Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Sustainable Brick Manufacturing Using Waste Plastic, Fly Ash, And Construction And Demolition Debris: Experimental Analysis And Material Characterization

Vikas Dnyandeo Gholap[1*], Nilesh Appasaheb Kapse[2], Omkar Anil Vaidya[3], Prashant Anil Chavan[4]

[1*]*Department of Civil Engineering,Pravara Rural Engineering College,Loni (MH), India*
[1]*vicksgholap@gmail.com*
[2,3,4]*Department of Civil Engineering,Pravara Rural Engineering College,Loni (MH), India*
[2]*nakapse@gmail.com*
[3]*vaidyaonkar007@gmail.com*
[4]*prashantchavan111@gmail.com*

This study investigates the feasibility of manufacturing plastic composite bricks utilizing waste polyethylene terephthalate (PET), fly ash, and construction and demolition (C&D) debris as primary raw materials. The approach aims to address the dual challenges of environmental pollution and resource depletion by diverting non-biodegradable, high-density waste materials from landfills and reintroducing them into the construction supply chain. C&D debris—comprising inert materials such as crushed concrete, glass, metal fragments, and masonry waste—was sourced locally and processed to a uniform gradation. Concurrently, post-consumer PET bottles were shredded and employed as a thermoplastic binder, replacing conventional cementitious binders. Class F fly ash, obtained from a nearby brick manufacturing facility, served as a pozzolanic filler to enhance particle packing and interfacial bonding. Plastic bricks were fabricated using three mix proportions by weight: 1.5:1:1, 2:1:1, and 2.5:1:1 for PET:C&D waste, fly ash, respectively. The plastic component was thermally softened and uniformly blended with the dry constituents before molding and compaction. Mechanical testing was conducted in accordance with IS 3495 (Part 1):1992 to determine compressive strength. The results revealed a nonlinear strength response with varying PET content. The optimal mechanical performance was achieved at a mix ratio of 2:1:1, yielding a peak compressive strength of 16.45 MPa, which significantly exceeds the standard strength of conventional fired clay bricks (10.3 MPa). This study validates the potential of thermoplastic-bound composite bricks as a viable, low-cost, and sustainable alternative to traditional masonry units, particularly for low- to medium-load-bearing applications in urban infrastructure.

Keywords: Plastic bricks, Waste PET, Fly ash, Construction and demolition waste, Sustainable construction materials, Compressive strength, Thermoplastic binder, Recycled aggregates, Solid waste valorization, Alternative masonry units.

1. Introduction

The exponential growth of industrial activities and urbanization, compounded by rising population levels, has led to a significant surge in the generation of solid waste worldwide. Major contributors include fly ash, plastics, construction and demolition (C&D) debris, and industrial by-products such as blast furnace slag and steel slag. The disposal and environmental impact of these non-biodegradable materials remain pressing issues, particularly in developing countries. Researchers and policy-makers are increasingly focused on identifying sustainable and efficient utilization pathways for these wastes to minimize environmental degradation (Cardoza & Colorado, 2023; Xiong et al., 2023).

India generates substantial volumes of fly ash due to its dependence on coal-based thermal power plants, which supply over 65% of the country's electricity. Fly ash, if left exposed to the environment, poses a considerable threat through air and groundwater pollution. However, due to its pozzolanic nature, fly ash can serve as a valuable supplementary construction material, thereby reducing reliance on cement and improving waste utilization (Gao et al., 2024; Kumar et al., 2021).

In parallel, the Indian brick industry demands approximately 60 billion bricks annually, consuming an estimated 185 million tons of fertile topsoil and resulting in the degradation of nearly 7500 hectares of agricultural land each year. This unsustainable practice is detrimental to the environment and long-term food security. Meanwhile, C&D waste generated from infrastructure projects such as roads, bridges, and buildings is heavy, bulky, and difficult to dispose of. Its high inert content, including concrete, masonry, glass, and metal, makes it suitable for reuse in sub-base layers, embankment fills, or as a replacement for natural aggregates (Cardoza & Colorado, 2023; Xiong et al., 2023; Gao et al., 2024).

Plastics, particularly polyethylene terephthalate (PET), are another major environmental concern due to their resistance to degradation and improper disposal practices. Recent studies demonstrate the feasibility of incorporating waste PET directly into construction materials as a binder, eliminating the need for energy-intensive recycling (Swinnerton et al., 2024; Sarwar et al., 2023). By integrating waste PET, fly ash, and C&D waste into brick production, a sustainable solution is achieved that not only diverts significant waste streams from landfills but also reduces construction costs and environmental burden (Sahani et al., 2022; Aneke & Shabangu, 2021).

This research aims to experimentally assess the compressive and thermal performance of plastic bricks manufactured with varying proportions of PET, fly ash, and demolition waste. The study contributes to the ongoing efforts toward circular economy principles and eco-friendly construction material development.

2. Waste Materials for Plastic Brick

2.1 Plastic Waste

Plastic waste has emerged as a significant environmental challenge due to its extensive use, chemical composition, and persistence in natural ecosystems. Plastics, primarily composed of high-molecular-weight synthetic polymers derived from petrochemicals, are valued for their moldability and durability. However, these same properties contribute to their resistance to degradation, leading to accumulation in landfills and water bodies (Swinnerton et al., 2024). In brick manufacturing, particularly in plastic-fly ash bricks, thermoplastic polymers such as polyethylene terephthalate (PET), high-density polyethylene (HDPE), and low-density polyethylene (LDPE) are preferred for their plasticity, which enables effective binding of fillers without the need for chemical recycling (Sahani et al., 2022; Sarwar et al., 2023).

Several studies have demonstrated the direct use of shredded or melted plastic waste as a binder in place of traditional cementitious materials. This not only diverts plastic waste from the environment but also reduces the energy footprint associated with conventional recycling methods (Aneke & Shabangu, 2021; Swinnerton et al., 2024). The thermomechanical behavior of plastics allows for their blending with fly ash and other inert fillers to form lightweight and structurally competent composite bricks.

2.2 Construction and Demolition (C&D) Waste

Construction and demolition (C&D) waste, generated from infrastructure development, renovation, and demolition activities, comprises materials such as concrete, bricks, metal, glass, and wood. These materials, while inert, present disposal challenges due to their high volume and density. Conventional landfilling of C&D waste not only consumes valuable land but also raises concerns regarding long-term environmental impacts and waste management logistics (Xiong et al., 2023). Recent research advocates the incorporation of processed C&D waste into construction materials, including bricks and concrete blocks, as partial or full replacements for natural aggregates. When appropriately crushed and sieved, C&D debris has been shown to enhance the sustainability of building products without significantly compromising mechanical performance (Cardoza & Colorado, 2023; Gao et al., 2024). This approach supports circular economy practices and contributes to low-cost housing solutions, especially in urbanizing regions with limited access to natural resources.

2.3 Fly Ash

Fly ash is a fine particulate by-product generated from coal combustion in thermal power plants. India, as the third-largest producer of coal-fired power, generates over 200 million tonnes of fly ash annually, much of which is underutilized and stockpiled in ash ponds or disposed of in landfills (Gao et al., 2024). This not only leads to land encroachment but also presents risks of groundwater and air pollution due to the leaching of heavy metals and other inorganic contaminants. Despite its environmental risks, fly ash exhibits pozzolanic properties, making it a valuable supplementary cementitious material in the construction industry. When mixed with water or in combination with plastic binders, it contributes to strength development, reduced permeability, and improved durability of bricks and concrete products (Kumar et al., 2021). Its use in brick manufacturing not only reduces the dependence on clay and topsoil but also offers a productive end-use for industrial by-products, aligning with waste valorization goals.

The resulting composite mixture was then poured into pre-cleaned moulds. Compaction was carried out simultaneously using a tamping rod to eliminate entrapped air and improve the density of the final product. The compacted moulds were left to cool naturally at atmospheric temperature for 24 hours (Sarwar & Shaibur, 2023; Swinnerton et al., 2024).
After the cooling period, the solidified plastic bricks were demoulded and made ready for further testing and evaluation.

3.Experimentation Procedure.

In this study, waste plastic bottles were first air-dried at ambient atmospheric temperature for 48 hours to eliminate surface moisture. Once dried, the bottles were shredded into flakes with an average particle size of approximately 4.75 mm (Swinnerton et al., 2024; Mohan et al., 2021). Simultaneously, construction and demolition (C&D) waste materials were manually crushed using a hammer and then passed through a 1.75 mm IS sieve to obtain uniform-sized particles suitable for mixing. Sun-dried fly ash was also prepared, ensuring that only the fraction passing through the 1.75 mm IS sieve was utilized (Xiong et al., 2023; Cardoza & Colorado, 2023). The shredded plastic was heated in a steel container until it reached its melting point. Once completely molten, the pre-processed C&D waste and fly ash were gradually added to the molten plastic. Continuous stirring was performed to ensure thorough and homogeneous mixing of all constituents (Aneke & Shabangu, 2021; Sahani et al., 2022).

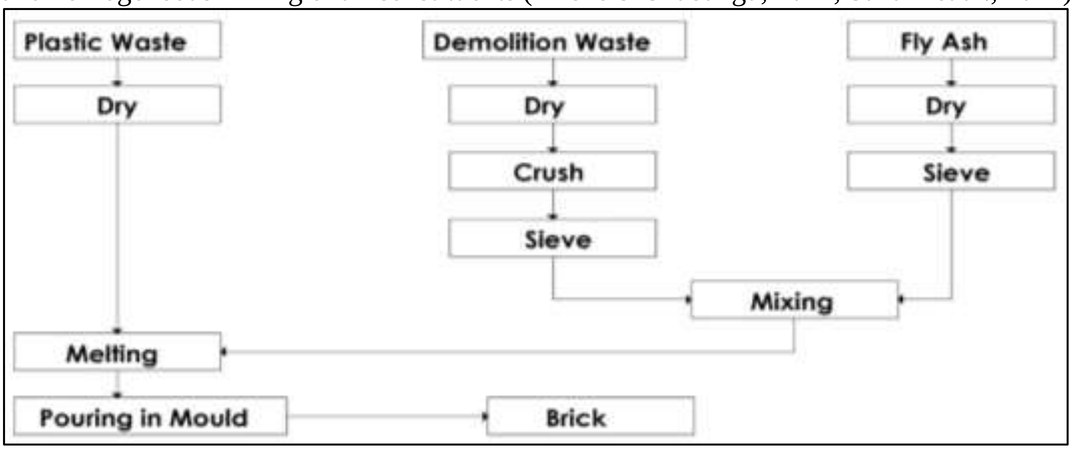

Figure 1. Methodology

3.1 Casting of Plastic Bricks

Cube moulds of standard dimensions were filled with a homogenized mix of plastic, demolition waste, and fly ash, followed by thorough compaction to ensure uniform density. Three specimens were cast for each mix design. The moulds were placed on a vibration-free surface and allowed to cure at ambient temperature. Based on preliminary trials, a final optimized mix ratio of 2:1:1 (plastic: demolition waste: fly ash) was adopted for subsequent testing.

Figure 2. Melting and mixing of plastic waste

Figure 3. Moulding of bricks

3.2 Water Absorption Test

The water absorption capacity of the plastic bricks was determined in accordance with IS 3495 (Part 2): 1992, which specifies the procedure for assessing water absorption in solid masonry units. Each brick specimen was first oven-dried at a temperature of 105 ± 5°C until a constant mass was achieved. The dry weight (W_1) was recorded. The bricks were then fully immersed in clean, cold water at ambient temperature for a period of 24 ± 0.5 hours. After immersion, the surface moisture was wiped off, and the saturated weight (W_2) was measured.

Water absorption (%) was calculated using the formula:

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

According to the Indian Standard, the maximum permissible limit for water absorption in solid bricks is 20% by weight for bricks intended for general use (IS 3495, 1992). Water absorption is a critical parameter, as it influences durability, dimensional stability, and resistance to freeze-thaw cycles (Swinnerton et al., 2024).

3.3 Compressive Strength Test

The compressive strength of the bricks was evaluated in accordance with IS 3495 (Part 1): 1992 using a uniaxial compression testing machine of 1000 kN capacity. Bricks were positioned such that the load was applied along the flat faces, perpendicular to the direction of molding. The load was applied gradually at a uniform rate until failure, and the peak load (P) was recorded in kilonewtons (kN).

Each mix proportion was tested using three replicates, and the average compressive strength was reported to account for material variability and test precision (Sarwar & Shaibur, 2023).

The compressive strength (f_s) in N/mm² was calculated using the formula:

$$fs = P/A$$

Where:

- P = maximum load at failure (N)
- A = loaded surface area (mm²)

A minimum strength of 10.3 MPa is generally expected for conventional clay bricks (Eskinder et al., 2014), whereas plastic composite bricks have shown the potential to exceed this benchmark, particularly when optimized mix proportions are used (Aneke & Shabangu, 2021; Gao et al., 2024). In this study, strength values were compared across various mix ratios, with a focus on the performance of the final selected mix (2:1:1 for plastic:demolition waste:fly ash).

Figure 4. Plastic brick

Figure 5. Compression strength test

Figure 6. Brick exposed to high temp

3.4 Temperature test

The compressive strength of plastic composite bricks was evaluated under ambient conditions to assess the influence of varying plastic content and thermal processing on mechanical performance. This test is essential for determining the engineering suitability of construction materials and is widely recognized as a primary indicator of structural integrity (IS 3495-1:1992). In this study, bricks were fabricated with different plastic content levels—40%, 50%, and 60% by weight—while maintaining consistent proportions of demolition waste and fly ash. The plastic waste was melted and mixed with the other constituents at elevated temperatures before moulding. It was observed that the compressive strength decreased with increasing plastic content, consistent with findings from similar research on thermoplastic composites (Sahani et al., 2022; Sarwar & Shaibur, 2023). The compressive strength of the bricks varied from 8 MPa to a maximum of 16.5 MPa, depending on the mix proportions and processing conditions. Higher plastic content resulted in reduced bonding with the filler materials, leading to lower load-bearing capacity. Conversely, the optimal strength was achieved at a mix ratio of 2:1:1 (plastic: demolition waste: fly ash), which demonstrated the best balance between matrix integrity and filler distribution.

These results align with previous literature that emphasizes the impact of plastic concentration and thermal processing on the mechanical performance of recycled composite bricks (Aneke & Shabangu, 2021; Gao et al., 2024). The test confirms that both material composition and processing temperature significantly influence the final compressive strength of plastic bricks.

4.Cost Analysis

Table 1. Costing of Bricks

Sr. No	Item	Quantity	Unit	Rate (Rs/-)	Amount (Rs/-)
	100 nos of bricks				
1	Plastic (Collection& Transportation)	200	Kg	1	200
2	Demolition waste (Transportation & Processing)	100	Kg	1	100
3	Fly-ash (Transportation & Processing)	100	Kg	1	100
4	Labor	Lump sum		350	350
5	**TOTAL**				**750**
6	Rate of one brick $=\frac{750}{100}$				7.5

5. Results And Discussions

The test results for the experimental work carried out to understand the behavior of plastic brick are as below.

5.1 Compressive Strength

Compressive strength tests were performed on brick specimens containing different percentages of plastic waste to assess the effect of plastic content on load-bearing capacity. The results demonstrated a nonlinear relationship between plastic content and compressive strength.An initial increase in compressive strength was observed as the plastic content increased, reaching a peak value of 16.5 N/mm² at 50% plastic content by weight. This enhancement in strength is attributed to the effective thermal bonding of molten plastic with the filler materials, which contributed to a denser and more cohesive matrix.However, beyond the 50% threshold, a gradual reduction in compressive strength was noted. This decline is likely due to excessive plastic content reducing the proportion of rigid filler material, thereby weakening the structural integrity and interfacial bonding within the brick matrix.

These results indicate that 50% plastic content offers an optimal balance between binder and filler phases, making it the most effective mix ratio for achieving high compressive strength. Similar trends have been reported in previous studies involving thermoplastic composite bricks (Aneke & Shabangu, 2021; Sahani et al., 2022).

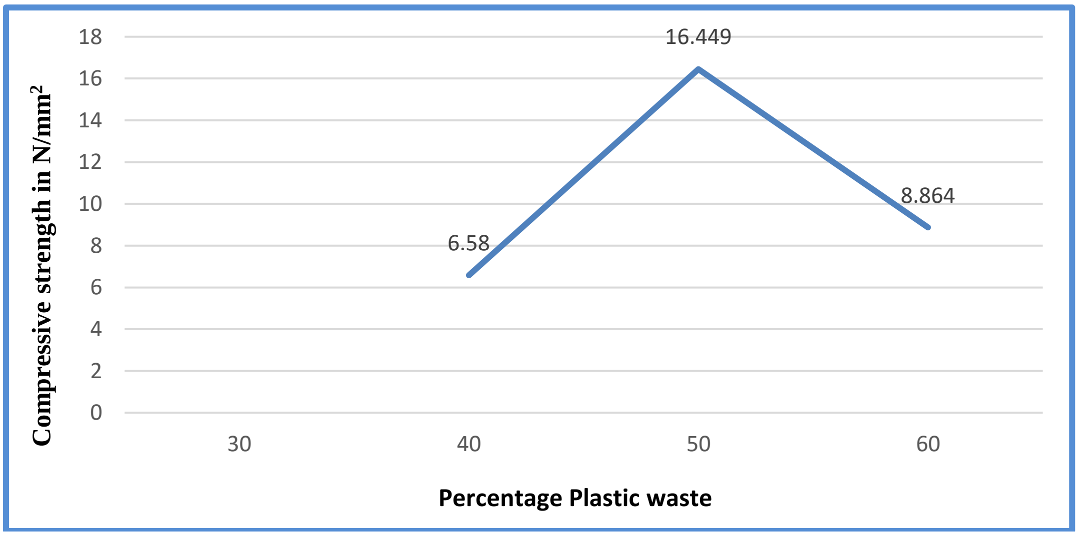

Figure 7. Compressive Strength vs waste plastic

5.2 Temperature Test

Assessing the thermal performance of plastic composite bricks is essential for their application in fire-prone or high-temperature environments, where structural materials may be subjected to thermal stress. To evaluate the thermal stability, compressive strength tests were performed on bricks exposed to controlled temperatures. The results revealed a gradual increase in compressive strength with temperature, reaching a maximum of 19.50 N/mm² at 110°C. This improvement is attributed to post-curing effects and enhanced matrix consolidation, which likely promoted stronger interfacial adhesion between the molten plastic binder and the inert filler materials (Aneke & Shabangu, 2021). Beyond 110°C, a decline in compressive strength was observed, indicating the onset of thermal degradation. The softening of the thermoplastic matrix at elevated temperatures likely reduced its load transfer capability, leading to diminished mechanical strength. Therefore, 110°C is identified as the thermal threshold for optimal mechanical performance. Exceeding this limit may compromise the structural integrity of the composite, emphasizing the need for careful temperature considerations in design applications involving thermal exposure.

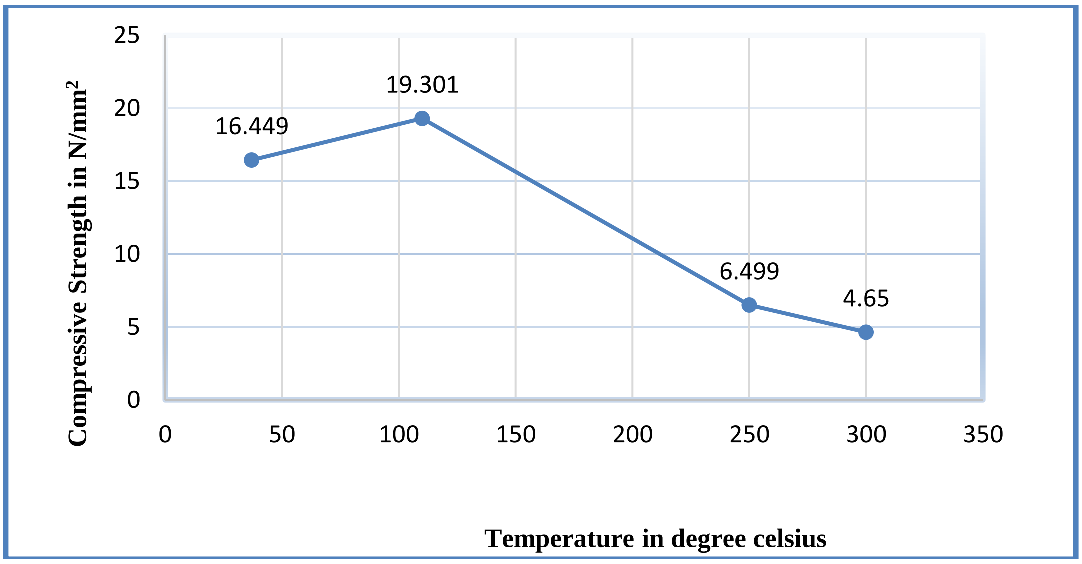

Figure 8. Compressive Strength vs Temperature

6.Conclusions

- The optimized mix ratio of 2:1:1 (plastic: fly ash: construction and demolition waste) demonstrated superior performance in the production of plastic composite bricks, indicating its suitability as an effective and sustainable alternative to conventional clay bricks.
- The compressive strength of the bricks developed with the 2:1:1 mix reached a maximum of 16.5 MPa, which is significantly higher than the typical compressive strength of standard fired clay bricks (~10.3 MPa), confirming their potential for structural and non-load-bearing applications.
- When subjected to elevated temperatures, the compressive strength of the bricks increased to 19.50 MPa at 110°C, likely due to post-curing and matrix densification. However, exposure to temperatures beyond this point resulted in a gradual reduction in strength, indicating 110°C as the optimal thermal threshold for application.
- The study confirms that plastic waste and construction and demolition debris can partially replace clay and cement in brick manufacturing. This not only diverts substantial waste from landfills but also contributes to reducing environmental pollution and promoting circular economy practices in the construction sector.

References

1. Aneke, B. P., & Shabangu, P. (2021). High-performance bricks using PET waste and foundry sand. Construction and Building Materials, 298, 123826. https://doi.org/10.1016/j.conbuildmat.2021.123826
2. Gao, S., Chu, H., Shi, W., Liu, Y., & Liu, Z. (2024). Utilization of municipal solid waste incineration fly ash in ecological concrete bricks. Case Studies in Construction Materials, 21, e03999. https://doi.org/10.1016/j.cscm.2024.e03999
3. IS 3495 (Part 1): 1992. (1992). Methods of tests of burnt clay building bricks—Part 1: Determination of compressive strength. Bureau of Indian Standards.
4. IS 3495 (Part 2): 1992. (1992). Methods of tests of burnt clay building bricks—Part 2: Determination of water absorption. Bureau of Indian Standards.
5. Sahani, R. R., Jena, S., & Panda, K. C. (2022). Performance evaluation of plastic sand bricks incorporating PET waste. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2022.03.167
6. Sarwar, M., & Shaibur, M. R. (2023). Utilization of HDPE plastic in eco-brick development. Environmental Science and Pollution Research. https://doi.org/10.1007/s11356-023-26238-3
7. Swinnerton, S., Kurtz, K., Nforsoh, S. N., Craver, V., & Tsai, C. (2024). The manufacturing process and environmental risks of plastic waste bricks in small-scale recycling plants. Journal of Cleaner Production, 477, 143818. https://doi.org/10.1016/j.jclepro.2024.143818
8. Leiter, F. C., Motta, R. A. S., Vasconcelos, K. L., & Bernice, L. (2011). Laboratory evaluation of recycled construction and demolition waste for pavements. Construction and Building Materials, 25(6), 2972–2979.
9. Eskinder, B. M., Pandit, A. K., Sheikh, A. Q., & Genia, B. A. (2014). Brick kilns: Cause of atmospheric pollution. Pollution Effects and Control, 2(2), Article 112.
10. Abdelhamid, M. S. (2014). Assessment of different construction and demolition waste management approaches. HBRC Journal, 10(3), 317–326.
11. Maneesh, P. D., Pramod, K., Kumar, K., & Shetty, S. (2014). Utilization of waste plastic in manufacturing of plastic-soil bricks. International Journal of Engineering Research & Technology (IJERT), 3(8). ISSN: 2278-0181.
12. Cristela, N., Vieira, C. S., & Lopes, M. L. (2016). Geotechnical and geo-environmental assessment of recycled construction and demolition waste for road embankments. Construction and Building Materials, 143, 51–58.
13. Patel, P. A., Shan, A., et al. (2016). Waste plastic bottles offering innovative building materials with sustainable application. International Journal of Innovative and Emerging Research in Engineering.
14. Verma, R., Vinod, K. S., Papreddy, M., & Gowda, A. N. S. (2016). Toxic pollutants from waste plastic – A review. Procedia Environmental Sciences, 35, 701–708.