Building Engineering 2024, 2(1), 1348.
https://doi.org/10.59400/be.v2i1.1348

Article

Potential of low-value plastic waste (LVPW) in concrete through latrine ring manufacturing

Mushtaq Ahmed[1], Muhammad Azizul Hoque[1], H. M. A. Mahzuz[1,*], Nazmul Islam Rafi[1], Md. Jubayer Hossan Salman[1], Khadijatul Kubra Mim[1], Krisha Rana[2], Md. Abdullah Al Ahad[2], Md. Ariful Islam[2], Ratan Kumar Roy[2]

[1] Department of Civil and Environmental Engineering (CEE), Shahjalal University of Science and Technology (SUST), Sylhet 3114, Bangladesh
[2] iDE, Sylhet 3100, Bangladesh
*** Corresponding author:** H. M. A. Mahzuz, mahzuz_211@yahoo.com

CITATION

Ahmed M, Hoque MA, Mahzuz HMA, et al. Potential of low-value plastic waste (LVPW) in concrete through latrine ring manufacturing. Building Engineering. 2024; 2(1): 1348.
https://doi.org/10.59400/be.v2i1.1348

ARTICLE INFO

Received: 30 April 2024
Accepted: 7 June 2024
Available online: 19 June 2024

Abstract: In this research, low-value plastic waste (LVPW) is used in concrete as a potential solution for sustainable waste management in the construction industry. In concrete, LVPW is utilized to produce Eco-Ring (Eco-conscious Latrine Ring). The use of a mix ratio of 1:2:3 and 1:2:4 in concrete mixes is studied. The impact of the percentage of recycled plastic on the mechanical properties of the final product is analyzed. The results show that the use of LVPW reduces both strength and unit weight but ensures its solidification. Sufficient strength for latrine rings is maintained, ensuring a balance between structural integrity and waste reduction. LVPW incorporation offers cost savings, with reductions of aggregate use up to 10%–15% in the present analysis. Justified consideration of the impact on mechanical properties, along with potential adjustments to optimize compatibility and address workability/aesthetics, can help maximize the benefits of this technology.

Keywords: concrete; latrine ring; mix ratio; solidification; waste management

1. Introduction

Plastics are synthetic organic polymers that are widely used in different applications ranging from water bottles, clothing, food packaging, medical supplies, electronic goods, construction materials, etc. [1]. In the last six decades, plastics have become an indispensable and versatile product with a wide range of properties, chemical compositions, and applications. Environmental pollution by plastic wastes is now recognized widely to be a major environmental burden [2], especially in the aquatic environment where there is prolonged biophysical breakdown of plastics [3], detrimental negative effects on wildlife [4], and limited plastic removal options [5].

Generally, waste plastic has a ‘recycle’ value. A good number of business policies are carried out in the total recycling process (**Figure 1**). For example, plastic waste from polyethylene terephthalate (PET) bottles, High-Density Polyethylene (HDPE) containers, Polypropylene (PP) packaging, including yogurt containers and food containers, Low-Density Polyethylene (LDPE) films, Flexible plastic packaging, including wraps and pouches, Expanded Polystyrene (EPS) foam, electronic devices with plastic components, end-of-life automotive plastics, including bumpers and interior components, etc. have certain economical values. A scenario of plastic reuse in Sylhet City, Bangladesh, is shown in **Figure 2** [6]. Since these plastics have economic value, they are not included as components of the research.

Figure 1. Wastes from **(a)** PET bottles; **(b)** HDPE waste; **(c)** expanded Polystyrene (EPS) foam; **(d)** electronic devices with plastic components.

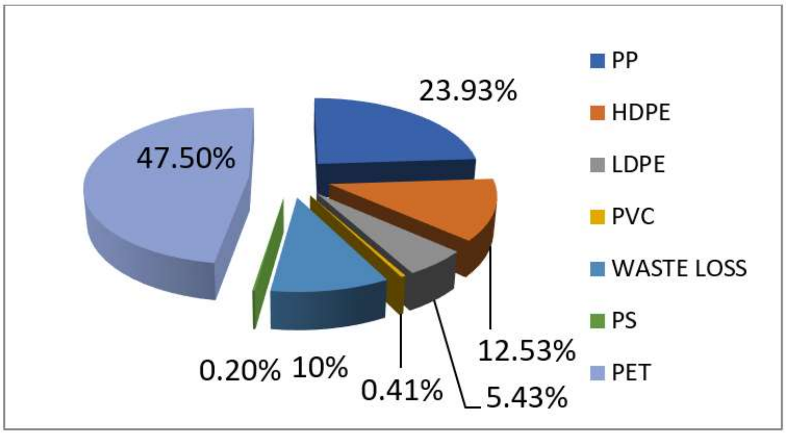


Figure 2. Present recycled plastic composition in Sylhet.

But some plastics have very low value for recycling or even have no value. These are termed as Low-Value Plastic Waste (LVPW). LVPW (**Figure 3**) has limited economic value in the recycling market due to various factors, like difficulties in collecting and processing, difficulties in recycling due to its low-grade or complex compositions, low demand for the recycled products, contamination probabilities etc. These are the plastics where the costs of collecting and processing are higher than the revenue generated from sales of the recovered plastic. Here are some examples of LVPW:

Figure 3. Some examples of low-value plastic wastes.

1) Mixed Plastic Waste: Plastic waste that is mixed with various materials, making it difficult to separate and recycle efficiently, may have little to no economic value.
2) Single-Use, Multi-Layered Packaging: Single-use packaging, especially those with multiple layers of different materials (e.g., Tetra Packs), can be challenging to recycle economically. Separating and processing the layers can be technically demanding and expensive.
3) Small Plastic Items and Fragments: These are microplastics, bottle caps, and plastic film scraps, which may have limited economic value.
4) Contaminated Plastics: Plastic waste contaminated with non-recyclable materials, such as food residues, oils, or hazardous substances, may have little to no economic value.
5) Low-grade Plastics or Plastics with Complex Compositions: Some specific types of plastics may be challenging to recycle economically due to their chemical composition or lack of demand in the recycling market.
6) Low-Quality Plastic Films: Thin, low-quality plastic films, such as those used in packaging for single-use items, may have limited economic value in recycling. These are often difficult to process due to their lightweight nature and do not meet the standards for recycling.

However, mismanagement of LVPW can cause water clogging in drains and canals, odor problems, land-water-air pollution, human-wildlife hazards, visual discomfort, lowering of soil fertility and so on. Since LVPW has little or no economic value, solidification in a concrete environment can ensure a management strategy for this issue. By this, not only the consumption of natural resources i.e., sand, brick and stone can be reduced but also environmental protection can be enhanced. Therefore, in this study, such an attempt is taken where use of Low-Value Plastic Waste in Concrete is going to be studied to produce Eco-Ring (Eco-conscious Latrine Ring), where very high strength of concrete may not be an issue.

2. Existing scientific knowledge on the subject

From 1964 to 2014, plastics production increased from 15 million metric tons to 311 million metric tons [7]. If this trend continues, it is expected that plastic production will double in 20 years and almost quadruple by 2050. In landfills, between 22% and 43% of plastics are disposed of, and at least 8 million tons of plastics are disposed of in the ocean [8]. Dhaka, the capital of Bangladesh—among the total solid waste, plastic was 4.15% in 2005 and 5.46% in 2014 [9]. Waste plastic can turn into a potential resource if it can be used in concrete, which can solidify this waste. Several studies have been conducted to evaluate the applicability of different types of plastics for such purposes. Hasan et al. [9] evaluated the properties of concrete with recycled plastic as coarse aggregate by 5%, 10%, 15%, and 20% replacement of stone. They used HDPE plastic and prepared a total of 90 cylinders and 5 beams. The maximum reduction in compressive strength was 44% for the 20% replacement of stone by recycled plastic. They concluded that up to 15% replacement of stone by recycled plastic is applicable for structural application. Another experiment was conducted by Subramani and Pugal [10] on partial replacement of coarse aggregate with polyhydroxybutyrate (PHB). 5% to 15% of coarse aggregate was replaced by plastic. It was observed that 20% of aggregate can be replaced with acceptable strength. Ghernouti et al. [11] studied the applicability of plastic bags as fine aggregate in concrete. 10%, 20%, 30%, and 40% fine aggregate was replaced with plastic fine aggregate. The conclusion was drawn by remarking that plastic bags can be used successfully to replace conventional fine aggregates in concrete. In another study, after thorough mixing, the hot molten paste was poured with standard brick dimensions. The brick was subjected to compressive and water absorption tests. The results showed that the plastic composite brick was more efficient than the clay brick and cement brick [12]. Similar results were achieved by Singhal and Netula [13] and Shah et al. [14]. Merbouh et al. [15] used low-density polyethylene (LDPE) to replace aggregate. They replaced 0% to 1.0% of the aggregate by LDPE. Noticeable ductility in fracture was recorded with a significant reduction in density. It was proposed to use LDPE in concrete where less compressive strength and tensile strength are required. In a few other studies, nine technologies [16,17] were assessed for processing low-value plastic (LVP) waste (recycling, plastic to product, plastic to lumber, pyrolysis, solvolysis, mixing with asphalt, mixing with construction materials, waste processing, and technology ranking).

In a couple of studies [18,19], compressive strength and unit weight of concrete were sorted out where plastic was used as a partial replacement (25% and 50%) of coarse aggregate. It was tried to find out the mix ratios that can be used as per the Local Government of Engineering Department of Bangladesh (LGED) and Bangladesh Standard (BDS) 208:2002 [20,21]. As the addition of plastic decreases the unit weight of concrete, it can be used to produce lightweight concrete. However, the strength of concrete using 25% and 50% plastic as coarse aggregate is not sufficient for structural purposes. So, this concrete can be used for non-load-bearing purposes as per LGED and BDS. Hasan [22,23] found that 25%–50% replacement of plastic waste with coarse aggregate in the concrete of the different mix ratios (1:3:6, 1:3:4, and 1:3:2) can ensure a compressive strength of solid concrete blocks 5.0 MPa (IS 2185-1) [24].

3. Relevance of the study to national or regional priorities

From the above-mentioned review of scientific findings, it can be concluded that the use of plastic waste reduces compressive strength and unit weight but ensures its solidification, thus protecting the environment from harmful effects. Also, it can be concluded that it is better to use such concrete for non-load-bearing structures only. In most of the studies, plastic wastes are replaced with coarse aggregates with a replacement from 5%–75%, while the best result is achieved between 5%–25%.

A “latrine ring” typically refers to a concrete ring used in the construction of latrines or pit toilets (**Figure 4**). In the context of sanitation and the construction of basic toilet facilities, these rings play a crucial role. Latrine rings are commonly made of concrete but can also be manufactured from other durable materials. They are designed to fit together, forming a circular structure that is placed over the pit or excavation. The rings provide structural support for the superstructure of the latrine, which includes the seat and any covering structure. They also help prevent the collapse of the pit walls. Therefore, the strength of the rings should be such that they will be able to withstand the side-soil pressure and overburden pressure. It is important to note that the specific design and use of latrine rings may vary based on local construction practices, available materials, and the type of sanitation facility being built. In regions without access to advanced sanitation infrastructure, these simple yet effective structures contribute significantly to public health and hygiene.

Figure 4. Typical latrine ring (diameter 30″, thickness 1.5″, height 12″).

Based on this logical reason in this study, LVPW is going to be used in concrete targeting the strength of latrine rings, and if plastic waste can be used here successfully, then let's also designate them as 'Eco-rings.'. If the expected outcome of the research is achieved, and if it is then practiced in construction, it will certainly reduce the present concerns about plastic waste in a quantified manner and will save the natural resources of Bangladesh.

4. Objectives of the study

1) To evaluate the effects on concrete if the aggregate is partially replaced by LVWP.
2) To identify its optimum percentage of replacement for the production of latrine rings.
3) To compare the cost of latrine rings with the traditional rings available in the market.

5. Materials and methodology

This experimental study approaches the utilization of Low-Value Plastic Waste in constructing Eco-conscious Latrine Ring. The required methodology is presented in **Figure 5**. Also, the properties of materials used are described in the following sections.

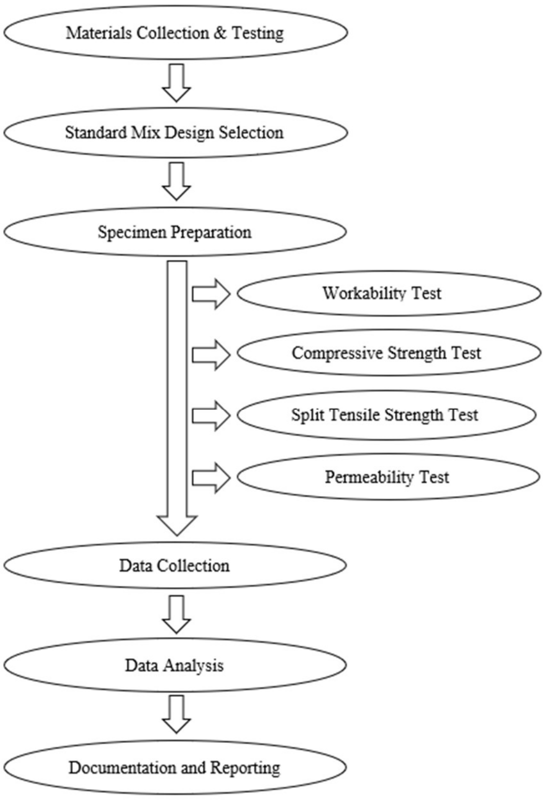


Figure 5. Experimental procedure.

In this study, cement (as a binding material), river sand (as fine aggregate), brick chips (as coarse aggregate), and LVPW (as fine and coarse aggregate) were used as the ingredients of concrete. Several tests were conducted to identify their properties and perform efficient mix proportions for concrete.

5.1. Experimental setups

The cement used in this study, Supercrete, is Portland Limestone Cement (PLC) and complies with BDS EN 197-1:2003, CEM II/ B-L, 42.5N standard. It has a composition of clinker 65% to 79%, limestone 21% to 35%, and slag/fly ash/gypsum 0% to 5%. For normal consistency of cement, ASTM designation C187 and for initial and final setting times of cement, ASTM designation C191 were followed. All data are presented in **Table 1**.

Table 1. Physical properties of cement.

Normal consistency	**28%**
Initial setting time	115 min
Final setting time	300 min

5.2. Low-value plastic waste (LVPW)

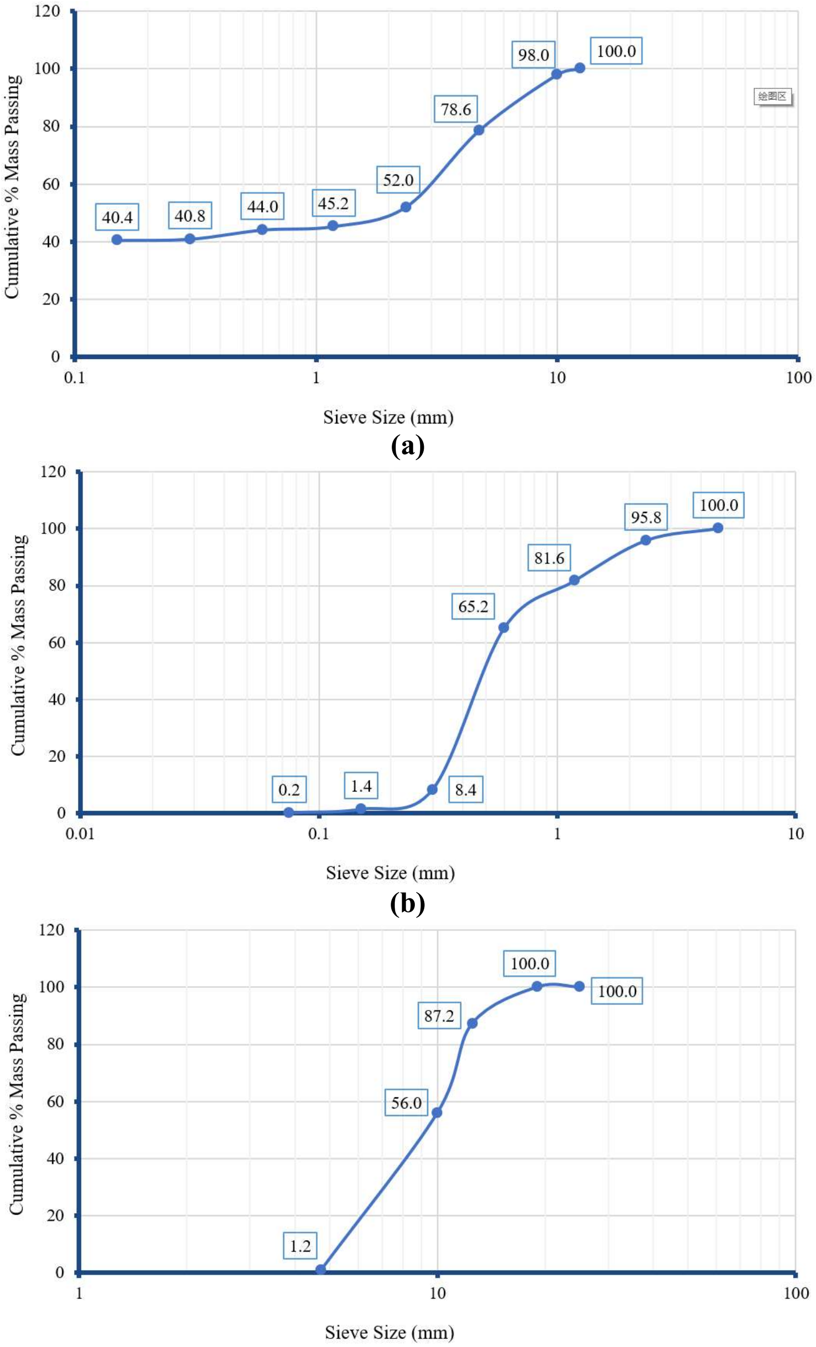
Low-value plastic waste (LVPW) refers to a mixture of different wastes (such as Styrofoam, PET, Polyethene bags, multilayer packaging, rubber, electronic, and medical waste, etc.). Here it is used as the replacement of both fine and coarse aggregate in concrete. Few studies [25, 26] have shown improved sorting of low-value recyclable waste, but in current studies LVPW is sorted manually from dumping sites. The particle size range varies from 0.075 mm to 12.5 mm. The shredded plastic waste was collected from a nearby recycling plant. Previously, they were collected from different sources and shredded into sizes in that plant. Examining the physical properties of the LVPW that were used was a challenge as it had a mixture of different types of plastics, each having different properties. Still, sieve analysis and tests for unit weight calculation were conducted on them. In sieve analysis, for proper sieving, both mechanical and manual sieving were done (**Figure 6**). The unit weight was obtained by compacting the wastes using a piston that was self-constructed, as shown in **Figure 7**. It was done by rodding procedure and followed by ASTM standard C29. Having a mixture of different types of plastic, including Styrofoam and polyethylene bags, made it unsuitable for oven drying. Furthermore, for this very reason, it was floating in water (**Figure 8**), which means it has less unit weight. The gradation curve for LVPW is presented in **Figure 9a**, and the physical properties results are summarized in **Table 2**.


(a) **(b)** **(c)**

Figure 6. Sieving **(a)** Mechanically **(b)** and **(c)** Manually.

Figure 7. Compaction of LVPW.

Figure 8. LVPW, sand & brick chips placed in water tank.



(a)

(b)

(c)

Figure 9. Particle size distribution of **(a)** LVPW; **(b)** sand; **(c)** brick chips.

Table 2. Physical properties of fine and coarse aggregates.

Properties	Standard	LVPW	Sand	Brick Chips
Maximum aggregate size (mm)	ASTM C136	12.5	4.75	14
Fineness modulus	ASTM C136	5.02	2.48	6.56
Unit weight (kg/m^3)	ASTM C29	473	1603.51	1007.65
Specific gravity (OD)	ASTM C128 & ASTM C127	-	2.59	1.92
Specific gravity (SSD)	ASTM C128 & ASTM C127	-	2.63	2.13
Water absorption capacity (%)	ASTM C128 & ASTM C127	-	1.63	10.93

5.3. Fine aggregate

The reddish-brown river sand collected from the local source was used as the fine aggregate in concrete. Gradation of sand was performed as per the ASTM standard requirements of specification C136. The particle size distribution of fine aggregate is presented in **Figure 9b**. Unit weight determination was done by rodding procedure that conformed to the ASTM standard requirements of specification C29. Water absorption capacity and specific gravity of the sand were measured following the ASTM standard requirements of specification C128. All the physical properties of sand are summarized in **Table 2**.

5.4. Coarse aggregates

As the latrine ring doesn't require higher strength, brick chips were used as coarse aggregate. It was collected from the local market and then crushed into the required size. The compressive strength of the bricks was 13.7 MPa. The thickness of the ring generally is very low (40–80 mm), so the highest size of brick chips is chosen between 14 and 12.5 mm. Gradation of brick chips was performed as per the ASTM standard requirements of specification C136, presented in **Figure 9c**. Also, unit weight determination was done by rodding procedure that conformed to the ASTM standard requirements of specification C29. Water absorption capacity and specific gravity of the sand were measured following the ASTM standard requirements of specification C127. All the physical properties of brick chips are summarized in **Table 2**.

5.5. Concrete mix proportions

During the test, two different mix ratios were used, which are 1:2:3 and 1:2:4. Here LVPW was replaced by the total aggregate in five different percentages (0%, 5%, 10%, 15%, 20%). All the aggregates, coarse and fine, used in the concrete mixture were in saturated surface dry (SSD) condition. No water-reducing admixture was used here. The mix proportion of various ingredients required for the 1:2:3 ratio was calculated and presented in **Table 3,** and for the 1:2:4 ratio, the same was calculated and presented in **Table 4**. Each mix design is designated with a unique name for ease in referencing within the text. As the ratio of coarse aggregate is the only variable here, for 1:2:3 it was named prototype 3P and for 1:2:4 named 4P. Then the said percentages of LVPW are added. For example, 3P10 means the prototype has a mix ratio of 1:2:3, where 10% total aggregate is replaced by LVPW. And the w/c ratio is fixed at 0.60 by the trial-and-error method, considering the convenient slump value.

Table 3. Materials quantities for 1:2:3 mix ratio.

Prototype Sample ID	Percent of LVPW	Cement (kg)	Sand (kg)	Brick chips (kg)	LVPW (kg)
3P00	0%	9.403	20.941	19.739	0.000
3P05	5%	9.403	19.894	18.752	0.772
3P10	10%	9.403	18.847	17.765	1.544
3P15	15%	9.403	17.800	16.778	2.316
3P20	20%	9.403	16.753	15.791	3.089

Table 4. Materials quantities for 1:2:4 mix ratio.

Prototype Sample ID	Percent of LVPW	Cement (kg)	Sand (kg)	Brick chips (kg)	LVPW (kg)
3P00	0%	8.060	17.949	22.559	0.000
3P05	5%	8.060	17.052	21.431	0.794
3P10	10%	8.060	16.155	20.303	1.588
3P15	15%	8.060	15.257	19.175	2.383
3P20	20%	8.060	14.360	18.047	3.177

5.6. Preparation of concrete specimens

Total 90 concrete cylinders were prepared in two different sizes following ASTM C 192-15 at room temperature of 25 °C. For each prototype, 6 cylinders were prepared for the compression and tensile strength tests, having a 100 mm inner diameter and a 200 mm height, and 3 cylinders for the permeability test, having an inner diameter of 175 mm and a height of 175 mm. So, for 5 different prototypes, 45 cylindrical molds at each mix ratio were prepared. Specimens were placed in a curing tank for 28 days, as shown in **Figure 10**. **Figure 11** shows the major tests of eco-ring concrete through a flowchart.

Figure 10. Concrete setup for curing.

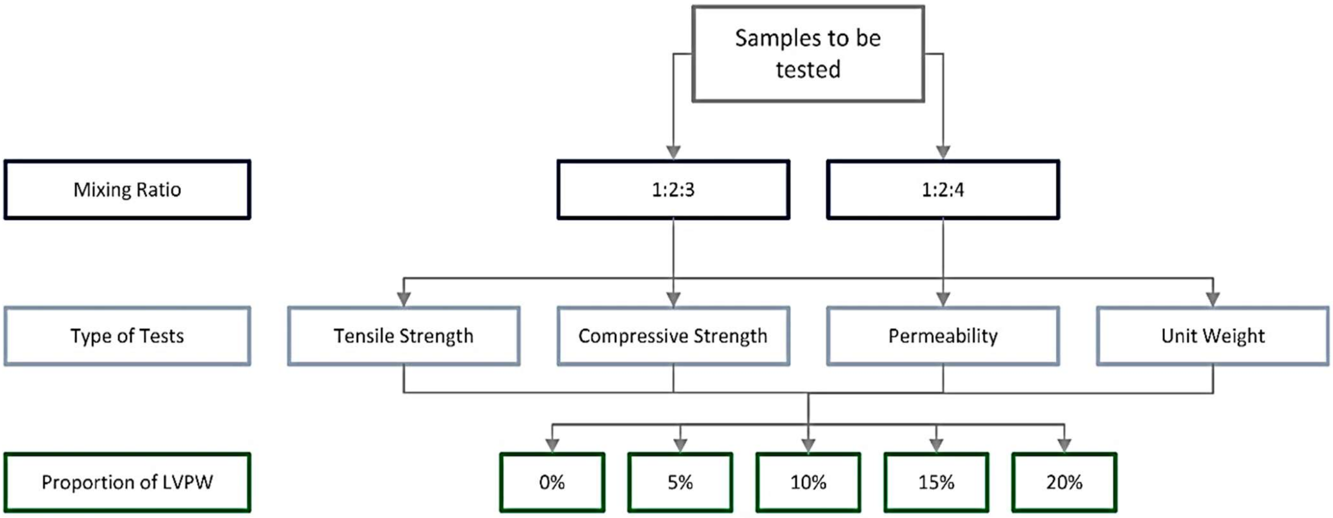


Figure 11. Tests of eco-ring concrete.

A process of testing the tensile strength of concrete involves splitting a cylinder across its vertical diameter. It is a method of evaluating the tensile strength of concrete that is done in an indirect manner. The splitting tensile strength of the concrete samples was determined using ASTM 496-17 after 28 days of curing.

According to ASTM, the splitting tensile strength is $\frac{2P}{\pi LD}$, where P = Applied highest load; D = Diameter of the specimen = 100 mm; L = Length of the specimen = 200 mm.

Latrine ring concrete is required to possess a good degree of impermeability to prevent subsoil water pressure. That's why the permeability of the LVPW concrete at 28 days was tested in this study. The relative permeability coefficient (Kr) of the concrete can be determined $K_r = a \times \frac{D_m^2}{2TH}$, where, K_r is the relative permeability coefficient, mm/s; a is the absorption ratio of the concrete, which was at a constant value of 0.03; T is the duration of the permeability test; D_m is the water-seepage height, which was 177.8 mm in this study; H is the water head (mm) of corresponding constant *pressure* $\left(H = \frac{\text{Pressure (MPa)}\times 10^6}{9.81}\right)$.

6. Results and discussions

Based on **Tables 5** and **6** as well as **Figures 12** and **13**, the results are consistent with the expectation. As the amount of LVPW increases, a decrease in:

Table 5. Mechanical properties for mix ratio 1:2:3.

LVPW	Slump Value (mm)	Splitting Tensile Strength (MPa)	Compressive Strength (MPa)	Unit Weight (Kg/m^3)
0%	57.2	2.99	20.25	22.47
5%	45.2	2.49	15.53	21.58
10%	30.2	2.27	13.97	21.35
15%	27.4	2.18	11.43	20.77
20%	21.6	1.74	8.64	20.46

Table 6. Mechanical properties for mix ratio 1:2:4.

LVPW	Slump Value (mm)	Splitting Tensile Strength (MPa)	Compressive Strength (MPa)	Unit Weight (Kg/m^3)
0%	25.4	2.37	14.90	22.52
5%	12.7	2.15	14.15	21.62
10%	9.5	1.22	10.25	21.14
15%	7.9	1.17	7.68	20.90
20%	9.5	1.14	6.39	20.44

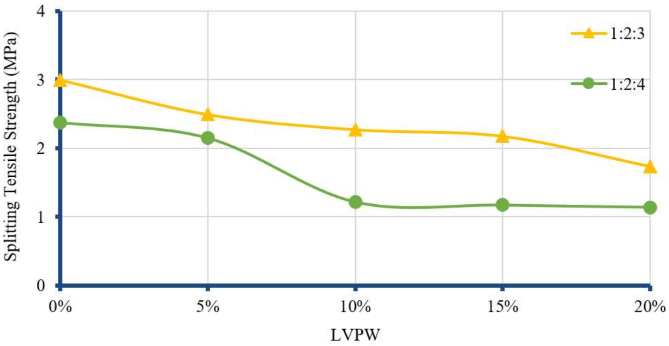


Figure 12. Impact of LVPW on split tensile strength.

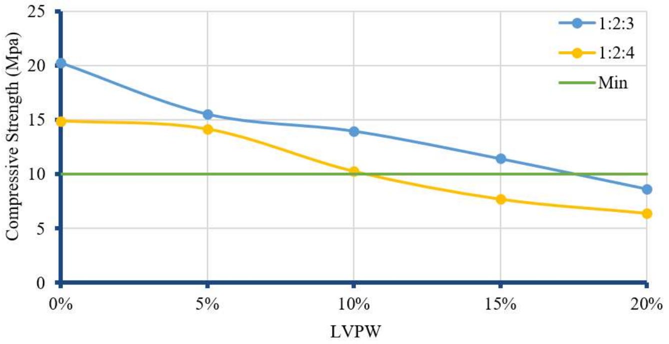


Figure 13. Impact of LVPW on compressive strength.

- Compressive strength: Similar to tensile strength, the concrete seems less resistant to compression with higher LVPW content. For instance, at 0% LVPW for a concrete mix ratio of 1:2:3, the compressive strength is 20.25 MPa, whereas at 20% LVPW, the compressive strength is 8.64 MPa.
- Tensile strength: The table shows that concrete specimens tend to withstand less tension before breaking as the LVPW content goes up. As per ACI code, the range of tensile strengths of normal weight concrete is $6\sqrt{f_c'} - 8\sqrt{f_c'}$ whereas $4\sqrt{f_c'} - 6\sqrt{f_c'}$ for lightweight concrete. For instance, at 0% LVPW for a concrete mix ratio of 1:2:3, the tensile strength is 2.99 MPa which is greater than both 2.98 MPa and 2.25 MPa determined from the above formulas. Again, at 20% LVPW, the tensile strength is 1.74 MPa which is greater than both 1.95 MPa and 1.46 MPa obtained from the above formulas. This indicates that the tensile strength of this concrete is in between an acceptable range.
- Unit weight: As LVPW is a lightweight material added to the concrete mix, it would naturally bring down the overall weight per unit volume of the concrete.

For instance, at 0% LVPW for concrete mix ratio 1:2:3, the unit weight is 22.47 Kg/m^3, whereas at 20% LVPW, the unit weight is 20.46 Kg/m^3.

The incorporation of LVPW into concrete mixes presents a potential solution for waste management, but it can have a significant impact on the mechanical properties of the final product. This phenomenon can be attributed to several factors related to the inherent properties of LVPW and its interaction with the concrete matrix. Here is a breakdown of the potential mechanisms:

a) Unlike traditional aggregates, LVPW particles, due to their smooth and often hydrophobic (water-repelling) nature, struggle to form strong bonds with the cement paste that binds the concrete together. This weak interface between plastic and cement hinders the effective transfer of stress throughout the concrete structure, leading to reduced overall strength.

b) The presence of LVPW particles within the concrete matrix can act as internal voids, separators, or points of weakness. These microscopic cracks can initiate and propagate under stress, compromising the structural integrity of the concrete and ultimately reducing its ability to withstand compressive and tensile forces.

c) LVPW is typically less dense than the natural aggregates it replaces. This lowers the overall density of the concrete, which can indirectly impact its strength. Denser concrete generally exhibits higher compressive and tensile strengths.

While LVPW offers a potential avenue for sustainable waste management in the construction industry, its inclusion requires careful consideration of its impact on the mechanical properties of concrete. Addressing the issues of weak bonding and internal cracking through surface treatment or compatible additives might be necessary to achieve a balance between waste reduction and structural performance.

However, the reduced density of LVPW concrete presents a significant advantage for low-cost toilet rings, slabs, and pillar projects for the following reasons:

1) Lighter weight, easier handling: LVPW concrete's lighter weight makes it easier to transport and maneuver during construction, reducing labor costs associated with handling heavier traditional concrete materials for these non-load-bearing applications.
2) Cost-effective alternative: LVPW can potentially offer a more cost-effective solution compared to virgin materials for toilet rings, slabs, and pillars. This aligns well with keeping costs low in these projects.

6.1. Selecting minimum compressive strength requirements

When constructing a latrine ring, selecting the appropriate concrete compressive strength is crucial for ensuring its durability and functionality. Standard codes provide guidelines for minimum compressive strength based on the intended use of the concrete. However, in the case of latrine rings, the specific application falls outside the typical categories. Considerations and the rationale for choosing a suitable strength can be as follows:

1) Minimum compressive strength for non-structural use: Indian code IS 2185-1 (2005) specifies a minimum compressive strength of 5 MPa for non-structural applications. Minimum compressive strength for structural use: The American Concrete Institute (ACI-318) code sets a range of 10–15 MPa.

2) Latrine Ring Classification: While a latrine ring experiences some load, it wouldn't be categorized as purely structural. It primarily supports the user's weight, a little lateral earth pressure, and doesn't carry significant building loads. On the other hand, it's not entirely non-structural, like decorative elements.
3) Earth Pressure Impact: Since the latrine ring's depth is limited to a maximum of 7 ft (approximately 2.1 meters) from the ground surface, the maximum potential earth pressure it encounters is estimated to be around 3 MPa.
4) Wired Reinforcement: The inclusion of minimal wired reinforcement in the latrine ring can further enhance its load-bearing capacity and provide additional crack resistance.

By considering standard building codes and the unique application, a benchmark of 10 MPa for compressive strength is a reasonable compromise, meaning it can withstand more pressure than it's likely to experience in this application. This falls between the minimums for non-structural and structural uses.

At 0% LVPW, the compressive strength is highest, and it declines steadily as the LVPW content goes up to 20%. However, **Figure 13** suggests that a maximum of 17.5% LVPW can be incorporated into a 1:2:3 concrete mix, while a maximum of 11% LVPW can be incorporated into a 1:2:4 concrete mix and still achieve a compressive strength above 10 MPa. Finally, maintaining a safe range, 15% LVPW can be recommended for a 1:2:3 mix ratio, and 10% LVPW can be recommended for a 1:2:4 mix ratio.

6.2. Water permeability test results

The permeability test results at 28 days, including the water head (*H*) corresponding to constant water pressure, the duration of water penetration into the concrete until creating a visible droplet on the surface, and the relative permeability coefficient (*Kr*), are presented in **Figure 14**. From **Figure 14**, it can be seen that the LVPW mixing percentage had a significant influence on the permeability of the concrete. As % of LVPW increases, permeability of concrete also increases. 1:2:4 mix concrete is more permeable than 1:2:3 mix concrete. For 1:2:4, permeability is high when LVPW is greater than 10%, which may not be acceptable for latrine rings.

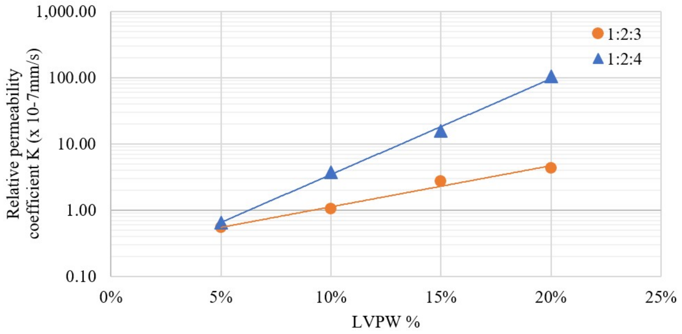


Figure 14. Impact of LVPW on permeability.

6.3. Comparative analysis for non-mechanical properties of LVPW in concrete mixes

The workability, appearance, and surface smoothness decrease with the addition of LVPW, whereas permeability increases (**Table 7**). With a water-cement ratio of 0.6, for sample 3P15 (15% LVPW), workability is rated as “Medium”. This might require moderate effort to achieve proper handling and pouring during construction compared to mixes with higher workability. But, for sample 3P10, workability is rated as “Good” which implies that it requires much less effort. On the other hand, for sample 4P10 (10% LVPW), workability is rated as “Fair”. This might require much more effort than normal concrete. But, in comparison to other percentages of LVPW for the same mixing ratio, it has a better form of workability. Surface smoothness and appearance are described as “LVPW is slightly/moderately/clearly visible on the surface” for both samples (**Table 7**). This might affect the aesthetic appeal of exposed concrete elements. Although surface roughness for 4P10 and 3P15 is comparatively much higher than the control mix (LVPW is moderately visible on the surface), it can be acceptable by giving a finishing with extra mortar. As the percentage of LVPW increases, the permeability increases as it produces smaller micro-cracks inside and makes paths for water seepage. However, medium permeability may be accepted for proposed eco-rings.

Table 7. Qualitative result of prototyping phase.

Prototype Sample ID	Mix Ratio	LVPW	Is Strength within Permissible Limit?	Workability	Appearance & Surface Smoothness	Permeability	Remarks
3P00	1:2:3	0%	Yes	Very Good	Smooth finish	Very Low	Passed
3P05		5%	Yes	Very Good	Smooth finish	Low	Passed
3P10		10%	Yes	Good	LVPW is slightly visible on the surface	Low	Passed
3P15		15%	Yes	Average	LVPW is moderately visible on the surface	Medium	Passed
3P20		20%	No	Fair	LVPW is clearly visible on the surface, rough finish	Medium	Failed
4P00	1:2:4	0%	Yes	Average	Smooth finish	Very Low	Passed
4P05		5%	Yes	Fair	LVPW is slightly visible on the surface	Low	Passed
4P10		10%	Yes	Fair	LVPW is moderately visible on the surface, slightly rough finish	Medium	Passed
4P15		15%	No	Poor	LVPW is clearly visible on the surface, rough finish	High	Failed
4P20		20%	No	Poor	LVPW is clearly visible on the surface, rough finish	Very High	Failed

Appearance & Surface Smoothness Classification

Smooth finish

LVPW is slightly visible on the surface

LVPW is moderately visible on surface

LVPW is clearly visible on surface, rough finish

Containing LVPW of a maximum of 15% for 1:2:3 and 10% for 1:2:4 mix ratio, both samples achieve a compressive strength exceeding the 10 MPa benchmark required for non-load-bearing applications like latrine rings, slabs, and pillars. This translates to a certain amount of cost savings compared to conventional concrete. While both offer a balance between maximizing LVPW for environmental and economic benefits and maintaining sufficient strength and workability, the slightly rough surface texture might be acceptable for unexposed elements or those receiving a thin grout finish.

6.4. Comparative analysis for cost-effectiveness of LVPW in concrete mixes

Few insightful studies [27–30] are made for in-depth management of the cost of the recycling sector for plastic packaging in a developing country context. In the current study, it can be seen from **Figure 15**, **Tables 8** and **9**, that the case for incorporating LVPW into concrete mixes is a highly cost-effective and sustainable solution. For the 1:2:3 mix with 15% LVPW (Sample ID: 3P15), the cost reduction is 3.37% for one latrine ring compared to the control mix (3P00). For the 1:2:4 mix with 10% LVPW (Sample ID: 4P10), the cost reduction is 2.74% for one latrine ring compared to the control mix (4P00). Both samples demonstrate cost savings when using LVPW. The minimal acquisition cost of LVPW further amplifies the cost-effectiveness of LVPW concrete. In most cases, the savings on aggregate costs are likely to outweigh any minor expenses associated with LVPW collection or processing. Beyond cost savings, LVPW utilization offers a significant environmental benefit. It provides a sustainable solution for managing low-value plastic waste by diverting it from landfills and promoting circular economy practices in the construction industry.

Table 8. Cost comparison (for mix ratio 1:2:3, per Latrine ring, height—12″, Dia—30″, Thickness—1.5″).

Raw materials	Cost/unit	With 0% LVPW (3P00)	With 15% LVPW (3P15)	Saving (%) Per Latrine ring
		Cost (TK)		
Cement	550 TK/bag	110	110	3.37*
Sand	40 TK/cft	20	17	
Bricks chips	160 TK/cft	120	102	
LVPW	5 TK/Kg	0	13	
Total cost		249	241	

*In cost calculation the cost of GI wire is not considered since it is common in all cases.

Table 9. Cost comparison (for mix ratio 1:2:3, per Latrine ring, height—12″, Dia—30″, Thickness—1.5″).

Raw materials	Cost/unit	With 0% LVPW (4P00)	With 10% LVPW (4P10)	Saving (%) Per Latrine ring
		Cost (TK)		
Cement	550 TK/bag	94	94	2.74*
Sand	40 TK/cft	17	15	
Bricks chips	160 TK/cft	137	123	
LVPW	5 TK/Kg	0	9	
Total cost		248	241	

*In cost calculation the cost of GI wire is not considered since it is common in all cases.

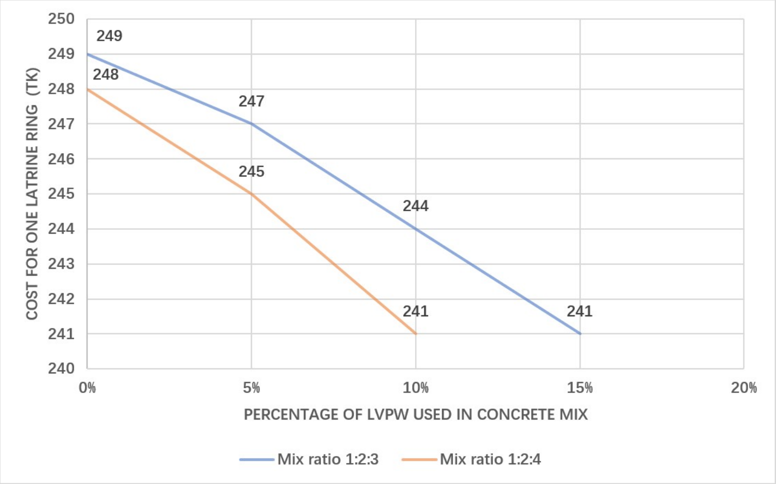


Figure 15. Cost comparison for one latrine ring (height—12″, Dia—30″, Thickness—1.5″).

7. Conclusion

Considering all tests done in this study, i.e., strength, appearance, cost, and seepage, the 1:2:3 ratio of concrete with 10% LVPW (3P10) can be considered the optimum choice. However, from an economic point of view, both 1:2:3 ratio concrete with 15% LVPW (3P15) and 1:2:4 ratio concrete with 10% LVPW (4P10) are good options. But, comparing these two cost-effective options, 1:2:3 ratio concrete with 15% LVPW (3P15) is a better option as it gives more strength and consumes more plastic waste. In conclusion it can be said that:

1) Increasing LVPW content leads to a decrease in tensile strength, compressive strength, and unit weight of concrete. This is weak bonding between LVPW and cement, internal cracking, and the lower density of LVPW compared to natural aggregates. Despite strength reductions, LVPW concrete remains a viable option for specific applications.
2) For non-load-bearing elements like latrine rings, the reduced weight of LVPW concrete offers advantages in handling and potentially lower labor costs associated with transporting and maneuvring the material during construction. This translates to cost savings alongside the reduced material costs of LVPW itself.
3) While the study suggests maximum LVPW contents for achieving 10 MPa strength (15% for 1:2:3 mix and 10% for 1:2:4 mix), further research might explore methods to improve the compatibility of LVPW with concrete, potentially allowing for higher LVPW incorporation rates.
4) LVPW concrete offers cost savings compared to conventional concrete, with a reduction of aggregate use of 15% for the 1:2:3 mix and 10% for the 1:2:4 mix. The minimal acquisition cost of LVPW further strengthens its economic advantage. From the optimized point of view, 1:2:3 ratio concrete with 15% LVPW is a better option as it gives more strength and consumes more plastic waste.
5) While workability is slightly reduced with LVPW, it remains within acceptable limits for construction. The slight decrease in surface smoothness might be

mitigated by using grouting or other finishing techniques.

In a nutshell, LVPW concrete presents a compelling solution for sustainable and potentially cost-effective construction in specific applications. Careful consideration of the impact on mechanical properties, along with potential adjustments to optimize LVPW compatibility and address workability/aesthetics, can help maximize the benefits of this promising technology. This solidification ensures waste management is expected to contribute significantly to the environment as well as to society.

Author contributions: Conceptualization, MA, HMAM and MAH; methodology, HMAM and NIR; software, MJHS; validation, KKM; formal analysis, HMAM, MJHS and KKM; investigation, MA, HMAM; resources, KR, MAAA; data curation, MAI and RKR; writing—original draft preparation, HMAM, MA, NIR; writing—review and editing, HMAM, MA, MAH; visualization, MJHS and KKM; supervision, MA; project administration, MA; funding acquisition, KR, MAAA, MAI and RKR. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: The authors are expressing their gratitude to iDE-Bangladesh for providing the necessary financial support and also to the Department of Civil and Environmental Engineering (CEE), Shahjalal University of Science and Technology (SUST), Sylhet, Bangladesh for providing the very important Lab-support.

Conflict of interest: The authors declare no conflict of interest.

References

1. Proshad R, Kormoker T, Islam MDS, et al. Toxic effects of plastic on human health and environment: A consequences of health risk assessment in Bangladesh. International Journal of Health. 2017; 6(1): 1-5. doi: 10.14419/ijh.v6i1.8655
2. Rochman CM, Browne MA, Halpern BS, et al. Classify plastic waste as hazardous. Nature. 2013; 494(7436): 169-171. doi: 10.1038/494169a
3. Derraik JG. The pollution of the marine environment by plastic debris: A review. Marine Pollution Bulletin. 2002; 44(9): 842-852. doi: 10.1016/S0025-326X(02)00220-5
4. Thompson RC, Olsen Y, Mitchell RP, et al. Lost at Sea: Where Is All the Plastic? Science. 2004; 304(5672): 838. doi: 10.1126/science.1094559
5. Kaiser J. The Dirt on Ocean Garbage Patches. Science. 2010; 328(5985): 1506-1506. doi: 10.1126/science.328.5985.1506
6. Sakib AN, Salma AI, Ahmed M. Plastic waste management and feasibility of fuel production—A case study in Sylhet. Journal of Environmental Technology and Construction Management. 2012; 1(1): 66-78.
7. Len N. The New Plastics Economy Rethinking the Future of Plastics. World Economic Forum; 2016.
8. Gourmelon G. Global Plastic Production Rises, Recycling Lags. Vital Signs, Worldwatch Institute; 2015.
9. Hasan MA, Hoque MA, Ahmed M. Application of Plastic Waste as an Alternative to Coarse Aggregate for Concrete Block Construction. In: Proceedings of the 7th International Conference on Engineering Research, Innovation and Education; 12-14 January 2023; Sylhet, Bangladesh.
10. Subramani T, Pugal VK. Experimental Study on Plastic Waste as a Coarse Aggregate for Structural Concrete. International Journal of Application or Innovation in Engineering & Management. 2015; 4(5).
11. Ghernouti Y, Rabehi B, Safi B, et al. Use of recycled plastic bag waste in the concrete. Journal of International Scientific Publications: Materials, Methods and Technologies. 2014; 8.
12. Kamble SA, Karad DM. Plastic Bricks. International Journal of Advance Research in Science and Engineering. 2017; 6.
13. Singhal A, Netula O. Utilization of Plastic Waste in Manufacturing of Sand Bricks. In: Proceedings of the 3rd International Conference on New Frontiers of Engineering, Science, Management and Humanities (ICNFESMH-2018); Pune.
14. Shah R, Garg H, Gandhi P, et al. Study of Plastic Dust Brick Made from Waste Plastic. International Journal of Mechanical and Production Engineering. 2017; 5(10).

15. Merbouh M, Glaoui B, Mazouz A, et al. Use Plastic Bag Waste in Cement Concrete. Waste Management Symposium EURASIA; 2014.
16. Soemadijo P, Anindita F, Akib R, et al. A Study of Available Technology for Recycling Low Value Plastic in Indonesia. Journal of Environmental Science and Sustainable Development. 2022; 5(2). doi: 10.7454/jessd.v5i2.1128
17. Shi Y, Chai J, Xu T, et al. Microplastics contamination associated with low-value domestic source organic solid waste: A review. Science of The Total Environment. 2023; 857: 159679. doi: 10.1016/j.scitotenv.2022.159679
18. Mahzuz HMA, Tahsin A. Use of Plastic as a Partial Replacement of Coarse Aggregate in Concrete for Brick Classifications. International Journal of Scientific & Technology Research. 2019; 8(8): 883-886.
19. Darwin D, Charles WDP, Nilson AH. Design of concrete structures. McGraw-Hill Education; 2015.
20. Mathew P, Ambika KP, Pavitra P, et al. Comparative Study on Waste Plastic Incorporated Concrete Blocks with Ordinary Concrete Blocks. International Research Journal of Engineering and Technology. 2016; 3(5).
21. Bangladesh Standards and Testing Institution. BDS 208: (2002), Bangladesh Standard. Bangladesh Standards and Testing Institution; 2002.
22. Local Government Engineering Department of Bangladesh. Local Government Engineering Department of Bangladesh (LGED); 2005.
23. Hasan A, Islam MN, Karim MR, et al. Properties of Concrete Containing Recycled Plastic as Coarse Aggregate. In: Proceedings of the International Conference on Recent Innovation in Civil Engineering for Sustainable Development (IICSD-2015); DUET, Gazipur.
24. Hollow and Solid Concrete Blocks. IS (2005). IS 2185-1. In IS Concrete masonry unit: Part-1. Hollow and Solid Concrete Blocks; 2005.
25. Ji T, Fang H, Zhang R, et al. Automatic sorting of low-value recyclable waste: a comparative experimental study. Clean Technologies and Environmental Policy. 2022; 25(3): 949-961. doi: 10.1007/s10098-022-02418-7
26. Fu S, Qian Y, Yuan H, et al. Effect of cone angles of a hydrocyclone for the separation of waste plastics with low value of density difference. Waste Management. 2022; 140: 183-192. doi: 10.1016/j.wasman.2021.11.028
27. Tianchen J, Huaiying F, Rencheng Z, et al. Low-value recyclable waste identification based on NIR feature analysis and RGB-NIR fusion. Infrared Physics & Technology. 2023; 131: 104693. doi: 10.1016/j.infrared.2023.104693
28. Nizamuddin S, Jamal M, Santos J, et al. Recycling of low-value packaging films in bitumen blends: A grey-based multi criteria decision making approach considering a set of laboratory performance and environmental impact indicators. Science of The Total Environment. 2021; 778: 146187. doi: 10.1016/j.scitotenv.2021.146187
29. Bening CR, Kahlert S, Asiedu E. The true cost of solving the plastic waste challenge in developing countries: The case of Ghana. Journal of Cleaner Production. 2022; 330: 129649. doi: 10.1016/j.jclepro.2021.129649
30. Gall M, Wiener M, Chagas de Oliveira C, et al. Building a circular plastics economy with informal waste pickers: Recyclate quality, business model, and societal impacts. Resources, Conservation and Recycling. 2020; 156: 104685. doi: 10.1016/j.resconrec.2020.104685