Fabrication of Inventive Hybrid Environmental Bricks (HEB) utilizing Poly-Ethylene Terephthalate (PET) by Advanced Stabilization Techniques

Muhammad Qamer[1*], Altaf ur Rahman[2], Saad Zaheer[3], Nasir Mumtaz[4], Rimsha Saddique[5], Muhammad Haroon[6]

[1] State Key Laboratory of Hydraulic Engineering, Simulation, and Safety, Tianjin University, Tianjin, China. chqamer306@tju.edu.cn

[2] Sarhad University of Science and Information Technology, Peshawar, Pakistan. altafengrcivil@gmail.com

[3] Centre of Excellence in Water Resources Engineering, University of Engineering and Technology (UET), Lahore, Pakistan. Civil Engineering Department, Bahauddin Zakariya University, Multan, Pakistan, E-mail: saad.ahmad4456@gmail.com

[4] The University of Haripur, Haripur, Pakistan, nasirmumtaz123@gmail.com

[5] Superior University, Lahore, Pakistan, rimshasaddique178@gmail.com

[6] Iqra National University, Peshawar, Pakistan, hkmohmand00007@gmail.com

Abstracts: Sand brick, also known as cement brick or sand brick constructed from sand and cement, is a typical brick used in the building industry. Due to concerns about ecological problems, particularly the scarcity of natural sand and plastic issues, the demand for sand increased due to the consumption of sand cement brick. Thus, research into possible alternatives to natural sand is needed. In this work, plastics were utilized in place of sand to create sand cement bricks with grades of 5 N/mm2 and 10 N/mm2, which are known as hybrid environmental bricks (HEB). This research identified and discussed the impact of plastic on the compressive strength and density of brick made of plastic as opposed to river sand. Three layers of HEB are cast using two distinct strength ratings and various components. The HEB created using this concept yielded brick distinct from regular sand-cement brick. This study recognized and provided all of the important characteristics of HEB. The ideal combination for HEB was then identified by the study of this comparison. The results demonstrated that the approved brick by the characteristics analysis was the best combination for this investigation. According to the results, plastic has a great deal of promise for usage as a material to substitute sand when making sand cement bricks. Although the plastic-containing sand cement has a decreased compressive strength, its other qualities are still sufficient for industrial application. Ultimately, it can be said that the HEB has the potential to become a novel brick type in the building sector as it requires less sand and cement to make high-quality bricks that meet specifications.

Keywords: Hybrid Environmental Bricks (HEB), Poly-Ethylene Terephthalate, Plastic, Sand bricks, Cement

1. INTRODUCTION

Optimizing the potential for reuse and recycling of solid waste is one of the primary objectives of sustainable solid waste management. Plastic and metal, which are widely available worldwide, are the most prevalent garbage [1]. As a result, using this trash is crucial for sustainability and the environment. As a consequence, less pollution enters the environment, and natural resources are preserved. One of the main issues facing the globe today is the garbage produced during various operations and the byproducts they produce. One of the main causes of environmental pollution is plastic garbage [2].

Since the building sector significantly contributes to environmental deterioration, finding sustainable building materials has become a critical concern. A vital component of construction, bricks have a significant environmental impact during manufacture. It is essential to design novel, environmentally friendly bricks that can take precedence over conventional bricks [3]. It is becoming increasingly difficult to develop a safe and sustainable construction system, which is why civil engineers and academics from all over the world are working on it [4]. The concept of the mortar-less construction method, which uses interlocking masonry block units arranged without mortar layers, was inspired by the need to construct structures faster and with fewer laborers. The interconnected block technology needs no expert labor and cuts down on the time needed for construction during placement [5]. When compared to masonry made of kiln-sintered clay or a structure made of concrete, the interlocking block construction offers a significant reduction in embodied power from an ecological standpoint [6]. In actuality, a second compaction process using a mechanical press replaces the extremely energy-intensive sintering process of the clay bricks at high temperatures. One major factor in the depletion of the environment is the production of conventional bricks and blocks. Several contaminants, including sugarcane bagasse ash, waste hematite tailings, fly ash class (F), granite sawing wastes, municipal solid waste incinerator slag, gold mill tailings, green and core foundry sand, waste marble dust, and dredged sediments, have been the subject of extensive research efforts in the past to produce bricks and blocks. Also, materials like sawdust, wasted earth from oil filtering, waste tea from the marble processing process, cigarette butts, rice husk ash, petroleum effluent treatment plant sludge, kraft pulp manufacturing leftovers, kaolin fine quarry residue, and contaminated river sediments were used in multiple types of research [7-12].

Plastic, which is composed of polymer compounds, is essential to this era because of its stiffness, resilience, and flexibility. There is an enormous amount of plastic trash as a result of the widespread use of plastic in almost every part of life, including food, buildings, agriculture, electrical and electronic devices, industrial packaging, and more. Plastic is a substance that has many applications, but it is also detrimental to the environment since it doesn't break down naturally and will impede attempts to promote sustainability for over a century [13]. Plastic garbage may damage aquatic life and the quality of saltwater if it is discarded into the ocean, but it can also soak into the land and affect fertility. If it is placed by a burning method, hazardous and dangerous gases may be released [14-15]. A novel approach to producing bricks from plastic trash involves substituting crushed and shredded polyethylene terephthalate (PET) bottles for natural coarse material [16-17].

Plastic is a substance that is both hazardous and helpful. It has been impeding our quest for sustainability for more than millennia and cannot naturally decay. These days, there is a lot of garbage, including plastic, as a result of fast industrial and population increase [18-19]. In Pakistan, structural walls are usually constructed using regular burnt clay, however, it's important to look at alternatives to these bricks to cut construction costs and time [20]. The most current study directly incorporated and included polyethylene or plastic fiber, shredded PET bottles, chemically processed PET fiber, and PET aggregate in place of natural coarse material. Volume calculations were used for the majority of replacements and the results showed that the amount of plastic fiber with a decrease in compressive strength [21].

Research is mostly concentrated on using plastic trash to make bricks. Compared to regular bricks, these plastic sand bricks provide several advantages. Some of the important points to learn from the investigation which is not yet explained are that despite many advantages of using PB bricks such as their high compressive strength and durability the main area in which the research still lack is the fact that the mortar made from PB (plastic bottle sand mix) does not adhere well due to its smooth surface and must be designed with a specific rough surface. It is also not anticipated that the mortar would adhere precisely, which hinders workability and raises labor costs. Skilled labor is also needed to place such bricks.

The objectives of this study are:

- To synthesize a hybrid environment brick (HEB) using stabilization techniques
- To study the physical and mechanical properties of HEB
- To compare the environmental impact of HEB production & traditional bricks

MATERIALS AND METHOD

In this section methodology used by different authors in making plastic sand bricks has been summarized. Most researchers adopted a similar method and procedure for making or casting plastic sand bricks. The materials which are used in the manufacturing of Sand bricks of plastic are the polyethylene terephthalate and the sand of river. For making these plastic bricks PET plastic is gathered and sorted. Normally, water bottles and cold drinks bottles consist of these types of plastic and those bottles can be used for this purpose. Firstly, the bottles are washed then moisture in the bottle is evaporated by drying it naturally. The bottles of PET cannot be used in the usual size and shape in which it is available, for using these bottles it is needed to cut them into smaller pieces. Plastic is then melted using the different proportions of sand and plastic and is mixed. The proportions used are 1:2, 1:3, and 1:4 by weight. To find the optimum proportion for the desired result the plastic is melted in the container mixed with the sand and later poured in the brick mold. The procedure is described below:

Material collection

This procedure is very easy as PET and LDPE plastic can be collected from the waste of cafes and restaurants and its minimum amount can also be collected from houses, and hospitals which will come under the LDPE plastic-type such as plastic bottles and food packages. Sand can be purchased from the local supplier.

Batching of material

Measurement of material is called Batching. After collection of plastic waste, it must be ensured that there should not be present water content in the plastic waste if presented, then dried. Medium particle-sized sand is used for making a brick and it can be achieved by sieving. Sieve the sand through a 600-micron sieve, which will be used for making plastic sand bricks.

Proportion of sand and plastic waste

For the production of plastic sand bricks containing various amounts of sand and plastic are to be mixed in different proportions. Various proportions are 1:2, 1:3, and 1:4, by weight.

Development of brick mold

Generally, the mold used in the manufacturing of bricks is wooden mold that can be obtained from the shop of carpentry. All the surfaces of mold should be smooth to make bricks of superior quality having better sharp edges and smooth surfaces. All the interior surfaces of the mold must be used oil so that bricks can be removed easily without any cracks. The mold size would be 19 cm× 9 cm× 9 cm.

Casting procedure of plastic sand bricks

Burning

Firstly, arrange the container and firewood or burner. And put the container on firewood and ignite it. The container is preheated to remove the moisture from it. Secondly, put the small cut pieces of plastic into the container and allow them to melt.

Mixing

When the temperature around 180-200 °C of melted plastic is maintained then the sand is mixed into the container. Molten plastic and sand are continuously stirred so that both get mixed properly and bonded.

Molding

Apply the oil on the inner surface of the mold so that the bricks can be removed easily. The brick will not come out easily after the solidification if proper oiling is not done. The prepared mixture is filled into the wooden mold and tamping is done by rod to achieve proper compaction and it is necessary to properly fill the wooden mold. Brick can be removed from the mold after 24 hours. All the materials must be prepared according to the mix that is being designed before the mixing process. Details for all the mixes are shown in Table 1.

Table 1: Mixes Proportion for one brick production.

Material	Sand Bricks		HEB	
	C5 (kg)	C10 (kg)	C5 (kg)	C10 (kg)
Ordinary Portland Cement (OPC)	0.42	0.59	0.42	0.59
Sand	2.51	2.35	0	0
Plastic	0	0	2.51	2.35
Water	0.34	0.35	0.34	0.35

Table 1 shows two types of brick which have been cast namely sand brick and HEB. Mix proportion in this study uses using water-cement ratio of 0.34 with a design mix ratio of 1:6 proportion by weight for grade 5 N/mm^2. However, for grade 10 N/mm^2, the water-cement ratio was 0.35 with a 1:4 design mix ratio proportion by weight. The mixture was placed in the mixer and mixed uniformly. Water was poured gradually until all the materials were uniformly mixed and the fresh mix was poured into a steel mold. The samples were placed in a drying area for 24 hours before the mold was removed. The bricks were cured in air sheltered area until the date of testing after the removal of the brick samples from the steel mold. HEB is produced by combining two different grades of strength in the brick matrix.

Mortar grade strength involved in the productivity of HEB is grade 5 N/mm^2 and grade 10 N/mm^2. The materials used in producing HEB are plastic as fine aggregate material, Ordinary Portland Cement (OPC) as binder, and water. HEB was prepared to have a size of 220mm x 102.5mm x 65mm. For the HEB, the layer is 20mm for both the outer layers and 25mm for the inner layer. The figure shows the dimensions of the HEB. All the tests were performed on the brick of dimensions 220 mm x 102.5 mm x 65 mm. The total number of brick unit samples prepared in this study for compressive strength, density, and water absorption test was 6 units for each mix. The test methods were carried out according to standard specified British Standard BS3921 and the average of the three bricks sample was measured to ensure the reliability of the results.

RESULTS AND DISCUSSION

The results of the testing are evaluated and discussed in this study as shown in Table 2. From the result, the discussion elaborates clearly.

Compressive Strength

Following are the outcomes of the compression test done on the hybrid environmental bricks.

Table 2: Results of the testing in the lab

Serial No.	Type	Compressive Strength (KN)	
		1st	2nd
1	0%	68.6	279.4
2	5%	80.4	102
3	10%	69.2	124.5
4	15%	63.7	85.9

The compressive strength test results for plastic sand bricks show varying strength levels based on the percentage of plastic content. At 0% plastic content, the bricks exhibit a significant strength difference, with one result showing a relatively low compressive strength of 68.6 KN and the other showing a significantly higher strength of 279.4 KN. With the addition of 5% plastic content, the compressive strength increases with results ranging from 80.4 KN to 102 KN. However, further increases in plastic content to 10% and 15% lead to a decrease in compressive strength with results ranging from 69.2 KN to 124.5 KN and 63.7 KN to 85.9 KN respectively. These results suggest that the optimal plastic content for achieving high compressive strength in plastic sand bricks may be around 5% but further testing and analysis are necessary to confirm this finding and understand the underlying reasons for the observed trends. Additionally, the significant variation in compressive strength between the two test results for each plastic content percentage indicates potential inconsistencies in the brick manufacturing process or testing conditions.

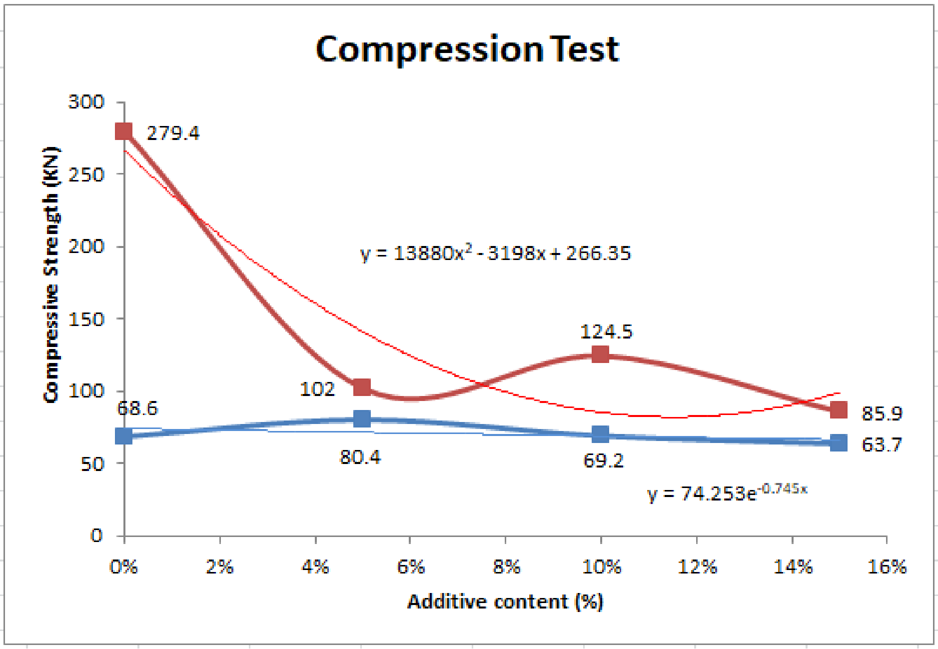

Figure 1: Graphical representation of compressive strength test

Water Absorption

Following are the outcomes of the water absorption test done on the hybrid environmental bricks.

Table 3: Water Absorption test of the HEB

Serial No.	Type	Water Absorption (%)
1	0%	19.46
2	5%	25.94
3	10%	27.62
4	15%	27.66

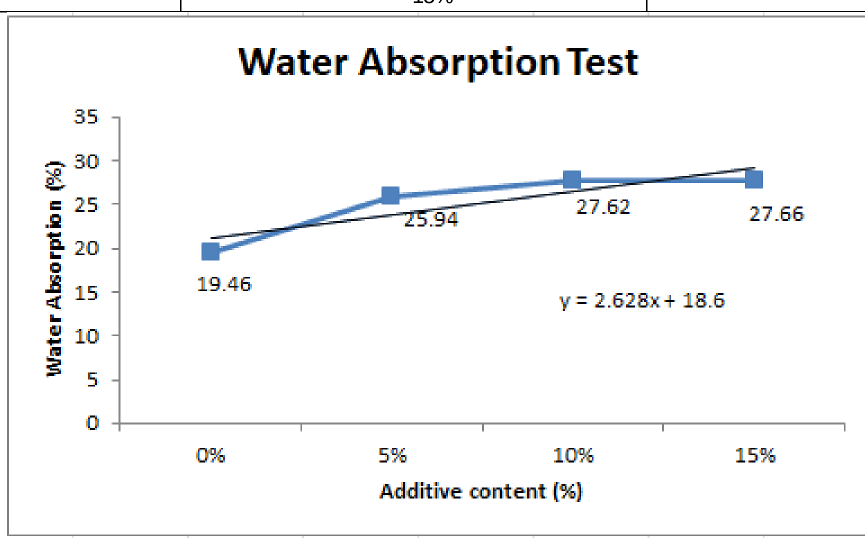

Figure 2: Water Absorption Test

The results of water absorption are illustrated in Figure 4. From Figure 4, it presents the value of water absorption by percentage for each mix of 0%, 5%, 10%, and 15%. It is shown that 0% brick with 19.46%, 5% brick with 25.9%, 10% brick with 27.62%, and 15% with 27.66% value of water absorption. Figure 3, also presents the differential between the highest and lowest value water absorption for this because the material itself and used more quantity of sand with a different grade may give different water absorption with surface and internal water absorption. The differences in results between both also could be explained by the differences in the pore structure between specimens. Additionally, brick has higher water absorption, and porosity affects the compressive strength of brick, water absorption and porosity of brick are decreased uniformly as the age of testing is getting longer.

Flexural Strength

Following are the outcomes of the flexure strength test done on the hybrid environmental bricks.

Table 4: Flexural strength of the HEB

Serial No.	Type	Length of Brick (in/mm)	Width of brick (in/mm)	Height of brick (in/mm)	Maximum Load in (KN)	Strength in (psi)
1	0%	9/230	4.5/115	3/75	9.9	1435.87
2	5%	9/230	4.5/115	3/75	8.2	1189.31
3	10%	9/230	4.5/115	3/75	9.3	1348.85
4	15%	9/230	4.5/115	3/75	7.6	1102.28

The flexural test results revealed the bending strength of plastic sand bricks with varying plastic content. The test measures the maximum load (in KN) and corresponding strength (in psi) that each brick can withstand before failing. The bricks have a consistent length, width, and height of 230 mm, 115 mm, and 75 mm, respectively. The results show that the brick with 0% plastic content exhibits the highest flexural strength, with a maximum load of 9.9 KN and strength of 1435.87 psi. The addition of plastic content leads to a decrease in flexural strength, with the 5% plastic content brick showing a strength of 1189.31 psi, followed by the 10% plastic content brick with a strength of 1348.85 psi. The brick with the highest plastic content (15%) exhibits the lowest flexural strength, with a maximum load of 7.6 KN and strength of 1102.28 psi. These results indicate that the incorporation of plastic content in sand bricks reduces their flexural strength, suggesting that the optimal plastic content for achieving high flexural strength may be minimal or zero. The findings highlight the need for further investigation into the effects of plastic content on the mechanical properties of plastic sand bricks.

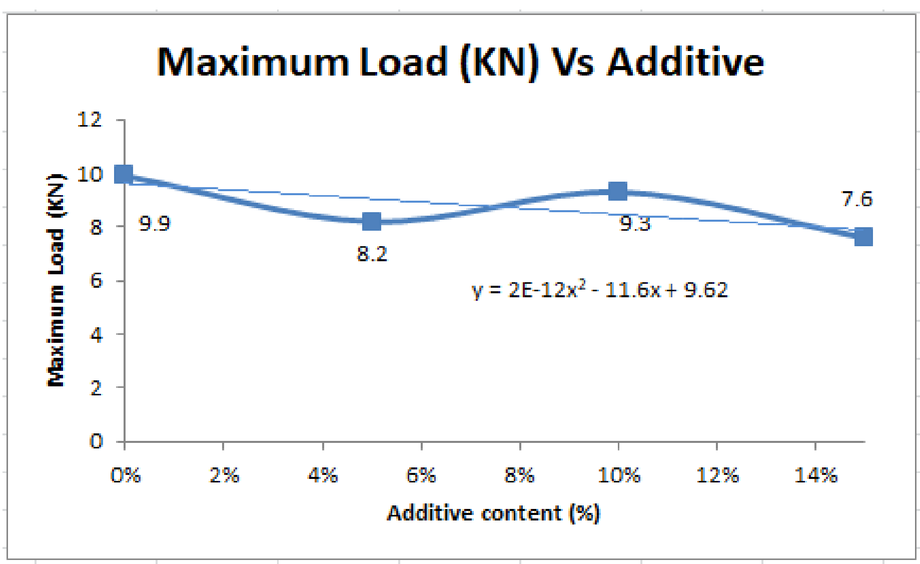

Figure 3: Maximum load in KN of HEB against each additive content

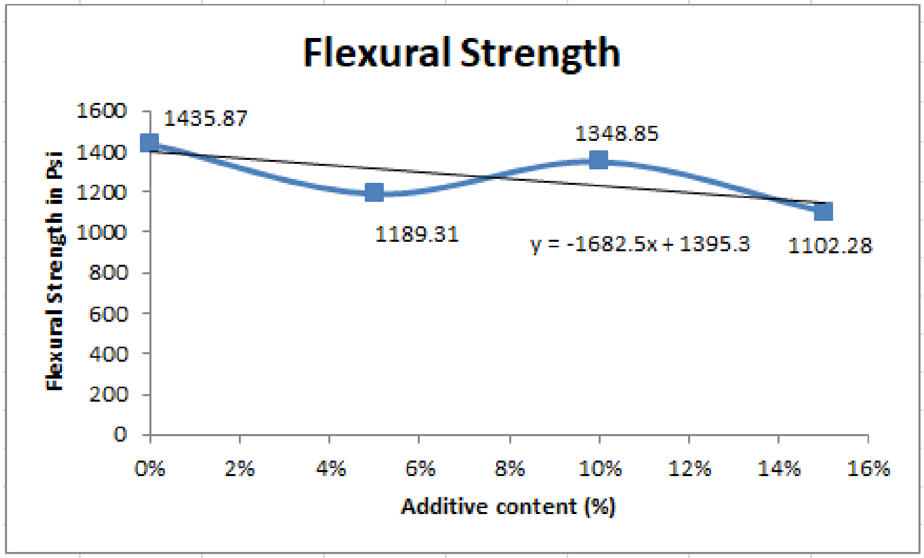

Figure 4: Flexure strength of HEB in psi against each additive content

The results of the testing reveal significant trends and insights into the effects of plastic content on the mechanical properties of plastic sand bricks. The compressive strength test shows a significant variation in strength levels based on the percentage of plastic content, with the optimal plastic content for achieving high compressive strength appearing to be around 5%. This suggests that the addition of plastic content up to 5% can improve the compressive strength of the bricks, but further increases in plastic content may lead to a decrease in strength. This could be due to the plastic content affecting the bonding between the sand particles, with too much plastic content leading to a weaker bond and reduced compressive strength.

The water absorption test results indicate a significant increase in water absorption with increasing plastic content, suggesting that the addition of plastic content increases the porosity of the bricks. This is likely due to the plastic content creating voids and pores within the brick, allowing more water to be absorbed. This increased water absorption could lead to reduced durability and resistance to weathering, as the water can seep into the brick and cause erosion or damage.

The flexural test results show a significant decrease in flexural strength with increasing plastic content, indicating that the incorporation of plastic content in sand bricks reduces their flexural strength. This suggests that the bricks with higher plastic content are more prone to cracking and breaking under bending forces, which could lead to reduced structural integrity and durability. This decreased flexural strength could be due to the plastic content affecting the bonding between the sand particles, with too much plastic content leading to a weaker bond and reduced flexural strength.

Overall, the results suggest that the addition of plastic content to sand bricks can improve their compressive strength up to a certain point, but excessive plastic content can lead to a decrease in strength, increased water absorption, and reduced flexural strength. This highlights the importance of optimizing the plastic content in plastic sand bricks to achieve the desired mechanical properties. Further investigation is needed to fully understand the effects of plastic content on the mechanical properties of plastic sand bricks and to determine the optimal plastic content for specific applications. Additionally, the results suggest that the manufacturing process and testing conditions may need to be refined to reduce the variability in the results and ensure consistent mechanical properties.

Implications of the Study

The findings of this study have significant implications for the development and use of plastic sand bricks in construction. The results suggest that plastic sand bricks with optimal plastic content could be used as a sustainable and durable alternative to traditional building materials. However, further research is needed to fully understand the long-term durability and performance of plastic sand bricks in various environmental conditions. Additionally, the study highlights the need for standardization of the manufacturing process and testing protocols to ensure consistent mechanical properties and quality of plastic sand bricks.

CONCLUSION AND RECOMMENDATIONS

The study on the effects of plastic content on the mechanical properties of plastic sand bricks has yielded valuable insights. The findings suggest that the addition of plastic content can have both positive and negative effects on the bricks' performance. On the one hand, the optimal plastic content of around 5% can improve the compressive strength of the bricks, making them more suitable for construction purposes. On the other hand, excessive plastic content can lead to a decrease in compressive strength, increased water absorption, and reduced flexural strength, which can compromise the bricks' durability and resistance to weathering.

These findings have significant implications for the construction industry. The use of plastic sand bricks with optimal plastic content can provide a sustainable and durable building material, reducing the environmental impact of traditional building materials. However, it is crucial to refine the manufacturing process to reduce variability in the results and ensure consistent mechanical properties. Standardization of testing protocols is also necessary to ensure accurate and reliable results.

Further research is needed to fully understand the long-term durability and performance of plastic sand bricks in various environmental conditions. This will enable the development of plastic sand bricks that can withstand different weather conditions and loading conditions, making them a reliable choice for construction purposes. Additionally, exploring other sustainable materials and technologies can further improve the mechanical properties of plastic sand bricks, leading to even more sustainable and resilient building solutions.

The study's findings also highlight the importance of careful consideration when using plastic sand bricks in construction. The use of bricks with high plastic content (above 5%) should be avoided, as they may exhibit reduced compressive strength, increased water absorption, and decreased flexural strength. Instead, builders and engineers should opt for bricks with optimal plastic content, ensuring that the structures they build are safe, durable, and sustainable.

Acknowledgment

First of all, we want to thank almighty Allah for allowing us to complete our research work. While doing this research, we have received a great deal of support and assistance. We would like to thank our family for their valuable guidance throughout our study. They provided us with the tools that we needed to choose the right direction and complete our dissertation.

REFERENCES

[1] Das, S., Lee, S. H., Kumar, P., Kim, K. H., Lee, S. S., & Bhattacharya, S. S. (2019). Solid waste management: Scope and the challenge of sustainability. Journal of cleaner production, 228, 658-678.

[2] Rajmohan, K. V. S., Ramya, C., Viswanathan, M. R., & Varjani, S. (2019). Plastic pollutants: effective waste management for pollution control and abatement. Current Opinion in Environmental Science & Health, 12, 72-84.

[3] Fořt, J., & Černý, R. (2020). Transition to circular economy in the construction industry: Environmental aspects of waste brick recycling scenarios. Waste Management, 118, 510-520.

[4] Brauer, R. L. (2022). Safety and health for engineers. John Wiley & Sons.

[5] Cheong, L. Q. L. (2020). Preliminary Study On Lightweight Interlocking Block Design (Doctoral dissertation, UTAR).

[6] Shakir, A. A., Ibrahim, M. W., Othman, N. H., Mohammed, A. A., & Burhanudin, M. K. (2020). Production of eco-friendly hybrid blocks. Construction and Building Materials, 257, 119536.

[7] Yaseen, N., Irfan-ul-Hassan, M., Saeed, A. U. R., Rizwan, S. A., & Afzal, M. (2022). Sustainable development and performance assessment of clay-based geopolymer bricks incorporating fly ash and sugarcane bagasse ash. Journal of Materials in Civil Engineering, 34(4), 04022036.

[8] Simão, F. V., Chambart, H., Vandemeulebroeke, L., Nielsen, P., Adrianto, L. R., Pfister, S., & Cappuyns, V. (2022). Mine waste as a sustainable resource for facing bricks. Journal of Cleaner Production, 368, 133118.

[9] Vieira, C. M. F., & Carvalho, J. P. R. G. (2016). Recycling of Granite Waste from Sawing Operation in Clay Brick for Civil Construction. Journal of Solid Waste Technology & Management, 42(1).

[10] Goel, G., & Kalamdhad, A. S. (2017). Degraded municipal solid waste as partial substitute for manufacturing fired bricks. Construction and building materials, 155, 259-266.

[11] Chen, H., Liu, Y., Cui, H., Zhang, W., Hu, L., & Mao, L. (2022). Effects of electric arc furnace slag on promoting quality and environmental safety of fired bricks incorporating municipal solid waste incineration fly ash. Construction and Building Materials, 345, 128327.

[12] Hossiney, N., Das, P., Mohan, M. K., & George, J. (2018). In-plant production of bricks containing waste foundry sand—A study with Belgaum foundry industry. Case studies in construction materials, 9, e00170.

[13] Hahladakis, J. N., & Iacovidou, E. (2018). Closing the loop on plastic packaging materials: What is quality and how does it affect their circularity?. Science of the Total Environment, 630, 1394-1400.

[14] Ghosh, A., Manna, M. C., Jha, S., Singh, A. K., Misra, S., Srivastava, R. C., ... & Singh, A. K. (2022). Impact of soil-water contaminants on tropical agriculture, animal and societal environment. Advances in Agronomy, 176, 209-274.

[15] da Silva, T. R., de Azevedo, A. R. G., Cecchin, D., Marvila, M. T., Amran, M., Fediuk, R., ... & Szelag, M. (2021). Application of plastic wastes in construction materials: A review using the concept of life-cycle assessment in the context of recent research for future perspectives. Materials, 14(13), 3549.

[16] Adiyanto, O., Mohamad, E., & Abd Razak, J. (2022). Systematic review of plastic waste as eco-friendly aggregate for sustainable construction. International Journal of Sustainable Construction Engineering and Technology, 13(2), 243-257.

[17] Saikia, N., & De Brito, J. (2014). Mechanical properties and abrasion behaviour of concrete containing shredded PET bottle waste as a partial substitution of natural aggregate. Construction and building materials, 52, 236-244.

[18] Ali, S. S., Elsamahy, T., Koutra, E., Kornaros, M., El-Sheekh, M., Abdelkarim, E. A., ... & Sun, J. (2021). Degradation of conventional plastic wastes in the environment: A review on current status of knowledge and future perspectives of disposal. Science of the Total Environment, 771, 144719.

[19] Akhtar, N., Zada, U., Soomro, A. A., Arif, M., Saad, M., & Ullah, R. (2024). Investigating the Influence of Trashed Polymeric Compounds (TPC) on the Mechanical Properties, XRD Pattern and Microstructure of the Brick. Journal of ICT, Design, Engineering and Technological Science, 1-10.

[20] Ali, S. S., Elsamahy, T., Koutra, E., Kornaros, M., El-Sheekh, M., Abdelkarim, E. A., ... & Sun, J. (2021). Degradation of conventional plastic wastes in the environment: A review on current status of knowledge and future perspectives of disposal. Science of the Total Environment, 771, 144719.

[21] Saikia, N., & De Brito, J. (2014). Mechanical properties and abrasion behaviour of concrete containing shredded PET bottle waste as a partial substitution of natural aggregate. Construction and building materials, 52, 236-244.

DOI: https://doi.org/10.15379/ijmst.v11i1.3775