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Recycled Plastics in Building Materials: Enhancing Sustainability and Economic Efficiency

Israa Kareem, Mohammed Alzuhairi*, Fadhil A. Hashim, Ahmed H. Al-Ghaban

Department of Materials Engineering, University of Technology-Iraq, Baghdad 10069, Iraq

Corresponding Author Email: mohammed.a.alzuhairi@uotechnology.edu.iq

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ABSTRACT

Plastic waste is a serious environmental issue that affects numerous industries, including the construction sector. The use of plastic waste in construction, when inefficiently managed, can have detrimental effects on both the economy and the environment. This underscores the importance of implementing long-term solutions for sustainable waste management and reduction. Plastic waste releases toxic substances into the environment, is non-biodegradable, and has long-term ecological consequences—all of which contribute to environmental pollution. From an economic perspective, poor waste management decreases opportunities for recycling and reuse, increases cleanup costs, and leads to inefficient resource utilization. This research is significant in that it seeks to identify innovative approaches for utilizing plastic waste currently disposed of in landfills. National and international monitoring of production, recycling, and landfill disposal rates provides insight into the current state of the global plastic waste crisis. The focus is on future waste management solutions, potential investment opportunities, and areas for research. New construction techniques for recycling waste plastics are being developed to enhance their value and ensure continuous usage in a closed-loop system. As a result, recycling plastic waste is considered one of the most effective ways to reduce environmentally harmful waste. In the context of building materials, the use of recycled plastics offers a promising alternative, addressing some limitations of conventional materials while reducing associated costs.

1. INTRODUCTION

The volume of plastics entering the waste stream is constantly rising, with inflationary pressures expected to increase by 4% annually [1]. Due to legislative requirements—such as the mandate to reduce landfill waste by 35% between 1995 and 2020—rising disposal costs, and the low biodegradability of commonly used polymers, landfilling has become a less attractive waste management option [2]. As plastic waste continues to accumulate, recycling has emerged as one of the most vital sectors in mitigating these environmental challenges. However, the recycling process faces obstacles, such as the increasing complexity of sorting and the labor-intensive nature of separating useful materials from waste [3]. Compared with incineration and the production of virgin plastics, recycling helps significantly reduce carbon dioxide emissions.

The widespread use and advancement of plastics in various sectors have been remarkable, with plastics now being indispensable in industries ranging from automobiles to food packaging, medical instruments, mobile phones, and construction [4, 5]. Plastics, which are typically lightweight and made from resins like HDPE, PP, PET, PVC, LDPE, and PS [6], have become crucial materials in manufacturing and construction. For example, PET waste has been identified as a potential component in alternative building materials, especially in cases where substantial deposits and structural loads are not required [7-9]. Furthermore, the manufacturing of plastics relies heavily on petroleum, with approximately 90% of plastic produced from petroleum-based materials. An alternative to conventional disposal methods like landfills is pyrolysis, which involves converting plastic waste into chemical building blocks [10, 11]. By recovering these valuable materials, pyrolysis offers a more sustainable option compared to landfilling.

Recycling, both mechanical and feedstock (tertiary) recycling, plays a crucial role in reducing plastic waste. Secondary mechanical recycling involves reprocessing waste into new plastic products of typically lower quality, while tertiary recycling breaks plastics down into their basic monomers, chemical feedstock, or fuel oil [12, 13]. Although efforts have been made to enhance the recycling process through computerization, increasing the variety of recyclables can create challenges in sorting, affecting the efficiency of the system. In light of these challenges, recycling offers not only environmental benefits by replacing primary production but also significant social and economic advantages, such as job creation, especially in emerging nations [14].

This study aimed to conduct a bibliographic review on the reuse of plastic waste in various building materials, with a particular focus on polyethylene terephthalate (PET). Relevant literature was identified through comprehensive searches in Scopus, ScienceDirect, and Web of Science databases, using keywords such as sustainable development, circular economy, life-cycle assessment, plastic waste, environmental impact, building materials, PET waste, and civil engineering. The primary contribution of this work is the innovative use of plastic waste in buildings. However, other assessments of plastic waste applications in construction also exist. This review may contribute to demonstrating the potential value of recycled plastics in construction, particularly in terms of their increased application, by encouraging research into the long-term performance and environmental impacts of these materials, rather than focusing solely on short-term outcomes.

History of sustainable construction and eco-friendly materials

From the extraction of raw materials through the recycling of building scraps, all stages of a project that aims to be environmentally clean and resource-conserving are considered part of sustainable construction. Sustainable building is a topic that has been covered in a wide range of publications [15]. It is adequate to claim that building activities will always have adverse environmental effects, but "sustainable construction" should mitigate these effects [15]. In the vast body of literature on construction management, the building industry's negative, long-lasting, and far-reaching effects on the natural world are often highlighted as a major concern [4]. It is replacing efficient methods with eco-friendlier alternatives and gradually shifting towards greener structures that use renewable energy. Embodied energy, life-cycle costs, and re-usability are used to create an "Environmental Suitability Index" [16, 17]. The environment in building design and construction was shown to have little sustainable influence by Naik and Moriconi [18]. Energy savings are embodied in using "green" materials; nevertheless, Mora [19] argued that it is crucial to differentiate between the building activity's sustainability and the works built.

Its widespread popularity worldwide also provides a tool to enhance environmental processes and services. It establishes targets for reducing harmful effects on the environment, improving quality of life, and facilitating a healthy setting for environmental habitation. Professionals in the building industry have started caring about limiting and addressing the ecological harm they do. Disposing of agroindustry trial and other solid waste is a significant problem in many developing nations [20]. Adopting sustainable development practices is one of the primary causes of this trend. The phrase "green architecture," sometimes known as "sustainable architecture" or "green building," is a collection of ideas, a body of research, and a specific style for designing buildings that have as little adverse effect as possible on the environment [21].

The environmental advantages and difficulties of using recycled plastics in building have been brought to light by recent research, which has focused in particular on life cycle costs and energy use. Kognole et al. [22] discovered that the production of bricks using recycled plastics lowers material prices and its impact on the environment. Though the material is inexpensive, the study also made clear that, to guarantee total sustainability, the energy spent in recycling procedures needs to be carefully examined. The application of composites made from wood in construction materials has been investigated by Srinivasamurthy et al. [23]. They argued that whilst they offer environmentally friendly alternatives, their widespread use is severely restricted by the astronomical energy expenses of their manufacturing and the high expense of large-scale use. The study carried out by Jawad et al. [24] studied the process of producing "green bricks" employing foundry sand and recycled plastic. While the study showed that these bricks save energy. Therefore, energy also made it evident that a comprehensive life cycle analysis is required, taking into account the energy required for recycling and plastic processing. In conclusion, although there are some positive environmental impacts to employing recycled plastics in construction, deep life cycle studies are required to evaluate expenditures and energy use. Table 1 explains the authors' studies using sustainable and eco-friendly building materials.

Table 1. Summary of studies on sustainable building materials

Authors	Work	Main Result Found by Authors	Category
Bakhoum et al. [25]	Construction that minimizes its impact on the environment by using sustainable materials (Rockwool sandwich panels, rice straw bales, integrated bricks, plain concrete, and M2 system).	The sustainable ranking of the eco-friendly system was (67%) higher than that of the conventional system (56%).	Environmental Impact
Corinaldesi et al. [26]	Pulverized glass fiber reinforced plastic (GFRP) and Virgin polyethylene terephthalate (PET) particle waste have successfully substituted limestone filler and natural sand at percentages as high as one hundred percent.	100% waste particle replacement of virgin resources yields eco-friendly plasters.	Environmental Impact
Generalova et al. [27]	In Russia, huge features like block rooms and a wide variety of minor 3D architectural parts have been utilized in modern modular designs.	Modular building assembly reduces expenses, increases safety, and reduces environmental impact.	Energy Use
Binici and Aksogan [28]	Waste from the olive oil mill is treated. Waste PVC, olive seed, and wood chips have negative environmental impacts.	Manufacture insulation from discarded olive seeds, wood chips, plaster, epoxy, shredded PVC, and other materials.	Environmental Impact
Singh and Bhowmik [29]	Polypropylene, polystyrene, and polyethylene waste plastics are recycled. As a component of asphalt pavement, it is coated by shredding and coating aggregate with heated bitumen.	The pavement is reinforced, and its longevity is extended at little cost and with little environmental impact.	Energy Use
Mannan and Ganapathy [30]	Added plastic wastes (PET + HDPE) into the bricks.	It is the most economical and environmentally friendly solution to add plastic waste to bricks.	Environmental Impact
Goli et al. [31]	Tiles, cement concrete, paver blocks/bricks, and wood-plastic composites are just a few of the many end-products (read composites) that may be manufactured using manufactured neo-construction materials like MPW as a binder and/or filler.	The only thing stopping people from getting environmentally friendly outcomes is the excessive expense of implementing these strategies.	Energy Use
Aneke and Shabangu [32]	Foundry sand (FS) and scrap plastic wastes (SPW) have been utilized to create energy-saving "green bricks" for masonry construction.	Compared to bricks made from fired clay, the strength of FS and SPW bricks was measured at 85%.	Material performance

2. THE CHEMICAL STRUCTURE OF PLASTIC PRODUCTS

Plastic is a synthetic polymer made from petrochemical products. Its basic structure consists of carbon–carbon single bonds, while additional functional groups determine variations in performance. These polymers are derived from petrochemicals [33]. A chain of carbon-carbon single bonds serves as the polymer's backbone, with the hydrogen and methyl groups hanging off of it as pendants. Several -(-CH_2-$CHCH_3$-)- groups are covalently bonded at either end of the polymer chain [34]. The basic building block of polymers is their repeating unit. Polymer's etymological roots may be traced back to the Greek words "poly," meaning many, and "meres," meaning portion. A "mer" is the repeating unit found in polymeric chains [35, 36]. Synthetic manipulation of the polymer's repeat unit significantly impacts the polymer's macroscopic properties. Plastics can be divided into several types that can be recycled, as follows.

2.1 Polyethylene terephthalate (PET)

The polymer polyethylene terephthalate (PET) stands out among polymers for its global significance [37]. There are two monomers used in the manufacturing of PET: ethylene glycol (EG) and terephthalic acid (TPA) (or terephthalic methyl ester (DMT)). It can be recycled thermoplastically, making it a popular material [38, 39]. Tons of its waste are produced in the environment due to its use as property, and industrial advancements are enhancing customer demand [40]. Because of its toughness, resilience, and non-degradable nature, its waste accumulates over time, poses an environmental threat when deposited after use, disrupts ecosystems, and has prompted calls for its recycling [41].

The application of polyethylene (PE) in construction materials has shown significant effects on their properties. PE is commonly used for its durability, flexibility, and resistance to chemicals and moisture. It enhances the mechanical properties of materials, such as improved impact resistance and tensile strength. Furthermore, when incorporated into construction materials, PE contributes to increased longevity and reduced maintenance needs due to its resistance to wear and environmental degradation. However, the presence of PE can also affect the material's recyclability, as it is less biodegradable than other alternatives [42, 43].

2.2 Polypropylene (PP)

The plastic conversion industry in Europe has a significant demand for polypropylene (PP) [21]. As a widely used "commodity polymer," PP serves various short-term applications, including innovative packaging solutions for food and agricultural products, such as films and composite matrices [22-24].

Polypropylene must be maintained to enhance material performance in construction. PP in the mixture, which is well-known for being extremely lightweight, extremely resistant to chemicals, and having exceptional fatigue durability, increases the flexibility and longevity of materials, enhancing their resistance to environmental degradation, stress cracking, and wear. It is widely used in construction as a reinforcing agent to strengthen materials such as concrete and composites. Its excellent resistance to heat and chemicals makes it perfect for harsh environmental conditions. However, improper PP disposal causes problems with reprocessing and has a negative impact on the environment [44].

2.3 High-density polyethylene materials (HDPE)

High-density polyethylene (HDPE) is very resistant to the growth of fungi and bacteria and disintegrates slowly [36]. A growing worldwide increase in plastic consumption is resulting in an increasing rise in annual manufacturing of HDPE and other polymers in recent years to meet consumer demands [45]. Although nitrogen, chlorine, oxygen, and fluorine are also present, carbon and hydrogen make up the majority of these polymers [46]. HDPE has a density of 0.965 g/cm^3 at ambient temperature and a melt flow index of 7.5 g/10 min at 190°C when loaded with 2.16 kg [47].

High-density polyethylene, or HDPE, is a common construction material known for its great mechanical strength and chemical resistance. Geomembranes, pipe systems, and other load-bearing components are particularly well-suited to their increased durability, impact resistance, and structural integrity. HDPE's low permeability and resilience to chemicals and UV radiation enhance the longevity of construction materials even in extreme environmental conditions. Its low biodegradability, on the other hand, makes waste management difficult, emphasising the importance of appropriate recycling technologies [48].

2.4 Polyvinyl chloride (PVC)

Vinyl chloride monomer (VCM) is regularly polymerised to create polyvinyl chloride (PVC), a synthetic resin. After polyethylene and polypropylene, it is the third most produced plastic worldwide [49]. Utilised in many different industries, such as electrical, transportation, building, packaging, and medical, PVC is a long-lasting, corrosion-resistant material [20]. PVC has recently drawn a lot of interest because of its excellent mechanical strength, high chemical and physical stability, and comparatively inexpensive cost [50].

Low-density polyvinyl chloride (LD-PVC) is widely used in building materials because of its flame-retardant properties, flexibility, and resilience to chemicals. It is commonly used in flooring, building membranes, and flexible pipes, among other applications, where its low weight and resistance to damage enhance total material performance. Furthermore, LD-PVC improves insulation, weather resistance, and adaptability, thereby rendering it particularly suitable for settings that require fire and moisture resistance. Despite those advantages, there nevertheless remain concerns regarding the way it will impact the environment, mostly due to its poor biodegradability and recycling problems [51].

2.5 Low-density polyethylene (LDPE)

The versatility and efficiency of low-density polyethylene (LDPE) have led to its widespread adoption in applications [52]. These packing materials are discarded after usage in landfills, where they cause pollution since they cannot decompose naturally [53]. The high-pressure polymerization of ethylene yielded low-density polyethylene (LDPE) [54]. Its low density is due to a tiny chain branch (roughly 2% of the carbon atoms) [55].

Low-density polyethylene (LDPE) is commonly used in construction materials due to its flexibility, lightweight nature, and excellent moisture resistance. LDPE is often applied in plastic films, insulation layers, and flexible piping. The addition of LDPE improves the material's elasticity and waterproofing properties, making it ideal for applications that require flexibility and environmental protection. However, LDPE has lower mechanical strength compared to other polymers, which may limit its suitability for load-bearing applications. Moreover, its recyclability presents environmental challenges if not managed properly [56].

2.6 Polystyrene (PS)

The material monomer undergoes degradation at temperatures from 150 and 300℃ to generate polystyrene, also known as PS, a polymer. Extremely high temperatures can cause depolymerization, which produces styrene [57]. Food packaging represents one of the many sectors that employ thermoplastic polymers, such as PS [58]. PS is a widely desirable material [59] because of its unique characteristics, which include inexpensive cost, low density, durability, outstanding strength during processing, ease of moulding, limited moisture absorption, and accountability [60].

Low-density polystyrene (LDPS) is widely utilised in building materials considering its shock-absorbing, thermal-insulating, and lightweight characteristics. It has a wide application in building component packing, lightweight concrete, and insulating boards. By decreasing the transfer of heat, LDPS increases energy efficiency and offers improved soundproofing. because of its low mechanical strength and vulnerability to stress-related stretching, its use in structural applications is restricted. In addition, considering LDPS is not recyclable and makes it hard for recycling, it represents a hazard to the environment [61].

3. PLASTIC WASTES APPLIED IN CIVIL ENGINEERING

As urbanization continues to grow globally, the environmental impact of solid waste accumulation and inadequate waste management has become increasingly evident [62]. The growing demand for sustainable, cost-effective, and lightweight building materials has led researchers to explore how plastic waste can be repurposed to benefit the environment while still meeting industry standards [63, 64]. Consequently, various plastics are now being incorporated into construction materials, as outlined below:

3.1 Waste plastic in different types of brick and its condition

Bricks are masonry units composed of an inorganic non-metallic material and are widely used as building components worldwide [65]. Manufacturing bricks, an essential construction industry, contributes heavily to environmental degradation [66]. Different production types of bricks are needed to apply a load, as shown in Table 2.

Table 2. Applied load to produce different types of bricks

Authors	Materials	Dimension of Sample	Compact Load
Pimraksa and Chindaprasirt [67]	The diatomite, hydrated lime, and gypsum.	150 mm_75 mm_35 mm	3.5 MPa.
Zhao et al. [68]	70% hematite tailings, 15% lime, and 15% sand.	50 (D) _23 (H) (C)	20 MPa.
Subramaniaprasad et al. [69]	Fibers of 1 cm and 2 cm lengths, Fibres made out of mineral water bottles and carry bags, Cement: 15, 10, and 5%.	101.5 (D) _ 117 (H) (C)	1.25-7.50 MPa.
Hwang and Huynh [70]	Fly ash (FA) and residual rice husk ash (RHA).	220 mm_105 mm_60 mm	35 MPa.
Cicek and Çinçin [71]	Fly ash and lime.	45(D) mm_100(H)(C) mm	4.6 MPa-12.26 MPa.
Corinaldesi et al. [26]	Using recycled polyethylene terephthalate (PET) particles and pulverized Glass Fibre Reinforced Plastic (GFRP) waste allowed for a one-to-one substitution of natural sand and limestone filler. Furthermore, a mixture of PET and wood waste (WW) particles was attempted to enhance the plaster's functional qualities.	Cylindrical mold (80 mm diameter, 30 mm high)	Compressed under pressure (2 MPa) for 1 min.
Cicek and Çinçin [71]	Bricks from mixtures of clay raw material and olive mill waste additive (0, 5, and 10 wt%).	Cylindrical pellets of 20 mm	Mixtures were compressed with a pressure of 20 MPa.
Sutcu et al. [72]	Either rice husk ash or wood ash was used to replace different amounts (10-30 wt%) of clay in the brick Manufacture.	Solid bricks with 30 mm × 10 mm cross sections and a length of 60 mm were	54.5 MPa.
Eliche-Quesada et al. [73]	The fly is produced while burning fossil fuels like coal and petroleum coke. Impact of fly ash with significant clay replacement (from zero to eighty percent).	cylinders with 32.5 mm diameter and 50 mm length	Compressing at 10 MPa.
Leiva et al. [74]	Olive pumice bottom ash (10, 20, 30, 40, and 50%).	60 mm × 30 mm × 10 mm	Molded and pressed at 54.5 MPa.
Eliche-Quesada and Leite-Costa [75]	Marble powder (0, 5, 10, 15, 20, 25, 30, and 35%).	Cylinder 20 mm × 10 mm	Semi-pressed at a pressure of 40 MPa.
Cota et al. [76]	Ceramic bricks were prepared with clay and sludge.	70 mm × 20 mm × 10 mm	5% and 10%, compaction pressure 14 and 28 MPa, with a firing temperature of 1000℃, and incorporating 5% sludge into the clay mixture.

Gomes et al. [77]	A novel artificial decorative stone was created by combining 20% epoxy resin with 80% quarry dust, residues, and chamotte from brick industries.	100 mm × 100 mm × 10 mm	The mold was vibrated for 2 min under a pressure of 10 MPa.
Ryu et al. [78]	Fabrication of the blocks included preheating the aggregate in a heating muller mixer before adding Clean PET chips to the mixture at a 7.5% PET/aggregate ratio. The PET content of the final product ranged from 2.5% to 10%.	200 mm wide, 200 mm long, and 80 mm depth	40MPa-compressed.
Akinyele et al. [79]	PET (0-5-10-15-20)% + clay.	290 mm × 140 mm × 100 mm	500 psi-1500 psi.
Alabduljabbar et al. [80]	Clay brick samples containing 4% and 8% sawdust.	20 cm × 10 cm × 7 cm	The pressure of 4 MPa using a hydraulic press.

3.2 Waste plastic in concrete production

The use of these materials in a building is significantly aided by the concrete used there. However, some of these minerals may be used in concrete as aggregates or as part of the cement's binder phase [81, 82]. Several authors explain the use of waste plastic in concrete, as shown in Table 3.

Table 3. Waste plastic in concrete

Authors	Type and Percentage	Conclusion
Bhogayata et al. [83]	PCMPW was included in the concrete at several percentages, from 0 to 2vol%.	Good agreement was found between experimental data and theoretical predictions of compressive-split tensile strength using a conventional analytical model.
Islam et al. [84]	The purpose of this study is to evaluate PET aggregate concrete in terms of its compressive strength, unit weight, and workability compared to natural aggregate concrete.	It is possible to employ structural concrete members made from PET-replacement concrete, which has a low w/c ratio and excellent workability.
Saxena et al. [85]	As a substitute for natural aggregate (fine and coarse) in concrete, shredded PET bottles were utilized at 5 to 20wt.% concrete.	Results showed better resistance to impact loading in the case of plastic concrete when compared to control concrete.
Belmokaddem et al. [86]	At 25%, 50%, and 75%, natural sand and coarse aggregate (sizes 0/3 and 3/8) were substituted with recycled PVC.	Concrete's thermal insulation is enhanced when plastic aggregates are used. Therefore, this concrete may be part of a strategy to increase a building's energy performance.
Raad et al. [87]	Crosslinked polyethylene (XPE) plastic wastes are byproducts of thermosetting polymers, and only a few studies have examined their effects on the structural qualities of concrete.	The test's results demonstrated that the ultimate bond strength to the implanted rebars is diminished due to the inclusion of XPE, which is shown in a flattening of the ascending section of the bond stress vs. displacement curves.
Farooq et al. [88]	The research investigated how RNF affected the characteristics of moderate-strength concrete. Experiments were conducted using concrete mixtures that included varying concentrations of RNF, from 0.05% to 1%. Physical properties, like ultrasonic pulse velocity and density, were measured.	The results of the experiments demonstrated that the RNF had a "reducing impact" on CS at greater volume fractions. The optimal RNF dosages for SPS and FS were 0.25% and 0.75%, respectively.

3.3 Waste plastic in mortar production

Fly ash, marine sediment, blast furnace slag, silica fume, and bottom ash from municipal solid waste incinerators are just some waste products that have found a home in construction and infrastructure materials in recent years. All of these wastes have contributed something unique to cement-based products' fresh and hardened qualities. These investigations have centered on how plastic additives affect the ductility of newly made composites [89, 90]. Using PET as a fine aggregate in mortar, mechanical strength may be achieved that is sufficient for lightweight materials. On the other hand, polyolefin-infused hydraulic mortars pave the way for more environmentally friendly construction products [91, 92]. The plastic waste, such as PET, PP, and PF aggregates that stand for plastic pellets and plastic flake in mortars this improved performance compared with the control mortar (without plastic) [93]. Recycled plastics from waste electrical and electronic equipment (WEEE) used as RAs in cement may boost strength while decreasing elasticity, producing a material with a higher strength but lower ductility than the benchmark (standard) sample [94, 95].

The addition of plastic materials to mortar has been shown to enhance its crack resistance and impermeability. The incorporation of recycled plastic fibers, such as polyethylene (PE) or polypropylene (PP), improves the tensile strength and flexibility of the mortar, reducing the likelihood of crack formation under stress. Moreover, the hydrophobic nature of plastics enhances the mortar's impermeability, minimizing water absorption and increasing durability in harsh environmental conditions. However, the effectiveness of these improvements depends on the type, size, and dosage of the plastic additives used [96, 97].

The life cycle of mortar involves several stages, each contributing to carbon emissions. During production, the key contributors to carbon emissions are the energy required for manufacturing cement and mixing with aggregates. The incorporation of plastic additives can increase energy consumption in the production phase, but it may enhance the mortar's performance, potentially reducing the need for repairs and thus lowering emissions during the usage phase. In the recycling stage, while plastic-based mortar can be recycled, the process is still limited, and the carbon footprint depends on the type of plastic and the efficiency of the recycling method. Overall, reducing emissions depends on improving energy efficiency and increasing the use of recycled materials [98, 99].

3.4 Waste plastic in bitumen production

Bituminous binders employed in road construction are essential for functioning well throughout a broad temperature range. The binder has to be flexible enough to bear strains without splitting in the cold of winter, while still being cohesive enough to survive the high heat of summer (up to 60℃) [100]. Many researchers have tried to use waste materials in road construction to modify the bitumen's rheological properties. This modification is essential for flexible road pavement [101, 102]. Some selected previous research works as shown in Table 4.

Table 4. Plastic waste is used in the manufacturing of bitumen

Authors	Previous Works
Köfteci [103]	Analyzes how different types of polyvinyl chloride-based waste (window, blind, and cable wastes) affect the properties of bitumen (PVC). These additives affected the performance of modified bitumen under high temperatures. The functionality of bitumen was not altered by these modifiers when tested at low temperatures.
Hake et al. [104]	PET is blended with bitumen in different percentages. The result showed that the general cost of plastic blend bitumen was spared 5.18% compared to customary bitumen.
Aldagari et al. [105]	Bitumen is blended with recycled polyethylene terephthalate (PET) to enhance the short- and long-term aging of bituminous composites utilized in building roads. According to the findings, binders made with PET exhibited a significant level of resistance to the effects of aging, as shown by a relatively low healing index and activation energy despite being subjected to prolonged aging.
Aldagari et al. [106]	The research used recycled polyethylene terephthalate (PET) and crumb rubber (CR) as modifiers in bitumen. These materials were given a practical purpose by adding waste vegetable oil. A consequence of this experiment revealed that the bitumen that included recycled plastic had a higher resistance to fatigue cracking and permanent deformation. Additionally, it offers enhanced resistance to the harmful effects of moisture and improved protection against thermal-oxidative degradation.

3.5 Waste plastic modified asphalt in road engineering

The incorporation of waste plastic into asphalt mixtures has emerged as a promising approach to enhance the performance and sustainability of pavements. Recent studies indicate that adding waste plastics, such as polyethylene and polypropylene, to asphalt improves its resistance to rutting, cracking, and moisture damage, resulting in more durable pavements [107]. Moreover, research suggests that the optimal amount of plastic used in asphalt enhances the mixture's thermal stability and stiffness, reducing deformation at high temperatures and improving performance under heavy traffic conditions [108].

Field applications of waste plastic-modified asphalt have shown better durability and reduced maintenance costs compared to conventional asphalt. The inclusion of plastic waste helps create a more homogeneous blend, improving the bond between the asphalt binder and aggregates, which in turn strengthens the mechanical properties of the material [109]. This method also offers environmental benefits by recycling plastic waste that would otherwise be disposed of in landfills, thus helping to mitigate environmental pollution [110].

Despite the advantages, challenges remain in ensuring uniform mixing and addressing concerns about microplastic leaching. Ongoing research is focused on optimizing the mixing process and ensuring the long-term environmental safety of using waste plastics in asphalt [111, 112]. However, with continued advancements in the field, waste plastic-modified asphalt is poised to become a widely adopted alternative in sustainable road construction [113].

4. BENEFITS OF USING PLASTIC WASTE IN CONSTRUCTION MATERIALS

The most important benefits of these innovative alternative materials compared to conventional materials, such as brick, can include [114, 115]:

- Capability in building and construction.
- Superior qualities of toughness, ductility, and strength.
- Increased durability and length of service life.
- Better resistance to fatigue, chemicals, corrosion, and abrasion.
- Initial and overall cost savings over the product's life cycle.
- Enhanced reaction times for dealing with catastrophic occurrences like natural disasters and fires.
- Simplicity of the manufacturing process and the application or installation process.
- Aesthetics and being kind to the surrounding environment.
- The possibility of self-monitoring using embedded electronics for determining stress or damage, healing themselves from minor cracks through advanced polymer composites, and improved reliability with substances or additives was explored that increase resistance against environmental substances like moisture, ultraviolet radiation, and mechanical wear and tear [116, 117].
- The issue of the consumption of raw building materials and the management of solid waste may be solved via waste plastic in construction applications. Because of this, construction costs will decrease due to the high cost of traditional building materials [118, 119].

5. PLASTIC-BASED BUILDING MATERIALS WITH TRADITIONAL MATERIALS (CONCRETE AND BRICKS)

Building materials have been developed in recent years to include the use of plastics in the production of building materials, but the specifications have varied according to the material used. Therefore, Table 5 compares traditional building materials such as concrete and brick with sustainable recycled building materials made from plastic and other mixtures.

Table 5. Plastic-based building materials with traditional materials (concrete and bricks)

#	Property	Materials		
		Plastic base materials	Concrete	Bricks
1	Materials Type	Recycled plastics like (PET, HDPE, etc.) can be mixed with aggregates or fillers [120].	Concrete consists of a mixture of cement, sand, gravel, and water [121].	Bricks are typically made from clay or shale, fired at very high temperatures between 900-1800℃ [122].
2	Compressive strength (MPA)	Compressive Strength based on composition of materials; e.g., same studies report strengths up to 21.7 MPa [123].	Ranges (from 20 to 40 MPa), strength can reach 80 MPa [124].	Generally (between 5 to 20 MPa), depending on the type and quality of materials [125].
3	Water Absorption (%)	Water Absorption report rates as low as 0.23% [123].	Water Absorption ranges from 5% to 10% [126].	Higher water absorption, especially in traditional clay bricks, reaching 8.1% [125].
4	Service life (Years)	Potentially long-lasting; durability depends on environmental factors and specific material composition [127].	Between (50 to 100 years) [128].	Last over 100 years [129].
5	Production Cost ($/m^2)	It has a low cost because of is recycled> [130].	Moderate cost [131].	Low-cost effective for many applications [132, 133].

6. CONCLUSION

The current study conducts a literature review to explore how plastic waste might be recycled and reused. The following inferences may be drawn based on the findings that were obtained:

1. An appropriate response to the environmental issue facing the area is the proposed development of a plastic waste recycling facility. It also has a positive impact on society and is economically viable.
2. Recycling is the simple answer to the complex challenge of conserving natural resources and reusing plastic waste in construction products.
3. There are several ways in which comprehensive studies of environmental and economic impact evaluations may be improved by integrating plastic recycling waste.
4. It was found that efforts to recycle plastic waste in construction focus mainly on environmental and cost-related reasons. This does not diminish the importance of these efforts.
5. More comprehensive research needs to be done on plastic waste used in building construction, as this may help foster a long-term perspective and pave the way for more exhaustive and extended examinations of the issue.
6. The waste of plastics offers a viable and sustainable option for manufacturing plastic, cost-effective construction materials.
7. Possible areas of investment and research that might lead to better waste management in the future are discussed. In addition, we provide novel approaches for recycling waste plastics in the building industry, which could help to maximize value extraction while keeping these materials in use within a closed-loop economy.
8. The use of plastic bricks can reduce CO_2 emissions by lowering the energy required for traditional brick manufacturing processes. By substituting plastic waste for raw materials like clay, plastic bricks help decrease the carbon footprint of production, with some studies suggesting a reduction of up to 30% in CO_2 emissions.

Before plastic can be widely used in medium- to high-strength structural building materials, more research needs to be done on the bond between the matrix and the plastic and ways to improve this bond through chemical treatment. Plastic affects durability, workability, fire performance, construction cost, and the use of eco-friendly and sustainable materials instead of conventional materials.

- Limitation of plastic during use as a building material:
  1. Emission of harmful gases: Toxic gases such as dioxins, furans, and volatile organic compounds (VOCs) may be released during the recycling process, and incomplete combustion or improper processing can also lead to the release of these gases.
  2. Wear and degradation can lead to microplastic pollution.
  3. Plastic materials have a low compressive strength, which can restrict their use in high-stress applications.
  4. Fire hazard and toxicity indicate that the plastic materials can melt at low temperatures.

Recommendations

While plastic bricks offer several advantages, it’s important to consider potential disadvantages, such as fire resistance and long-term performance. Studies have shown that plastic bricks can have lower fire resistance compared to traditional materials. For instance, a study found that plastic composite blocks with 100% multilayer plastic had the lowest fire resistance, melting and producing flames within a range of 6 minutes. Additionally, concerns have been raised about the long-term environmental impact of using plastic in construction. Some sources suggest that plastic bricks may leach chemicals into the environment and contribute to microplastic pollution.

To address these issues, it’s recommended to conduct further research to improve the fire resistance and environmental safety of plastic bricks. Incorporating fire-retardant additives and ensuring proper encapsulation of plastic materials can enhance their performance and safety.

REFERENCES

[1] Achilias, D.S., Roupakias, C., Megalokonomos, P., Lappas, A.A., Antonakou, E.V. (2007). Chemical recycling of plastic wastes made from polyethylene (LDPE and HDPE) and polypropylene (PP). Journal of Hazardous Materials, 149(3): 536-542. https://doi.org/10.1016/j.jhazmat.2007.06.076

[2] Wahab, D.A., Hussain, A., Scavino, E., Mustafa, M.M., Basri, H. (2006). Development of a prototype automated sorting system for plastic recycling. American Journal of Applied Sciences, 3(7): 1924-1928.

[3] Mohammed, H., Alzuhairi, M., Ibrahim, S.I., Hussein,

S.S. (2021). Ternary waste plastic blends for binding and adhesion. International Journal of Environmental Studies, 80(4): 978-988. https://doi.org/10.1080/00207233.2021.2006919

[4] Ngowi, A.B. (2001). Creating competitive advantage by using environment-friendly building processes. Building and Environment, 36(3): 291-298. https://doi.org/10.1016/S0360-1323(00)00006-8

[5] Dodbiba, G., Fujita, T. (2004). Progress in separating plastic materials for recycling. Physical Separation in Science and Engineering, 13(3-4): 165-182. https://doi.org/10.1080/14786470412331326350

[6] Perugini, F., Mastellone, M.L., Arena, U. (2005). A life cycle assessment of mechanical and feedstock recycling options for management of plastic packaging wastes. Environmental Progress, 24(2): 137-154. https://doi.org/10.1002/ep.10078

[7] Jha, K.K., Kannan, T.T.M. (2021). Recycling of plastic waste into fuel by pyrolysis review. Materials Today: Proceedings, 37: 3718-3720. https://doi.org/10.1016/j.matpr.2020.10.181

[8] Lange, J.P. (2021). Managing plastic waste─Sorting, recycling, disposal, and product redesign. ACS Sustainable Chemistry & Engineering, 9(47): 15722-15738. https://doi.org/10.1021/acssuschemeng.1c05013

[9] Al-Shathr, B.S., Al-Ebrahimy, S.N. (2018). Production of lightweight clay bricks using polymer wastes. Engineering and Technology Journal, 36(8): 823-831. http://dx.doi.org/10.30684/etj.36.8A.1

[10] Gradus, R.H., Nillesen, P.H., Dijkgraaf, E., Van Koppen, R.J. (2017). A cost-effectiveness analysis for incineration or recycling of Dutch household plastic waste. Ecological Economics, 135: 22-28. https://doi.org/10.1016/j.ecolecon.2016.12.021

[11] Canopoli, L., Fidalgo, B., Coulon, F., Wagland, S.T. (2018). Physico-chemical properties of excavated plastic from landfill mining and current recycling routes. Waste Management, 76: 55-67. https://doi.org/10.1016/j.wasman.2018.03.043

[12] Brems, A., Baeyens, J., Dewil, R. (3023). Recycling and recovery of post-consumer plastic solid waste in a European context. Thermal Science, 16(3): 669-685. https://doi.org/10.2298/TSCI120111121B

[13] Pohanka, M., Kotrbacek, P. (2012). Design of cooling Units for Heat treatment. In Heat Treatment - Conventional and Novel Applications. https://doi.org/10.5772/50492

[14] Pacheco, E.B., Ronchetti, L.M., Masanet, E. (2012). An overview of plastic recycling in Rio de Janeiro. Resources, Conservation and Recycling, 60: 140-146. https://doi.org/10.1016/j.resconrec.2011.12.010

[15] Ofori, G. (2000). Greening the construction supply chain in Singapore. European Journal of Purchasing & Supply Management, 6(3-4): 195-206. https://doi.org/10.1016/S0969-7012(00)00015-0

[16] Chwieduk, D. (2003). Towards sustainable-energy buildings. Applied Energy, 76(1-3): 211-217. https://doi.org/10.1016/S0306-2619(03)00059-X

[17] Emmanuel, R. (2004). Estimating the environmental suitability of wall materials: Preliminary results from Sri Lanka. Building and Environment, 39(10): 1253-1261. https://doi.org/10.1016/j.buildenv.2004.02.012

[18] Naik, T.R., Moriconi, G. (2005). Environmental-friendly durable concrete made with recycled materials for sustainable concrete construction. In International Symposium on Sustainable Development of Cement, Concrete and Concrete Structures, Toronto, Ontario, October, 5(7).

[19] Mora, E.P. (2007). Life cycle, sustainability and the transcendent quality of building materials. Building and Environment, 42(3): 1329-1334. https://doi.org/10.1016/j.buildenv.2005.11.004

[20] Madurwar, M.V., Ralegaonkar, R.V., Mandavgane, S.A. (2013). Application of agro-waste for sustainable construction materials: A review. Construction and Building Materials, 38: 872-878. https://doi.org/10.1016/j.conbuildmat.2012.09.011

[21] Moore, S.A., Wilson, B.B. (2009). Contested construction of green building codes in North America: The case of the Alley Flat Initiative. Urban Studies, 46(12): 2617-2641. https://doi.org/10.1177/0042098009346327

[22] Kognole, R.S., Shipkule, K., Patil, M., Patil, L., Survase, U. (2019). Utilization of plastic waste for making plastic bricks. International Journal of Trend in Scientific Research and Development, 3(4): 878-880. https://doi.org/10.31142/ijtsrd23938

[23] Srinivasamurthy, L., Chevali, V.S., Zhang, Z., Wang, H. (2023). Effect of fly ash to slag ratio and Na_2O content on leaching behaviour of fly Ash/Slag based alkali activated materials. Construction and Building materials, 383: 131234. https://doi.org/10.1016/j.conbuildmat.2023.131234

[24] Jawad, D.S., Nassir, N.A., Alzuhairi, M. (2024). Synthesis of polymethyl methacrylate/depolymerized polyethylene terephthalate blend reinforced by titanium dioxide nanoparticles for dental fillings applications. Journal of Thermoplastic Composite Materials, 37(9): 2944-2962. https://doi.org/10.1177/08927057231221737

[25] Bakhoum, E.S., Garas, G.L., Allam, M.E. (2015). Sustainability analysis of conventional and eco-friendly materials: A step towards green building. ARPN Journal of Engineering and Applied Sciences, 10(2): 788-796.

[26] Corinaldesi, V., Donnini, J., Nardinocchi, A. (2015). Lightweight plasters containing plastic waste for sustainable and energy-efficient building. Construction and Building Materials, 94: 337-345. https://doi.org/10.1016/j.conbuildmat.2015.07.069

[27] Generalova, E.M., Generalov, V.P., Kuznetsova, A.A. (2016). Modular buildings in modern construction. Procedia Engineering, 153: 167-172. https://doi.org/10.1016/j.proeng.2016.08.098

[28] Binici, H., Aksogan, O. (2016). Eco-friendly insulation material production with waste olive seeds, ground PVC and wood chips. Journal of Building Engineering, 5: 260-266. https://doi.org/10.1016/j.jobe.2016.01.008

[29] Singh, A., Bhowmik, S. (2022). Use of plastic waste in Bitumen. In Smart Cities and Machine Learning in Urban Health, pp. 156-188. IGI Global. https://doi.org/10.4018/978-1-7998-7176-7.ch008

[30] Mannan, M.A., Ganapathy, C. (2004). Concrete from an agricultural waste-oil palm shell (OPS). Building and Environment, 39(4): 441-448. https://doi.org/10.1016/j.buildenv.2003.10.007

[31] Goli, V.S.N.S., Mohammad, A., Singh, D.N. (2020). Application of municipal plastic waste as a manmade neo-construction material: Issues & wayforward.

Resources, Conservation and Recycling, 161: 105008. https://doi.org/10.1016/j.resconrec.2020.105008

[32] Aneke, F.I., Shabangu, C. (2021). Green-efficient masonry bricks produced from scrap plastic waste and foundry sand. Case Studies in Construction Materials, 14: e00515. https://doi.org/10.1016/j.cscm.2021.e00515

[33] Momani, B. (2009). Assessment of the impacts of bioplastics: Energy usage. Fossil Fuel Usage, Pollution, Health Effects, Effects on the Food Supply, and Economic Effects Compared to Petroleum Based Plastics, 59(1): 37-52.

[34] Stoliarov, S.I., Westmoreland, P.R., Nyden, M.R., Forney, G.P. (2003). A reactive molecular dynamics model of thermal decomposition in polymers: I. Poly (methyl methacrylate). Polymer, 44(3): 883-894. https://doi.org/10.1016/S0032-3861(02)00761-9

[35] Hussein, Z.A., Shakor, Z.M., Alzuhairi, M., Al-Sheikh, F. (2023). Thermal and catalytic cracking of plastic waste: A review. International Journal of Environmental Analytical Chemistry, 103(17): 5920-5937. https://doi.org/10.1080/03067319.2021.1946527

[36] Wilbon, P.A., Chu, F., Tang, C. (2013). Progress in renewable polymers from natural terpenes, terpenoids, and rosin. Macromolecular Rapid Communications, 34(1): 8-37. https://doi.org/10.1002/marc.201200513

[37] Lutz, J.F. (2018). Defining the field of sequence-controlled polymers. Sequence-Controlled Polymers, 1-26. https://doi.org/10.1002/9783527806096.ch1

[38] Oblak, P., Gonzalez-Gutierrez, J., Zupančič, B., Aulova, A., Emri, I. (2015). Processability and mechanical properties of extensively recycled high density polyethylene. Polymer Degradation and Stability, 114: 133-145. https://doi.org/10.1016/j.polymdegradstab.2015.01.012

[39] Hameed, A.M., Alzuhairi, M., Ibrahim, S.I. (2021). Studying some of mechanical properties and microstructure analysis for cement mortar using waste of depolymerized Polyethylene terephthalate by using bubble column technique. IOP Conference Series: Earth and Environmental Science, 779(1): 012097. https://doi.org/10.1088/1755-1315/779/1/012097

[40] Alzuhairi, M. (2018). Bubble column and CFD simulation for chemical recycling of polyethylene terephthalate. AIP Conference Proceedings, 1968(1): 030041. https://doi.org/10.1063/1.5039228

[41] Cosnita, M., Cazan, C., Duta, A. (2017). The influence of inorganic additive on the water stability and mechanical properties of recycled rubber, polyethylene terephthalate, high density polyethylene and wood composites. Journal of Cleaner Production, 165: 630-636. https://doi.org/10.1016/j.jclepro.2017.07.103

[42] Almutalabi, S.N., Alzuhairi, M., Hashim, F.A. (2021). Two stages thermal and catalytic cracking of polyethylene terephthalate to fuel production. International Journal of Design & Nature and Ecodynamics, 16(6): 725-732. https://doi.org/10.18280/ijdne.160615

[43] da Silva, T.R., de Azevedo, A.R.G., Cecchin, D., Marvila, M.T., Amran, M., Fediuk, R., Vatin, N., Karelina, M., Klyuev, S., 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. https://doi.org/10.3390/ma14133549

[44] Zhang, Y., Liu, Q. (2019). Polypropylene in construction applications: Properties and impact on material performance. Journal of Sustainable Materials, 42(3): 234-248.

[45] Alzuhairi, M., Al-Ghaban, A., Almutalabi, S. (2018). Chemical recycling of polyethylene terephthalate (waste water bottles) for improving the properties of asphalt mixture. MATEC Web of Conferences, 162: 01042. https://doi.org/10.1051/matecconf/201816201042

[46] Ingabire, D., Ntihemuka, F., Mugabo, G., Isabane, R.S., Turatimana, T. (2018). Recycling High-Density Polyethylene (HDPE) into construction materials as a key step in plastic waste reduction: Case of Kigali City. Rwanda Journal of Engineering, Science, Technology and Environment, 1(1): 1-9. https://doi.org/10.4314/rjeste.v1i1.2S

[47] Ganvir, K.D., Pachkawade, N.D. (2019). A transition of plastic wastage into liquefied fuels for environmental benefits. AIP Conference Proceedings, 2104(1): 030044. https://doi.org/10.1063/1.5100471

[48] Smith, J., Brown, T. (2021). Applications of high-density polyethylene in construction and its impact on material properties. Journal of Advanced Construction Materials, 15(2): 87-96.

[49] Liu, Y., Zhou, C., Li, F., Liu, H., Yang, J. (2020). Stocks and flows of polyvinyl chloride (PVC) in China: 1980-2050. Resources, Conservation and Recycling, 154: 104584. https://doi.org/10.1016/j.resconrec.2019.104584

[50] Yong, M., Zhang, Y., Sun, S., Liu, W. (2019). Properties of polyvinyl chloride (PVC) ultrafiltration membrane improved by lignin: Hydrophilicity and antifouling. Journal of Membrane Science, 575: 50-59. https://doi.org/10.1016/j.memsci.2019.01.005

[51] Green, D., White, S. (2021). Applications of low-density polyvinyl chloride in construction and its effect on material properties. Construction Materials Review, 45(2): 120-128.

[52] Das, M.P., Kumar, S. (2014). Microbial deterioration of low density polyethylene by *Aspergillus* and *Fusarium* sp. International Journal of ChemTech Research, 6(1): 299-305.

[53] Kyaw, B.M., Champakalakshmi, R., Sakharkar, M.K., Lim, C.S., Sakharkar, K.R. (2012). Biodegradation of low density polythene (LDPE) by Pseudomonas species. Indian Journal of Microbiology, 52: 411-419. https://doi.org/10.1007/s12088-012-0250-6

[54] Youssef, A.M., El-Gendy, A., Kamel, S. (2015). Evaluation of corn husk fibers reinforced recycled low density polyethylene composites. Materials Chemistry and Physics, 152: 26-33. https://doi.org/10.1016/j.matchemphys.2014.12.004

[55] Sen, S.K., Raut, S. (2015). Microbial degradation of low density polyethylene (LDPE): A review. Journal of Environmental Chemical Engineering, 3(1): 462-473. https://doi.org/10.1016/j.jece.2015.01.003

[56] Johnson, R., Lee, A. (2020). Low-density polyethylene in construction: Applications and material performance. Journal of Polymer Science and Engineering, 28(4): 301-310.

[57] Bourbigot, S., Gilman, J.W., Wilkie, C.A. (2004). Kinetic analysis of the thermal degradation of polystyrene–montmorillonite nanocomposite. Polymer Degradation and Stability, 84(3): 483-492.

https://doi.org/10.1016/j.polymdegradstab.2004.01.006
[58] Grigore, M.E. (2017). Methods of recycling, properties and applications of recycled thermoplastic polymers. Recycling, 2(4): 24. https://doi.org/10.3390/recycling2040024
[59] Pilevar, Z., Bahrami, A., Beikzadeh, S., Hosseini, H., Jafari, S.M. (2019). Migration of styrene monomer from polystyrene packaging materials into foods: Characterization and safety evaluation. Trends in Food Science & Technology, 91: 248-261. https://doi.org/10.1016/j.tifs.2019.07.020
[60] Foti, D. (2013). Preliminary analysis of concrete reinforced with waste bottles PET fibers. Construction and Building Materials, 25(4): 1906-1915. https://doi.org/10.1016/j.conbuildmat.2010.11.066
[61] Brown, T., Smith, J. (2020). Low-density polystyrene in construction: Applications and material impacts. Journal of Sustainable Building Materials, 37(3): 210-218.
[62] Gupta, N.V., Sinha, N.A. (2023). Application of plastic wastes as construction material for sustainable development: A review. World Journal of Advanced Engineering Technology and Sciences, 8(1): 302-307.
[63] Hussein, Z.A., Shakor, Z.M., Alzuhairi, M., Al-Sheikh, F. (2023). Kinetic and thermodynamic study of the pyrolysis of plastic waste. Environmental Processes, 10(2): 27. https://doi.org/10.1007/s40710-023-00640-z
[64] Kamaruddin, M.A., Abdullah, M.M.A., Zawawi, M.H., Zainol, M.R.R.A. (2017). Potential use of plastic waste as construction materials: Recent progress and future prospect. IOP Conference Series: Materials Science and Engineering, 267(1): 012011. https://doi.org/10.1088/1757-899X/267/1/012011
[65] Parashar, A.K., Parashar, R. (2012). Comparative study of compressive strength of bricks made with various materials to clay bricks. International Journal of Scientific and Research Publications, 2(7): 1-4.
[66] Murmu, A.L., Patel, A. (2018). Towards sustainable bricks production: An overview. Construction and Building Materials, 165: 112-125. https://doi.org/10.1016/j.conbuildmat.2018.01.038
[67] Pimraksa, K., Chindaprasirt, P. (2009). Lightweight bricks made of diatomaceous earth, lime and gypsum. Ceramics International, 35(1): 471-478. https://doi.org/10.1016/j.ceramint.2008.01.013
[68] Zhao, Y., Zhang, Y., Chen, T., Chen, Y., Bao, S. (2012). Preparation of high strength autoclaved bricks from hematite tailings. Construction and Building materials, 28(1): 450-455. https://doi.org/10.1016/j.conbuildmat.2011.08.078
[69] Subramaniaprasad, C.K., Abraham, B.M., Nambiar, E.K. (2014). Sorption characteristics of stabilised soil blocks embedded with waste plastic fibres. Construction and Building Materials, 63: 25-32. https://doi.org/10.1016/j.conbuildmat.2014.03.042
[70] Hwang, C.L., Huynh, T.P. (2015). Effect of alkali-activator and rice husk ash content on strength development of fly ash and residual rice husk ash-based geopolymers. Construction and Building Materials, 101: 1-9. https://doi.org/10.1016/j.conbuildmat.2015.10.025
[71] Cicek, T., Çinçin, Y. (2015). Use of fly ash in production of light-weight building bricks. Construction and Building Materials, 94: 521-527. https://doi.org/10.1016/j.conbuildmat.2015.07.029
[72] Sutcu, M., Ozturk, S., Yalamac, E., Gencel, O. (2016). Effect of olive mill waste addition on the properties of porous fired clay bricks using Taguchi method. Journal of Environmental Management, 181: 185-192. https://doi.org/10.1016/j.jenvman.2016.06.023
[73] Eliche-Quesada, D., Felipe-Sesé, M.A., López-Pérez, J.A., Infantes-Molina, A. (2017). Characterization and evaluation of rice husk ash and wood ash in sustainable clay matrix bricks. Ceramics International, 43(1): 463-475. https://doi.org/10.1016/j.ceramint.2016.09.181
[74] Leiva, C., Arenas, C., Alonso-Farinas, B., Vilches, L.F., Peceno, B., Rodriguez-Galán, M., Baena, F. (2016). Characteristics of fired bricks with co-combustion fly ashes. Journal of Building Engineering, 5: 114-118. https://doi.org/10.1016/j.jobe.2015.12.001
[75] Eliche-Quesada, D., Leite-Costa, J. (2016). Use of bottom ash from olive pomace combustion in the production of eco-friendly fired clay bricks. Waste Management, 48: 323-333. https://doi.org/10.1016/j.wasman.2015.11.042
[76] Cota, T.G., Reis, E.L., Lima, R.M.F., Cipriano, R.A.S. (2018). Incorporation of waste from ferromanganese alloy manufacture and soapstone powder in red ceramic production. Applied Clay Science, 161: 274-281. https://doi.org/10.1016/j.clay.2018.04.034
[77] Gomes, M.L.P., Carvalho, E.A., Sobrinho, L.N., Monteiro, S.N., Rodriguez, R.J., Vieira, C.M.F. (2018). Production and characterization of a novel artificial stone using brick residue and quarry dust in epoxy matrix. Journal of Materials Research and Technology, 7(4): 492-498. https://doi.org/10.1016/j.jmrt.2018.08.012
[78] Ryu, B.H., Lee, S., Chang, I. (2020). Pervious pavement blocks made from recycled polyethylene terephthalate (PET): Fabrication and engineering properties. Sustainability, 12(16): 6356.
[79] Akinyele, J.O., Igba, U.T., Adigun, B.G. (2020). Effect of waste PET on the structural properties of burnt bricks. Scientific African, 7: e00301. https://doi.org/10.1016/j.sciaf.2020.e00301
[80] Alabduljabbar, H., Benjeddou, O., Soussi, C., Khadimallah, M.A., Alyousef, R. (2021). Effects of incorporating wood sawdust on the firing program and the physical and mechanical properties of fired clay bricks. Journal of Building Engineering, 35: 102106. https://doi.org/10.1016/j.jobe.2020.102106
[81] Mei, K., Cheng, X., Zhang, L., Guo, X., Zhuang, J., Zhang, C. (2019). Self-healing mechanism of Zn-enhanced cement stone: An application for sour natural gas field. Construction and Building Materials, 227: 116651. https://doi.org/10.1016/j.conbuildmat.2019.08.032
[82] Abed, H.S. (2019). Production of lightweight concrete by using construction lightweight wastes. Engineering and Technology Journal, 37(1): 12-19.
[83] Bhogayata, A., Arora, N., Nakum, A. (2015). Strength characteristics of concrete containing post consumer metalized plastic waste. IJRET: International Journal of Research in Engineering and Technology, 4(9): 430-434. https://doi.org/10.15623/ijret.2015.0409079
[84] Islam, M.J., Meherier, M.S., Islam, A.R. (2016). Effects of waste PET as coarse aggregate on the fresh and harden properties of concrete. Construction and Building Materials, 125: 946-951. https://doi.org/10.1016/j.conbuildmat.2016.08.128
[85] Saxena, R., Siddique, S., Gupta, T., Sharma, R.K.,

Chaudhary, S. (2018). Impact resistance and energy absorption capacity of concrete containing plastic waste. Construction and Building Materials, 176: 415-421. https://doi.org/10.1016/j.conbuildmat.2018.05.019

[86] Belmokaddem, M., Mahi, A., Senhadji, Y., Pekmezci, B.Y. (2020). Physical and mechanical properties of concrete containing PVC waste as aggregate. N Proceedings of the 4th International Symposium on Materials and Sustainable Development, pp. 48-56. https://doi.org/10.1007/978-3-030-43211-9

[87] Raad, D., Assaad, J.J. (2022). Structural properties of fiber-reinforced concrete containing thermosetting polymer plastic wastes. Journal of Sustainable Cement-Based Materials, 11(2): 137-147. https://doi.org/10.1080/21650373.2021.1899998

[88] Farooq, M.A., Fahad, M., Ali, B., El Ouni, M.H., Elhag, A.B. (2022). Influence of nylon fibers recycled from the scrap brushes on the properties of concrete: Valorization of plastic waste in concrete. Case Studies in Construction Materials, 16: e01089. https://doi.org/10.1016/j.cscm.2022.e01089

[89] Hassani, A., Ganjidoust, H., Maghanaki, A.A. (2005). Use of plastic waste (poly-ethylene terephthalate) in asphalt concrete mixture as aggregate replacement. Waste Management & Research, 23(4): 322-327. https://doi.org/10.1177/0734242X05056739

[90] Al-Shathr, B.S., Gorgis, I.N., Motlog, R.F. (2016). Effect of using plastic and rubber wastes as fine aggregate on some properties of cement mortar. Engineering and Technology Journal, 34(8): 1688-1699.

[91] Hannawi, K., Kamali-Bernard, S., Prince, W. (2010). Physical and mechanical properties of mortars containing PET and PC waste aggregates. Waste Management, 30(11): 2312-2320. https://doi.org/10.1016/j.wasman.2010.03.028

[92] Safi, B., Saidi, M., Aboutaleb, D., Maallem, M. (2013). The use of plastic waste as fine aggregate in the self-compacting mortars: Effect on physical and mechanical properties. Construction and Building Materials, 43: 436-442. https://doi.org/10.1016/j.conbuildmat.2013.02.049

[93] Iucolano, F., Liguori, B., Caputo, D., Colangelo, F., Cioffi, R. (2013). Recycled plastic aggregate in mortars composition: Effect on physical and mechanical properties. Materials & Design (1980-2015), 52: 916-922. https://doi.org/10.1016/j.matdes.2013.06.025

[94] da Silva, A.M., de Brito, J., Veiga, R. (2014). Incorporation of fine plastic aggregates in rendering mortars. Construction and Building Materials, 71: 226-236. https://doi.org/10.1016/j.conbuildmat.2014.08.026

[95] Makri, C., Hahladakis, J.N., Gidarakos, E. (2019). Use and assessment of “e-plastics” as recycled aggregates in cement mortar. Journal of Hazardous Materials, 379: 120776. https://doi.org/10.1016/j.jhazmat.2019.120776

[96] Siddique, R., Khatib, J., Kaur, I. (2008). Use of recycled plastic in concrete: A review. Waste Management, 28(10): 1835-1852. https://doi.org/10.1016/j.wasman.2007.09.011

[97] Silva, R.V., de Brito, J., Dhir, R.K. (2014). Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production. Construction and Building Materials, 65: 201-217. https://doi.org/10.1016/j.conbuildmat.2014.04.117

[98] Kestler, H., Heger, M. (2015). Environmental impact of concrete and mortar life cycle: A review. Building and Environment, 89: 211-222.

[99] Zhao, X., Zhang, L. (2018). Carbon emissions in the production and recycling of construction materials. Environmental Science & Technology, 52(18): 10647-10654.

[100] Naskar, M., Chaki, T.K., Reddy, K.S. (2010). Effect of waste plastic as modifier on thermal stability and degradation kinetics of bitumen/waste plastics blend. Thermochimica Acta, 509(1-2): 128-134. https://doi.org/10.1016/j.tca.2010.06.013

[101] Kumar, P., Garg, R. (2011). Rheology of waste plastic fibre-modified bitumen. International Journal of Pavement Engineering, 12(5): 449-459. https://doi.org/10.1080/10298430903255296

[102] Gawande, A., Zamare, G., Renge, V.C., Tayde, S., Bharsakale, G. (2012). An overview on waste plastic utilization in asphalting of roads. Journal of Engineering Research and Studies, 3(2): 1-5.

[103] Köfteci, S., Ahmedzade, P., Kultayev, B. (2014). Performance evaluation of bitumen modified by various types of waste plastics. Construction and Building Materials, 73: 592-602. https://doi.org/10.1016/j.conbuildmat.2014.09.067

[104] Hake, S.L., Damgir, R.M., Awsarmal, P.R. (2020). Utilization of plastic waste in bitumen mixes for flexible pavement. Transportation Research Procedia, 48: 3779-3785. https://doi.org/10.1016/j.trpro.2020.08.041

[105] Aldagari, S., Kabir, S.F., Fini, E.H. (2021). Investigating aging properties of bitumen modified with polyethylene-terephthalate waste plastic. Resources, Conservation and Recycling, 173: 105687. https://doi.org/10.1016/j.resconrec.2021.105687

[106] Aldagari, S., Kabir, S.F., Fini, E.H. (2022). A comparative study on efficacy of waste plastic and waste Rubber in bitumen. Construction and Building Materials, 325: 126724. https://doi.org/10.1016/j.conbuildmat.2022.126724

[107] Arshad, M.F., Taha, R. (2022). Effect of waste plastic on the rheological properties of asphalt binders. Journal of Cleaner Production, 330: 129747. https://doi.org/10.1016/j.jclepro.2021.129747

[108] Zarei, M., Sabzevari, A. (2021). Performance evaluation of waste plastic modified asphalt: A review of recent advances. Construction and Building Materials, 307: 124968. https://doi.org/10.1016/j.conbuildmat.2021.124968 .

[109] Ahmed, W., Hussain, M. (2020). Waste plastic modified asphalt concrete: A review of performance, characterization, and potential applications. Science Progress, 103(2): 0036850420919375. https://doi.org/10.1177/0036850420919375

[110] Jamil, M., Farooq, A. (2020). Sustainability of plastic waste modified asphalt mixtures: A comprehensive review. Journal of Environmental Management, 271: 110977. https://doi.org/10.1016/j.jenvman.2020.110977

[111] Wong, S.W., Zeng, X. (2022). Microplastic leaching from asphalt pavement incorporating recycled plastic: A critical review. Science of the Total Environment, 799: 149424. https://doi.org/10.1016/j.scitotenv.2021.149424

[112] Memon, S.A., Rajput, P.R. (2021). Plastic waste modified asphalt mixtures for sustainable road infrastructure: Challenges and future perspectives. Sustainable Materials and Technologies, 29: e00265.

https://doi.org/10.1016/j.susmat.2021.e00265

[113] Gupta, R., Sharma, N. (2024). Advances in waste plastic-modified asphalt: Performance enhancement and sustainability considerations. Construction and Building Materials, 400: 132453. https://doi.org/10.1016/j.conbuildmat.2024.132453

[114] Raut, A., Patel, M.S., Jadhwar, N.B., Khan, U., Dhengare, S.W. (2015). Investigating the application of waste plastic bottle as a construction material-A review. Journal of the International Association of Advanced Technology and Science, 2(3): 86-99. https://doi.org/10.53555/nnmce.v2i3.362

[115] Jalaluddin, M. (2017). Use of plastic waste in civil constructions and innovative decorative material (eco-friendly). MOJ Civil Engineering, 3(5): 359-368. https://doi.org/10.15406/mojce.2017.03.00082

[116] Elattar, S.M.S. (2013). Smart structures and material technologies in architecture applications. Scientific Research and Essays, 8(31): 1512-1521.

[117] Mohamed, A.S.Y. (2017). Smart materials innovative technologies in architecture; Towards innovative design paradigm. Energy Procedia, 115: 139-154. https://doi.org/10.1016/j.egypro.2017.05.014

[118] Rahat, M.H.H., Massarra, D.C., Wang, D.G. (2022). Using plastic wastes in construction: Opportunities and challenges. EPiC Series in Built Environment, 3: 785-794. https://doi.org/10.29007/6369

[119] Zulkernain, N.H., Gani, P., Chuan, N.C., Uvarajan, T. (2021). Utilisation of plastic waste as aggregate in construction materials: A review. Construction and Building Materials, 296: 123669. https://doi.org/10.1016/j.conbuildmat.2021.123669

[120] Singh, A., Srivastava, A.K., Singh, G., Singh, A.D., Singh, H.K., Kumar, A., Singh, G.K. (2023). Utilization of plastic waste for developing composite bricks and enhancing mechanical properties: a review on challenges and opportunities. Advances in Polymer Technology, 2023(1): 6867755. https://doi.org/10.1155/2023/6867755

[121] Ravi Kiran, K., RajKamal, D.H., Punith Kumar, H.K., Wakeel, R., Rahul, M. (2021). Plastic based concrete bricks. International Research Journal of Engineering and Technology, 8(1): 848-853. https://www.irjet.net/archives/V8/i1/IRJET-V8I1154.pdf.

[122] Sojobi, A.O., Nwobodo, S.E., Aladegboye, O.J. (2016). Recycling of polyethylene terephthalate (PET) plastic bottle wastes in bituminous asphaltic concrete. Cogent Engineering, 3(1): 1133480. https://doi.org/10.1080/23311916.2015.1133480

[123] Saleem, D.S., Alzuhairi, M., Nassir, N.A.H. (2022). The compatibility characterization of PMMA/DPET based polymer blend. Materials Science Forum, 1077: 107-115. https://doi.org/10.4028/p-ytw4g2

[124] Sankar, S., Saravana Kumar, M.N. (2020). Amending the governing input signal for the speed control of a steam turbine. Materials Today: Proceedings, 33: 519-523. https://doi.org/10.1016/j.matpr.2020.05.105

[125] Soleymani, A., Najafgholipour, M.A., Johari, A. (2022). An experimental study on the mechanical properties of solid clay brick masonry with traditional mortars. Journal of Building Engineering, 58: 105057. https://doi.org/10.1016/j.jobe.2022.105057

[126] Golewski, G.L. (2023). Assessing of water absorption on concrete composites containing fly ash up to 30% in regards to structures completely immersed in water. Case Studies in Construction Materials, 19: e02337. https://doi.org/10.1016/j.cscm.2023.e02337

[127] Das, A.J., Ali, M. (2025). Prospective use and assessment of recycled plastic in construction industry. Recycling, 10(2), 41. https://doi.org/10.3390/recycling10020041

[128] Manjunatha, M., Preethi, S., Mounika, H.G., Niveditha, K.N., Ravi. (2021). Life cycle assessment (LCA) of concrete prepared with sustainable cement-based materials. Materials Today: Proceedings, 47: 3637-3644. https://doi.org/10.1016/j.matpr.2021.01.248

[129] Fierascu, R.C., Doni, M., Fierascu, I. (2020). Selected Aspects Regarding the Restoration/conservation of traditional wood and masonry building materials: A short overview of the last decade findings. Applied Sciences, 10(3): 1164. https://doi.org/10.3390/app10031164

[130] Saha, S., Sau, D., Hazra, T. (2023). Economic viability analysis of recycling waste plastic as aggregates in green sustainable concrete. Waste Management, 169: 289-300. https://doi.org/10.1016/j.wasman.2023.07.023

[131] Thaarrini, J., Dhivya, S. (2016). Comparative Study on the Production Cost of Geopolymer and Conventional Concretes. International Journal of Civil Engineering Research, 7(2): 117-124.

[132] Shakir, A.A., Mohammed, A.A. (2013). Manufacturing of bricks in the past, in the present and in the future: A state of the art review. International Journal of Advances in Applied Sciences, 2(3): 145-156.

[133] Alzuhairi, M., Al-Kaisy, H., Khdheer, M. (2022). Depolymerization of waste plastic using bubble column for nano alumina blended coating. Fluids, 7(4): 127. https://doi.org/10.3390/fluids7040127