Research Article
ISSN 2304-6295
Received: January 4, 20245 Accepted: January 18, 2025 Published: January 26, 2025

# Mechanical and microstructural characterization of recycled plastic waste in sustainable building applications

Hassan, Muhammad Khizar[1]
Siddiqui, Aiman[1]
Ahmed, Rana Rabnawaz[1]
Ahmed, Anas[2*]
Tanoli, Muhammad Ashraf[3]
Ali, Rashid[3]

[1] NED University of Engineering and Technology; Karachi, Pakistan; hassan4205342@cloud.neduet.edu.pk or m.khizar.hassan@hotmail.com (H.M.K); aimanzeesiddiqui@gmail.com (S.A); enawaz@neduet.edu.pk (A.R.R)
[2] Peter the Great St. Petersburg Polytechnic University; Saint-Petersburg, Russian Federation; ahmed.a@edu.spbstu.ru or anas4200082@gmail.com (A.A)
[3] Ghulam Ishaq Khan Institute of Engineering Sciences and Technology; Topi, Swabi, Khyber Pakhtunkhwa, Pakistan; matanoli@giki.edu.pk (T.M.A), rashidali@giki.edu.pk (A.R)
Correspondence: *email ahmed.a@edu.spbstu.ru; Contact phone +7 (999) 209-78-36

**Keywords:**

Plastic Waste; Waste Management; Sustainable Construction; Material Characterization; Microscopic Analysis; Environmental Impact; Circular Economy

**Abstract:**

**The object of research** is Acrylonitrile Butadiene Styrene (ABS) plastic waste, amalgamated with sand, as a viable alternative for constructing plastic-sand composite blocks. **Method**. The research employs a systematic approach to determine the optimal ratio of plastic to sand, ultimately establishing a 1:1 ratio that optimizes the compressive strength. **Results**. Experimental results revealed that the developed plastic-sand composite blocks achieved a maximum average compressive strength of 15 MPa, significantly surpassing the minimum requirement of 5 MPa outlined in the IS 2185-2005 (Part 1) code for solid concrete blocks. Comprehensive testing, including comparative analyses of compressive strength and water absorption, demonstrated the superior mechanical properties of the plastic-sand composite blocks compared to conventional concrete blocks. Additionally, thermal, hardness, soundness, and density assessments confirmed adherence to relevant standards. Microstructural examinations using Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD) tests revealed a compact microstructure with reduced porosity, indicating enhanced strength and durability. The XRD analysis further confirmed the presence of silica in the composite, supporting its structural integrity. These findings underscore the feasibility of utilizing plastic waste in environmentally friendly construction applications, promoting sustainable building practices.

## 1 Introduction

The use of plastic has exponentially increased since 1855, when it first emerged in the market [1]. This mainly happened because of its multi-purpose properties, ease of use, durability, and moldability and soon it became popular in various industries such as construction, aerospace, and packaging [2]. Due to this, the production of plastic waste is increasing in tandem with the overall global population growth. Plastic pollution has become ubiquitous, contaminating land, sea, and coastlines, while also posing a devastating threat to marine ecosystems [3,4]. This vast amount of waste generated annually is not scientifically managed, negatively impacting our environment and creating more issues for society

[5,6]. There are multiple sources of plastic waste, primarily including the packaging industry responsible for 40.5%, followed by the building and construction sectors at 20.4%, the automotive sectors at 8.8%, and various other sources[7]. Worldwide plastic manufacturing increased almost 250 times from the years 1950 to 2020, reaching from 1.5 to 367 million metric tonnes in 2020 [8]. Figure 1 showcases the cumulative data depicting trends in plastic waste management and disposal from 1950 to 2015 and includes projections up to 2050 [9]. This data underscores the importance of implementing substantial measures to address this issue and exploring sustainable approaches for its management. What is of utmost importance is to change our perspective on waste and consider it as a resource instead of viewing it as mere waste [10].

The global solid waste stream is largely comprised of plastic waste [11]. Pakistan's solid waste generation amounts to about 49.6 million tons each year, equating to a daily production of roughly 87,000 tons [12]. The ease and low cost of landfilling often lead to the disposal of mixed waste, rather than separating and processing recyclable materials [13]. While there are multiple authorities tasked with waste collection and management in major cities in Pakistan, the system is not as effective in rural areas of the country. In major urban centers, the collection rate stands at around 80%, whereas the remaining regions of the country experience an average waste collection rate of approximately 50% [14]. Major cities grapple with substantial challenges in waste management, and an estimated 170 engineered landfill sites would be needed to handle the annual waste generation nationwide [15].

Despite the pressing need for effective waste management, the current infrastructure is insufficient to address the magnitude of the issue. The lack of a comprehensive national strategy and coordination between urban and rural areas exacerbates the problem, leading to environmental and public health concerns. Furthermore, the disparity in waste collection rates between urban and rural regions underscores the need for targeted interventions tailored to the specific challenges faced by each locality. Owing to inadequate waste management practices, policy guidelines, and enforcement, Pakistan exhibits the highest proportion of mismanaged plastic in South Asia [16]. The repercussions of this mismanagement extend beyond environmental concerns, affecting the overall well-being of communities.

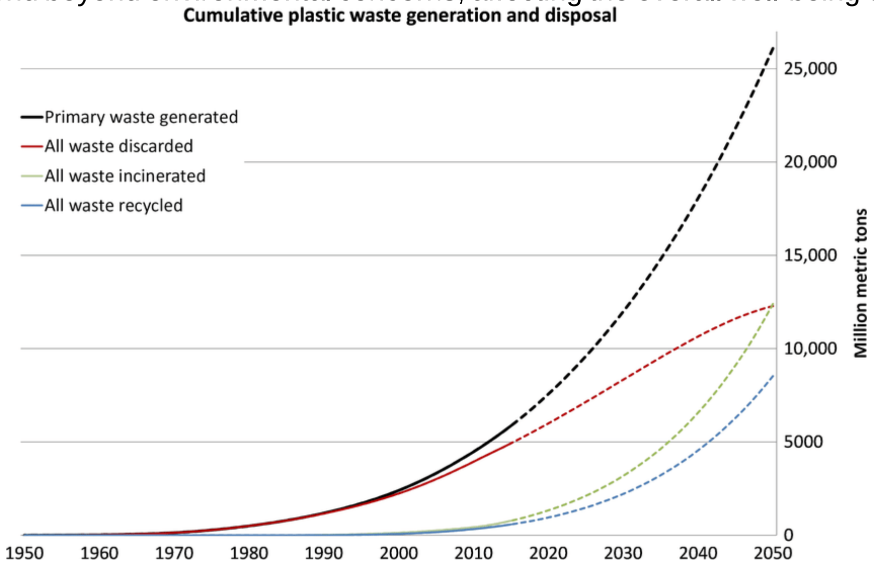


**Fig. 1 – Cumulative Plastic Waste Generation and Disposal**

The building and construction sector is a significant contributor to greenhouse gas emissions, accounting for approximately 40% of process-related emissions, with 11% attributed to the production of building materials [17]. The most common material in the construction sector is concrete, which relies heavily on natural resources and has resulted in their depletion [11]. This depletion not only threatens the long-term sustainability of the construction industry but also exacerbates environmental concerns. To mitigate this issue, there is a pressing need to develop sustainable alternative materials. One potential solution is the incorporation of recycled plastic waste in the production of construction materials, such as bricks, blocks, pavers, and other products [18–20].

Numerous studies have been conducted to explore the feasibility of utilizing waste materials in the construction sector, and plastic waste is no exception. In a study by Akinwuni et al., a plastic brick was formed by mixing molten shredded plastic waste with a soil sample. Then it was tested to determine properties that were compared with Compressed Earth Bricks properties. Plastic was taken in different percentages to create the optimized value, which later came out to be 1%, at which the brick gave the maximum compressive strength [21]. In 2020, Limami et al. conducted thorough research by adding HDPE and Polyethylene Terephthalate (PET) waste in a clay brick. Some analyses, such as X-ray Diffraction and Fluorescence, were conducted to learn about the changes in its properties and characteristics. It is concluded that adding additives to the brick helps in reducing its weight which will lead to an economic benefit. Furthermore, the compressive strength increased by 28%, and the water absorption capacity improved [22].

A study by Hamza et al demonstrated the making of plastic bricks with molten LDPE, sawdust, and sand. Two different samples were prepared with the addition of 20% sawdust and 60% sand respectively. The products were tested for their compressive strength, water absorption, density, and hardness in conjunction with the SEM test. The resulting properties were much enhanced as the compressive strength exceeded 60 MPa for both compositions [23]. In 2022, Kulkarni et al. conducted an experimental study in which plastic bricks were formed by mixing molten High-Density Polyethylene (HDPE) and Polypropylene (PP) separately with the soil sample. Moreover, a wall was constructed using those bricks, and then a comparative analysis was performed between a conventional wall and a plastic brick wall. The maximum load that a conventional brick wall can carry is 153.9 kN, whereas a plastic wall can bear up to 197.5 kN. Similarly, the compressive strength of plastic brick was also greater than conventional brick, almost 14.63% greater. It is concluded that plastic bricks can also be used for load-bearing structures [24].

Yadav et al. undertook an empirical examination in 2022, in which a plastic brick was formed by mixing molten Low-Density Polyethylene (LDPE) with a soil sample, and then it was tested for determining properties which were then compared with the properties of traditional brick. The tests that were performed include the water absorption test, the fire test, the hardness test, the soundness test, and the compressive strength test. It is concluded that plastic bricks fulfill all the criteria of a standard brick. The compressive strength of the plastic brick samples came out to be 7.143 N/mm which is greater than the normal brick, whereas no difference was observed in the hardness and soundness test of both bricks [25]. Many researchers have partially replaced waste plastic to explore its utility and improve the mechanical and durability properties of bricks and blocks, but there are still some loopholes that need further research, and some of those are being addressed in this study.

Previous studies have investigated the use of plastic waste in construction materials, but several research gaps remain unaddressed. In studies conducted by Yadav et al., and Kulkarni et al. in 2022, it is evident from the provided figures given in the paper that during the formation of plastic bricks, the melting process was done in an open environment [24,25]. This practice, in itself, is environmentally unfriendly and highlights the need to melt plastic in a closed environment to ensure the prevention of harmful emissions. Moreover, the lack of a controlled environment can lead to inconsistent material properties and reduced product quality, ultimately affecting the structural integrity and durability of the construction materials. This issue is resolved in this experimental study by creating a machine in which plastic is melted along with sand in a closed environment ensuring prevention of any harmful emission in the environment.

Furthermore, existing research has emphasized the need for optimizing the composition of plastic-based construction materials. Another study suggests that further research is needed to come up with optimum balance in all aspects of the plastic brick which requires extensive experimental research [26]. This is addressed in this study by taking plastic and sand in different proportions to get the most optimized ratio to get the maximum strength, especially the Acrylonitrile Butadiene Styrene (ABS) plastic on which not much research has been conducted to explore its utility in the construction sector. The use of ABS plastic waste in construction materials offers a promising solution for sustainable waste management and reduced environmental impact. Additionally, the incorporation of ABS plastic waste can provide a valuable outlet for the large volumes of plastic waste generated globally, helping to mitigate the environmental and health problems associated with plastic waste.

In addition to the aforementioned research gaps, previous studies have also highlighted the need for improving the bonding mechanism between plastic bricks and mortar, as well as enhancing the aesthetics and color of plastic bricks. In 2022, Kulkarni et al., suggested that more work is to be conducted to improve the bonding mechanism between the plastic brick and mortar [24]. Similarly, another study in 2022 by Yadav et al suggested that more research is needed for better aesthetics and color of plastic bricks [25]. In this study, both these research gaps are addressed by employing a simple technique that is by applying a half-inch concrete cover over the surface of a plastic sand composite block. This innovative approach enhances the bonding mechanism and improves the overall appearance of the plastic-sand composite blocks, making them more suitable for use in construction projects.

Therefore, the objectives of this study are:
1. To investigate the potential of utilizing ABS waste in the production of construction blocks.
2. To assess the microstructure and draw a comparative analysis of plastic-sand composite block with a traditional concrete block.
3. To minimize the emissions produced in the manufacturing process.

# 2 Materials and Methods

## 2.1 Conceptual Framework

This study explores the development of sustainable construction material by converting ABS plastic waste into plastic bricks, Fig. 2. The process begins with manual shredding of ABS, followed by mixing the shredded plastic with manufactured sand (M-sand) in two different ratios (1:1 and 1:3). The mixture undergoes a series of steps, including weighing, proportioning, melting, densification, molding, compaction, and curing, to produce the plastic bricks. The engineering properties of the bricks, such as dimension, density, compressive strength, water absorption, thermal conductivity, soundness, hardness, and advanced characteristics (XRD and SEM analysis), are thoroughly investigated. The findings from these tests are analyzed to assess the bricks' performance compared to traditional materials, leading to recommendations on optimal mix ratios and their potential application in construction.

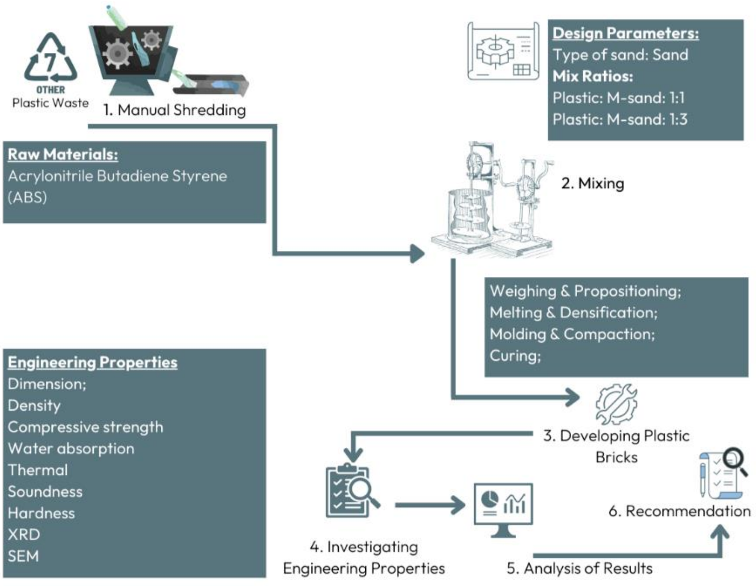


Fig. 2 – Framework of Study

## 2.2 Material

Acrylonitrile-butadiene-styrene plastic, commonly termed ABS plastic, is a type of thermoplastic used in this research for manufacturing the plastic-sand composite block. ABS plastic, known for its superior properties such as thermal stability, mechanical toughness, and high gloss, accounts for approximately 75% of the plastic plating market [27]. However, the increasing market demand has resulted in a growing number of ABS plated plastics reaching the end-of-life stage each year. Consequently, the proper disposal of this waste ABS-plated plastic has become a significant challenge.

For all these reasons, ABS plastic waste can be considered one of the best types of plastic to be integrated and to explore its applications in the construction industry, hence used in this study. The local sand was used as fine aggregate with a particle size of less than 2.36 mm and was collected using sieve number 8. As a binding material in mortar, Ordinary Portland Cement of 43 grade is used. Normal tap water with a pH value of 7.0 is used for making mortar.

## 2.3 Methodology

Initially, the ABS plastic waste was collected from a local recycled plastic supplier in Karachi, Pakistan. However, to make these waste plastics appropriate for manufacturing blocks they needed to be further chopped down into smaller fragments. The shredding process was therefore done manually for easy burning after which the plastic waste was sun-dried to remove any moisture content present. The plastic waste and sand were taken in a ratio of 1:1 that was established through trial and error, as it was found to result in the highest strength. Then that plastic waste was mixed with sand and heated in a plastic-sand melting and mixing machine, Fig. 3.

**Fig. 3 – Production Procedure of ABS Plastic-Sand Composite Bricks**

This machine was prepared for melting plastic waste along with sand in a closed environment to ensure the prevention of potentially harmful emissions as a result of melting plastic waste. After preparing a dough-like mixture of plastic waste and sand, it was poured into a steel mold of dimension 3.5 x 5.0 x 9.5 $in^3$. It was then left for 1 hour to let it cool after which mold was removed, and that mixture attained the shape of a block. In the end, a 0.5-inch layer of concrete was applied to the surface of the prepared block to increase the fire-resistant capacity, enhance the bonding capability with other blocks, and eliminate the odor of plastic-sand composite block.

In the present study, compression strength test, water absorption test, thermal test, soundness, and hardness test were conducted on both plastic-sand composite block and traditionally used concrete block after which a comparative analysis was drawn to check the suitability of plastic-sand composite block in the construction sector. The X-ray diffraction is performed on the fine powder of concrete block and plastic sand composite block which is produced in this study with Proto X-ray diffraction system in Bragg-Brentano (θ-2θ) scan mode using monochromatic Cu-Kα radiation source with an accelerating voltage of 30 kV and tube current of 30 mA at room temperature, to reveal the structural information and crystalline content present in the materials powders. The goniometer scanned a 2θ range between 10° and 80° with a step size of 0.05° and X-ray diffractograms of concrete block and plastic sand composite block.

The morphologies of the produced plastic sand composite block produced in this study are examined using Carl Zeiss Evo 15 Scanning Electron Microscope (SEM) coupled with EDX. The sample surface was coated with platinum before SEM imaging and EDX analysis. The SEM micrographs and EDS of plastic sand.

# 3 Results and Discussion

## 3.1 Compressive Strength Test

Compressive strength is the most critical property of construction materials that determines their suitability for construction [28]. In this study, the compressive strength test was conducted following IS 2185-2005 (Part 1) standards to determine the load-bearing capacity of the plastic-sand composite blocks. The test was conducted using a compression testing machine to evaluate the compressive strength of plastic-sand composite blocks. The blocks were sequentially placed into the compression testing machine, and a load was applied gradually. The load at which the blocks were crushed was recorded, and further calculations were conducted to determine the compressive strength of the blocks based on that data using the following formula,

$$Compressive\,Strength = {Maximum\,Load\,(Kips)} \Big/ {Area\,of\;Specimen\,(in^2)} \quad (1.1)$$

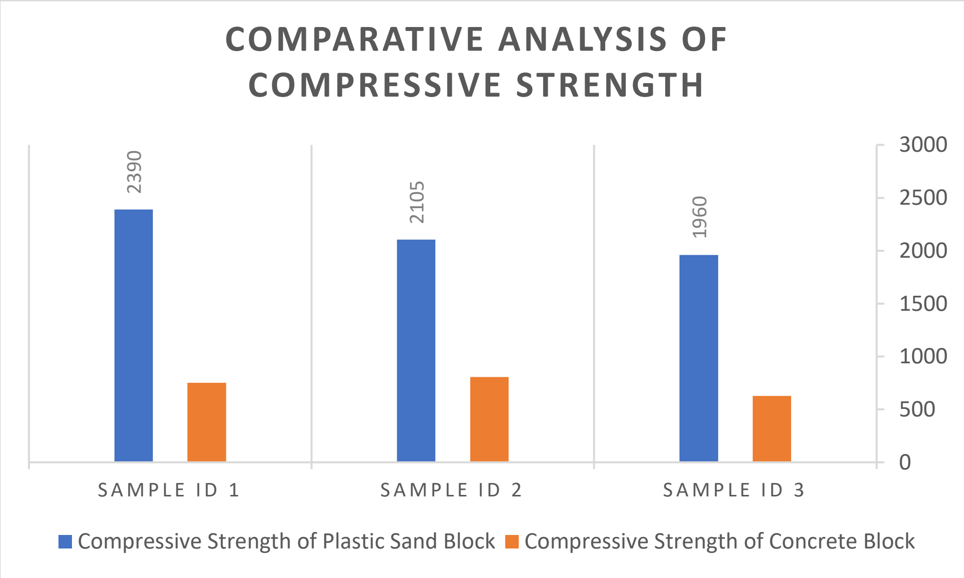


**Fig. 4 – Comparative Analysis of Compressive Strength Test**

The compressive strength of the traditional concrete blocks that were tested after 28 days of manufacturing is 752, 806, and 627 psi, respectively. On the other hand, the compressive strength of the plastic-sand composite blocks was determined as 2390, 2105, and 1960 psi, respectively, Table 1. Figure 4 presents a comparative analysis of the compressive strengths between a plastic-sand composite block and a traditionally used concrete block, demonstrating that plastic-sand composite blocks exhibit significantly greater strength than the traditionally used concrete blocks. The compressive strength of plastic-sand composite blocks also complies with the strength criteria specified in IS 2185-2005 (Part 1), meeting the 725 psi (5 MPa) requirement for solid concrete blocks.

**Table 1. Comparison of Compressive Strength**

| Sample Type | Block Size (in) | Test Size (in) | Cross Section (in2) | Max Load (Kips) | Compressive Strength (psi) |
|---|---|---|---|---|---|
| Plasic-Sand Composite Block | 4 x 5.5 x 10 | 5.5 x 10 | 55 | 150.62 | 2390 |
| | | | | 132.64 | 2105 |
| | | | | 123.53 | 1960 |
| Concrete Block | 3.5 x 4 x 7 | 3.5 x 18 | 63 | 18.8 | 752 |
| | | | | 20.23 | 806 |
| | | | | 15.7 | 627 |

### 3.1 Water Absorption Test

A water absorption test is an indirect measure of the percentage of pores in the construction blocks and therefore can be considered as an assessment criterion for monitoring durability properties, indicating their quality and behavior in different weathering and harsh climatic conditions [29]. The research confirmed that the water absorption test results complied with the standard range stated in IS 2185(2005).

The test specimens were initially immersed in water for 24 hours at room temperature, followed by weighing samples. The oven-dried samples were weighed again after undergoing a 24-hour drying process in a ventilation oven at 100°C. The procedure was repeated for three full-size units after which the average results were calculated.

Table 2. Comparison of Water Absorption

| Sample Type | Block Size (in) | Dry Weight, W1 (Kgs) | Wet Weight, W2 (Kgs) | %Water Absorbed |
|---|---|---|---|---|
| Plastic-Sand Composite Block | 4 x 5.5 x 10 | 7.67 | 8.2 | 6.46 |
| | | 7.89 | 8.34 | 5.39 |
| | | 7.26 | 7.49 | 4.81 |
| Concrete Block | 3.5 x 4 x 7 | 4.75 | 5.63 | 15.73 |
| | | 4.75 | 5.42 | 12.5 |
| | | 4.75 | 5.46 | 13 |

The blocks exhibit percentages of 6.46%, 5.39%, and 4.81% of water absorption as shown in Table 2, all of which are well below the code limit of 10%. This result underscores the robustness of the plastic-sand composite blocks in meeting and even surpasses the stipulated criteria set by the code. Figure 5 illustrates a comparison of percentage water absorption between a plastic-sand composite block and a traditionally used concrete block, indicating that plastic-sand composite blocks demonstrate significantly higher water resistance compared to the traditional concrete block. Water absorption serves as an indirect indicator of the presence of pores within the blocks. Therefore, these findings suggest that the blocks possess a minimal number of pores, contributing to their higher level of compactness. Equation 2 is used to determine the water absorption in the plastic-sand composite blocks.

$$Water\ Absorption = \frac{W_A - W_B}{W_B} \times 100 \qquad (1.2)$$

Where;
A = wet mass of units, in kg; and
B = dry mass of units, in kg

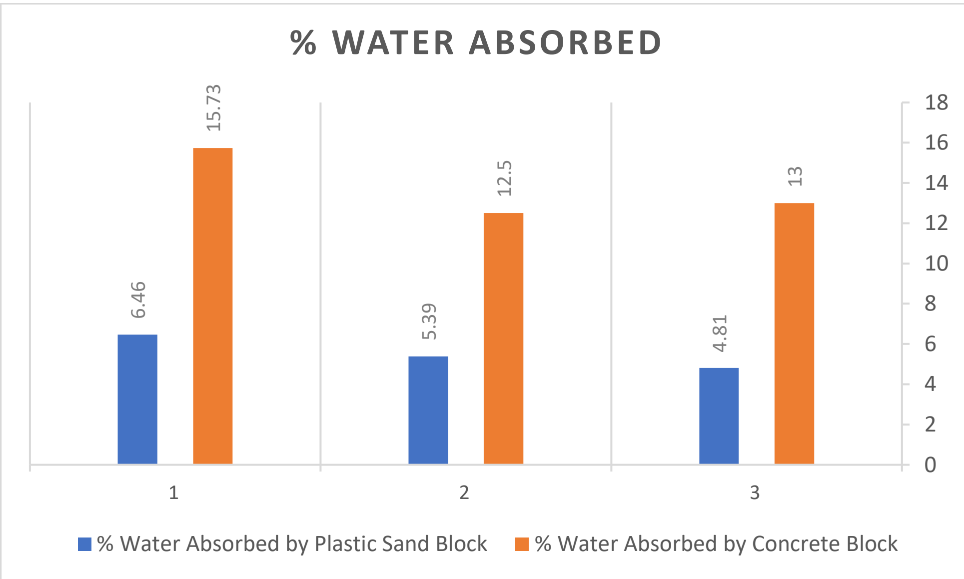


Fig. 5 – Comparative Analysis of Water Absorption Test

### 3.2 Thermal Test

A thermal test is performed to get to know more about how structures behave when exposed to high temperatures. Construction blocks that have higher density exhibit better heat resistance. On the contrary plastic, as a material, is susceptible to fire. However, the plastic-sand composite block contains a significant proportion of sand with high thermal resistance. Therefore, the block as a whole is less susceptible to high temperatures and can withstand them. The block was placed inside the muffle furnace and heated at high temperatures, with the temperature being increased every 30 minutes. Tests showed that plastic bricks retain their structure up to 290°C, beyond which fissures appear, and their strength diminishes.

### 3.3 X Ray Diffraction Test

The X-ray diffractograms of concrete block and plastic sand composite block are presented in Fig. 6. The X-ray diffraction confirms the presence of silica sand which is much more in crystalline form as compared to its presence in construction concrete blocks. The X-ray diffractogram shows the main crystalline phases found in the clay are quartz and calcite. The sharp peaks around 2θ of 70° indicate high crystallinity of silica. The XRD peaks match with the standard ICDD database of quartz PDF # 04-006-1757 and calcite PDF # 04-002-9082.

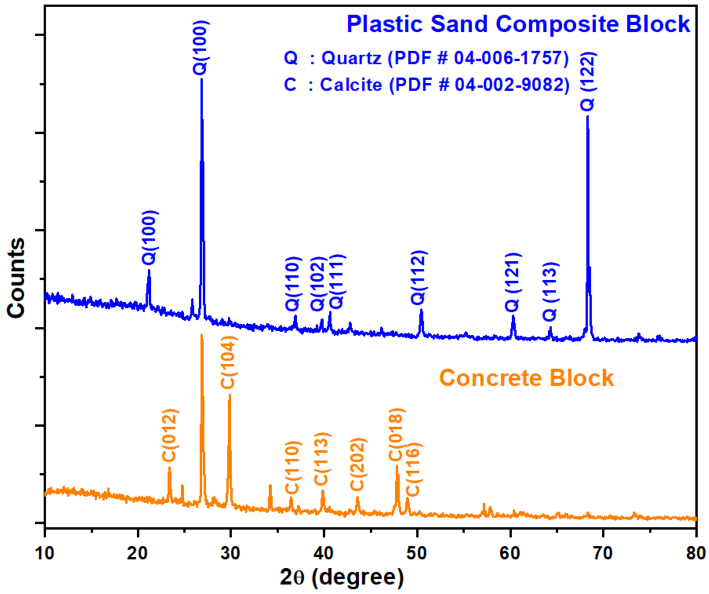


**Figure 6 – X-Ray diffractograms of concrete block and plastic sand composite block**

### 3.4 Soundness Test

The plastic-sand composite blocks are air-dried for 48 hours after manufacturing. They are then tapped together, producing a ringing sound that signifies good quality. A clear ringing sound is an indication of high-quality blocks.

### 3.5 Hardness Test

A hardness test was performed on the plastic-sand block to assess its hardness by using a sharp nail by running it over the surface of the block while carefully observing the process. There were no scratches observed after the test, therefore it can be inferred that the block has a high level of hardness.

### 3.6 Density Test

Density is the measure of mass per unit volume for the block [30]. This test was conducted on three plastic-sand composite blocks, and the average result was determined from these three, as specified in IS 2185-2005 (Part 1). The weight of the block was measured to be 4.2 kg, and its density was calculated as 1510 kg/m³, determined by the ratio of its dry weight to its volume. This meets the minimum requirement of 1500 kg/m³ for a Grade A quality concrete block as stipulated in the code.

#### 3.6.1 SEM Characterization

The SEM micrographs and EDS of plastic sand composite block are presented in Fig. 7. The SEM micrographs of plastic sand composite block (Fig. 7a and b) show a more compact microstructure with less pores, and voids, indicating good physical and mechanical properties, which are consistent with the data of water absorption, hardness, thermal test, and compressive strength.

The SEM-EDX shows agglomerates of silica sand in composite. The platinum in SEM-EDX is due to platinum coating done before SEM imaging. The mixing of blue (silica in EDX map) and yellow color (oxygen in EDX map) forms the sky-blue color Fig. 7f indicates silica sand. Similarly, Fig. 7e shows light yellow which contains high oxygen (yellow color in EDX map) and silica (blue color in EDX map). Both EDX maps Fig. 7e and f show silica sand as agglomerates of silicon and oxygen.

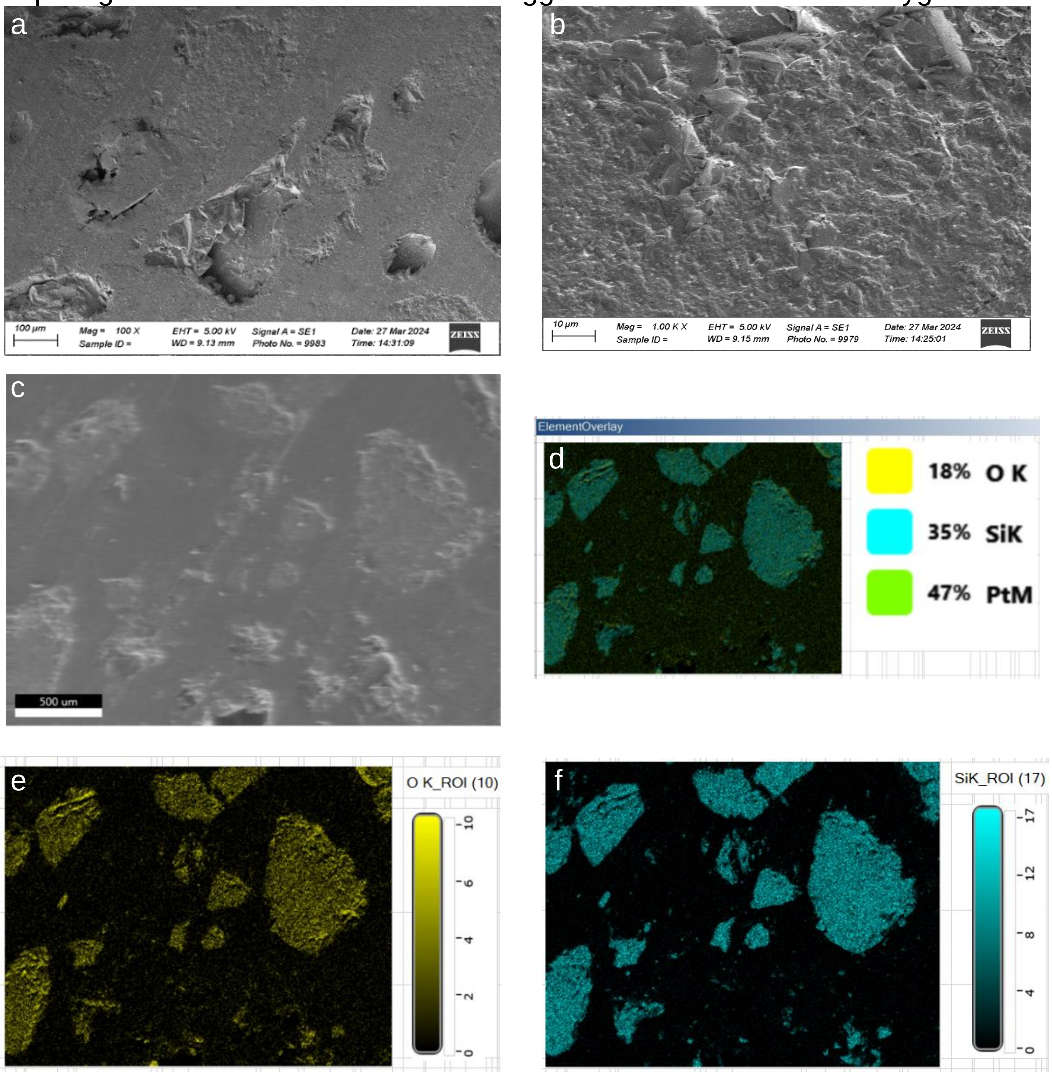


**Figure 7 – The SEM micrographs and energy dispersive spectroscopy (EDS) maps of produced plastic sand composite block: (a) SEM micrographs at 100X; (b) SEM micrograph at 1,000X; (c) SEM-EDX map location; (d) overlay of elements in EDS map; and corresponding mapping images of oxygen and silicon, (e) and (f), respectively**

## 4 Conclusions

This study investigates the feasibility of utilizing Acrylonitrile Butadiene Styrene (ABS) plastic waste as a sustainable alternative in construction through the development of plastic-sand composite blocks. An experimental approach was adopted, involving the collection of ABS plastic waste and processing it using a specialized plastic-sand melting and mixing machine designed to minimize environmental pollution. Various material characterization tests, including compressive strength analysis, water absorption, thermal conductivity assessment, X-ray diffraction (XRD), and scanning electron microscopy (SEM), were conducted.

The research focused on optimizing the formulation of plastic-sand composite blocks and evaluating their mechanical and physical properties through laboratory testing. A key aspect of the study was addressing plastic melting emissions by integrating a closed-system melting and mixing process to mitigate environmental concerns. The experimental evaluation provided critical insights into the mechanical, microstructural, and environmental performance of the composite blocks. The following key findings reinforce the feasibility of using ABS plastic waste as a sustainable alternative in construction applications while addressing mechanical performance, material integrity, and environmental concerns:

- The plastic-sand composite block achieved an average compressive strength of 15 MPa, exceeding the IS 2185-2005 (Part 1) minimum requirement by three times, confirming ABS waste as a viable construction material.
- XRD analysis confirms a significantly more crystalline silica structure in plastic-sand blocks than in conventional concrete, enhancing material integrity.
- SEM analysis reveals a compact microstructure with fewer pores, indicating improved mechanical strength and durability compared to traditional concrete blocks.
- The study mitigated plastic melting emissions using a closed-system melting and mixing machine, reducing environmental impact.
- The application of a concrete layer over the composite block enhanced thermal resistance and minimized odor emissions from recycled plastic waste.

## 5 Acknowledgements

All authors whose names appear on the submission have made substantial contributions to the conception and design of the study. The experimental work and data analysis were performed by [Muhammad Khizar Hassan], [Anas Ahmed] and [Aiman Siddiqui]. The first draft of the manuscript was written by [Muhammad Khizar Hassan], [Anas Ahmed], [Rana Rabnawaz Ahmed], and [Rashid Ali]. The final draft was prepared by [Muhammad Khizar Hassan] and [Anas Ahmed] and reviewed by [Rana Rabnawaz Ahmed] and [Muhammad Ashraf Tanoli]. All authors provided critical feedback on previous versions of the manuscript. All authors have read and approved the final manuscript for submission.

## 6 Conflict of Interests

All authors declared that there is no conflict of interest in this submission.

## References

1 Zulkernain, N.H., Gani, P., Chuck Chuan, N. and Uvarajan, T. (2021, August 16) Utilisation of Plastic Waste as Aggregate in Construction Materials: A Review. Construction and Building Materials, Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2021.123669.

2 Musab Manzoor, K. and EhtishamUddin, S. (2023) Utilization of a Mixture of Waste Plastic Materials and Granite Particles as a Partial Replacement of Coarse Aggregate in Concrete Blocks. *Materials Today: Proceedings*, Elsevier BV. https://doi.org/10.1016/j.matpr.2023.05.095.

3 Jefferson, A.J., Kearns, K., Snyder, K., Mitchell, A., Muratori, S. and Rowan, C.J. (2025) Anthropogenic Litter and Plastics across Size Classes on a Mechanically Groomed Great Lakes Urban Beach. *Journal of Great Lakes Research*, International Association of Great Lakes Research. https://doi.org/10.1016/j.jglr.2024.102505.

4 Nuno, A., Duncan, E.M., Dias, D., dos Santos, Y., Ramilo-Henry, M. and Matilde, E. (2025) Understanding Plastic Pollution at a Remote Tropical Island (Príncipe Island, Gulf of Guinea): Consumer Behaviour and Management Preferences. *Regional Studies in Marine Science*, Elsevier B.V., **81**. https://doi.org/10.1016/j.rsma.2024.103982.

5 Rahman Shaibur, M. Mechanical Characterization of PET (Polyethylene Terephthalate) Bottles Randomly Collected from South-Western Part of Jashore District, Bangladesh. https://www.researchgate.net/publication/365182223.

6 Rahman Shaibur, M., Hasnat Shamim, A., Imamul Huq, S., Shaibur, M.R., Shaibur, T., M Shamim, A.H. and Imamul Huq, S.M. (2009) Availability of Ca. Mg and S. https://www.researchgate.net/publication/343599070.

7 PlascticsEurope. Plastics-the Facts 2021 An Analysis of European Plastics Production, Demand and Waste Data. https://plasticseurope.org/knowledge-hub/plastics-the-facts-2021/.

8 Sarwar, S., Shaibur, M.R., Hossain, M.S., Hossain, M.R., Ahmmed, I., Ahmed, F.F., Sarker, M.A.H. and Shamim, A.H.M. (2023) Preparation of Environmental Friendly Plastic Brick from High-Density Polyethylene Waste. *Case Studies in Chemical and Environmental Engineering*, Elsevier Ltd, **7**. https://doi.org/10.1016/j.cscee.2022.100291.

9 Geyer, R., Jambeck, J.R. and Law, K.L. (2017) Production, Use, and Fate of All Plastics Ever Made. https://doi.org/https://doi.org/10.1126/sciadv.1700782.

10 Assaad, J.J., Khalil, M., Khatib, J., Assaad, J.J., Khalil, M. and Khatib, J. (2022) Citation: Alternatives to Enhance the Structural Performance of PET-Modified Reinforced Concrete Beams. https://doi.org/10.3390/environments.

11 Tudu, C., Mohanty, M., Mohapatra, S.S. and Nayak, S. (2024, May 17) A Systematic Review Exploring the Feasibility of Waste Plastic as Different Constituents towards Sustainable Concrete. Construction and Building Materials, Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2024.136210.

12 Ahmad, I., Aslam, S. and Hussain, U. (2023) Assessment of Plastic Pollution in Coastal Areas of Karachi: Case Study of West Warf, Kemari Jetty, and Manora. *Marine Pollution Bulletin*, Elsevier Ltd, **195**. https://doi.org/10.1016/j.marpolbul.2023.115501.

13 Ranjbar, I., Ventikos, Y. and Arashpour, M. (2025) Deep Learning-Based Construction and Demolition Plastic Waste Classification by Resin Type Using RGB Images. *Resources, Conservation and Recycling*, Elsevier B.V., **212**. https://doi.org/10.1016/j.resconrec.2024.107937.

14 Asian Development Bank. (2022) Solid Waste Management Sector in Pakistan. Manila, Philippines. https://doi.org/10.22617/TCS220086-2.

15 Korai, M.S., Ali, M., Lei, C., Mahar, R.B. and Yue, D. (2020) Comparison of MSW Management Practices in Pakistan and China. *Journal of Material Cycles and Waste Management*, **22**, 443–453. https://doi.org/10.1007/s10163-019-00951-0.

16 Mukheed, M. and Khan, A. (2020) Plastic Pollution in Pakistan: Environmental and Health Implications. *J Pollut Eff Cont*, **8**, 251. https://doi.org/10.35248/2375-4397.20.8.251.

17 Amjad, M.S. and Diaz-Elsayed, N. (2024) Evaluating the Environmental Impacts of Brick Production from Waste Plastic. *Manufacturing Letters*, **41**, 1683–1695. https://doi.org/10.1016/j.mfglet.2024.09.196.

18 Shaibur, M.R., Sarwar, S. and Alshehri, M. (2025) Production and Characterization of Plastic Bricks Produced from PET, PP, and HDPE Types of Plastic Wastes. *Physics and Chemistry of the Earth, Parts A/B/C*, **138**, 103859. https://doi.org/10.1016/j.pce.2025.103859.

19 MEKIDECHE, S., ROKBI, M., RAHMOUNI, Z.E.A., Phiri, R., Mavinkere Rangappa, S. and Siengchin, S. (2024) Manufacture and Characterization of Lightweight Sand-Plastic Composites Made of Plastic Waste and Sand: Effect of Sand Types. *International Journal of Lightweight Materials and Manufacture*, Elsevier BV. https://doi.org/10.1016/j.ijlmm.2024.08.004.

20 Swinnerton, S., Kurtz, K., Neba Nforsoh, S., Craver, V. and Tsai, C. (2024, October 20) The Manufacturing Process and Consequent Occupational Health and Environmental Risks Associated with the Use of Plastic Waste in Construction Bricks in Small-Scale Recycling Plants. Journal of Cleaner Production, Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2024.143818.

21 Akinwumi, I.I., Domo-Spiff, A.H. and Salami, A. (2019) Marine Plastic Pollution and Affordable Housing Challenge: Shredded Waste Plastic Stabilized Soil for Producing Compressed Earth Bricks. *Case Studies in Construction Materials*, Elsevier Ltd, **11**. https://doi.org/10.1016/j.cscm.2019.e00241.

22 Limami, H., Manssouri, I., Cherkaoui, K., Saadaoui, M. and Khaldoun, A. (2020) Thermal Performance of Unfired Lightweight Clay Bricks with HDPE & PET Waste Plastics Additives. *Journal of Building Engineering*, Elsevier Ltd, **30**. https://doi.org/10.1016/j.jobe.2020.101251.

23 Hamzah, A.F. and Alkhafaj, R.M. (2022) An Investigation of Manufacturing Technique and Characterization of Low-Density Polyethylene Waste Base Bricks. *Materials Today: Proceedings*, Elsevier Ltd, **61**, 724–733. https://doi.org/10.1016/j.matpr.2021.08.318.

24 Kulkarni, P., Ravekar, V., Rama Rao, P., Waigokar, S. and Hingankar, S. (2022, September 1) Recycling of Waste HDPE and PP Plastic in Preparation of Plastic Brick and Its Mechanical Properties. Cleaner Materials, Elsevier Ltd. https://doi.org/10.1016/j.clema.2022.100113.

25 Yadav, A., Chandra, A. and Singh, S. (2022) Study on Application of Waste Plastic in the Construction Industry. *Materials Today: Proceedings*, Elsevier Ltd, **64**, 1455–1458. https://doi.org/10.1016/j.matpr.2022.04.743.

26 Yusof, N.Z. (2018) Plastic in Brick Application. *Trends in Civil Engineering and its Architecture*, Lupine Publishers LLC, **3**. https://doi.org/10.32474/tceia.2018.03.000152.

27 Hiremath, N., Evora, M.C., Naskar, A.K., Mays, J. and Bhat, G. (2017) Polyacrylonitrile Nanocomposite Fibers from Acrylonitrile-Grafted Carbon Nanofibers. *Composites Part B: Engineering*, Elsevier Ltd, **130**, 64–69. https://doi.org/10.1016/j.compositesb.2017.07.031.

28 Arun Solomon, A., Shelton, J.J. and Daniel, C. (2023) Turning Low-Density Polyethylene Plastic Waste into Plastics Bricks for Sustainable Development. *Materials Today: Proceedings*, Elsevier Ltd. https://doi.org/10.1016/j.matpr.2023.03.482.

29 Idrees, M., Akbar, A., Saeed, F., Gull, M. and Eldin, S.M. (2023) Sustainable Production of Low-Shrinkage Fired Clay Bricks by Utilizing Waste Plastic Dust. *Alexandria Engineering Journal*, **68**, 405–416. https://doi.org/10.1016/j.aej.2023.01.040.

30 Ornam, K., Kimsan, M., Ngkoimani, L.O. and Santi. (2017) Study on Physical and Mechanical Properties with Its Environmental Impact in Konawe - Indonesia upon Utilization of Sago Husk as Filler in Modified Structural Fly Ash - Bricks. Procedia Computer Science, Elsevier B.V., 420–426. https://doi.org/10.1016/j.procs.2017.06.043.