 28 days using seven proportions of sugarcane bagasse ash 0%, 5%, 10%, 15%, 20%, 25%, and 30% and plastic chips. Concrete cubes were prepared with these varying ash contents, and three trials were performed for each mix. The results of the water absorption tests are presented in Table 8, corresponding to the 7-day and 28-day curing periods. The Fig. 2a & 2b shows the graphical representation of 7- and 28-days water absorption test value for the concrete cube.

Table 8. Water Absorption test - 7 & 28 Days

S. No.	Sugarcane Bagasse ash	Water Absorption (%)					
		7-days			28-days		
		Cube-1	Cube-2	Cube-3	Cube-1	Cube-2	Cube-3
1	0%	3.31	1.72	1.3	1.32	1.3	1.5
2	5%	9.1	2.86	6.4	4.98	7.13	6.7
3	10%	3.53	4.26	9.9	2.59	5.5	4.07
4	15%	0.78	4.15	3.03	5.78	5.27	3.26
5	20%	9.93	6.31	3.56	7.62	10.06	6.65
6	25%	13.72	5.89	10.03	8.72	10.36	7.14
7	30%	2.46	14.51	3.9 4	6.6	11.56	11.76

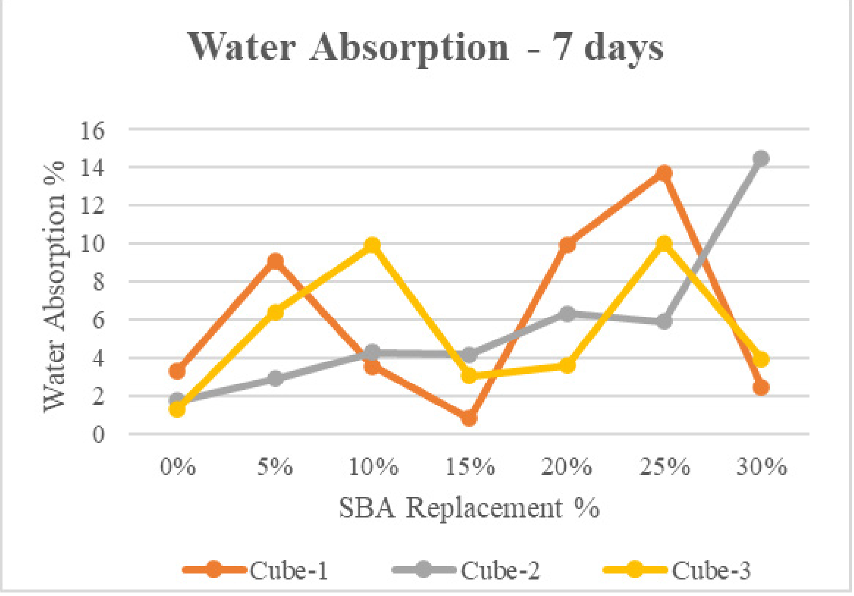

Fig. 2a. Water Absorption test- 7 days

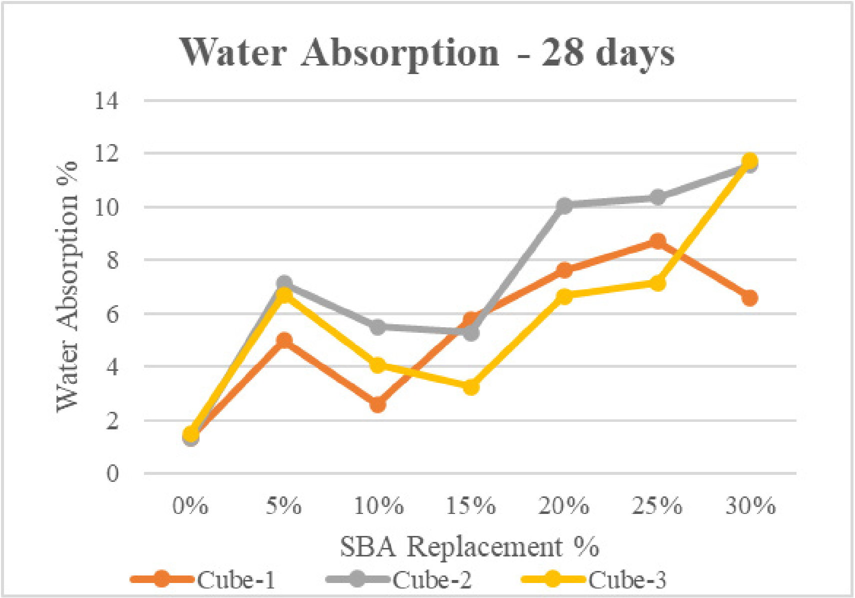

Fig. 2b. Water Absorption test- 28 days

At both 7 days and 28 days, the water absorption of concrete cubes with varying levels of Sugarcane Bagasse Ash will show a trend toward more water absorbed, but the amount absorbed will not increase proportionally to the amount of SBA added into the mix. In addition, many concrete cubes with a percentage SBA content of 5%, 20% and 25% had higher levels of water absorbency after 7 days of curing than those with lower percentages of SBA. The absorption values decreased after 28 days; however, when compared to other concrete mixtures with lower percentages of SBA used in their mixtures, concrete cubes with a percentage of SBA between 20%-30% had high levels of water absorbency. Due to the use of higher percentages of SBA, concrete Cubes 2, 1, and 3 had the highest water absorption values among their respective mix design groups (respectively). It is evident that the addition of Sugarcane Bagasse preserves concrete from absorbing water for a longer period of time when curing takes place over a longer duration (28 days vs 7 days) than the other two concrete mixes. However, both Cube 2 and Cube 3 retain the highest absorbency value of their mix designs after the same curing periods.

4.3 Flexural strength test

Using beams made with different amounts of sugarcane bagasse ash (SBA) 0%, 5%, 10%, 15%, 20%, 25%, and 30% the flexural strength of concrete was assessed at 7 and 28 days. To guarantee accuracy, three trials were carried out for every mix. The results of the flexural strength tests are presented in Tables 9, corresponding to the 7-day and 28-day curing periods. The fig. 3 shows the graphical representation of 7- and 28-days Flexural strength value for the concrete Beam.

The graph illustrates the impact of Sugarcane Bagasse Ash (SBA) content on the flexural strength of concrete beams at 7 and 28 days of curing. As the percentage of SBA increases from 0% to 30%, the 7-day and 28-day flexural strengths are found to decrease, showing that increasing SBA percentages weaken the concrete. However, at 30% SBA, there is an increase in the flexural strength. At all percentages of SBA, the 28-day strength is found to be greater than the 7-day strength.

Table 9. Flexural Strength Test (Beam)

S. No.	Sugarcane Bagasse ash	7-days Strength N/mm^2	28-days Strength N/mm^2
1	0%	2.25	2.5
2	5%	1.25	1.9
3	10%	1.5	1.82
4	15%	1.375	1.77
5	20%	1.3	1.5
6	25%	1	1.25
7	30%	1.4	1.5

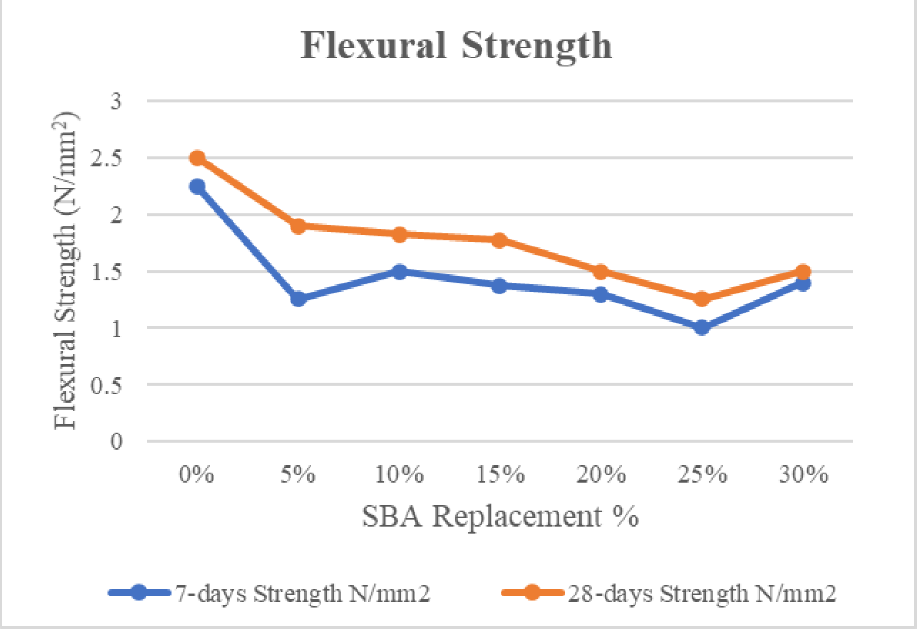

Fig. 3. Flexural strength test

From the test compression test results of 7 and 28 days we have a maximum strength in the proportion of 15% and 25%, and also for the flexural strength test with the proportion of above-mentioned higher strength we have taken for a paver block as an optimum strength.

4.4 Compression test (Paver block):

The paver block was casted with 0%, 15%and 25% of SBA and the test was done. The table 10 and Fig.4 represent the compression strength of paver block.

Table 10. Compression Test

S.No.	Sugarcane Bagasse ash	Waste Plastic Chips	Compressive Strength (N/mm^2)			Mean compressive strength	Standard Deviation
			Trial 1	Trial 2	Trial 3		
1	0%	5%	19.85	20.20	19.50	19.85	8
2	15%	5%	18.46	17.85	18.20	18.17	7.02
3	25%	5%	16.02	13.93	15.06	15.00	24.03

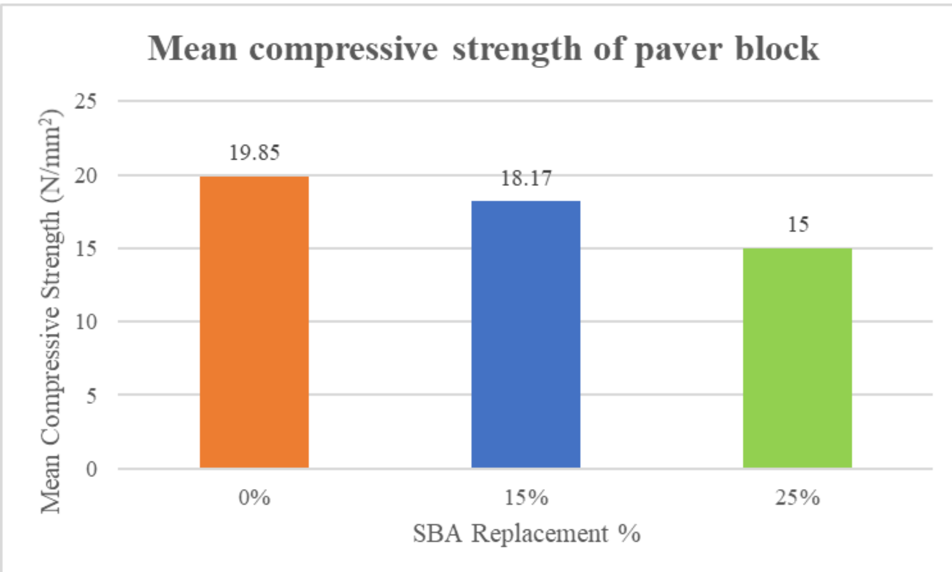

Fig. 4. Compression strength of paver block

The compressive strength of the specimens made with constant 5% waste plastic chip and various amounts of sugarcane bagasse ash was assessed in terms of average strength from three experimental runs. As expected, the control specimen prepared with 0% sugarcane bagasse ash yielded the maximum average compressive strength of 19.85 N/mm^2, reflecting thereby higher load-carrying capacity. With the increase in the content of sugarcane bagasse ash to 15%, the average compressive strength marginally reduced to 18.17 N/mm^2, while test results were quite consistent and thus showed stable material response and acceptable retention of strength beyond this level. Beyond this, a sharp loss in compressive strength is recorded for the case of replacement at 25%, where the mean value comes out to be 15.00 N/mm^2 along with greater deviation in the test results. The significant reduction thus indicated matrix deterioration and loss of bond between the matrices at higher replacement levels. Corresponding to this, based on the strength performance coupled with material consistency, use of 5% plastic chips and sugarcane bagasse ash as replacement up to 15% was the optimum replacement in which acceptable compressive strength is reflected without significant loss of strength seen at higher replacement percentages.

4.5 Water absorption test (Paver block):

The paver block was casted with 0%, 15%and 25% of SBA and the test was done. The table 11 and Fig.5 represent the water absorption of paver block.

Table 11. Water Absorption Test

S.No.	Sugarcane Bagasse ash	Waste Plastic Chips	Water Absorption %			Mean Water Absorption	Standard Deviation
			Trial 1	Trial 2	Trial 3		
1	0%	5%	2.49	2.06	2.81	2.45	0.38
2	15%	5%	3.60	3.52	3.90	3.67	0.19
3	25%	5%	6.90	5.96	6.67	6.51	0.48

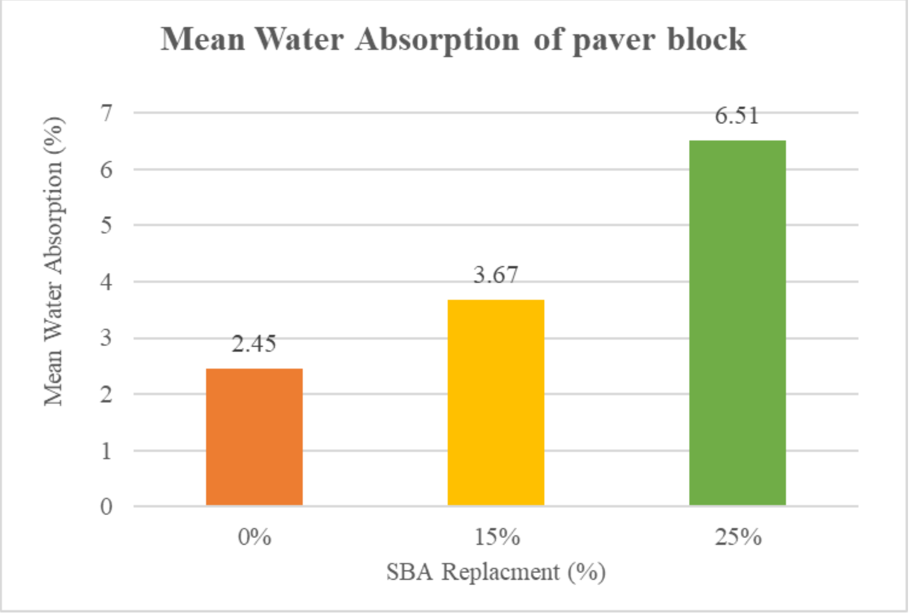

Fig. 5. Water absorption test (Paver block)

The plot shows water absorption variation with the inclusion of increasing amounts of sugarcane ash, plotted as the average values of three experimental runs with standard deviation shown as error bars. When the sugarcane ash is 0%, the average water absorption is low, about 2.45%, reflecting a dense matrix with little porosity. Then, for a 15% ash content, the water absorption rises moderately to about 3.67%, showing that partial replacement does create pores. It then increases very sharply at 25% sugarcane ash with an average water absorption of around 6.51%, which indicates that the porosity and permeability increase sharply at this higher replacement percentage. The low standard deviation for the 15% indicates good consistency in the results, while the high standard deviation for the 25% indicates more variation in the results. Therefore, it can be deduced that 15% replacement can be considered the optimum replacement based on the results for the water absorption, while the increase in replacement percentage results in a sharp increase in porosity and the amount of absorbed water.

5 Conclusion

This experimental investigation exhibits that Sugarcane Bagasse Ash and waste plastic chips can be effectively used in the production of sustainable concrete paver blocks. It has been identified by this investigation that a combination of 5% waste plastic chips and 15% SBA is optimum to replace to generate green paver blocks for pavement construction. At this optimum percentage of SBA, it was identified that the specimens produced a high average compressive strength of 18.17 kN with higher consistency among the results, as reflected by the minimal value of standard deviation at 7.02 which maintains structural viability compared to the 19.85 kN strength of the control mix. At this percentage of SBA and waste plastic chips combination, it was also noted that water absorption was within the acceptable limits, attaining a satisfactory average level of 3.67% and a minimal standard deviation of merely 0.19, making it widely applicable as a walking pathway. However, when SBA was replaced up to a higher percentage of 25%, a sharp decline was noted in the average compressive strength to merely 15.00 kN along with a steep rise in water absorption up to a level of 6.51% which compromises long-term durability. Consequently, the 15% SBA and 5% plastic chip mix meet out the environmental valorization with engineering performance, provided that a full 28-day curing period is observed to ensure proper strength development. The combined use of SBA and plastic waste contributes to resource conservation, waste reduction, and environmentally responsible construction.

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