Utilization of Waste Materials for Making Plastic Bricks

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Abstract: Currently, due to urbanization, there has been a notable rise in the use of plastic in our daily lives, owing to its widespread utility and popularity. However, its non-biodegradable nature presents a significant drawback. One potential solution for recycling plastic waste involves creating plastic bricks by blending plastic with sand, offering a substitute for conventional bricks. The primary challenge lies in managing plastic waste, particularly as continued reuse of PET bottles carries the risk of carcinogenic transformation, with only a small percentage currently being recycled. To address this issue, PET bottles are meticulously cleaned and combined with fine aggregate (sand) at various ratios (3:7, 2:3, 1:1) to produce high-quality brick blocks with excellent thermal and acoustic insulation properties. This environmentally friendly approach tackles the non-biodegradability problem of plastics while reducing the overall cost of construction and pollution. The resulting bricks exhibit high compressive strength, minimal water absorption, and thermal resistance, rendering them suitable for diverse applications. Increasing the sand-to-plastic ratio enhances the strength of the bricks, ensuring durability with minimal water absorption and no efflorescence. This method shows promise in recycling plastic waste and mitigating its environmental impact. Furthermore, various tests including split tensile strength test, penetration test, and specific gravity were conducted to validate the efficacy of the approach.
Key Word*: PET (polyethylene terephthalate), compressive strength, water absorption, split tensile strength test, efflorescence, specific gravity test*

I. Introduction

Plastic products have become essential components of our daily lives, meeting fundamental needs. Their production occurs on a massive scale globally, surpassing 150 million metric tons annually. In India, around 8 million metric tons of plastic products were consumed in 2008, with an anticipated increase to 12 million tons by 2012. These products find diverse applications in packaging films, wrapping materials, shopping and waste bags, containers for fluids, clothing, toys, household and industrial items, as well as building materials. It's well-established that plastics persist in the environment for numerous years without degrading. Recycled plastics, often containing a mixture of colors, additives, stabilizers, flame retardants, etc., can be more environmentally detrimental than virgin products. Moreover, the recycling of virgin plastic material is limited to 2-3 cycles due to the degradation of its strength through thermal processes. While there's no precise estimate of the total plastic waste generation in the country, it's approximated that about 70% of total plastic consumption is discarded as waste. This leads to an estimated annual generation of approximately 5.6 million tons of plastic waste, equivalent to around 15,342 tons per day. (Bhawan, 2006)

In a recent investigation, researchers explored the direct integration of polyethylene terephthalate (PET) bottles in shredded and aggregate forms to substitute and supplement natural coarse aggregate. The majority of substitutions were calculated volumetrically, revealing a reduction in compressive strength as the proportion of plastic fibers increased. The process involves melting the plastic in a dry container, then thoroughly mixing sand into it. Once mixed, the combination is placed into brick molds, submerged in water after 3–4 minutes, and removed from the mold after 10–15 minutes. This research delved into how plastic waste could be combined with various raw materials to produce plastic sand bricks. (Wahid, 2015) utilized a 9:9:4 ratio with a water-cement ratio of 2 to manufacture sand bricks. (Bhushaiah, 2019) blended 0.992 kg of cement, 4.04 kg of fly ash, and 3.24 kg of fine aggregate, substituting 5% to 20% with finely crushed plastic waste. (Wahab, 2020) replaced fine aggregate with finely crushed sand entirely, maintaining a mix ratio of 1:6 (cement: fine aggregate) and a water-cement ratio of 0.34, comparing the results with standard sand bricks made with a mix ratio of 1:4 and a water-cement ratio of 0.35. The first two studies indicated that at 5% and 15% plastic inclusion, compressive strength peaked at 11.618 N/mm^2 and 20 N/mm^2, respectively.

The third study reported a compressive strength of 5.56 N/mm^2, surpassing Malaysia's standard of 5.2 N/mm^2. Other studies explored the use of plastic as a binder (plastic binder) rather than cement, suggesting that incorporating plastic waste holds promise in brick manufacturing. (Mohan, 2016) Plastic sand bricks offer advantages over traditional bricks, particularly in compressive strength, water absorption, and efflorescence. However, previous studies lacked focus on specific gravity testing of plastic and sand, penetration testing and FTIR analysis of plastic, split tensile strength testing, and thermal resistance testing of brick samples. The objective of the present experiment was to examine the physical and mechanical properties of plastic sand bricks with varying mixes of plastic and sand, incorporating all aforementioned tests. Additionally, an effort was made to utilize plastic waste in producing plastic sand bricks as a construction material, addressing one of the most critical global concerns today. (Liu, 2021)

II. Material and Methodology

Plastic: For this study, waste PET plastic (polyethylene terephthalate) sourced from nearby garbage dumps, industrial waste, and food containers was utilized (Figure 1). A plastic penetration test, following (1203, 1978) standards, gauged the material's consistency. This test also determined the setting time of molten plastic (Sarker, 2011). Figure 5 depicts the apparatus employed for penetration testing in this research. The specific gravity test, conforming to IS 2720:1980, assessed the material's strength and quality. Plastic's specific gravity was determined using a 1-liter capacity pycnometer (figure 2). Plastic has a specific gravity of 1.58, according to a specific gravity test of sample.

Mold Fabrication: A handmade wooden mold was crafted with dimensions mirroring those of a standard brick (190*90*90) mm. (figure 3)

Sand: The investigation employed well-graded natural river sand passing through a 4.75 mm sieve, meeting all criteria for producing plastic sand bricks (Sheshachala, 2019). Particle size distribution of the fine aggregates was determined through sieve analysis (figure 4), in accordance with IS 2386:1963 (Part I) protocols. D_{60} =0.917, D_{30} =0.478, D_{10} =0.212, where D_{60}, D_{30}, D_{10} are particle size corresponding to 60%, 30%, and 10% finer, respectively.

Coefficient of uniformity (Cu) = $\frac{D_{60}}{D_{10}}$ = 4.32

Coefficient of curvature (Cc) = $\frac{D_{30}^2}{D_{60} * D_{10}}$ = 1.17

The value of the coefficient of curvature (Cc) lied between 1 and 3, and the value of the coefficient of uniformity (Cu) was less than 6. The specific gravity test, which was used to determine the strength of plastic, was used to test the strength of sand as well.
The specific gravity of sand was calculated as 2.659.

Mix Proportion: To ascertain plastic sand bricks with high compressive strength across various mix proportions, specimens were manufactured and tested using a Compressive Testing Machine (figure 6). The mix proportions adhered to ratios of (3:7, 2:3, and 1:1), representing plastic and river sand, respectively. Table 1 shows the different mix ratio of (plastic: sand) proportions.

TABLE 1: Mix ratio

S.N.	Sample ratio (plastic: sand)	Percentage of plastic (%)	Percentage of sand (%)
1.	3:7	30	70
2.	2:3	40	60
3.	1:1	50	50

Figure 1: PET bottles **Figure 2: Specific gravity test** **Figure 3: Wooden mold**

Figure 4: Sieve analysis **Figure 5: penetration test** **Figure 6: Universal testing machine**

Procedure of Casting Plastic Sand Brick

Plastic Batching: Plastic sourced from nearby garbage was carefully batched. After categorizing the types of plastic, any residual water content was eliminated by oven-drying the sample at temperatures ranging from 20°C to 25°C. Hand segregation was employed to remove any extraneous garbage. Subsequently, the components required for preparing plastic sand bricks were measured.

Melting: The plastic waste underwent melting following batching, with 8 kg of plastic melted within 2 minutes at temperatures ranging from 105°C to 115°C.

Mixing: Following the melting process at temperatures ranging from 105°C to 115°C, river sand was introduced. The molten plastic and river sand were vigorously mixed until achieving a homogeneous blend, uniform in color and consistency. Hand mixing method was employed during this process.

Molding: During molding, the prepared mixture was poured into the mold and compacted using a tamping rod to ensure proper filling. Oil was applied to the mold walls before filling to facilitate easy removal of the bricks later. After 6 hours, the brick was extracted from the mold. Figure 6 illustrates the mold arranged for brick casting

Water Absorption Test: Four brick specimens (3:7, 2:3, 1:1, and conventional bricks) were weighed in dry conditions (W1). Subsequently, they were immersed in fresh water for 24 hours. After this period, the bricks were removed from the water, wiped with a cloth, and weighed in wet condition (W2). The difference between the weights indicates the amount of water absorbed by the bricks, and the percentage of water absorption was calculated. The lower the water absorption, the higher the quality of the brick. A quality brick typically absorbs no more than 20% of its own weight.

$$\text{Water Absorption (W)} = \frac{W_2 - W_1}{W_1} * 100\%$$

Efflorescence Test: A brick was immersed in distilled water for 24 hours, then removed and allowed to dry in the shade. The presence of a whitish layer on the surface indicates the presence of alkalis in the brick. If the whitish layer covers about 10% of the surface, it indicates an unacceptable level of alkalis. If it covers approximately 50% of the surface, the alkali presence is moderate. If the presence of alkalis exceeds 50%, the brick is severely affected.

Hardness Test: A scratch was made on the brick surface using a steel rod or any hard material. Difficulty in making the scratch indicates high-quality, hard bricks.

Soundness Test: The soundness test was conducted in the field using both plastic sand bricks and conventional bricks. The bricks were taped together, and the clear ringing sound produced indicated good quality.

Compressive Strength Test: This test determines the load-carrying capacity of bricks under compression. Four specimens of each type of brick were tested individually using a compression testing machine. The load was applied until the specimen failed, and the maximum load at failure was recorded as the compressive strength.

Penetration Test: Place the sample in the transfer dish and place the whole assembly under the stand of the penetration apparatus. Release the needle on the surface of the sample with a load of 100 gr for only 5 seconds.

Split Tensile Strength Test: Split tensile strength test is a method of determining tensile strength using a cylinder with a split across the vertical diameter. To conduct the split tensile test, a load was applied continuously without shock at a rate ranging from 0.7 to 1.4 MPa/min (1.2 to 2.4 MPa/min) until the cylinder broke. The procedure for split tensile strength testing was followed as per IS 5816 :1999. The splitting tensile strength of the specimens is calculated by the following equation: $T = \frac{2*P}{\pi DL}$ where T =splitting tensile strength (MPa). P =the maximum applied load indicated by the machine at failure (N). D =diameter of cylinder (mm). L = length of cylinder (mm).

TABLE 3: Sieve Analysis of sand

S.N.	Sieve size (mm)	Weight retained (kg), W_1	Cumulative weight retained (kg)	Cumulative % weight retained	% finer
1	4.75	0.046	0.046	3.067	96.933
2	2	0.262	0.308	20.53	79.467
3	1	0.228	0.536	35.733	64.267
4	0.6	0.310	0.846	56.4	43.6
5	0.425	0.286	1.132	75.466	24.534
6	0.212	0.204	1.336	89.066	10.934
7	0.150	0.143	1.479	98.6	1.4
8	0.75	0.012	1.491	99.4	0.6
9	Pan	0.009	1.5	100	0

III. Result

TABLE 4: Compressive strength test on different ratios of plastic and sand.

SN	Sample (plastic: sand)	Applied load (KN)	Contact area(mm^2)	Compressive strength(N/mm^2)	Average compressive strength(N/mm^2)
1	3:7	117		6.842	
		134.42		7.86	7.34
		125.23		7.32	
2	2:3	180	190*90= 17100	10.52	
		172.1		10.06	10.19
		170.88		9.992	
3	1:1	165		9.64	
		161.1		9.43	9.536
		163.1		9.538	

TABLE 5: Compressive strength test results on locally available conventional brick.

SN	Applied load (KN)	Contact area (mm^2)	Compressive strength(N/mm^2)	Average compressive strength(N/mm^2)
1	77.01		4.5	
2	72.6	17100	4.24	4.58
3	85.7		5.01	

TABLE 6: Water absorption test result on the different ratios of plastic and sand.

SN	Proportion (plastic: sand)	Number of bricks sample	Average Water absorption (%)
1	3:7	3	1.39
2	2:3	3	0.7879
3	1:1	3	0.868

TABLE 7: Water absorption test result on locally available conventional brick bought from a local market

SN	Class of brick sample	Number of bricks	Average water absorption (%)
1			
2	1st	3	3.51
3			

Penetration test: The results of a penetration test on a plastic sample are shown in the table below (Table 8). The sample was made of plastic only, and the test was used to assess how long it took for the melted plastic to set. With the increase in time of observation, the penetration value decreased. First, complete penetration was detected till the
5th minute, whereas the plastic sample revealed nil penetration by the 30th minute. Plastic took 40 minutes to settle completely. In addition, after 25minutes, the exterior borders of the plastic sample exhibited no penetration while the center area still had penetration. This demonstrates that the outer layer of plastic hardens faster than the inner layer. As a result, there was non-uniformity in the plastic throughout the setting process.

TABLE 8: Penetration Test

Minute	Time initial	Final penetration (mm)	Difference
5	0	433	433
10	0	390	390
15	0	266	266
20	0	180	180
25	0	73	73
30	0	52	52

Split tensile strength test: The split tensile strength of plastic sand bricks is shown in the table below (Table 9). The average split tensile strength of the samples was found to be 371.38 MPa, 648.63 MPa, and 463.17 MPa for plastic sand ratio of 3:7, 2:3, and 1:1, respectively. The split tensile strength of bricks increased when the percentage of plastics was increased by up to 10%, but as the percentage (%) of plastics was increased further, the split tensile strength dropped. Because the amount of sand used was notably less than the amount of plastic used, this loss of strength was caused by a reduction in the bonding between plastic and sand.

TABLE 9: Split Tensile Strength Test

SN	Plastic: Sand	Applied Load (KN)	Split Tensile Strength(T)= 2*p/ΠDL	Mean Value
1	3:7	51.7	387.21	
2		49.25	368.86	371.38
3		47.81	358.07	
4	2:3	81.2	608.89	
5		86.9	650.85	648.63
6		91.7	686.08	
7	1:1	65.78	492.66	
8		55.95	419.04	463.17
9		63.8	477.83	

IV. Discussion

Motivation for Selecting this Project:
The decision to undertake this project stems from the recognition that plastic bricks offer a sustainable solution for managing plastic waste and mitigating its environmental impact. By utilizing recycled plastics, this initiative contributes to waste reduction efforts while addressing pressing environmental concerns. Additionally, the lightweight nature of plastic bricks facilitates easier transportation and handling, potentially leading to reduced construction costs overall.

Factors Hindering the Adoption of Plastic Bricks:

1. Regulatory Compliance: Existing building codes and regulations often favor or mandate the use of conventional materials with established standards. Plastic bricks may encounter challenges in meeting these regulatory requirements, potentially impeding their widespread adoption.
2. Limited Applicability: Plastic bricks may not be suitable for all construction purposes due to potential limitations in load-bearing capacities or resistance to specific environmental factors. This restricts their use to certain projects and applications.
3. Perception and Trust: Traditional bricks enjoy a longstanding history of use and are widely trusted in the construction industry. Plastic bricks may face skepticism regarding their strength, fire resistance, or other performance attributes, leading to reluctance in their adoption.
4. Initial Cost Concerns: Despite the long-term cost-effectiveness of plastic bricks, their initial investment may not always align favorably with traditional bricks. Investors and builders may prioritize short-term budget considerations over the long-term sustainability benefits offered by plastic bricks.

V. Conclusion

The test findings reveal that the compressive strength of conventional bricks, with a maximum load of 85.7 KN, stands at 5.01 N/mm^2 (as per table 5). Conversely, in the case of plastic sand bricks, the compressive strength diminishes as the ratio of plastic to sand increases. The utilized mix proportions include 3:7, 2:3, and 1:1. The average compressive strengths for plastic sand bricks are recorded as 7.34 N/mm^2, 10.19 N/mm^2, and 9.536 N/mm^2, respectively (referencing table 4).

Plastic bricks exhibit an absence of alkali, unlike conventional bricks where it is present. Consequently, the water absorption test indicates a significant reduction in alkali presence, highlighting plastic sand bricks' ability to curtail water absorption and resist alkali reactions. Furthermore, they demonstrate enhanced quality and durability in comparison to traditional bricks. Additionally, plastic sand bricks weigh less than their conventional counterparts. Notably, the strength of plastic sand bricks surpasses that of conventional bricks. Opting for a 2:3 mix ratio (plastic: sand) yields superior strength compared to other ratios. However, from an economic standpoint, the 3:7 ratio may be preferable as its production cost is lower than the other options.

The applications of plastic sand bricks in civil engineering are diverse, including their use in precast bricks, partition walls, and canal lining.

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