E3S Web of Conferences 659, 03010 (2025) https://doi.org/10.1051/e3sconf/202565903010
ICONGEET2025

Upcycling Plastic Straw Waste into Sustainable Sand Brick Solutions for Effective Natural Resources Management

Norlia Mohamad Ibrahim[1,2*], *Shamshinar* Salehuddin[1], *Roshazita* Che Amat[1,2], *Mustaqqim* Abdul Rahim[1], *Nur Liza* Rahim[1,2], Irnis Azura Zakarya[1,2], and *Warid Wazien Ahmad Zailani*[3]

[1]Faculty of Civil Engineering & Technology, Universiti Malaysia Perlis (UniMAP), 02600 Arau, Perlis, Malaysia
[2]Geopolymer & Green Technology, Centre of Excellence (CEGeoGTech), Universiti Malaysia Perlis (UniMAP), 02600 Arau, Perlis, Malaysia
[3]School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

Abstract. This study introduces a sustainable approach to producing low-cost sand bricks by incorporating plastic straw waste. It addresses the urgent need to reduce plastic waste and dependency on landfills while conserving natural sand resources. By upcycling discarded plastic straws as a partial replacement material, this work promotes circular economy practices and transforms waste into valuable construction inputs. The integration of plastic straws not only mitigates environmental pollution but also contributes to enhancing the environmental performance and sustainability of building materials. The physical and mechanical properties of sand bricks with varying proportions of plastic straw were evaluated through bulk density, water absorption, and efflorescence tests. The bricks prepared in this research consist of the control brick, which has no plastic straw (0%), and samples containing 2%, 4%, and 6% proportions of plastic straw in bricks. The ratio of the mixture is 1:6 (1 part of ordinary Portland cement and 6 parts of sand). In the compressive test, the results show that higher compressive strength was obtained for bricks exposed to high temperatures, where it increased by 7.5% compared to unexposed bricks. For water absorptions, the average value for the control brick is 16.76%, which is the highest, and the lowest is obtained for 6% sample brick, which is at 16.37%. As for the density of bricks, it shows that the 2% sample brick has the highest wet and dry density compared to the other samples. For the efflorescence test results, all the sample bricks had insignificant differences compared to the control brick, and most of the results can be categorized as moderate. This research supports waste minimization to enhance environmental sustainability, enhances construction material performance, and promotes sustainable practices within the construction sector.

* Corresponding author: norlia@unimap.edu.my

1 Introduction

The building sector is at a crucial turning point due to the rapid deterioration of the environment and the depletion of resources. Researchers are being driven to investigate sustainable solutions as the growing demand for the exploitation of natural resources and energy usage. Incorporating waste materials into building materials not only lessens the impact on the environment but also supports global efforts for sustainable material innovation and a circular economy. Among the many wastes generated by human activity, plastic remains one of the most dominant and enduring pollutants. Plastic waste has drawn worldwide attention due to growing concerns about its effects on human and environmental health. 150 million tons of plastic trash are generated annually globally because of the single-use disposal of more than 50% of produced plastics [1]. In some countries, the disposal of plastic waste was ranging from 0.14 to 0.37 million tons each year. Plastic products that are regularly used include bags, bottles, containers, food packaging, and straws. Plastic is almost non-biodegradable material, and those particles do not disintegrate completely, meaning that it will exist in our environment for a very long time. Plastics manufacturing has seen one of the strongest growth rates across all industries since 2000. Global trade in rubber and plastics reached $964 billion in 2023. Trade in this category has increased at an annualized rate of 2.32% during the last five years. The seven main sectors that make up the global plastic industry are: agriculture, housing, packaging, construction, electronics, automotive, and other subsectors, including plastic furniture and medical devices. Global plastic waste production overwhelms waste management systems, with most plastic ending up in landfills and harming the environment and people. In Kuala Lumpur and Putrajaya, landfills received 101,949 metric tons of plastic in 2021 (13% of total waste), with only 16% recycled. In 2022, waste increased to 796,795 metric tons, with 210,966 metric tons of plastic (13%), and the plastic recycling rate rose to 18%. However, the overall recycling rate remained low at 33.16%.

The two main techniques employed in the country to deal with plastic waste are using incinerators and dumping at the landfill. One of the adverse impacts of landfilling is pollution of the air, water, and land, as well as climate change caused by the release of greenhouse gases into the environment. Because of the growing concerns on the adverse impact of plastic waste in the landfill, many attempts have been made to recycle the plastic waste. One of the attempts is by recycling the plastic waste is by incorporating it as one of the main alternative components in the production of construction material. Plastic straw is one type of plastic waste that has been introduced as part of raw materials in building materials such as in concrete and brick. Researchers have attempted to utilize discarded plastic straws by incorporating them into concrete mixtures, typically as synthetic fibre reinforcement in small proportions, ranging from 0.5% to 10% replacement of sand by volume. Some of the previous studies also make a study on its influence in asphalt or bituminous mixes and some others use it as material in paver tiles by melting the plastic straw to form a plastic-sand composite. Many have investigated the use of plastic straw in brick as additional material rather than replacement material. Thus, this study was conducted to investigate whether the addition of plastic straw will compromise the quality of the bricks.

2 Materials and methods

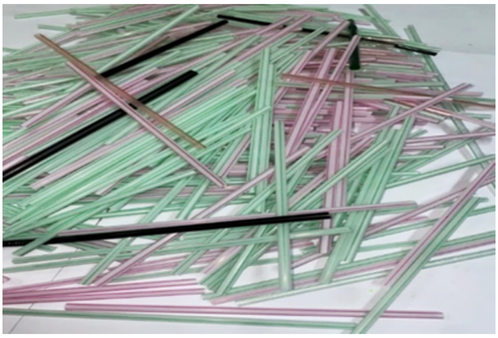
2.1 Materials preparation and mixing composition

Traditional attempt of using waste materials in brick is normally by replacing one or more main component of brick with waste materials. However, in this study, rather than replacing one of the components, the waste materials were added into the brick mixtures. Materials used in this study are cement, sand, and plastic straw waste. Plastic straw waste was collected from local restaurants as part of their garbage. Plastic straw was added in different percentage which is 0% (control samples), 2%, 4% and 6% in which was calculated based on the total amount of sand. The design mixtures were drawn from the MS76: 1972 [2]. Using volume fraction calculations, amount of plastic straw needed in each mixture was calculated. The size of the plastic straw was selected to match the sand's size since the weight of the plastic straw was depending on the weight of the sand. The used plastic straw waste and sand is set to have passed through a 4.8-mm-mesh British Standard (BS) sieve. Table 1 shows the mixing composition and the number of raw materials used in this study for four brick mixtures.

Table 1. Mixing composition for all plastic straw mixtures.

Plastic Straw (%)	Cement (kg/m^3)	Sand (kg/m^3)	Plastic Straw Waste (kg/m^3)
0	16.38	98.31	0
2	16.38	98.31	1.97
4	16.38	98.31	3.93
6	16.38	98.31	5.90

Laboratory tests were conducted to evaluate the properties of bricks containing plastic straws, including compressive strength, water absorption, density, heat resistance, and efflorescence. All tests followed the procedures outlined in [3]. A total of 72 brick samples, each measuring 215 mm x 102.5 mm x 65 mm, were produced. The samples included 18 control bricks (0% plastic straw), 18 with 2% plastic straw, 18 with 4%, and 18 with 6%. Brick dimensions were based on MS76: 1972 [2]. To ensure consistency, plastic straws collected from waste bins were thoroughly cleaned before use. Figure 1 displays the plastic straws used, while Figure 2 shows the other main raw materials.



a) Plastic straw after being cleaned

b) Plastic straw that has been cut to desired size

Fig. 1. The plastic straw used in this study.

 https://doi.org/10.1051/e3sconf/202565903010

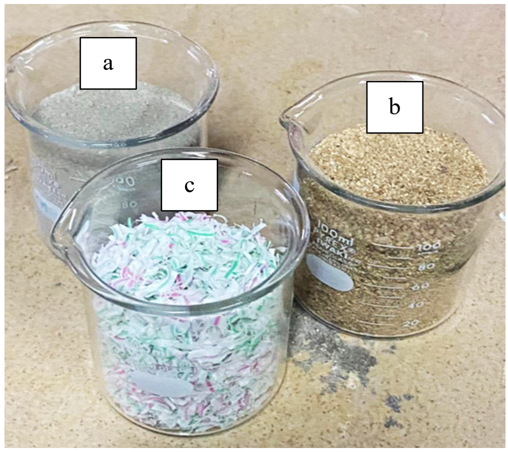


Fig. 2. Main raw materials used in this study a) cement, b) sand and c) plastic straw.

2.2 Materials testing

In this study, compressive strength, water absorption, density, heat resistance, and efflorescence tests were conducted to assess brick quality. Compressive strength assessment varies based on material fragility, ductility, and load-displacement characteristics. The yield of a construction unit under compression reliably indicates its overall toughness, regardless of failure mode. Effective manufacturing management is expected to minimize batch variances, although production flaws are considered in building design. According to ASTM C129 [4], bricks must withstand a minimum compressive force of 3.75 MPa.

The water absorption test followed the ASTM C67 [3] standard procedure. First, the bricks are weighed in their dry state. Next, they are submerged in fresh water for 24 hours. After soaking, the bricks are removed from the water, surface-dried, and weighed again to determine their wet mass. Lower water absorption indicates better brick quality. A high-quality brick does not absorb more than 20% of its own weight in water [5]. Bulk density is defined as the mass per unit volume of raw plastic materials obtained from the source, expressed in kilograms per cubic meter (kg/m^3). This measurement is used to determine the density of plastic straws, which may influence the physical properties of bricks. Additional tests may be required depending on the intended application. Brick density is a crucial factor as the plastic straw have been added into the mixtures. All brick samples that have been dried in an oven and been submerged in water for 24 hours is weighed and measured in volume. The calculation was based on standard procedure stipulated in BS 12390-7 [6]. The heat resistance test, which has been the principal testing in this study, was conducted to evaluate the potential impact it may cause to the structures if the brick was exposed to heat, for example if the structure is on fire. Sand and plastic straws may be able to resist higher temperatures that polymers by themselves typically cannot. The bricks were heated between the range of 139 °C to 180 °C for around 4 hours to see if any significant features changes.

To determine whether any alkalis were present, an efflorescence test was performed. For the efflorescence test, the standard method of MS 76: 1972 was adopted. As seen in Figure 3, each brick end is placed in a tray with 25 mm of room-temperature water until the water is either totally absorbed or evaporated. Once again, water is added to the dish until it reaches a depth of 25 mm. It is then left to either evaporate or soak into the bricks. According to the following definitions, which are listed in Table 2, the liability to efflorescence shall be classified as nil, slight, moderate, heavy, or significant.

Fig. 3. Efflorescence test.

Table 2. Liability to efflorescence [2].

Category	Result	Description
1	Nil	No perceptible deposit of efflorescence.
2	Slight	Not more than 10 % of the area of the face covered with a thin deposit of salts.
3	Moderate	A heavier deposit than 'slight and covering up to 50 % of the area of the face, but unaccompanied by powdering or flaking of the surface.
4	Heavy	A heavy deposit of salts covering 50 % or more of the area of the face but unaccompanied by powdering or flaking of the surface.
5	Serious	A heavy deposit of salts accompanied by powdering and/or flaking of the surface and tending to increase with repeated wettings of the specimen.

3 Results and discussions

3.1 Bulk density of raw materials

Based on the raw materials testing, plastic straw has the lowest density compared to other with only 200 kg/m^3. Meanwhile, sand has the highest density which was at 1700 kg/m^3. This is because most drinking plastic straws are made from polypropylene which is a commonly used polymer. A polymer consists of many identical small particles that are strung together like a chain. On the other hand, sand is made up of small, granular particles of quartz. These particles are generally more closely packed together, leaving little space between them. The hollow tubes of plastic take up more space than the granular particles of quartz, so plastic has a lower density. In addition to the difference in particle size, the chemical composition of plastic also contributes to its lower density. Plastic is made up of carbon, hydrogen, and oxygen, while sand is made up of silicon, oxygen, and other elements. The carbon, hydrogen, and oxygen atoms in plastic are lighter than the silicon and oxygen atoms in sand, so plastic has a lower density [7].

3.2 Compressive strength

The compressive strength test results shown in Figure 4 indicate that all brick samples exhibit a similar pattern in compressive strength at both 7 and 28 days. The 7 days testing was done to examine whether the bricks have achieved reached its early strength as what has been done for concrete testing. For all samples, 28 days results show an increasing trend. The samples containing only 2% of plastic straws had the highest compressive strength after 28 days, measuring 6.08 MPa, while the 6% sample brick had the lowest, measuring only 3.67 MPa. The highest compressive strength was attained at 2% plastic straw content because the amount of plastic in this brick is adequate to fill in the gaps without weakening the bricks. Due to the excessive amount of plastic in this brick, which may weaken the capacity of plastic straw particles to connect with other constituents, the 6% sample brick had the lowest compressive strength for both 7 days and 28 days. The percentage increment of compressive strength when compared with control samples is nearly 14%. The standard minimum requirement for general use of brick is 5.00 MPa.

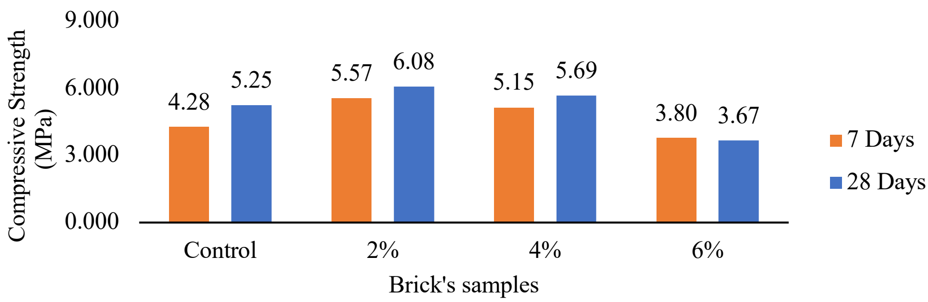


Fig. 4. Compressive strength of brick’s samples without heat treatment.

The compressive strength at 28 days for all samples that were heated and those that were not heated was compared. According to Figure 5, each sample brick exhibits a similar pattern in terms of compressive strength for heat resistance. When compared to other samples, the control sample brick had the lowest compressive strength with only 4.39 MPa. The reason for this is likely due to the composition of the control sample brick. The control sample brick is made of a mixture of cement and sand, while the other sample bricks are made of a mixture of cement, sand, and plastic. Plastic straw is susceptible to heat, which can make the change in the strength property of bricks. However, the existence of other components such as sand can reduce the probability of the severe adverse effect from heating the samples. In higher temperature plastic straw can fully melted and functioned as stronger aggregate in the mixtures. Melted plastic straw can also help to improve the strength and durability of bricks. This is because plastic can help to bind the other materials in the brick together, making it more difficult for them to break apart. However, if the content of plastic waste was too high it will become more fragile and reduce the strength [8]. In this study, the temperature is quite low, and the plastic straw was not heated directly but it was heated when the bricks have been manufactured. Therefore, it could not combine with other materials to create larger particles that may contribute to increasing the strength. If the compressive strength of the tested brick is at least 11.70 MPa, it can be qualified as a load bearing brick. On the other hand, minimum compressive strength for brick is regulated at 3.75 MPa [4].

https://doi.org/10.1051/e3sconf/202565903010

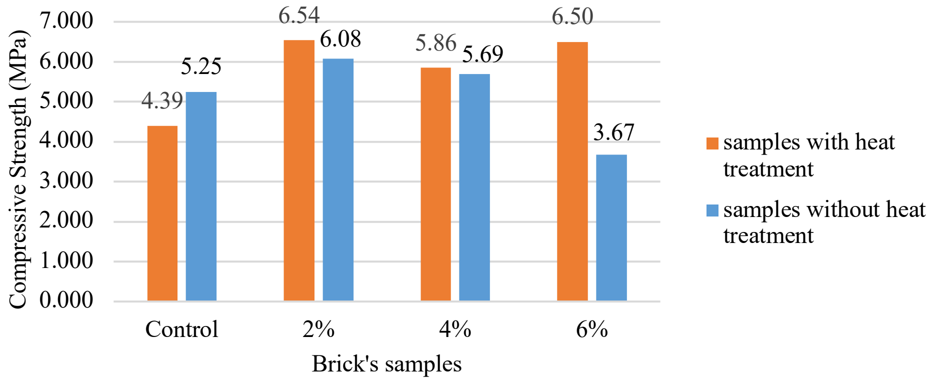


Fig. 5. Compressive strength of brick's samples with and without heat treatment

3.3 Water absorption

Figure 6 shows that the average water absorption for the control brick is 16.76%, which is the highest. While for the 2% sample brick it is 16.70%, for the 4% sample brick it is 16.50% and for the 6% sample brick it is 16.37%, which is the lowest. However, the differences between these outcomes are insignificant. Plastic straws in the sample bricks fill in some of the voids in the bricks and make the bricks less porous. This also makes it more difficult for water to penetrate the bricks. It is an advantage if the bricks absorb less water. Higher water absorption ability can cause in many severe issues including cracking, efflorescence, and mould development which can affect the durability of the bricks. It was observed from Figure 6 that specimens containing a higher percentage of plastic straw exhibited lower water absorption capacity. Plastic straws are non-porous materials and do not absorb water thus can ensure the hardened process occurs optimally. Plastic straw resisted water rather than absorbing it due to their hydrophobic nature. When these plastic straws are put into bricks, they create a barrier that reduces the brick's overall capacity to absorb excess water. In this study, the amount of water absorb is still below 20%.

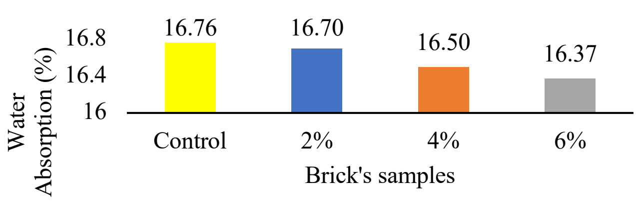


Fig. 6. Water absorption of brick's samples.

3.4 Density

The density of bricks can be tested either in their fresh state, known as wet density, or in their hardened state, also referred to as dry density. Figure 7 shows that the wet density of the 2% sample brick is the highest at 2012.34 kg/m^3, while the wet density of the control brick is the lowest at 1967.33 kg/m^3. In contrast, 2% sample brick had the maximum dry density (1778.34 kg/m^3), while control brick had the lowest dry density (1679.20 kg/m^3). According to BS 12390-7 [6], mortar brick typically has a density between 1300 and 2200 kg/m^3. The average value for the density test is similar to the density of the control samples. Density has an impact on the bricks' compressive strength. Bricks' compressive strength increases with their density.

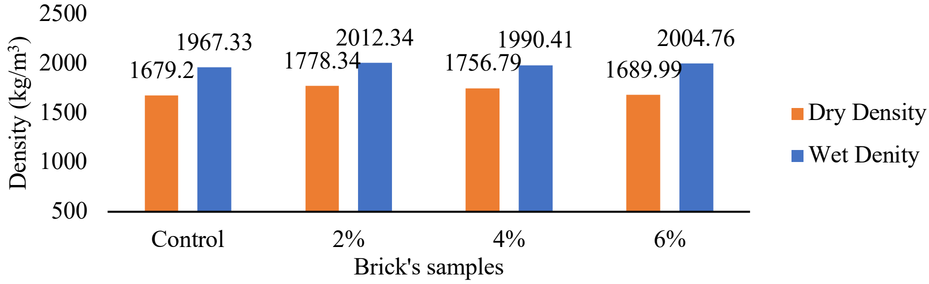


Fig. 7. Wet and dry density of brick's samples.

3.5 Efflorescence

The purpose of this experiment is to determine whether any alkalis were present on the bricks. When the alkaline salt in the bricks dries, it produces powder on the surface after absorbing moisture from the water. Not only does efflorescence degrade the aesthetics of the construction material, but it also weakens it and shortens the structure's lifespan [9]. Based on the result, it can be noted that all the sample bricks can be categorized as moderate except for samples containing 6% plastic straws which is categorized as heavy [2]. The category is tabulated in Table 3. For first-class bricks, it should only be slight, while it must be none for heavy-duty bricks. Further observation on the efflorescence can also being done by incorporating other waster material that contained more sodium compound such as in [10].

Table 3. Efflorescence test results.

Sample	Control	2%	4%	6%
Category	Moderate	Moderate	Moderate	Heavy

4 Conclusions

In conclusion, incorporating plastic waste into brick production offers not only technical benefits such as greater durability, reduced water absorption, and improved insulation, but also an opportunity to address one of greatest ecological problem and environmental challenges. By transforming discarded plastic straws into useful construction materials specifically in bricks manufacturing, this approach helps reduce landfill dependency and promotes more responsible and sustainable building practices. However, it remains important to recognize the structural and thermal limitations of plastic-containing bricks, as well as their potential long-term environmental impacts. Detailed design, responsible processing, and comprehensive research are important to ensure that these innovative materials meet both performance and environmental sustainability goals. With greater understanding and a commitment to responsible innovation, plastic waste can be transformed from an environmental burden into a valuable resource that helps build a more sustainable future.

References

1. P. Roy, L. Ashton, T. Wang, M. G. Corradini, E. D. G. Fraser, M. Thimmanagari, M. Tiessan, A. Bali, K. M. Saharan, A. K. Mohanty and M. Misra. J. Clean. Prod., **316**, 128234 (2021).

2. Malaysian Standard, MS7.6:1972 Specification for Bricks and Blocks of Fired Brickearth, Clay or Shale Part 2: Metric Units, Ms 7.61972, 1972.
3. ASTMC67, Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile, ASTM Int., vol. i, 2012.
4. American Society for Testing & Mater, *Standard Specification for NonLoadbearing Concrete Masonry Units* (ASTM, 2017).
5. N. M. D. Siti Aishah Wahid, S. M. Rawi. Int. J. Res. Appl. Sci. Eng. Technol. **5**, 4, 977–982 (2017).
6. British Standards Institute, *BS EN 12390-7:2000 Testing hardened concrete — Part 7: Density of hardened concrete*, (BSI Stand. Publ., 2000).
7. I. M. Susila, N. P. G. Suardana, C. I. P. K. Kencanawati, I. N. A. Thanaya, and I. W. B. Adnyana. IOP Conf. Ser. Mater. Sci. Eng., **539**, 1 (2019).
8. K. Sahani, B. R. Joshi, K. Khatri, A. T. Magar, S. Chapagain, and N. Karmacharya. Civ. Eng., **2022** (2022).
9. X. Liu, E. Liu, and Y. Fu. Appl. Sci., **13**, 5 (2023).
10. K. Hyeok-Jung, SP. Kang, and GC. Choe. Int J Concr Struct Mater **12**, 18 (2018).