



An experimental investigation on concrete pavers block by replacement of fine aggregate with plastic waste

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Abstract: Plastic waste poses a significant global challenge, occupying an ever-increasing amount of landfill space. Our project focuses on addressing this issue by repurposing polypropylene (PP) plastic waste for the manufacturing of pavers. To achieve this, we meticulously melted and cut the plastic into 4mm granules, suitable for integration into concrete mixtures. In our experimental approach, we developed a concrete mix design specifically tailored for paver production, wherein we replaced a targeted portion of the fine aggregate (specifically, the fraction ranging from 4.75mm to 2.36mm) with the 4mm plastic granules. Following a standardized curing period of 28 days, we conducted compressive tests to assess the structural integrity of the resulting pavers. Remarkably, our findings revealed a slight decrease in compressive strength compared to traditional pavers. However, this reduction remained well within the acceptable limits stipulated by codal provisions. Additionally, the density of the pavers exhibited a decrease, attributable to the lightweight nature of the incorporated plastic. This project not only presents a sustainable solution to the plastic waste predicament but also underscores the feasibility of integrating such waste materials into construction practices. Furthermore, it sheds light on the nuanced effects of plastic incorporation on material properties, providing valuable insights for future endeavours in sustainable construction.

IndexTerms – Pavers, Polypropylene plastic, Cement, Compressive strength, Density.

I INTRODUCTION

A paver is a paving stone, tile, brick or brick-like piece of concrete commonly used as exterior flooring. These pavers are generally placed on top of a foundation which is made of layers of compacted stone and sand. The paver is placed in a desired pattern and the space between them is filled with polymeric sand. No actual adhesive or retaining method is used other than the weight of paver itself except edging. Pavers can be used to make roads, driveways, patios, walkways and other outdoor platforms.

Concrete paver which are also known as Segmental pavers which involves interlocking system. These pavers have been used for thousands of years (not specifically cement concrete). In addition to being economical, interlocking concrete pavers are widely available in water permeable designs. By allowing water to drain through pavers in way that mimics natural absorption, landscapers are able to limit the surface runoff and prevent soil erosion.

The increasing Global concern over plastic waste pollution has led to innovative strategies to recycle and repurpose plastic. One such solution involves use of waste plastics in the construction industries, particularly in the creation of eco-friendly pavers.

Plastic paver can be employed in a variety of construction projects, such as walkways, driveways, parking lots, footpath and even in the creation of green, permeable surfaces that facilitate water infiltration and reduce urban heat.

1.1 Different types of plastic

- PET (Polyethylene Terephthalate)- Food and Drink packaging.
- HDPE (High Density Polyethylene)- grocery bags, milk jugs, recycling bins, agricultural pipe, but also playground equipment, lids, and shampoo bottles among others.
- PVC (Polyvinyl Chloride)- door and window profiles and pipes (drinking & wastewater).
- LDPE (Low Density Polyethylene)- Used in plastic bags, six-pack rings, various containers, dispensing bottles, and most famously for plastic wraps, is not often recycled.
- PP (Polypropylene)- Tupperware, car parts, thermal vests, yogurt containers, and even disposable diapers.



Fig 1: Types of plastic and their uses

1.2 Global Waste generation

Global plastic waste generation refers to the total amount of plastic waste produced by human activities worldwide within a specific period. Plastic waste includes various items such as packaging, bottles, containers, bags, and other single-use plastics. Plastic waste generation has been increasing rapidly due to factors such as population growth, urbanization, industrialization, and the widespread use of plastics in various sectors.

Plastic waste poses significant environmental challenges, including pollution of oceans, waterways, and terrestrial ecosystems, as well as harm to wildlife. In addition, plastic waste contributes to greenhouse gas emissions and affects human health through microplastic ingestion and chemical exposure.

Efforts to address global plastic waste generation include initiatives to reduce plastic consumption, improve waste management infrastructure, promote recycling and circular economy approaches, and develop alternative materials. International agreements and policies also play a crucial role in tackling the global plastic waste problem.

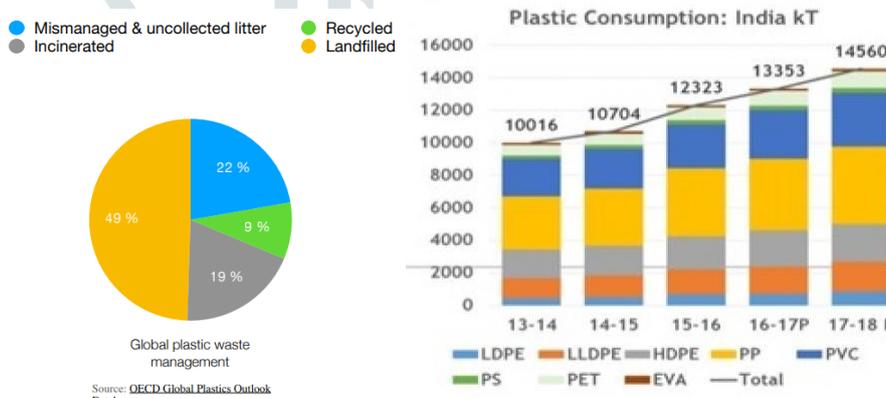


Fig 2: Statistics on plastic waste management and consumption

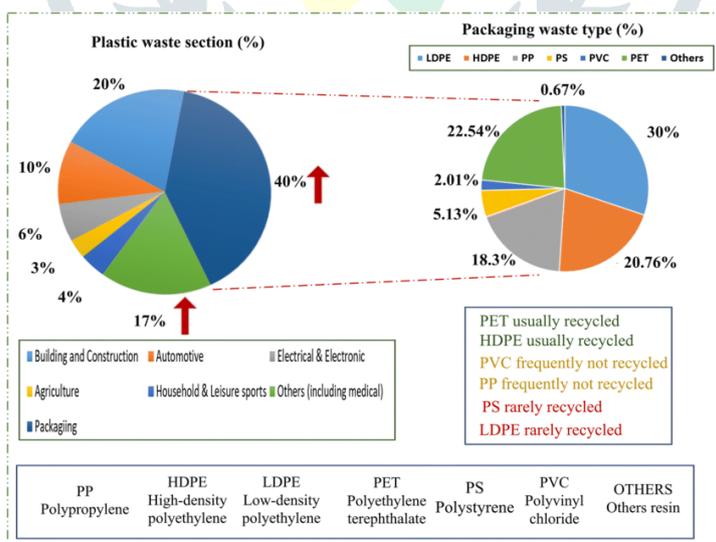


Fig 3: Chart of production of all waste

1.3 Management of plastic waste

The management of plastic waste involves various strategies and approaches aimed at reducing the environmental impact of plastic pollution and promoting sustainable practices. Here are some key aspects of plastic waste management:

1. **Reduce:** The first step in plastic waste management is to minimize plastic consumption by reducing unnecessary plastic packaging, promoting reusable products, and encouraging alternatives to single-use plastics.
2. **Reuse:** Encouraging the reuse of plastic products and packaging helps extend their lifespan and reduce the amount of waste generated. This can include refillable containers, reusable bags, and durable plastic products.

3. Recycle: Recycling is a critical component of plastic waste management, where plastic materials are collected, sorted, and processed to produce new products. Improving recycling infrastructure, increasing collection rates, and promoting consumer education are essential for effective plastic recycling.
4. Recovery: Plastic waste can be recovered through various methods such as energy recovery (e.g., waste-to-energy incineration) and resource recovery (e.g., pyrolysis and gasification), where plastics are converted into energy or valuable materials.

Control Measures on plastic waste

1. Policy making
2. Plastic waste management & recycling
3. Education and Public awareness
4. Bioplastic as alternative

II LITERATURE SURVEY

Table 1: List of Literature review

Sl. NO	Material	Plastic Content	Compressive strength	Water absorption	Reference
1	LDPE, 10% M-sand	Melted plastic	15.5	-	Ms. Anila Mary Jacob (2023)
2	LDPE, 3% Coconut Fiber	LDPE: Sand= 3:7	23.23	0.99	Salman Ahmad (2022)
3	LDPE, M-sand MSW	1:0.5:0.5	13.38(82% of conventional M20 block)	1.1	B Anupriya (2021)
4	LDPE, cement, Aggregate	20% of Course aggregate	31.18 28 days		Kazi Bushra Abdulla (2021)
5	Cement, sand, soil, PET	1:2:3 5% PET of sand weight	14	1.65	Lillian Gunga (2021)
6	Thermoplastic, pit sand,	90%- strength 60%- water absorption	38	0.75	Samuel Kofi Tulashie (2020)
7	LDPE, M-Sand, Quarry dust	1:1:0.5	15.9	0.45	S. Raju (2019)
8	PET, cement, Fine & Coarse aggregate	5%	19.1		Nor Farah Atiqah Ahmad (2018)
9	Plastic, Quarry dust, Gravel, ceramic waste	1:1.5:2:0.75	13.03		B. Sanmugavalli (2017)
10	Cement, sand, Aggregate, HDPE	0%-4%	26.9	-	S Vanitha (2015)

III MATERIAL AND METHODOLOGY

3.1 Objective

- Production of Economical and Eco-friendly pavers.
- Preparing a mix design & replacing sand by waste plastic.
- Assessment of Physical properties of paver blocks.

3.2 Facilities used for proposed work

- Basic material testing equipment
- Compression Testing Machine
- Mould for casting pavers

3.3 Materials Used

- Cement
- Plastic waste
- Fine Aggregate
- Coarse aggregate

A) Cement: -

- Specific gravity – 3.15
- Grade of cement = OPC 43 grade
- Initial and final setting time of cement resulted 28 minutes and 9 hours 30minutes respectively.

B) Fine aggregate: -

- Specific gravity – 2.68
- Zone gradation – II

Table 2: Sieve Analysis

IS Sieve size (mm)	Weight of retained (kg)	% weight retained	Cumulative % weight retained	Cumulative % weight passing
4.75	0.0265	2.65	2.65	97.35
2.36	0.0305	3.05	5.7	94.3
1.18	0.121	12.1	17.8	82.2
0.6	0.238	23.8	41.6	58.4
0.3	0.367	36.7	78.35	21.65
0.15	0.153	15.3	93.65	6.35
Pan	0.0165	1.65	-	-
	=0.952			

Table 3: Grading zones of fine aggregate as per IS 383

IS Sieve size (mm)	Grading zone I	Grading zone II	Grading zone III	Grading zone IV
10	100	100	100	100
4.75	90-100	90-100	90-100	95-100
2.36	60-95	75-100	85-100	95-100
1.18	30-70	55-90	75-100	90-100
0.6	15-34	35-59	60-79	80-100
0.3	5-20	8-30	12-40	15-50
0.15	0-10	0-10	0-10	0-15

C) Coarse aggregate: -

- Specific gravity – 2.74
- Impact strength – 7.5%

D) Plastic (PP): -

- Specific gravity – 0.98

3.4 Collection of waste plastic

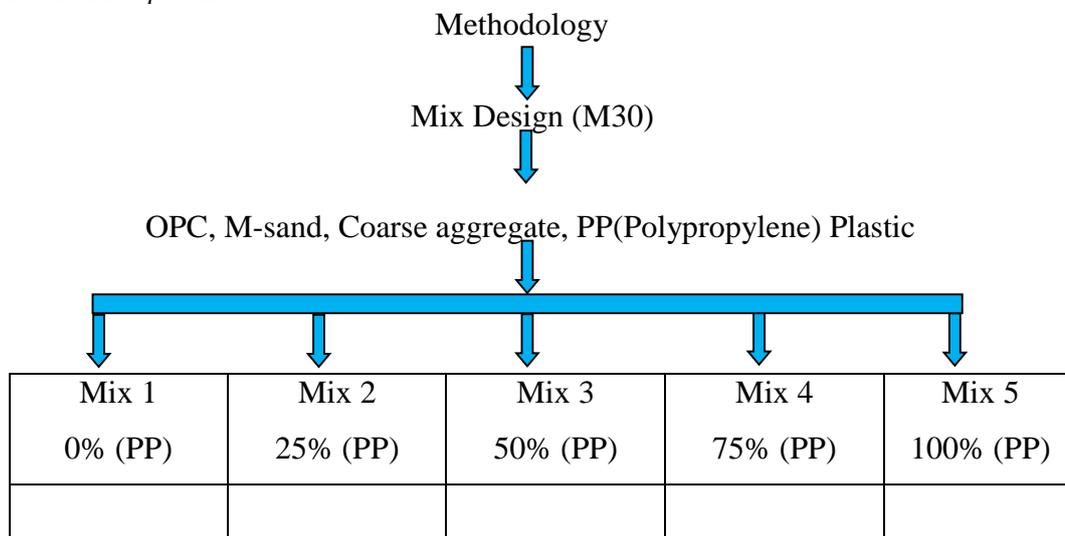
- Collected from KSSIDC Industrial estate, Ballari, Karnataka 583104
- PP was melted and made it to the size of 4mm.
- Cost per kg of this material is Rs.40



Fig 4: Plastic granules

3.5 Methodology/ Planning of work

Steps involved in process



3.5.1 Mixed design

Designing concrete mix involves determining the proportion of various ingredients like cement, aggregate, water and admixtures to achieve desired properties such as strength, durability, workability and economy. Factors like project requirements, environmental conditions and material availability influence the mix design process.

According to IS10262:2019, mix designing is as follows:

$$f_{ck}^2 = 30 + 1.65 \times 5 = 38.25 \text{ N/mm}^2$$

For 10mm aggregate, air content = 1.5%

Water-cement ratio = 0.425

For 10mm aggregate, water content = 195.52 kg/m³

Cement = 195.52 / 0.425 = 460.05 kg/m³

Cement content = 450 kg/m³

Water content = 450 * 0.425 = 191.25 kg/m³

Volume of Coarse aggregate per unit total volume of aggregate = 0.5 (for zone 2)

For 0.45 w-c ratio CA per unit of total aggregate = 0.515

FA per unit of total aggregate = 0.485

Volume of concrete = 1m³

Volume of air content = 1.5 * 1 / 100 = .015 m³

Volume of cement = 450 / (3.15 * 1000) = 0.143 m³

Volume of water = 191.25 / (1 * 1000) = 0.19125 m³

Volume of Aggregate = 1 - 0.143 - 0.19125 - 0.015 = 0.65075 m³

Mass of Coarse aggregate = 0.65075 * 0.515 * 2.7 * 1000 = 951.787 kg

Mass of Fine aggregate = 0.65075 * 0.485 * 2.65 * 1000 = 836.376 kg

Mix Proportion

- Cement = 450kg/ m³
- Fine Aggregate = 845.845 kg/ m³
- Coarse Aggregate = 951.787 kg/ m³
- Water = 191.25 kg/ m³

3.5.2 Casting of pavers

- Casting is done for zig-zag type of mould.
- Size of mould is 250 X 125 X 75mm.
- Casting is done for above designed mix proportion.
- Plastic is replaced with M-sand (passing 4.75mm and retained on 2.36mm).
- Firstly, cement, M-sand, Coarse aggregate (10mm) and water are measured appropriately.
- M-sand passing through 4.75mm sieve and retained on 2.36mm sieve are collected and measured in measuring jar.



Fig 5: Casting of Pavers

- Replace M-sand by volume with plastic by 25%, 50%, 75% and 100%.
- Mixing is done manually with w/c ratio 0.42.
- Mould is filled with the mix and compacted with table vibrator machine which can help ensure uniformity and proper compaction including removal air bubbles and achieves dense finish.

Table 4: Quantity of material for mixing as per mix design

% of plastic in M-sand of size 4.75-2.36 mm	No. of Cubes	Cement (kg)	Sand (kg)	coarse aggregate (kg)	Water (Lit)
0	5	5.56	10.35	11.19	2.36
	4	4.45	8.28	8.95	1.89
25	5	5.56	10.35	11.19	2.36
	4	4.45	8.28	8.95	1.89
50	5	5.56	10.35	11.19	2.36
	4	4.45	8.28	8.95	1.89
75	5	5.56	10.35	11.19	2.36
	4	4.45	8.28	8.95	1.89

100	5	5.56	10.35	11.19	2.36
	4	4.45	8.28	8.95	1.89
Total		54.67	101.61	109.93	23.23

3.5.3 Curing

- Curing is done for 7- and 28-days using pond curing method.
- Pond curing of pavers involves keeping them submerged in water for a specific period after they are laid. This helps to prevent premature drying, ensuring stronger, more durable pavers.



Fig 6: Curing of pavers

IV RESULT AND DISCUSSION

4.1 Fresh concrete testing

Slump cone test

It is the standard method used to access the consistency and workability of fresh concrete. It involves filling cone-shaped container with freshly mixed concrete, then lifting the cone and measuring the extent to which the concrete slumps or settles. The degree of slump indicates the concrete’s consistency.

Procedure of slump cone test is as follows:

- Volume of slump cone = $\frac{1}{3}\pi h(R^2 + r^2 + Rr)$
 $= \frac{1}{3} * \pi * 30(20^2 + 10^2 + 20*10)$
 $= 2199.115 \text{ cm}^3$
- Weight of cement = $450 * 2199.115 * 10^{-6} = 0.989\text{kg}$
- Weight of fine aggregate = $845.845 * 2199.115 * 10^{-6} = 1.86\text{kg}$
- Weight of coarse aggregate = $951.787 * 2199.115 * 10^{-6} = 2.06\text{kg}$
- Quantity of water = $191.25 * 2199.115 * 10^{-6} = 0.42\text{kg} = 420\text{ml}$

Table 5: Slump test values for different % of plastic content

% waste plastic replaced with FA	Slump
0%	50mm
25%	58mm
50%	63mm
75%	70mm
100%	76mm

4.2 Harden paver testing

Test like compression test, water absorption and density test are conducted.



Fig 7: Compression test of pavers using CTM

IS 15658 : 2006

Table 3 Compressive Strength Requirements of Concrete Paver Blocks
(Clauses 6.2.5.2 and 9.1.4)

Sl No.	Grade of Paver Blocks	Minimum Average 28 Days Compressive Strength N/mm ²
(1)	(2)	(3)
i)	M-30	$\geq f_{ck} + 0.825 \times \text{established standard deviation (rounded off to nearest 0.5 N/mm}^2)$
ii)	M-35	
iii)	M-40	
iv)	M-50	
v)	M-55	

Fig 8: Compression strength requirement as per IS 15658:2006

Above table which is provided in IS15658:2006(Precast concrete block for paving).

Table 6: Correction Factors for different thickness of pavers

Sl.No.	Paver block thickness	Correction factor	
		Plain block	Chamfered block
1	50	0.96	1.03
2	60	1.00	1.16
3	80	1.12	1.18
4	100	1.18	1.24
5	120	1.28	1.34

Interpolation of correction for thickness of 75mm = $\frac{1.18-1.16}{80-60} * (75 - 60) + 1.16 = 1.175$

Formulae:

Compression strength = Actual strength X correction factor
 $= \frac{\text{Load in kN}}{\text{Area of paver}} \times 1.175$

Water absorption = $\frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} \times 100$

Density = $\frac{\text{weight of paver}}{\text{volume of paver}}$ (Volume of paver = 0.25 X 0.125 X 0.075=0.00234 m³)

Table 7: Compression testing report

Sl.NO.	% of volume replacement of sand with plastic (in 2.36mm retained sieve)	Compression load (kN)		Compressive Strength (N/mm ²)	
		7 days	28 days	7 Days	28 Days
1	0	990	1150	38.775	45.041
		920	1240	36.033	48.566
		680	1210	26.633	47.391
2	25	770	1130	30.158	44.258
		740	1100	28.983	43.083
		800	1320	31.333	51.7
3	50	890	1170	34.858	45.825
		700	1140	27.416	44.65
		810	1020	31.725	39.95
4	75	740	1140	28.983	44.65
		770	1110	30.158	43.475
		720	1080	28.2	42.3
5	100	600	910	23.5	35.641
		650	1060	25.458	41.516
		1060	730	41.516	28.591

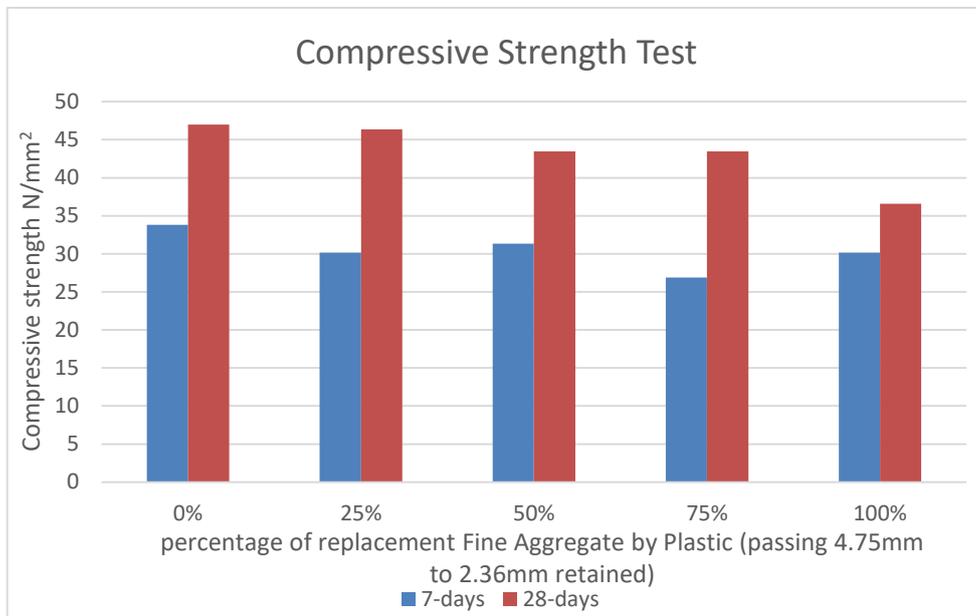


fig 9: Compressive Strength test

Table 8: Water absorption report

Sl.NO.	% of volume replacement of sand with plastic (in 2.36mm retained sieve)	dry weight of paver, kg	wet weight of pavers, kg	water absorption in %	Average water absorption
1	0	5412	5421	0.166	0.09
		5345	5353	0.149	
		5312	5319	0.131	
2	25	5303	5310	0.132	0.145
		5220	5228	0.153	
		5325	5333	0.15	
3	50	5014	5039	0.496	0.27
		5260	5294	0.646	
		5238	5263	0.477	
4	75	5148	5161	0.252	0.43
		5149	5160	0.213	
		5162	5174	0.232	
5	100	5347	5383	0.673	0.56
		4918	4942	0.488	
		5013	5050	0.738	

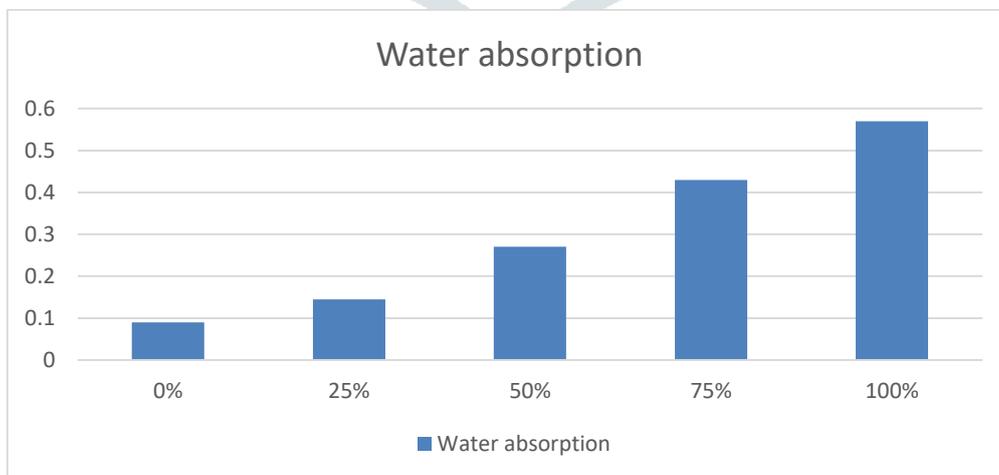


fig 10: Water Absorption of pavers

Table 9: Density report

Sl.NO.	% of volume replacement of sand with plastic (in 2.36mm retained sieve)	Weight of paver, kg	density, kg/m ³	Average density, kg/m ³
1	0	5412	2309.12	2285.36
		5345	2280.53	
		5312	2266.45	
2	25	5303	2262.61	2253.93
		5220	2227.2	
		5325	2272	
3	50	5014	2139.30	2221.15
		5260	2244.26	
		5238	2234.88	
4	75	5148	2196.48	2198.61
		5149	2196.90	
		5162	2202.45	
5	100	5347	2281.38	2172.87
		4918	2098.34	
		5013	2138.88	

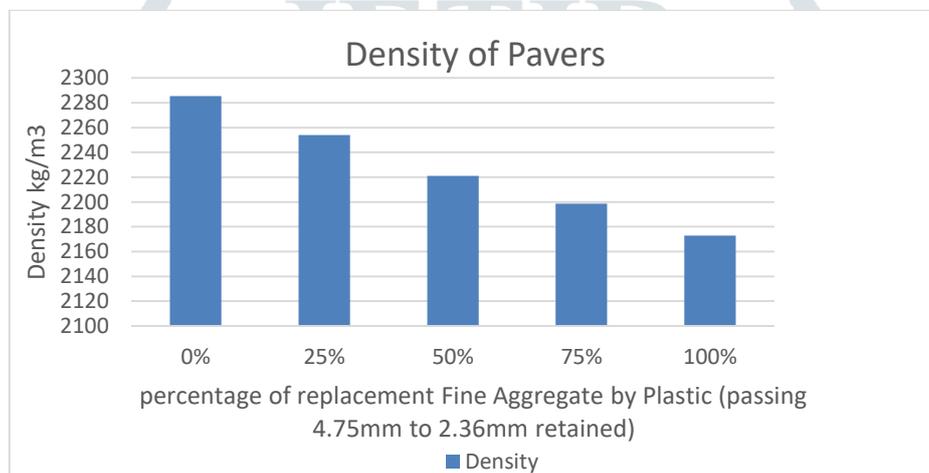


fig 11: Density of pavers

4.3 Discussion

Replacing Fine Aggregate by plastic waste of size passing 4.75mm and 2.36mm retained could contribute to the decrease in strength of the pavers due to following reasons:

1. **Material Properties:** Plastic granules may not have the same mechanical properties as sand. Sand is typically composed of mineral particles, which have higher strength and cohesion compared to plastic granules.
2. **Particle Shape and Surface Area:** The shape and surface area of the particles can influence how well they compact together. Sand grains usually have a more angular shape, allowing them to interlock better compared to the smoother surface of plastic granules.
3. **Interlocking and Compaction:** Sand particles tend to interlock and compact more efficiently during the manufacturing process, providing better structural integrity to the pavers. Plastic granules may not compact as effectively, leading to a weaker overall structure.
4. **Compatibility with Binding Agents:** If binders are used in the paver manufacturing process, they may not adhere as effectively to plastic granules compared to sand, resulting in weaker bonding between particles.

The decrease in density could also be attributed to the replacement of sand with plastic granules:

1. **Material Density:** Plastic granules typically have a lower density than sand. Since density is mass per unit volume, replacing sand with plastic granules of the same size will inherently result in a lower overall density due to the lighter weight of the plastic.
2. **Compaction Efficiency:** As mentioned earlier, plastic granules may not compact as efficiently as sand during the manufacturing process. This inefficient compaction can lead to a looser arrangement of particles and, consequently, a lower density in the final product.
3. **Void Spaces:** Plastic granules may leave more void spaces within the paver compared to sand due to differences in particle shape and surface characteristics. These void spaces contribute to a lower overall density of the paver.
4. **Binder Distribution:** If binders are used in the manufacturing process, they may distribute differently between sand and plastic granules, affecting the density of the final product.

Even with a constant water-cement ratio, the increase in slump values with higher plastic content can be attributed to several factors related to the properties and behaviour of the plastic granules:

1. **Reduced Internal Friction:** Plastic granules typically have smoother surfaces compared to traditional aggregates like sand. This smoothness reduces internal friction within the mix, allowing the particles to move more freely and increasing the mixture's workability.
2. **Lower Density of Plastic Granules:** Plastic is generally less dense than traditional aggregates. When plastic granules replace a portion of the sand, the overall density of the mix decreases. This can lead to a mixture that is easier to handle and has a higher slump.
3. **Improved Lubrication:** Plastic granules can create a more lubricated mix. The smoother surface of plastic granules compared to rough sand particles can result in less resistance to flow, thereby increasing the slump.
4. **Reduced Water Absorption:** Traditional aggregates like sand can absorb water, which might reduce the amount of free water available for improving workability. Plastic granules, on the other hand, typically do not absorb water, leaving more free water in the mix to enhance slump.

In summary, the increase in slump values with higher plastic content, despite a constant water-cement ratio, is due to the smoother surface, lower density, reduced water absorption, and better lubrication provided by the plastic granules, all of which contribute to improved workability of the concrete mixture.

4.4 Cost analysis

Table 10: Cost Analysis

Materials	Normal concrete without plastic			Normal concrete with plastic		
	Qty	rate	Amt	Qty	Rate	Amt
Cement	450kg	350/bag	3150	450kg	350/bag	3150
M-sand	0.313m ³	1600/m ³	500.8	0.304m ³	1600/m ³	486.4
Corse aggregate	0.359m ³	1400/m ³	502.6	0.359m ³	1400/m ³	502.6
Plastic				9.31kg	40/kg	372.4
	Amount per m ³		4153.4	Amount per m ³		4511.4
	Amount per paver (0.00225m ³)		9.34	Amount per paver (0.00225m ³)		10.15

V Conclusion

1. Incorporating plastic granules gradually enhances the fluidity of the mixture. With 0% plastic content, the slump value is 50mm. As increase the plastic content to 25%, 50%, 75% and 100% slump value increases with respect to 0% plastic content by 16%, 26%, 40% and 52% respectively
2. Adding plastic granules will reduce compressive strength but not significantly. Starting from 0% plastic content, the compressive strength measures 47 N/mm². As the plastic content increases to 25%, 50%, 75% and 100% compressive strength decrease with to 0% plastic content by 1.39%, 7.5%, 13.88% and 25% respectively.
3. Adding plastic granules will reduce the density of pavers. Starting from 0% plastic content, the density measures 2285.36 kg/m³. As the plastic content increases to 25%, 50%, 75% and 100% density decreases with respect to 0% plastic content by 1.38%, 2.81%, 3.79% and 4.92% respectively

On adding waste plastic compressive strength reduces, but not significantly. The reduced compressive strength is within the limit of codal provision. So, we suggest 100% of fine aggregate of size between 4.75mm and 2.36mm sieve can be replaced by plastic granules of same size.

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