Plastic Sand as a Construction Material

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Plastic waste pollution poses a serious environmental concern. At the same time, the cement industry is among the biggest sources of CO_2 emissions, which poses another environmental challenge. Plastic sand bricks could be a workable solution for combating issues related to solid waste. The compressive strength decreased with increasing ratios of plastic to sand. Plastic sand bricks weighed less than the conventional bricks.

Keywords: plastic sand bricks ; plastic sand blocks ; plastic sand paving

1. Introduction

The circular economy presents an alternative to the linear "take, make, use, dispose" system. It attempts to keep resources in use for as long as possible, maximize their value while they are in use, and recover and regenerate products at the end of their useful lives [1]. The production and use of plastic sand bricks and blocks is a good example of the innovation required to establish a circular economy.

Plastic waste (e.g., plastic bottles, bags, and sheets) is not readily biodegradable, which makes it one of the most challenging sources of pollution. Worldwide, plastic waste exceeds 25 million tons per year [2]. From 1950 to 2015, only about 10% of plastic waste was recycled; the rest was disposed of in landfills or elsewhere in the environment, according to the United Nations Development Program (2019).

An additional benefit of replacing widely used concrete (cement) blocks and bricks with plastic sand blocks or bricks is that this could contribute to reducing cement consumption and the associated carbon dioxide (CO_2) emissions. The cement industry's CO_2 emissions are among the highest of all industries [3], with the cement manufacturing process producing about 8–10% of global CO_2 emissions [4].

The wide use of sand is unsustainable, which poses another environmental challenge [5]. According to the United Nations Environment Program (UNEP) (2019), the extraction of sand and gravel is one of the greatest challenges to sustainability in the twenty-first century. Yet, in many regions, these materials are among the least regulated of all the resources extracted and traded. Consequently, rivers, river deltas, and coastlines erode, while sand mafias prosper and demand increases [6]. Plastic sand is a sustainable construction material, since it can be easily recycled, whereas recycling sand cement (concrete) is more challenging and less economically feasible.

In addition to advances being made in recycling plastic to reduce plastic pollution, research has been conducted on mixing plastic waste with sand to produce alternative construction bricks and blocks [7][8][9][10]. Moreover, some studies have focused on adding plastic waste to concrete mix to improve its physical characteristics [11][12][13][14][15][16]. Considerable research has been conducted in countries such as the USA and the UK on adding plastic waste to concrete mix [12]. Other studies have examined sand-filled plastic bottles as a construction system [17]. The idea of producing a construction material by mixing plastics with concrete goes back to the 1980s. In 1986, a patent was granted by the United States Patent and Trademark Office that involved mixing plastic with concrete [11].

2. Plastic (PET, HDPE, and LDPE) Sand Glass and Paper Brick

Ursua [18] examined eco-bricks that were 55–65% sand by weight, 29–39% plastic by weight, 5% crushed glass bottles, and 1% shredded paper. River sand was sieved through 4.75–0.075 mm sieves. The plastic waste was a mix of bottles (PET), grocery bags (LDPE), and soft drink and milk bottles (HDPE). The researcher did not specify the percentage of each plastic type utilized [18].

The results indicate that all the plastic sand brick samples exceeded the American Society for Testing and Materials (ASTM) C129 (standard specification for non-load bearing concrete masonry) minimum requirement of 500 psi (3.45 MPa) per brick. During the water absorption test, the samples gained less than 20% of the water absorbed by the various sand brick samples, and all the sand brick samples were classified as ≤10% using the efflorescence test. Finally, when the brick surfaces were scratched, there was only a very light impression made by a four-inch common nail. When plastic waste was used as a binder, with sand and crushed glass bottles as fillers, extremely dense bricks were the result. Therefore, all the plastic sand brick samples were classified as "hard." Ursua [18] concluded that plastic sand bricks could be a potential alternative building material. The use of plastic sand bricks is also a workable solution for combating issues related to solid waste [18].

Suriyaa et al. [8] used recycled PET bottles, LDPE carry bags, and HDPE thermocol to make plastic bricks. The research did not indicate the percentage of each type of plastic used. The waste materials were cut up into small pieces, which were then melted at temperatures of 90–110 °C. River sand was sieved to 600 microns and added to the liquid plastic. The mixture was stirred continuously, poured into a mold, compacted, and cured for either 7 or 28 days [8].

The plastic bricks were compared with conventional bricks using the following tests: compressive strength test, water absorption test, efflorescence test, hardness test, and soundness test [8]. It was found that a conventional brick's compressive strength for a maximum load of 32 KN was 1.27 Mpa, while that of a plastic sand brick decreased with increasing ratios of plastic to sand. Economically, a brick-like conventional brick can be produced using a 1:4 ratio.

The water absorption of the conventional bricks was 7.08%. According to the efflorescence test results, the plastic bricks had no alkali, while the conventional bricks did. The hardness test demonstrated the hardness of the brick. The soundness test produced a clear ringing sound, indicating good quality. Finally, the plastic sand bricks weighed less than the conventional bricks.

3. Plastic (LDPE and HDPE) Sand

In a study by Tufa et al. [19], the effect of plastic (LDPE and HDPE) weight percentages on compressive strength variation were evaluated using Design-Expert software. An analysis of variance (ANOVA) table and fit summary were used to verify the setup model. In addition to diagnostic case statics, graphic representations of the model were assessed using adjusted R-Square, predicted R-Square, DFFITS, and Cook's D graphs. The greatest compressive strength of a sand and plastic mixture was predicted through graph analysis to be 4.95 MPa. The result was achieved with a plastic weight percentage of 60% (40% LDPE and 20% HDPE). The plastic was melted and blended with sand at a weight percentage of 40% (25% 1.18 mm sand and 15% 0.5 mm sand). The results were negatively impacted by a plastic waste content higher than 70%, and this was likely due to impurities within the materials. Compressive strength was negatively affected by sand when its percentage weight was >42%; this was due to pores created in the bricks by the noncoherent plastic and sand mixture. Sand plastic composite bricks (SPCBs) derived from plastic waste have many environmental and economic advantages, according to the authors.

4. Plastic (LDPE) Sand

Abdel Tawab et al. [20] replaced cement in the production of bricks and concrete blocks with melted plastic bags. The bricks were produced from melted waste plastic and sand, while the blocks were created by mixing melted waste plastic, sand, and gravel. The resultant molded materials were found to differ in thermal conductivity based on their plastic content. The thermal conductivity of both the bricks and the concrete blocks decreased as the plastic content increased.

In both bricks and blocks with similar plastic content (50%), the thermal conductivity values were similar. For both bricks and blocks, the bending moment and therefore, the bending stress increased with the plastic content. By increasing the plastic content of the blocks from 20% to 50% (150%), the bending moment increased from 901.40 N·m to 1442.55 N·m (60%), and the bending stress increased from 5.40 $N \cdot m^2$ to 8.65 $N \cdot m^2$ (60%).

It was found that plastic waste could be used for making bricks and blocks because of its high versatility, its ability to be tailored to meet specific needs, and its light weight, which reduces fuel consumption during transport. Substituting cement with plastic waste will further reduce environmental problems associated with both plastic waste disposal and cement production.

Osarumwense et al. [21] conducted a study in which molten plastics were mixed with sand to produce paving tiles at varying plastic to sand ratios (1:1, 1:2, 1:3, and 1:4). Curing took place over 28 days.

A conventional sand-cement composite (control) could withstand a maximum load of 29 KN. The tile (sample) could sustain a maximum load of 39 KN at a 1:3 ratio. The frictional coefficients for the sample and control were 0.372 N/kg and

0.289 N/kg, respectively. This is an indication that a 1:3 ratio is optimal for LDPE-based tiles. The authors concluded that for constructions, plastic sand-bonded tiles can replace sand-cement composites.

Susila et al. [22] examined the compressive strength of samples with 1:3, 1:5, and 1:7 ratios of LDPE plastic to sand at 200 °C. The samples with a 1:3 plastic to sand ratio and 3 mm sand grains were found to have the greatest average compressive strength of 32.7 Mpa. The samples with a 1:7 plastic to sand ratio and 3 mm granules had the lowest average compressive strength 12.0 Mpa. The higher the ratio of plastic to sand, the lower the compressive strength of the composite; the higher the ratio of plastic to sand, the higher the density of the composite. The authors emphasized the need to recycle plastic waste, especially plastic bags, and suggested that paving blocks could be made from plastic waste instead of cement.

5. Plastic (HDPE) Sand Paving Material

Dominique [2] mixed HDPE plastic and sand to produce pavers and then tested their compressive strength. Three sand to plastic ratios (1:3, 1:4, and 1:5) were tested. The samples were placed in molds (100 mm diameter and 65 mm height), heated in a closed drum, and their temperatures were observed at 30 min intervals. It was observed that HDPE melts at 120–400 °C.

A standard water absorption test was conducted. After measuring the dry weights, the three samples with the highest compressive strength were immersed in water for 24 h. The results showed that the water absorption value was 0.052% higher than that of cement concrete pavers [2]. This mix was found to reduce construction costs, especially those for repairs, as well as reduce environmental impact.

Valarmathy and Sindhu [23] compared conventional HDPE paver blocks with paver blocks containing manufactured sand (M-Sand), sugarcane bagasse ash, and HDPE plastic. The blocks were coated with lime hydrate after molding because plastic is not a good heat insulator, and lime acts as a good thermal insulator. It was determined that the paver blocks manufactured with HDPE plastic waste are more durable and more resilient than many other types of paver blocks, creating an exceptionally low-cost, renewable, and eco-friendly alternative.

6. Plastic (PP), M-Sand, and Sawdust Brick

Clement et al. [24] evaluated brick samples (190 × 90 × 90 mm) made from plastic waste (PP), wood dust (sawdust), and M-Sand. The sawdust was used to reduce brick weight. The five molded samples were all 20% plastic (PP), and the percentages of sawdust and sand were 5% and 75%, 10% and 70%, 15% and 65%, 20% and 60%, and 25% and 55%. A study found that a mix of 20% plastic, 10% sawdust, 70% M-sand provided the maximum strength of 9.3 MPa out of the five proportions. It was concluded that plastic bricks are stronger than normal bricks, which provide compressive strength of 6.6 MPa.

7. Plastic (PET) Sand Brick

Chauhan et al. [25] conducted a study to assess plastic waste (PET) and river sand bricks with 1:2, 1:3, and 1:4 ratios of plastic to sand. The bricks were 230 × 100 × 75 mm

Water absorption reached a maximum of 4.56% in the 1:4 ratio specimen, and it was as low as 0.95% in the brick with the 1:2 plastic to sand ratio. Water absorption in conventional clay bricks is around 15–20%.

According to the study, plastic bricks are less conductive than clay bricks. Despite this, continuous exposure to temperatures above 350 °C caused partial melting of the bricks. Therefore, these plastic bricks are not suitable for use where fire risks exist.

8. Plastic (PET) Sand Roof Tile

Bamigboye [26] tested the performance of roof tiles manufactured from river sand and recycled PET in varying proportions (10%, 20%, 30%, 40%, 50%, 60%, and 100% PET). A study found that 10% PET composites had the highest water absorption (2.94%), while 30% PET composites had the lowest (0.15%). Additionally, the study reported that the tile samples with the lowest density were 100% PET (852.07 kg/m^3), and the samples with the highest density were 10% PET (1899.56 kg/m^3). Finally, it was found that the highest value among the composite tiles was for those with 40% PET (1.59 Mpa), followed by those with 50% PET (1.48 MPa).

Reta and Mahto [27] conducted a study to assess roof tiles made of a plastic waste (PET) and sand mix. Three samples containing 20%, 30%, and 40% PET were assessed. The compressive strengths of the 20%, 30%, and 40% PET samples were 25 MPa, 23.5 MPa, and 18.2 MP, respectively. The findings indicated that plastic sand tiles are more cost-effective than conventional concrete tiles.

9. Plastic (PET) Brick

Akinyele et al. [28] tested PET as a replacement for burnt bricks. They reported that PET-containing materials melted during firing because the PET melting point is only 250 °C. During firing, a sample containing more than 10% PET collapsed, whereas one with less than 10% PET deformed, but did not collapse. The PET bricks also had low compressive strength. Nevertheless, bricks containing <5% PET can perform well. Based on the study, replacing burnt bricks with PET is feasible, provided that the amount of PET is <5% and the temperature is closely monitored.

10. Plastic (HDPE and PP) Brick

Mohan et al. [29] examined the viability of using HDPE and PP plastic waste to create bricks. The mix was heated up to the plasticity zone, then transferred into a mold and compressed to attain the final brick product. **Table 1** shows the compressive strengths of the bricks with HDPE:PP with various ratios, and the percentage of water absorption.

Table 1. Compressive strength of various HDPE:PP ratios [29].

HDPE:PP Ratio	Compressive Load (KN)	Compressive Strength MPa	Water Absorption %
50:50%	157	7.5	0.44
40:60%	97	4.64	0.25
70:30%	128	6.12	0.23

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