Hindawi
Advances in Polymer Technology
Volume 2023, Article ID 6867755, 24 pages
https://doi.org/10.1155/2023/6867755

*Review Article*

# Utilization of Plastic Waste for Developing Composite Bricks and Enhancing Mechanical Properties: A Review on Challenges and Opportunities

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Received 5 January 2023; Revised 4 April 2023; Accepted 15 April 2023; Published 2 May 2023

Academic Editor: Minna Hakkarainen



The population increases demand for plastic in every sector along with single-use plastic rapidly increasing, but it still has a low recycling rate. The use of plastic in the form of brick is challenging and overall has a better impact on the ecosystem, economy, and industrial revolution. In this paper, a study has been done of the available research work on plastic bricks from different plastic waste materials. It discusses the processes used to make bricks from plastic waste materials, the possibility of contamination from the waste materials utilized, the lack of pertinent standards, and the public adoption of waste materials-based bricks. Furthermore, it focused on research and development required for the widespread production and use of bricks made from waste materials, not only in terms of technical, economic, and environmental considerations but also in terms of standardization, governmental policy, and public awareness of waste recycling and sustainable development. It has been observed from the study that PET has mostly recycled plastic with greater efficiency compared to other plastics. However, worldwide global production is followed by PE, PVC, and PP. PET has only 5% contribution to the global recycling of plastics.

## 1. Introduction

The introduction of hazardous elements into the ecosystem is known as pollution. These dangerous compounds are classified as pollutants. Natural pollutants, like volcanic ash, are possible. They may also be generated by individuals, such as waste or runoff from the industry. Air, water, and land are all harmed by pollution [1]. The availability of air, water, and land on the globe is essential to all living things, ranging in size from single-celled microorganisms to blue whales. All living creatures risk pandemonium when their resources are polluted. The problem of pollution is global. Even though cities are typically more polluted than rural areas, pollution can occur in remote areas where no humans live. The basic types of pollution are shown in Figure 1.

Plastic has an impact on the air, land, and water. Plastic is treated as soil pollution when it is thrown away in landfills, air pollution when it is incinerated, and water pollution when it is dumped. Most environmental diseases and early deaths are caused by pollutants [2–4]. Most underdeveloped countries, where recycling is ineffective, exhibit plastic pollution. But advanced nations also struggle with properly managing waste plastic because of a lack of composting and facilities [5]. Single-use plastic bags frequently wind up in soil and waterbodies and take an average of 1,000 years to completely degrade [6–8]. Plastic degrades in landfills due to a variety of variables, including moisture, sunlight, temperature, and biological activity. In dumps, polyethylene deteriorates as a result of chemical, thermal, biological, and photochemical processes [9]. We have developed a dependence on one-time-use

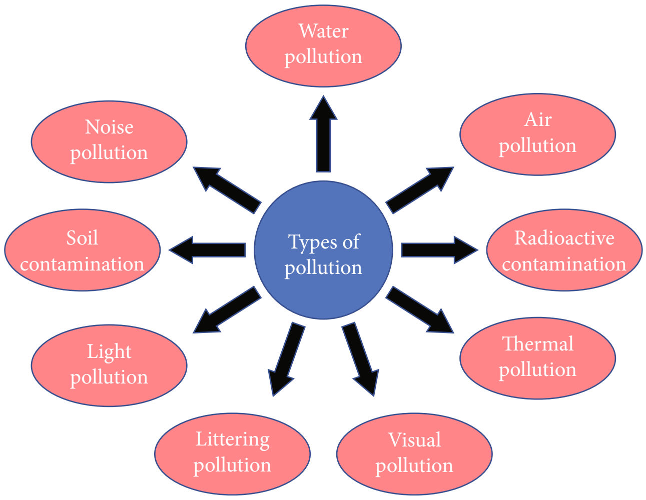


Figure 1: Types of pollution.

products with terrible consequences for the environment, society, economy, and our health. Various admixtures in plastic reflect serious issues with the environment and health [10].

Polymers are artificial materials made from fossil fuels that are used in a variety of ways in our daily lives. Due to polymers' flexibility over the past few decades, demand for them has rapidly grown. Plastic resins use about 10% of the annual petroleum produced worldwide; 4% is used as raw material, and 6% is used as fuel or energy during production [11]. A polymer is something composed of multiple units, according to the most basic description. Molecule chains make up polymers. Typically, silicon, hydrogen, oxygen, and carbon are used to create each link in the chain. Many links are hooked or polymerized together to form the chain [12, 13]. Petroleum and other materials are heated under precise control to break down into smaller molecules known as monomers, which are then used to make polymers. Plastic resins with various properties, such as strength or molding capacity, are created by mixing various monomer combinations [14].

By 2021, annual production has increased by about 4.2 times from 1988 reaching 399 million tonnes. About 7.7 billion tonnes of plastic was produced cumulatively between 1988 and 2021, or around a couple of tonnes of plastic for every person alive today. Only a modest amount of plastic was produced between 1950 and 1988; thus, waste plastic was relatively plausible [15]. Today, we generate roughly 400 million tonnes of plastic garbage annually [15].

Since 1970, the rate of plastic manufacture has increased more rapidly than the rate of several other materials. Ninety-five million tonnes of plastic per year was generated in 1988 whereas in 2020, the rate of growth stopped, in significant part due to the COVID-19 pandemic's negative effects on demand [16]. According to forecasts, 12,000 MT of plastic garbage would wind up in landfills by the year 2050 if past boom trends continue [16]. Global plastic garbage increased by more than three times to 299 million tonnes between 1988 and 2021. The recycling rate is still low. Even so, recycling only makes up a relatively minor fraction of waste. The global plastic production and waste generation are shown in Figure 2.

According to estimates from 2021, Asia has the highest production rates, accounting for 49% of the world's total output, with China being the top worldwide producer by 32%, followed by Europe and North America, with 15% and 19% whereas the remaining countries are followed with less significance in terms of plastic consumption [17]. Based on the study, the global plastic pollution rate is shown in Figure 3.

PVC (16%), PP (20%), and PE (33%) are the nonfiber plastic that has been produced in a large frame, observed with the aid of PS, PET, and PUR (<18% each). These seven groups belong to the family of thermoplastic which has a total 87% contribution toward the plastic family. The ultimate 13% is thermosetting polymers [18]. For packaging purposes, about 36% of nonfiber plastics are used. Predominantly, PET, PP, and PE are used for the motive. 69% of all PVCs are used in the building and construction sector, while PVC has a percentage of 16% of all plastics in the exceptional sector, which is the next largest consuming sector. 12% of all nonfiber plastics are used in textiles, and others are accompanied with the aid of 10% in consumer and industrial products, 7% in transportation, 4% in electrical and electronics, 1% in industrial machinery, and the ultimate 14% in other sectors [16]. Plastic consumption as per resin and its share in different sectors are shown in Figure 4.

Among all the packing waste, 14% is incinerated for power recycling in industries, 40% is gone to landfills, 14% is amassed and recycled, and the rest of 32% is leaked into the ecosystem [19]. The overall contribution of packing waste to nature is shown in Figure 5.

*1.1. Classification of Plastics and Their Properties.* The two primary types of plastic are thermosetting and thermoplastic. While thermosetting plastics are irreversible, thermoplastics are reversible. Thermoplastic can be repeatedly frozen, reheated, and molded. Thermosetting plastics cannot be remelted and reformed again and again, as they develop a three-dimensional community. Examples of thermoplastics and thermosetting plastic are shown in Figure 6 [20–22].

There are certain properties to differentiate thermoplastic and thermosetting plastics. The separation is done based on their definition, nature, process, strength, recyclability, shape, advantages, and disadvantages. The basic characteristics of thermoplastics are shown in Table 1, and the basic difference between thermoplastics and thermosetting plastics is shown in Figure 7.

*1.2. Impact of Plastics.* Plastic wastes incorporate harmful chemicals that are released into the surroundings in the form of components such as additives which cause an adverse effect on human health [23–25]. These polymers are often landfilled along with municipal solid trash when their useful lives are through [20, 21]. Phthalates, polyfluorinated compounds, bisphenol A (BPA), brominated flame retardants, and antimony trioxide are just a few of the harmful components found in plastics that can seep out and harm the environment and people's health [10, 22, 26–28]. The basic additives with different plastics with their impact on life forms are shown in Figure 8. The threat posed by plastic

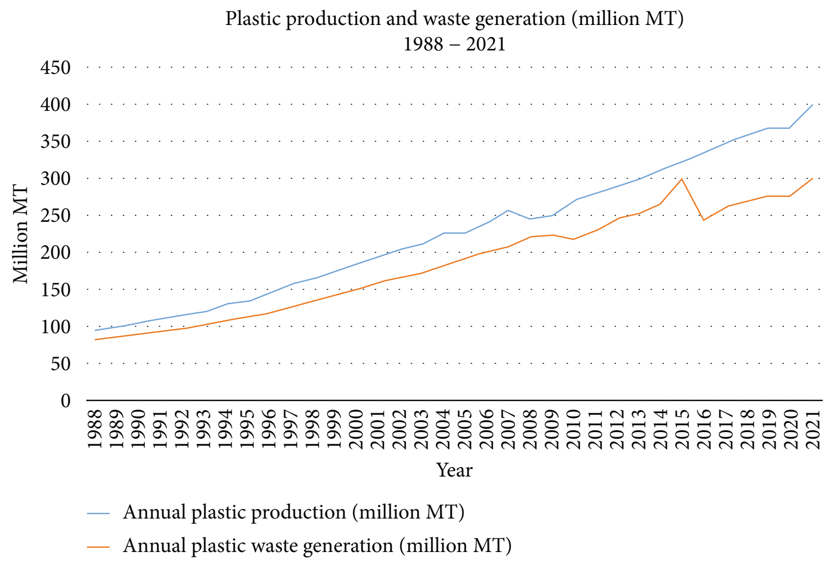


Figure 2: Plastic production and waste generation (million MT).

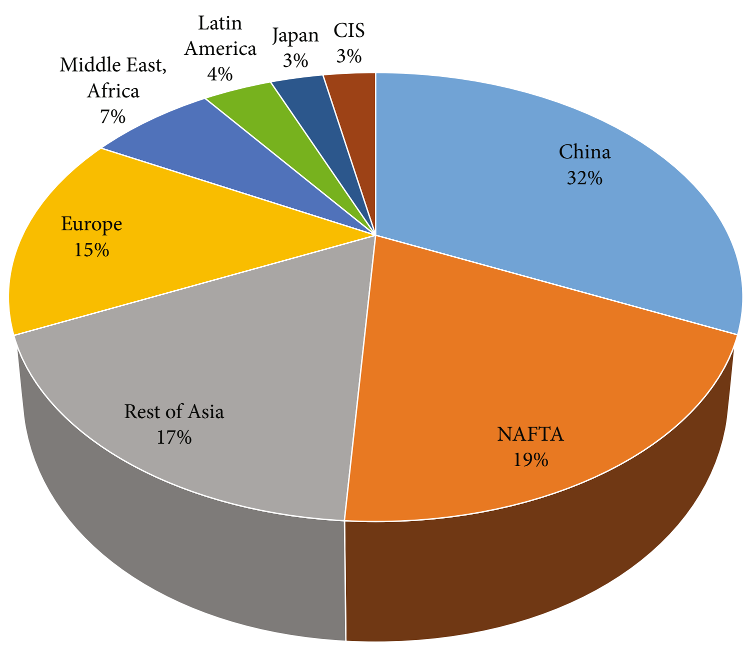


Figure 3: Global plastic consumption rate.

pollution to seabirds is widespread, persistent, and increasing [29–31]. Microplastics have now been discovered in human blood [32–34]. Microplastics are detected in the human lungs [35–37]. According to several researches, plastic elements may have an impact on neurological growth and reproductive processes [38–40]. Some researchers have found evidence of plastic in the soil in the nano- or microform, with effects on soil constituents, soil microorganisms, plant biomass, and proteins in the plant's leaves and stems [41–43]. We are aware of how plastic affects global warming and greenhouse gas emissions [18, 44–47]. The main danger to the ocean life and carbon fixation process [48–52] enters the scene, which is a global threat.

*1.3. Plastic Management in India.* Plastic is classified into two groups: one is recyclable (94% of the overall plastic generation in India is thermoplastics), while the other is nonrecyclable (6% of the overall generation in India is thermoset plastic) [53]. It is to be found that 94% of overall recyclable plastic includes 67% HDPE and LDPE, 10% PP, 9% PET, and 4% each of PVC and PS. The remaining 6% of the thermoset group is followed by sheet molded composite, fiber-reinforced plastic, and multilayered and expanded polystyrene [54]. The classification of plastics as per recyclability and resin in India is shown in Figure 9. The annual plastic consumption is 5 million tonnes/year in 2005, which rose to 8 million tonnes/year in 2008, and is estimated to be

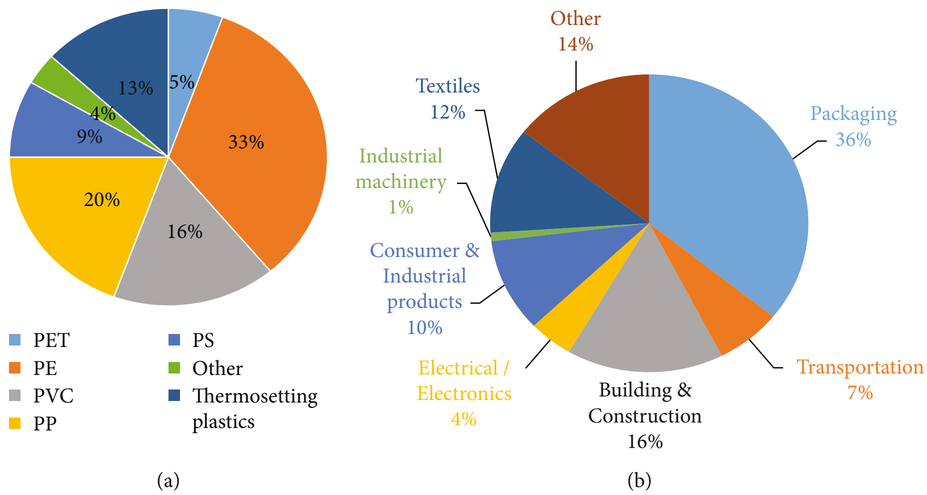


Figure 4: (a) Plastic consumption as per resin with (b) share in different sectors.

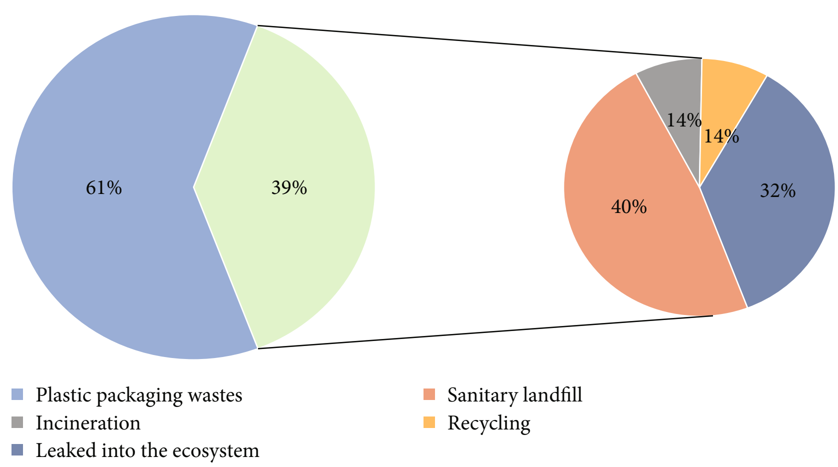


Figure 5: Plastic packaging waste by regions.

further increased to 24 million tonnes/year by 2020 [55]. According to the government of India, the per capita consumption in India in 2022 would increase to 20 kg annually [56]. A study published in 2015, according to the Central Pollution Control Board (CPCB), suggests that around 1.28 million tonnes of plastic is generated each year in India out of which 0.77 million tonnes of plastic is recycled and 0.51 million tonnes of plastic remains uncollected or littered [57]. According to the report of CPCB for the years 2018-2019, the total waste generation in India is about 9.46 million tonnes each year. However, the cities with major plastic waste generated are shown in Figure 10 [58].

It is estimated that India contributes to the marine environment by discarding 0.09-0.24 million tonnes of plastics each year into the ocean [59]. Plastic wastes that cannot be recycled are used as building materials for roadways or for energy recovery, according to the PWM Rules, 2016. In India, it is standard practice to use plastic waste as an alternative fuel in cement kilns to recover energy. The Cement Manufacturers Association (CMA) claims that by cutting the cost of conventional fuel used in the cement business by about 20%, single-use plastics can be used as an alternative fuel [60]. 4,773 registered plastic manufacturing/recycling units, including 7 compostable plants, and 1,084 unregistered plastic manufacturing/recycling sectors were used to handle such a large amount of plastic waste. Even though the municipalities and unorganized sectors make regular efforts to recycle plastic waste, some of it still winds up in landfills [61].

*1.4. History of Bricks.* For a very long time, bricks have been a crucial component of construction and building materials. In 8300-7600 B.C. (at the time of neolith), the first dried clay bricks were used having the dimension of $260 \times 100 \times 100$ mm. Unfired brick production began between 3100 and 2900 B.C. with the help of hot weather, and in 604–562 B.C., the first burnt clay bricks were utilized [62].

*1.4.1. Clay Brick.* Clay and water are the primary ingredients of traditional bricks. Due to their production from clay and kiln firing at high temperatures, conventional bricks have a high embodied energy and a considerable carbon footprint. They can also be constructed using Ordinary Portland Cement (OPC) concrete [63]. Many regions of the world

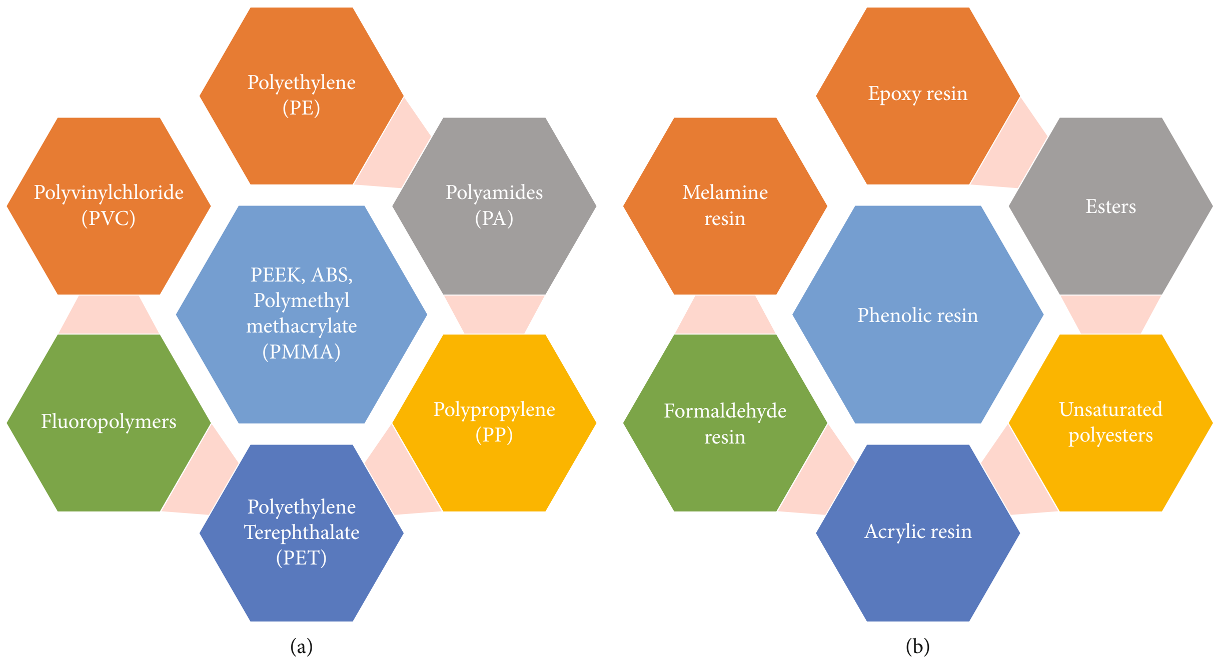


Figure 6: Examples of (a) thermoplastics and (b) thermosetting plastics.

Table 1: Plastic types with their characterization.

| Plastic type | Short name | Characteristics |
|---|---|---|
| Polyethylene terephthalates | PET | Clear, tough, solvent-resistant, the barrier to gas and moisture, softens at 80°C |
| High-density polyethylene | HDPE | Hard to semiflexible, resistant to chemicals and moisture, waxy surface, opaque, softens at 75°C; easily colored, processed, and formed |
| Low-density polyethylene | LDPE | Soft, flexible, waxy surface, translucent, softens at 70°C, scratches easily |
| Polyvinyl chloride | PVC | Strong, tough, softens at 80°C, can be clear, and can be solvent welded. Flexible, clear, elastic, can be solvent welded |
| Polypropylene | PP | Hard and translucent, soften at 140°C, translucent, withstand solvents, and versatile |
| Polystyrene | PS | Clear, glassy, rigid, opaque, semitough, soften at 95°C; affected by fat, acids, and solvents, but resistant to alkalis and salt solutions; low water absorption, clear when not pigmented, is odor- and taste-free. Special types of polystyrene (PS) are available for special applications |
| Other | — | Includes all resins and multimaterials (e.g., laminates); properties dependent on plastic or a combination of plastics |

already lack the natural resources necessary to produce common bricks. Clay bricks typically release 0.41 kg of $CO_2$ per brick and have an embodied energy of about 2.0 kWh [64, 65]. Additionally, it should be emphasized that clay is in scarce supply in many regions of the planet. Some nations, including China, have begun to restrict the usage of clay-based bricks to safeguard the clay supply and the environment [66–68]. Each year, 375,000,000 tonnes of coal is used in brick kilns worldwide. Annual global brick production is 1,500 billion, with 1,300 billion (or 87%) of those coming from Asia [69, 70].

*1.4.2. Fly Ash Bricks.* Fly ash bricks are an alternative option to traditional bricks. These bricks are also known as green bricks. The components are fly ash, gypsum, sand, lime/red earth, and water. The flow chart of fly ash brick preparation is shown in Figure 11. Fly ash is an industrial waste product, and its disposal in large quantities is the problem. Hence, the researcher comes to the outcome to use it as a building material such as bricks. Hydrated lime and gypsum are used as the binder materials with these bricks. This review article's primary goal is to offer an assessment of the recent use of recyclable plastic refuse as a raw material for building and as aggregate in the manufacture of bricks and paving stones. The benefits and drawbacks of using plastic waste as a raw substance and aggregate are further clarified.

## 2. Materials and Methods

The literature review is divided into two sections based on the type of bricks ($1^{st}$ class, $2^{nd}$ class, etc.). The sections are divided as a result of compressive strength greater than $1^{st}$ class bricks and compressive strength less than $1^{st}$ class bricks. For this purpose, compressive strength greater than 10.5 MPa is suggested for $1^{st}$ class bricks while less than


Figure 7: Difference between thermoplastic and thermosetting plastics.

10.5 MPa and greater than 7.5 MPa is suggested for 2$^{nd}$ class bricks; at the end, 3$^{rd}$ class bricks have compressive strength in the range between 3.5 MPa and 7.5 MPa.

*2.1. Class One Bricks.* The first-class bricks are categorized as compressive strength more than 10.5 MPa. Several authors have reported the study to develop this class of bricks with different processes and plastic materials such as Ikechukwu and Naghizadeh [71] who introduced 20%, 30%, and 40% of PET plastic waste with the addition of foundry sand. It is observed that compressive strength increases with an increase in plastic content by up to 30%, and further addition of plastic reduces the strength. The pattern of tensile strength was observed to be increasing with an increase in plastic content. Density follows the same pattern as compressive strength. Continuous decrement in water absorption with an increase in plastic content is investigated. The reference value is taken as 13.41 MPa for compressive strength, 2.8 MPa for tensile strength, 10% for water absorption, and 1,894 kg/m$^3$ for density. It is found that the plastic content brick shows greater compressive strength, least water absorption, high tensile strength, and least density in comparison to the reference brick. Chauhan et al. [72] introduced 1 : 2, 1 : 3, and 1 : 4 ratios by weight of PET plastic waste with the addition of river bed sand. It is observed that compressive strength decreases with an increase in the plastic content, and at the same time, an increment in water absorption is witnessed. Al-Shathr and Al-Ebrahimy [73] introduced 2%, 4%, 6%, 8%, and 10% of PET waste plastic bottles by adding soil to it. It is observed that compressive strength decreases continuously with an increase in plastic content, while continuous increment in water absorption is recorded. The pattern of thermal conductivity showed a decrease, and density followed the same pattern when the

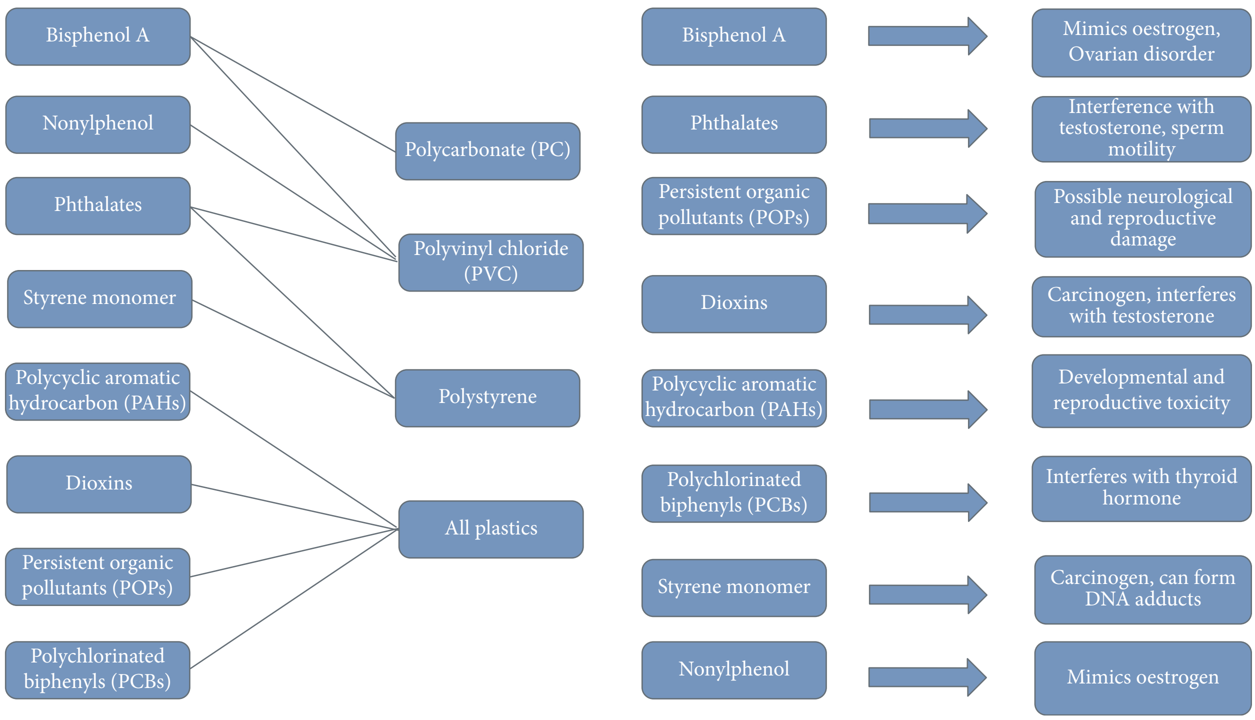


Figure 8: Some additives in plastic and their impact on life forms.

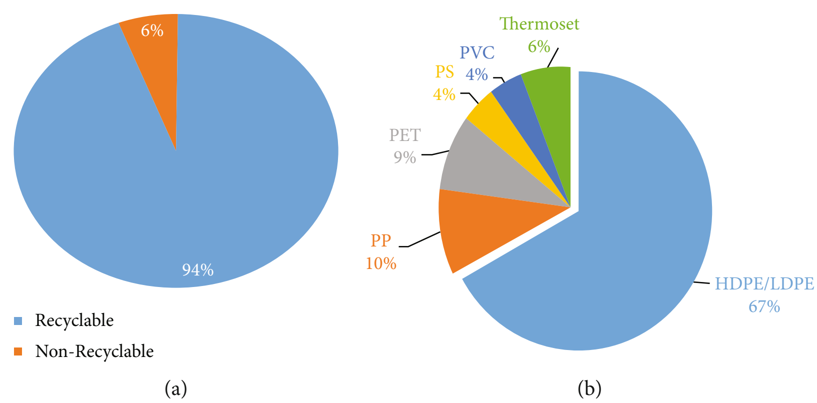


Figure 9: (a) Classification as per recyclability and (b) classification as per resin in India.

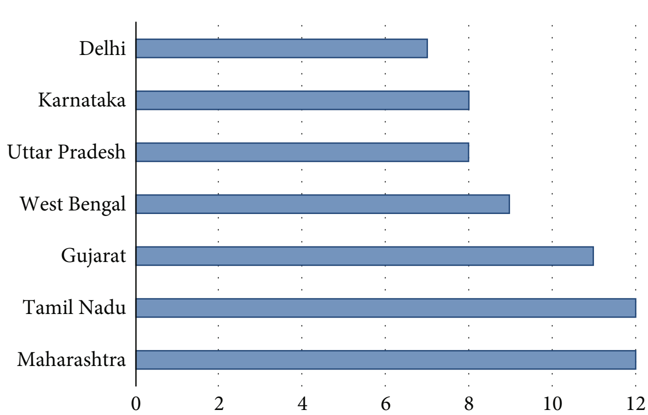


Figure 10: Major plastic waste generation in Indian cities.

plastic content was increased. It might be investigated that decreasing sieve size increases compressive strength, reduces water absorption, and increase thermal conductivity and bulk density. The reference value is taken as 12.4 MPa for compressive strength, 21.66% for water absorption, 0.47 W/mK for thermal conductivity, and 1.67 $g/cm^3$ for bulk density. It is observed that the plastic content brick shows the least compressive strength, greater water absorption, least thermal conductivity, and bulk density compared to the reference brick. Veyseh and Yousefi [74] introduced 0.5%, 1.0%, 1.5%, and 2% of polystyrene foam plastic waste by adding clay to it. It is observed that compressive strength decreases with an increase in plastic content, and the same pattern is observed with body density, while an increment in water absorption is recorded. 1.5% PSF is taken as an optimum value under various firing temperature ranges of 900°C, 950°C, 1,000°C, and 1,050°C. A maiden decrement in body density up to 950°C of temperature increment is observed, and after that, a minor increment is observed on the continuous rising of temperature. A continuous decrement in water absorption is found, while a standard increment in compressive strength is observed with an increase in temperature. The thermal conductivity of brick with 1.5% PSF is found to be 0.24 W/mK. The reference value is taken as 30.30 MPa for compressive strength, 16% for water absorption, and 1.7 g/cm$^3$ for body density. It is observed that the plastic content brick shows the least compressive strength, greater water absorption rate, and least density compared to the reference brick. Velmurugan et al. [75] introduced 20%, 25%, and 30% of polyethylene plastic waste with the addition of M-sand, river sand, and fly ash. It is observed that compressive strength increased with an increase in plastic content, while an increment in hardness was also recorded. It can be observed that plastic with fly ash content impacts greater strength and hardness. The reference value is taken as 17-28 MPa for the compressive strength. The plastic content samples have strength in the reference list. Khan et al. [76] introduced 5% and 10% of PET plastic waste by adding cement and silica fumes into it. It is observed that compressive strength decreased on the 1$^{st}$, 7$^{th}$, and 28$^{th}$ days of observation with an increase in plastic content, while with tensile strength, the same pattern was observed on the 28$^{th}$ day. The study is done on the flexural tensile type strength. However, irradiated PET plastic waste shows greater compressive and flexural strength than normal PET waste with the same plastic content. The reference value is taken as 30.17 MPa on the 1$^{st}$ day, 40.06 MPa on the 7$^{th}$ day, and 56.83 MPa on the 28$^{th}$ day for compressive strength and 7.08 MPa on the 28$^{th}$ day for tensile strength. It is observed that the plastic content brick shows the least compressive and flexural strength compared to the reference brick. It might seem that density, compressive strength, and water absorption increase with time in comparison to past values. Bhogayata and Arora [77] introduced 0.5%, 1.0%, 1.5%, and 2.0% metalized plastic waste. It is observed that compressive strength decreases with an increase in plastic content while a decrement in density is recorded. Tensile strength was observed to increase up to 1%, and after that, a decrement was seen for both flexural and splitting tensile strength. The reference value is taken as 41 MPa for compressive strength; 3.55 MPa and 3.10 MPa for flexural tensile strength and splitting tensile strength, respectively; and 2,460 kg/m$^3$ for density. It is observed that the plastic content brick shows less compressive strength, greater tensile strength, and less density compared to the reference brick. Kulkarni et al. [78] introduced HDPE and PP plastic waste. It is observed that compressive strength is greater for HDPE and less for PP plastic compared to the conventional brick, while both the HDPE and PP bricks show less density, specific gravity, and water absorption compared to the conventional brick. The reference value is taken as 10.5 MPa for compressive strength, 1.2% for water absorption, and 1,897.335 kg/m$^3$ for density. Intan and Santosa [79] introduced 9 : 1, 8 : 2, 7 : 3, 6 : 4, and 5 : 5 ratios of PET or LDPE plastic waste by adding building material waste into it. It is observed that compressive strength increases up to the 6 : 4 ratio with an increase in plastic content; more addition reduces the strength suddenly for PET waste. Brick with LDPE plastic waste reflects increment up to 8 : 2; more addition reduces the strength; the highest strength for LDPE is found to be 8.54 MPa at 5 : 5, while continuous increment in water absorption, porosity, and density is recorded. PET shows greater compressive strength and density but less water absorption and porosity compared to LDPE plastic brick for the same content of the plastic sample. Awoyera et al. [80] introduced 1.5% and 2.5% of PET plastic waste with the addition of ceramics, cement, waste tiles, sand, and granite. It is observed that compressive strength increases with an increase in plastic content on the 7$^{th}$, 14$^{th}$, and 28$^{th}$ days of observation, while s decrement in water absorption is noticed on the 7$^{th}$ and 14$^{th}$ days. The pattern of split tensile strength was observed to increase with content. The reference value is 21.7 MPa for compressive strength, 2.70 MPa for split tensile strength on the 28$^{th}$ day, and 8.1% for water absorption on the 14$^{th}$ day of observation. Compressive strength and tensile strength increase; however, water absorption shows irregularities with time. It is observed that the plastic content brick shows greater compressive strength, greater tensile strength at certain plastic content, and greater water absorption rate compared to the reference brick. Wahid et al. [81] introduced 5%, 10%, and 15% of PET plastic waste by adding sand to it. It is observed that compressive strength decreases continuously with an increase in plastic content, while a regular decrement in water absorption is recorded. The density of the brick follows the same pattern. The reference value is taken as 12.404 MPa for compressive strength, 23.08% for water absorption, and 1,994.4 kg/m$^3$ for density. It is observed that the plastic content brick shows the least compressive strength, density, and water absorption rate compared to the reference brick. Kumar and Kumar [82] introduce 1 : 2, 1 : 3, and 1 : 4 ratios by the proportion of municipal waste plastic waste with an addition of sand. It is observed that compressive strength decreases with an increase in plastic content while an increment in water absorption is recorded. Bhushaiah et al. [83] introduced 5%, 10%, 15%, 20%, and 25% of LDPE plastic waste by adding cement, fly ash, and sand to it. It is observed that compressive strength increases with an increase in plastic content up to 20% of total content after that decrement is observed. At the same time, a continuous decrement in water absorption is recorded. The reference value is 18 MPa for compressive strength and 0.23% for water absorption. It is observed that the plastic content brick shows greater compressive strength and less water absorption rate than the reference brick. Ikechukwu and Shabangu [84] introduced 20%, 30%, and 40% of PET plastic waste by adding recycled crushed glass to it. It is observed that compressive strength increases with an increase in plastic content up to 30%; after that, more addition of plastic leads to a decrease in strength. At the same time, a decrement in water absorption of up to 30% of plastic content is recorded; above that, an increase in the plastic percentage causes a rise in the water absorption rate. The density follows the same pattern as compressive strength for the same plastic content.

The reference value is taken as 14.34 MPa for compressive strength, 10% for water absorption, and 1,894 kg/m$^3$ for density. It is observed that the plastic content brick shows greater compressive strength and least water absorption rate and density compared to the reference brick. Aneke and Shabangu [85] introduced 60%, 70%, and 80% of scrap plastic waste (PET) with the addition of foundry sand. It is observed that compressive strength increases up to 70% of plastic content; moreover, the addition of plastic leads to a sudden decrease in strength. The optimum splitting tensile strength is 9.51 MPa. The reference value is taken as 14.25 MPa for compressive strength. It is observed that the plastic content brick shows greater compressive and tensile strength compared to the reference brick. Aiswaria et al. [86] introduced 1 : 2, 1 : 3, 1 : 4, 1 : 5, and 1 : 6 ratios by the proportion of PET plastic waste with the addition of M-sand. It is observed that compressive strength increases to 1 : 4 proportion by weight of M-sand with constant plastic content; further addition of M-sand with a constant rate of plastic proportion leads to a decrease in compressive strength. At the same time, a decrement in water absorption is recorded up to a 1 : 4 ratio by weight, and further addition causes an increment in the water absorption rate. The reference value is taken as 8.92 MPa for compressive strength and 15.28% for water absorption for burnt clay brick. It is observed that the plastic content brick shows greater compressive strength and least water absorption rate compared to the burnt clay brick. Yanti and Megasari [87] introduced 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90% of HDPE plastic waste with the addition of concrete. It is observed that compressive strength increases with an increase in plastic content up to 40%, and more than 40% addition leads to a decrease in strength. While decrement in porosity is recorded up to 60% plastic content, further addition of plastic increases its porosity. Islam and Shahjalal [88] introduced 10%, 20%, and 30% of PP aggregate plastic waste with cement, crushed stone aggregate, and crushed brick aggregate. It is observed that compressive strength decreases with increased plastic content for various samples with different coarse aggregates on the 28$^{th}$ and 90$^{th}$ days of observation, while a decrement in tensile strength is recorded. Density follows the same pattern as compressive or tensile strength with an increase in the plastic content. The reference value is taken as 29 MPa and 20.1 MPa for the crushed stone aggregate sample and 24 MPa and 22 MPa for the crushed brick aggregate sample on the 90$^{th}$ day of observation of compressive strength and 2.31 MPa and 2.08 MPa for the crushed stone aggregate sample and 2.23 MPa and 2 MPa for the crushed brick aggregate sample of tensile strength, and 2,370 kg/m$^3$ and 2,350 kg/m$^3$ for the crushed stone aggregate sample and 2,070 kg/m$^3$ and 2,060 kg/m$^3$ for the crushed brick aggregate sample on the 28$^{th}$ day of observation of density. It is observed that the plastic content brick shows great compressive and tensile strength for some plastic content with different aggregates and the least density compared to the reference brick. It is noticed that compressive strength increases with the rise of time. Mahdi et al. [89] introduced 1 : 1 and 2 : 1 ratios by a proportion of PET plastic waste with an addition of different dibasic acids, initiator promoters, and glycol. Various transitions in compressive and tensile strength with mixed dibasic acid and initiator promoter are recorded. However, higher compressive strength and split tensile strength are noted to be 42.2 MPa at a 1 : 1 ratio by a proportion of plastic content and 7.60 MPa at a 1 : 1 ratio by a proportion of plastic content, respectively, with malice anhydride and phthalic anhydride as dibasic acid for compressive strength and malice anhydride as basic acid for tensile strength with methyl ethyl ketone peroxide (MEKP) and cobalt naphthenate (CoNp) used as an initiator promoter in both the tests. Gesoglu et al. [90] introduced 5%, 10%, 15%, 20%, and 25% of PVC plastic waste with the addition of cement, crushed rock, natural coarse aggregate, river sand, fine natural aggregate, fly ash, and superplasticizer. A continuous decrement in compressive strength, splitting tensile strength, and flexural strength with increased plastic content is observed. The reference value for the control sample is 60.40 MPa for compressive strength, 4.99 MPa for splitting tensile strength, and 4.64 MPa for flexural tensile strength. It is observed that the plastic content sample has the least compressive strength, splitting tensile strength, and flexural strength than the reference sample. Rahmani et al. [91] introduced 5%, 10%, and 15% of PET plastic waste with the addition of cement, water, gravel, and sand. It is observed that compressive strength decreases with the increase of plastic content for both 0.42 and 0.54 water-cement ratios. The same pattern is observed with splitting tensile strength, flexural strength, and dry weight unit. The control value is taken as 42.12 MPa and 33.39 MPa for compressive strength, 6.25 MPa and 5.52 MPa for flexural strength, 4 MPa and 3.77 MPa for splitting tensile strength, and 2,281.58 kg/m$^3$ and 2,221.83 kg/m$^3$ for dry unit weight with $W/C$ ratio of 0.42 and 0.54, respectively. It is observed that the plastic content sample shows greater compressive and flexural strength at 5% PET content for $W/C$ concentration ratios, least splitting tensile strength, and dry unit weight compared to the control sample. It is also noticed that increasing the $W/C$ ratio for the same plastic content affects the decrease of compressive strength, flexural strength, splitting tensile strength, and dry unit weight. However, a decrement in dry unit weight with time is witnessed. Anumol and Elson [92] introduced 10%, 15%, 20%, and 25% of plastic aggregate waste with the addition of coarse aggregate, fine aggregate, superplasticizer, and cement. It is observed that compressive strength decreases with an increase in plastic content on the 7$^{th}$ and 28$^{th}$ days of observation. About 15% plastic content is taken as the optimum plastic content sample in the study. Some other tests are carried out for a 15% plastic content sample (optimum) and noted the result to compare with the control sample. The value of flexural strength and split tensile strength is noted to be 3.67 MPa and 2.4 MPa, respectively, for optimum plastic content. The reference value is found as 17.2 MPa and 28.2 MPa for compressive strength on the 7$^{th}$ and 28$^{th}$ days of observation and 3.79 MPa and 2.45 MPa for flexural and split tensile strength, respectively. It is observed that the plastic content sample shows the least compressive strength, flexural strength, and split tensile strength compared to the reference sample. Cadere et al.

[93] introduced 20%, 40%, 60%, 80%, and 100% of polystyrene granule plastic with the addition of cement, river aggregate, water, and fly ash. It is observed that compressive strength and density decrease continuously with an increase in plastic content, while a decrement in flexural strength is recorded up to 60% plastic content; however, a sudden increment is seen with the further addition of plastic in the sample. Irregularities with the pattern of split tensile strength were observed. The reference value is taken as 33.45 MPa for compressive strength, 2,250 kg/m$^3$ for density, and 1.82 MPa and 1.72 MPa for flexural and split tensile strength, respectively. It is observed that the plastic content sample shows the least compressive strength, tensile strength, and density compared to the reference sample. Hannawi et al. [94] introduce 3%, 10%, 20%, and 50% of PET and PC plastic waste with an addition of water, cement, and sand. A continuous decrement in compressive strength, flexural strength, and density with an increase in plastic content is recorded, while a continuous increment in water absorption and apparent porosity is observed for both types of plastic. The reference value is 54 MPa for compressive strength, 5.2 MPa for tensile strength, 7.22% for water absorption, 2,173 kg/m$^3$ for dry density, and 2,331 kg/m$^3$ for dry fresh density. The plastic content sample shows the least compressive strength and density, excellent water absorption, porosity, and flexural strength (at some content of plastic) compared to the reference sample. However, the sample with PET plastic content appears with greater density and compressive strength compared to the PC plastic sample, but PET plastic content up to 10% shows greater water absorption, apparent porosity, and flexural strength compared to the PC plastic content sample; more addition leads to a decrease in the respective value compared to the PC content sample. Xu et al. [95] introduced 15%, 20%, and 25% of polystyrene plastic waste with the addition of cement and sand. It is observed that compressive strength decreases with an increase in plastic content, respectively, for 0.45, 0.50, and 0.55 $W/C$ ratios on the 7$^{th}$ and 28$^{th}$ days of observation, while the same pattern is recorded for density. However, a decrement in compressive strength and density for the same content of plastic is observed with an increase in the $W/C$ ratio. It seems that compressive strength increases with time. Ghuge et al. [96] introduced 600 g of plastic waste with cement, quarry dust, and 10 mm coarse aggregate. It is observed that the compressive strength of the plastic content sample showed less strength compared to the ordinary brick on the 7$^{th}$ and 28$^{th}$ days of observation. However, it is observed that the compressive strength of a sample increases with time. Muyen et al. [97] introduced 9 and 12 PET plastic bottles, filled them with cement and sand, and observed their compressive and split tensile strength. A decrement in compressive strength and an increment in split tensile strength with an increase in plastic bottle number is found. Ikechukwu and Naghizadeh [98] introduced 20%, 30%, and 40% of PET plastic waste in addition to foundry sand and clay. It is observed that compressive strength, tensile strength, and density increase with an increase in plastic content of up to 30% plastic in the sample. More plastic content leads to a decrease in the respective values, while a continuous decrement in water absorption is recorded. The reference value is taken as 28.88 MPa for compressive strength, 3.90 MPa for tensile strength, 32.5 g/min/m$^2$ for water absorption, and 1,894 kg/m$^3$ for density. It is observed that the plastic content brick shows greater compressive strength and tensile strength, while the least water absorption rate and density compared to the reference brick. Aleena et al. [99] introduce 1 : 1, 1 : 2, 1 : 3, and 1 : 4 proportion by weight of plastic waste (except PET waste) with the addition of M-sand and glass powder. It is observed that compressive strength increases with an increase in M-sand content by a 1 : 2 ratio proportion of weight; further addition leads to a decrease in strength, while a continuous increment in water absorption is recorded with an increasing rate of M-sand content. The ratio of 1 : 2 by weight is taken as per the optimum ratio content in the research. After that, M-sand is partially replaced with glass powder by 10%, 20%, 30%, 40%, and 50%. It seems to lead to a better improvement in compressive strength while a proportionate decrement in water absorption by replacing some content of foundry sand with glass powder. Further replacement above 40% of M-sand with glass powder leads to a decrease in compressive strength. The reference value is taken as 10.7 MPa, 7 MPa, and 3.5 MPa for compressive strength and 15%, 20%, and 25% for water absorption for the 1$^{st}$, 2$^{nd}$, and 3$^{rd}$ class bricks, respectively. It is observed that the plastic content brick shows greater compressive strength when the optimum plastic M-sand proportion is replaced by 40% glass powder and overall least water absorption rate compared to the 1$^{st}$, 2$^{nd}$, and 3$^{rd}$ class bricks. Awoyera et al. [100] introduce 5% and 10% of plastic fiber with river sand, laterite, cement, and ceramics. Variation in compressive strength with different samples containing various elementary contents is observed; however, 5% plastic content with 100% laterite brick has minimum compressive strength, and 10% plastic with 100% ceramic brick has maximum compressive strength. Maximum water absorption is observed for 5% plastic content, but minimum water absorption is obtained for 10% plastic content. The maximum compressive strength is 16 MPa, and the minimum compressive strength is 6.80 MPa on the 7$^{th}$ day of observation. It is investigated that compressive strength increases with time. Aneke et al. [101] introduced 20%, 30%, and 40% of PET plastic waste with the river sand. It is observed that compressive strength increases with an increase in plastic content by up to 30%, and extending more plastic content leads to a decrease in the respective value. While a continuous decrement in water absorption and density is recorded, a continuous increment in tensile strength is seen with the increase in plastic content. The reference value is taken as 8 MPa for compressive strength, 3.08 MPa for tensile strength, 32.5 g/min/m$^2$ for water absorption, and 1,894 kg/m$^3$ for density. It is observed that the plastic content brick shows greater compressive strength and tensile strength and the least water absorption rate and density compared to the reference brick. Hamzah and Alkhafaj [102] introduce 40%, 50%, 60%, 70%, 80%, 90%, and 100% of LDPE plastic waste with the addition of sand and sawdust. It is observed that compressive strength decreases with an increase in plastic

content for sand admixture and increases with an increase in sawdust admixture. However, sudden increments with sand and decrement with sawdust are seen for compressive strength at 90% of LDPE plastic content addition in bricks. At the same time, continuous increments and decrements in water absorption are recorded for sand and sawdust admixture, respectively. A regular decrement with sand and increment with sawdust are observed for density and hardness with an increase in the plastic content. Mohan et al. [103] introduced 5%, 15%, 25%, and 35% of plastic waste scrap with M-sand and thermo-coal. An increment in compressive strength with an increase in plastic content up to 25% plastic sample is observed, while more addition beyond 25% leads to a drop in the value of compressive strength. Somehow, 0% water absorption is recorded with overall plastic content samples. Ikechukwu and Naghizadeh [104] introduce 20%, 30%, and 40% of PET plastic waste with foundry sand and clay. It is observed that compressive strength, tensile strength, and density increase with an increase in plastic content up to 30%, extending to more plastic content drop-down in the respective values, while a continuous decrement in water absorption and apparent porosity is recorded. The reference value is taken as 28.88 MPa for compressive strength, 3.90 MPa for tensile strength, 32.5 $g/min/m^2$ for water absorption, 32% for porosity, and 1,894 $kg/m^3$ for density. It is observed that the plastic content brick shows greater compressive strength and tensile strength while having less water absorption rate, porosity, and density compared to the reference brick. Patil et al. [105] introduce a 1 : 2 proportion by weight of plastic waste with sand. It is observed with 203.56 $kg/cm^2$ compressive strength and 1.318% water absorption rate.

*2.2. Class Two and Class Three Bricks.* It has compressive strength of less than 10.5 MPa or compressive strength less than the range of the 1st class brick. Panyakapo and Panyakapo [106] introduce a 0.5 to 4.0 by-weight ratio of melamine plastic waste with the addition of cement, sand, and fly ash. It is observed that compressive strength decreases with an increase in plastic content. Density follows the same pattern as compressive strength. Increasing sand content with minimum plastic content increases compressive strength and density; afterward, the addition of fly ash to the sand results in an increase in strength to a certain value; then, a decrement is shown in further addition. Alaloul et al. [107] introduced 20%, 40%, 60%, and 80% of PET plastic waste by adding polyurethane binder (PU). It is observed that compressive strength increases with plastic content up to 60%, and further addition causes a reduction in strength. The pattern of tensile and impact strength is the same as compressive strength. Thermal conductivity follows a continuous decrement with a proportionate increase in the plastic content. The reference value is 33 MPa for compressive strength, 1.28 MPa for tensile strength, and 0.41 W/mK for thermal conductivity. It is found that the plastic content brick shows the least strength, high tensile strength, and least thermal conductivity compared to the reference brick. Parthiban et al. [108] introduced 5%, 10%, 15%, and 20% of polyethylene plastic waste by adding M-sand. It is observed that compressive strength increases with an increase in the plastic content. At the same time, there is a decrement in water absorption, which is to be investigated. An increase in compressive strength with days is observed. Shiri et al. [109] introduced 67%, 70%, and 100% of LDPE and PP plastic waste, with an addition of waste rubber powder and $CaCO_3$. It is observed that compressive strength decreases with an increase in the plastic content for LDPE, while 70% PP shows the highest compressive strength of 6.333 MPa. Density decreases with an increase in plastic content; the type of plastic does not make a difference. However, a large drop is witnessed when PP industrial waste is introduced. The reference value is taken as 3.636 MPa for compressive strength and 1,791.63 $kg/m^3$ for density. It is observed that the plastic content brick shows greater compressive strength and lower density than the reference brick. Maneeth et al. [110] introduced 65%, 70%, 75%, and 80% of PET and PP plastic waste by adding laterite soil with 2%, 5%, and 10% bitumen as binder into it. It is observed that compressive strength increases with an increase in plastic content up to 65% along with 2% of bitumen binder; on further addition of plastic waste with the same binder content, compressive strength remains constant up to 70%, and then, it starts decreasing rapidly. The researchers proposed the theory that when bitumen content is enhanced up to 5% along with 70% plastic content, it reaches the maximum compressive strength value; however, when further additions are made, then it leads to a reduction in the compressive strength. Also, a continuous decrement in water absorption is recorded. The reference value is taken as 2.16 MPa for compressive strength and 1.8242% for water absorption. It is observed that plastic content bricks show greater compressive strength and less water absorption than reference bricks. Akinwumi et al. [111] introduced 1%, 3%, and 7% of PET shredded plastic waste by adding soil to it. It is observed that compressive strength reduces with an increase in plastic content. It is investigated that an increase in plastic size decreases the strength of the brick. The reference value is taken as 0.45 MPa for compressive strength. It is found that the plastic content brick shows greater compressive strength compared to the reference brick. Selvamani et al. [112] introduced a 1 : 2, 1 : 3, and 1 : 4 ratio by a proportion of PET plastic waste with an addition of sand. It is observed that compressive strength increases with an increase in plastic content up to 1 : 3 by weight ratio; however, more addition of plastic results in a sudden decrement in strength. While decrement in water absorption is observed up to 1 : 3 by weight ratio, further addition of plastic waste rapidly increases the water absorption rate. The reference value is 5.58 MPa for compressive strength and 12.24% for water absorption. It is found that the plastic content brick shows greater compressive strength at 1 : 3 and less water absorption than the reference brick. Akinyele et al. [113] introduced 5% and 10% of PET plastic waste with the addition of laterite clay. It is observed that compressive strength decreases with an increase in plastic content, while a decrement in water absorption is also recorded. Density follows the same pattern. The reference value is taken as 5.15 MPa for compressive strength, 10.29% for water absorption, and 1,674 kg/m$^3$ for density. It is observed that the plastic content brick shows less compressive strength, water absorption, and density compared to the reference brick. Deraman et al. [114] introduced 2.5%, 5.0%, and 7.5% of PET plastic waste with the addition of cement and sand. It is observed that compressive strength decreases on the 7$^{th}$ and 28$^{th}$ days of observation with an increase in plastic content, while an increment in water absorption is recorded on the 7$^{th}$ and 28$^{th}$ days. The pattern of density and thermal conductivity was observed to decrease. The reference value is taken as 8.60 MPa on the 7$^{th}$ day and 13.40 MPa on the 28$^{th}$ day for compressive strength, 211.64 kg/m$^3$ on the 7$^{th}$ day and 226.62 kg/m$^3$ on the 28$^{th}$ day for water absorption, and 2,265.64 kg/m$^3$ on the 7$^{th}$ day and 2,258.74 kg/m$^3$ on the 28$^{th}$ day for density, and 0.725 W/mK for thermal conductivity on the 28$^{th}$ day of observation. It is observed that the plastic content brick shows less compressive strength, greater water absorption, and lower thermal conductivity and density compared to the reference brick. It is to be observed that density decreases, compressive strength increases, and water absorption increases over time. Limami et al. [115] introduced 1%, 3%, 7%, 15%, and 20% of HDPE and PET plastic waste by adding clay to it. It is observed that compressive strength decreases with an increase in plastic content for both plastic types, while an increment in water absorption is recorded. The density pattern was observed to be continuously decreasing, but porosity increases with plastic content for both types of plastic. The reference value is taken as 5.62 MPa for compressive strength, 27.95 g/cm$^2$ mm$^{1/2}$ for water absorption, 1.78 g/cm$^3$ for bulk density, and 1% for porosity. It is found that an increase in particle size reduces bulk density and compressive strength and increases porosity and water absorption for both the HDPE and PET plastic bricks. Thirugnanasambantham et al. [116] introduce 1 : 3, 1 : 4, and 1 : 5 weight ratios of PE plastic waste by adding sand to it. It is observed that compressive strength increases with an increase in sand content, while water absorption decreases with increases in sand content with constant plastic proportion up to a 1 : 4 ratio by weight after that sudden increment is noticed. The reference value is taken as 3.83 MPa for compressive strength and 6.97% for water absorption for the fly ash brick. Ebadi Jamkhaneh et al. [117] introduced 2%, 4%, 8%, and 10% of PET plastic waste with the addition of clay. It is observed that compressive strength decreases with an increase in plastic content for both fine and coarse aggregates, while an increment in water absorption is recorded. The porosity follows the same pattern as compressive strength. In some content of plastics, a sudden decrement in the absorption rate is investigated. The reference value is taken as 7.3 MPa for compressive strength and 30% for porosity. Kumar et al. [118] introduced 60%, 65%, 70%, and 75% of PET plastic waste with laterite quarry waste and gypsum. It is observed that compressive strength increases with an increase in plastic content by up to 70% after that sudden drop in strength is observed, while a continuous decrement in water absorption is recorded. The reference value is taken as 2.5 MPa for compressive strength. It is observed that the plastic content brick shows greater compressive strength compared to the reference brick. Maddodi et al. [119] introduced 25% and 40% PET plastic waste by adding chopped wood fibers. It is observed that compressive strength increases with an increase in plastic content, while a decrement in hardness is recorded by the R-scale Rockwell hardness number test (HRR). Adiyanto et al. [120] introduced 1.65 kg and 2.38 kg of plastic waste with the addition of cement, sand, and quarry dust. It is observed that compressive strength increases with an increase in plastic content by the 7$^{th}$, 14$^{th}$, and 21$^{st}$ days of observation. Somehow, an increment in bulk and dry density is seen. The reference value is taken as 4.92 MPa, 5.33 MPa, and 6.07 MPa for compressive strength. It is observed that the plastic content brick shows greater compressive strength, less water absorption rate, greater bulk and dry density, and less porosity than the reference brick. Akinyele et al. [121] introduced 1%, 2%, 3%, 4%, and 5% of polypropylene plastic granules with an addition of glass and laterite. It is observed that compressive strength and water absorption decrease with increased plastic content. More addition of granules leads to an increase in strength by up to 4%, and extending to these limits leads to a decrement in strength. The reference value is taken as 6.15 MPa for compressive strength, 5.5 MPa for tensile strength, 16% for water absorption, and 1,376 kg/m$^3$ for density. It is observed that the plastic content brick shows the least compressive strength, density, and water absorption rate but is high in tensile strength compared to the reference brick. Ursua [122] introduced 29%, 34%, and 39% of plastic waste by adding it to the river sand, glass bottles, and paper. It is investigated that compressive strength increases with an increase in plastic content up to 34%; more addition leads to a sudden drop in compressive strength, while a continuous decrement in water absorption and density is recorded with the increase in plastic content. Nursyamsi et al. [123] introduced 20% of LDPE plastic pellets with sand and cement. The reference values are taken as 1.943 g/cm$^3$ for content weight, 9.25% for water absorption, 9.82 MPa for compressive strength, and 1.79 MPa for tensile strength. It is observed that the plastic content brick shows the least compressive strength, water absorption, tension, and content weight compared to the reference brick. Khalil et al. [124] introduced 10% of HDPE plastic with the addition of metakaolin, coarse aggregate, superplasticizer, crushed clay brick waste aggregate, alkaline solution, and water. Various transitions with compressive strength and water absorption are recorded with different contents. But brick with 10% plastic and plastic-waste brick powder brick show the least compressive strength and higher water absorption compared to other bricks. Chow and Rosidan [125] introduced 1.275 kg of plastic waste with cement, sand, and water. It is observed that compressive strength decreases, and at the same hand, an increment in water absorption is recorded up to 3 × 3 cm of plastic size admixtures; further increases in dimension cause an increase in compressive strength as well as a decrease in water absorption for the same plastic size admixtures. Jayaram et al. [126] introduced 2%, 4%, 6%, and 8% of virgin plastic waste with cement, lime, gypsum, crusher sand, and GGBS. It is observed that compressive strength decreases with an

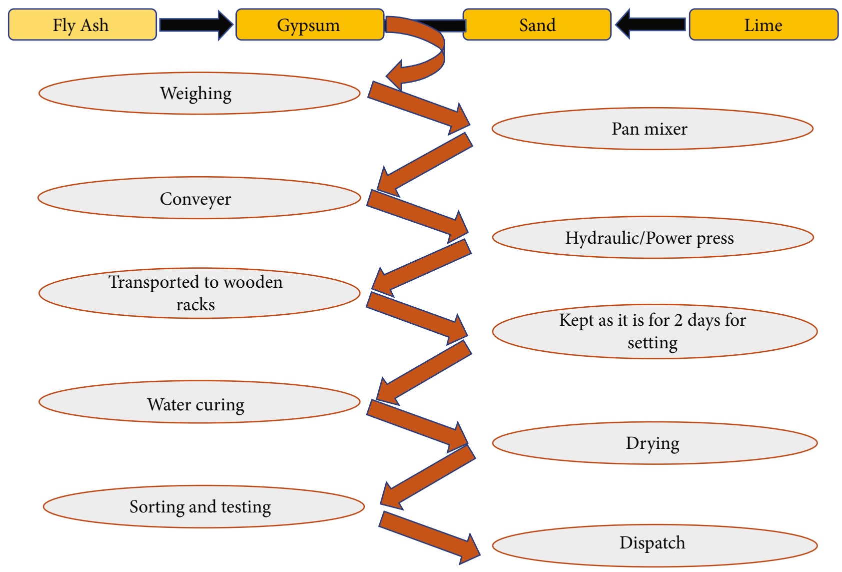


Figure 11: Flow chart of fly ash brick preparation.

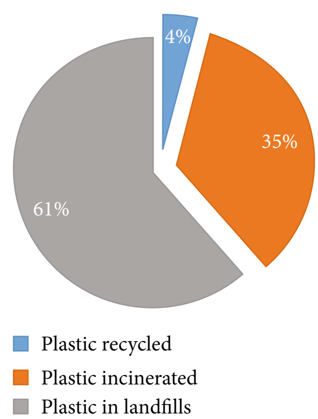


Figure 12: UN plastic management report.

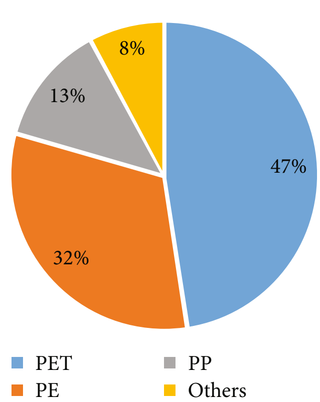


Figure 13: Global plastic recycling.

increase in plastic content on the 7th and 28th days of observation, while a decrement in water absorption is recorded. The reference value is taken as 8.5 MPa for compressive strength and 1.52% for water absorption. Chougale et al. [127] introduce 60%, 70%, and 80% of LDPE plastic waste with brick powder. It is observed that compressive strength increases with an increase in plastic content.

## 3. Discussion

From the review of the large range of published work, it is clear that the utilization of plastic waste for building materials has been a subject of extensive research over the years. Much work has been done through the utilization of various admixtures with waste plastic in the construction sector, and it is accepted by many researchers nowadays [128–132]. The majority of plastics made globally (77%) have carbon-carbon backbones. The powerful resistance to environmental deterioration provided by this molecular structure makes for durable materials that in the absence of incineration last for decades or longer [133]. One of the reasons for this interest is the fact that bricks developed from waste plastic have not only attracted industry but also replaced conventional bricks. A country developed by utilizing its maximum waste, i.e., lean manufacturing. Due to the labor-intensive nature of the process and the low recycling rate (less than 10% of the total PW composition), recycling plastic waste was not very efficient [134]. According to the UN report, 2017, only 9% of plastic is recycled, while 12% is burned and 79% of the overall is discarded in landfills [135]. Global waste plastic management data as per the UN report is shown in Figure 12.

It is a matter of fact that many of the past reviews suggest a lower recycling rate of plastic. Hence, its utilization in the industry not only increases its recycling efficiency but also reduces dependency on natural resources for brick production. The recyclability of plastic is obtained by a review of plastics in past research. Polyethylene terephthalate (PET) is the maximum usually recycled sort of plastic, which has a 47% recycling rate throughout the world. PE accounts next by 32%. Exclusive to these are hardly ever recycled. From the investigation of the published journals, the recycling data as

Table 2: Comparative study of the characteristics of bricks.

| S.no. | Plastic type | Admixtures | Plastic content (%) | Compressive strength (MPa) | | | Water absorption (%) | | | Density (kg/m$^3$) | | | Tensile strength (MPa) | | | Thermal conductivity (W/mK) | | Porosity (%) | | Ref. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Sample without plastic content | Sample with plastic content | | Sample without plastic content | Sample with plastic content | | Sample without plastic content | Sample with plastic content | | Sample without plastic content | Sample with plastic content | | Sample without plastic content | Sample with plastic content | Sample without plastic content | Sample with plastic content | |
| (1) | PET | Foundry sand | 20%, 30%, 40% | 13.41 | 36.18 | 28.40 | 10 | 1.7 | 0.4 | 1894 | 1887 | 1784 | 2.8 | 9.26 | 4.23 | — | — | — | — | [71] |
| (2) | PET | River bed sand | 1 : 2, 1 : 3, 1 : 4 | — | 19.96 | 5.70 | — | 4.560 | 0.949 | — | — | — | — | — | — | — | — | — | — | [72] |
| (3) | PET | Rubber tire waste, soil | 2%, 4%, 6%, 8%, 10% | 12.4 | 11.66 | 7.41 | 21.66 | 31.1 | 23.09 | 1670 | 1600 | 1250 | — | — | — | 0.47 | 0.44 | — | — | [73] |
| (4) | Polystyrene | Clay | 0.5%, 1%, 1.5%, 2% | 30.30 | 18.14 | 5.59 | 16 | 30.3 | 20.5 | 1700 | 1380 | 900 | — | — | — | 1 | 0.24 | — | — | [74] |
| (5) | Polyethylene | M-sand, river sand, fly ash | 20%, 25%, 30% | 28 | 22.85 | 17.6 | — | — | — | — | — | — | — | — | — | — | — | — | — | [75] |
| (6) | PET | Cement, silica fumes | 5%, 10% | 56.83 | 64 | 6.5 | — | — | — | — | — | — | 7.08 | 7.97 | 5.98 | — | — | — | — | [76] |
| (7) | Metalized plastic waste | Liquid fly ash, oxides, sodium hydroxide, sodium silicate | 0.5%, 1%, 1.5%, 2% | 41 | 40.1 | 38.1 | — | — | — | 2460 | 2410 | 2285 | 3.55 | 3.89 | 3.6 | — | — | — | — | [77] |
| (8) | HDPE, PP | — | — | 10.5 | 11.19 | 10.02 | 1.2 | 0.752 | 0.370 | 1897.335 | 877.192 | 864.197 | — | — | — | — | — | — | — | [78] |
| (9) | LDPE, PET | Building material waste | 9 : 1, 8 : 2, 7 : 3, 6 : 4, 5 : 5 | — | 10.5 | 1.76 | — | 0.95 | 0.11 | — | 1790 | 1140 | — | — | — | — | — | — | 1.56 | [79] |
| (10) | PET | Ceramic waste tiles, cement, sand, granite | 1.5%, 2.5% | 21.7 | 24.9 | 9.6 | 8.4 | 40.5 | 8.2 | — | — | — | 2.70 | 3.15 | 1.25 | — | — | — | — | [80] |
| (11) | PET | Sand | 5%, 10%, 15% | 12.40 | 11.62 | 2.98 | 23.08 | 14.46 | 9.52 | 1994.4 | 1856.3 | 1610.8 | — | — | — | — | — | — | — | [81] |
| (12) | Municipal solid waste | Sand | 1 : 2, 1 : 3, 1 : 4 | — | 19.96 | 6.27 | — | 4.560 | 1.318 | — | — | — | — | — | — | — | — | — | — | [82] |
| (13) | LDPE | Cement, fly ash, sand | 5%, 10%, 15%, 20%, 25% | 18 | 19.8 | 18.65 | 0.23 | 0.14 | 0.075 | — | — | — | — | — | — | — | — | — | — | [83] |
| (14) | PET | Recycled crushed glasses | 20%, 30%, 40% | 14.34 | 43.14 | 33.45 | 10 | 3 | 1 | 1894 | 1887 | 1784 | — | — | — | — | — | — | — | [84] |
| (15) | PET | Foundry sand | 60%, 70%, 80% | 14.25 | 38.14 | 29.45 | — | — | — | — | — | — | — | 9.51 | — | — | — | — | — | [85] |
| (16) | PET | M-sand | 1 : 2, 1 : 3, 1 : 4, 1 : 5, 1 : 6 | 8.92 | 18.13 | 11.50 | 15.28 | 1.66 | 0.27 | — | — | — | — | — | — | — | — | — | — | [86] |
| (17) | HDPE | Concrete | 10%, 20%, 30%, 40%, 50% 60%, 70%, 80%, 90% | — | 14.48 | 5.36 | — | — | — | — | — | — | — | — | — | — | — | — | 4.8 | [87] |
| (18) | PP | Cement, crushed stone, crushed brick | 10%, 20%, 30% | 29 | 34 | 8 | — | — | — | 2370 | 2310 | 1840 | 2.31 | 2.82 | 1.6 | — | — | — | — | [88] |
| (19) | PET | Glycol, Malice anhydride, phthalic anhydride, benzoic peroxide, NN-diethyl aniline, methyl ethyl ketone peroxide, cobalt naphthenate | 1 : 1, 2 : 1 | — | 42.2 | 18.7 | — | — | — | — | — | — | — | 7.60 | 3.40 | — | — | — | — | [89] |
| (20) | PVC | Cement, crushed rock, river sand, fly ash, superplasticizer | 5%, 10%, 15%, 20%, 25% | 60.40 | 57.27 | 45.54 | — | — | — | — | — | — | 4.99 | 4.69 | 3.29 | — | — | — | — | [90] |
| (21) | PET | Cement, water, gravel, sand | 5%, 10%, 15% | 42.12 | 44.27 | 29.57 | — | — | — | 2322.53 | 2303.55 | 2147.68 | 6.25 | 6.51 | 5.25 | — | — | — | — | [91] |
| (22) | — | CA, FA, SP, cement | 10%, 15%, 20%, 25% | 28.2 | 27.8 | 18.7 | — | — | — | — | — | — | 3.79 | 3.67 | — | — | — | — | — | [92] |
| (23) | Polystyrene | Cement, river aggregate, water, fly ash | 20%, 40%, 60%, 80%, 100% | 33.45 | 17.50 | 8.24 | — | — | — | 2250 | 2134 | 1880 | 1.82 | 1.59 | 1.01 | — | — | — | — | [93] |
| (24) | PET, PC | Water, cement, sand | 3%, 10%, 20%, 50% | 54 | 50 | 16 | 7.22 | 9.50 | 7.21 | 2173 | 2154 | 1643 | 5.2 | 5.5 | 3.6 | — | — | 15.4 | 15.8 | [94] |
| (25) | Polystyrene | Cement, sand | 15%, 20%, 25% | — | 20.77 | 7.31 | — | — | — | — | 2060 | 1720 | — | — | — | — | — | — | — | [95] |

Table 2: Continued.

| S.no. | Plastic type | Admixtures | Plastic content (%) | Compressive strength (MPa) | | | Water absorption (%) | | | Density ($kg/m^3$) | | | Tensile strength (MPa) | | | Thermal conductivity (W/mK) | | Porosity (%) | | Ref. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Sample without plastic content | Sample with plastic content | | Sample without plastic content | Sample with plastic content | | Sample without plastic content | Sample with plastic content | | Sample without plastic content | Sample with plastic content | | Sample without plastic content | Sample with plastic content | Sample without plastic content | Sample with plastic content | |
| (26) | — | Cement, quarry dust, 10 mm CA | 600 g | 19.54 | 16.05 | 10.93 | — | — | — | — | — | — | — | — | — | — | — | — | — | [96] |
| (27) | PET | Cement, sand | 9 bottles, 12 bottles | — | 35 | 33.7 | — | — | — | — | — | — | — | 2.1 | 1.4 | — | — | — | — | [97] |
| (28) | PET | Foundry sand, clay soil | 20%, 30%, 40% | 28.88 | 42.20 | 33.84 | 32.5 g/$m^2$/min | 25 g/$m^2$/min | 9 g/$m^2$/min | 1894 | 1887 | 1784 | 3.90 | 8.88 | 6.78 | — | — | — | — | [98] |
| (29) | Except for PET, all plastics | M-sand, glass powder | 1 : 1, 1 : 2, 1 : 3, 1 : 4 | 10.7 | 9.36 | 3.5 | 25 | 3.84 | 2.15 | — | — | — | — | — | — | — | — | — | — | [99] |
| (30) | PP, PET, HDPE | River sand, laterite, cement, ceramics | 5%, 10% | — | 18 | 6.3 | — | 11 | 4.8 | — | — | — | — | — | — | — | — | — | — | [100] |
| (31) | PET | River sand | 20%, 30%, 40% | 8 | 37 | 28.88 | 32.5 g/$m^2$/min | 25 g/$m^2$/min | 9 g/$m^2$/min | 1894 | 1887 | 1784 | 3.08 | 9.60 | 4.03 | — | — | — | — | [101] |
| (32) | LDPE | Sand, sawdust | 40%, 50%, 60%, 70%, 80%, 90%, 100% | — | 66.89 | 16.97 | — | 21.05 | 0 | — | 1432.1 | 706.5 | — | — | — | — | — | — | — | [102] |
| (33) | Plastic scrap | M-sand, thermo-coal | 5%, 15%, 25%, 35% | — | 11 | 9.86 | — | 0 | — | — | — | — | — | — | — | — | — | — | — | [103] |
| (34) | PET | Foundry sand clay | 20%, 30%, 40% | 28.88 | 42.20 | 33.84 | 32.5 g/$m^2$/min | 25 g/$m^2$/min | 9 g/$m^2$/min | 1894 | 1887 | 1784 | 3.90 | 8.88 | 6.78 | — | — | 32 | 18.41 | [104] |
| (35) | — | Sand | 1 : 2 | — | 19.96 | — | — | 1.318 | — | — | — | — | — | — | — | — | — | — | — | [105] |
| (36) | Melamine | Cement sand, fly ash | 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0; the proportion by the weight of other materials | — | 5.32 | 0.05 | — | — | — | — | 1826 | 765 | — | — | — | — | — | — | — | [106] |
| (37) | Ground PET | Polyurethane binder | 20%, 40%, 60%, 80% | 33 | 5.3 | 2.1 | — | — | — | — | — | — | 1.28 | 1.301 | 0.416 | 0.41 | 0.221 | — | — | [107] |
| (38) | Polyethylene waste | M-sand | 5%, 10%, 15% | — | 13.8 | 7.8 | — | 8.15 | 6.62 | — | — | — | — | — | — | — | — | — | — | [108] |
| (39) | LDPE, PP | Waste rubber powder, $CaCO_3$ | 100% LDPE, 70% PP, 67% LDPE | 3.636 | 6.333 | 5.422 | — | — | — | 1791.63 | 741.21 | 551.39 | — | — | — | — | — | — | — | [109] |
| (40) | PET, PP | Laterite soil, bitumen | 65%, 70%, 75%, 80% | 2.16 | 10 | 2.04 | — | 1.8242 | 0.5954 | — | — | — | — | — | — | — | — | — | — | [110] |
| (41) | PET | Soil | 1%, 3%, 7% | 0.45 | 1.54 | 0.5 | — | — | — | — | — | — | — | — | — | — | — | — | — | [111] |
| (42) | PET | Sand | 1 : 2, 1 : 3, 1 : 4 | 5.58 | 8.06 | 4.41 | 12.24 | 4.72 | 0.62 | — | — | — | — | — | — | — | — | — | — | [112] |
| (43) | PET | Laterite clay | 5%, 10% | 5.15 | 2.30 | 0.85 | 10.29 | 9.43 | 6.57 | 1674 | 1404 | 1330 | — | — | — | — | — | — | — | [113] |
| (44) | PET | Cement, sand | 2.5%, 5%, 7.5% | 13.40 | 5.10 | 2.00 | 13.40 | 5.10 | 2.00 | 2265.64 | 2198.19 | 2093.24 | — | — | — | 0.725 | 0.645 | — | — | [114] |
| (45) | HDPE, PET | Clay | 1%, 3%, 7%, 15%, 20% | 5.62 | 5.04 | 1.72 | 27.95 | 64.15 | 30.06 | 1780 | 1740 | 1440 | — | — | — | — | — | 1 | 29 | [115] |
| (46) | PE | Sand | 1 : 3, 1 : 4, 1 : 5 | 3.83 | 5.56 | 4.49 | 6.97 | 1.033 | 0.727 | — | — | — | — | — | — | — | — | — | — | [116] |
| (47) | PET | Clay | 2%, 4%, 8%, 10% | 7.3 | 8 | 0.1 | — | 26.5 | 36.5 | — | — | — | — | — | — | — | — | 30 | 40.2 | [117] |

Table 2: Continued.

| S.no. | Plastic type | Admixtures | Plastic content (%) | Compressive strength (MPa) | | | Water absorption (%) | | | Density (kg/m$^3$) | | | Tensile strength (MPa) | | | Thermal conductivity (W/mK) | | Porosity (%) | | Ref. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Sample without plastic content | Sample with plastic content | | Sample without plastic content | Sample with plastic content | | Sample without plastic content | Sample with plastic content | | Sample without plastic content | Sample with plastic content | | Sample without plastic content | Sample with plastic content | Sample without plastic content | Sample with plastic content | |
| (48) | PET | Laterite quarry waste, gypsum, bitumen | 60%, 65%, 70%, 75% | 2.5 | 8.2 | 6.8 | — | 2.4 | 0.6 | — | — | — | — | — | — | — | — | — | — | [118] |
| (49) | PET | Chopped wood fiber | 25%, 40% | — | 3.37 | 2.49 | — | — | — | — | — | — | — | — | — | — | — | — | — | [119] |
| (50) | Polythene bags, sachet water bags, wrappers, etc. | Cement, sand, quarry bust | 1.65, 2.38 kg | 6.07 | 8.53 | 5.96 | 4.9 | 2.7 | 0.50 | 1057.15 | 1072.64 | 1064.89 | — | — | — | — | — | 35.35 | 19.22 | [120] |
| (51) | Polypropylene | Glass, laterite | 1%, 2%, 3%, 4%, 5% | 6.15 | 4.02 | 2.61 | 16 | 15 | 14.2 | 1376 | 1376 | 1322 | 5.5 | 7.1 | 7.02 | — | — | — | — | [121] |
| (52) | — | River sand, glass bottles, paper | 29%, 34%, 39% | — | 5.68 | 4.34 | — | 1.509 | 1.285 | — | 1678.67 | 1556 | — | — | — | — | — | — | — | [122] |
| (53) | LDPE | Sand, cement | 20% | 9.82 | 4.22 | — | 9.25 | 7.11 | — | 1943 | 1630 | — | 1.79 | 0.98 | — | — | — | — | — | [123] |
| (54) | HDPE | Metakaolin CA, FA, SP, clay brick waste powder, alkaline solution, water | 10% | 47.7 | 32.10 | 31.43 | 4.16 | 5.32 | 3.66 | — | — | — | — | — | — | — | — | — | — | [124] |
| (55) | Plastic bottles | Cement, sand, water | 1.275 g | 3.4 | 7.5 | 4 | 4.10 | 4.95 | 3.54 | — | — | — | — | — | — | — | — | — | — | [125] |
| (56) | Virgin plastic | Cement, lime, gypsum, crusher sand, bottom ash, GGBS | 2%, 4%, 6%, 8% | 8.5 | 11.3 | 5.6 | 1.52 | 1.80 | 1.60 | — | — | — | — | — | — | — | — | — | — | [126] |
| (57) | LDPE | Brick powder | 60%, 70%, 80% | — | 19 | 0.114 | — | — | — | — | — | — | — | — | — | — | — | — | — | [127] |
| (58) | HDPE, PET | Clay | 1%, 3%, 7%, 15%, 20% | — | — | — | — | — | — | — | — | — | — | — | — | 0.48 | 0.46 | — | — | [136] |
| (59) | PET | Red soil, river sand, stone crush | 50 g, 750 g | — | — | — | 5 | 3 | 0 | — | — | — | — | — | — | — | — | — | — | [137] |
| (60) | — | Sand, gravel | 2 : 1, 1 : 1, 1 : 2, 2 : 1 : 1, 1 : 1 : 1, 1 : 2 : 2 | — | — | — | — | — | — | — | — | — | — | — | — | — | 0.00171 | — | — | [138] |

Table 3: Plastic type, global consumption, and moisture, carbon, volatile, and ash contents in different plastics.

| Type of polymers for plastic | Moisture (Wt %) | Carbon (Wt %) | Volatile (Wt %) | Ash (Wt %) | Global consumption (%) | Ref. |
|---|---|---|---|---|---|---|
| PET | 0.46 | 0.77 | 91.75 | 0.02 | 5.5 | [141] |
| PET | 0.00 | 13.17 | 86.83 | 0.00 | | [142] |
| PE | 0.10 | 0.04 | 98.87 | 0.99 | 33.5 | [143] |
| HDPE | 0.00 | 0.01 | 99.81 | 0.18 | | [144] |
| HDPE | 0.00 | 0.03 | 98.57 | 1.40 | | [142] |
| LDPE | 0.30 | 0.00 | 99.70 | 0.00 | | [145] |
| LDPE | — | — | 99.60 | 0.40 | | [146] |
| PVC | 0.00 | 6.30 | 93.70 | 0.00 | 16.5 | [147] |
| PVC | 0.00 | 5.18 | 94.82 | 0.00 | | [142] |
| PP | 0.15 | 1.22 | 95.08 | 3.55 | 19.5 | [143] |
| PP | 0.18 | 0.16 | 97.85 | 1.81 | | [142] |
| PS | 0.25 | 0.12 | 99.63 | 0.00 | 8.5 | [148] |
| PS | 0.30 | 0.20 | 99.50 | 0.00 | | [145] |
| PA, ABS, nylons PBT | 0.00 | 1.12 | 97.88 | 1.00 | 3.5 | [149] |
| PA, ABS, nylons PBT | 0.00 | 0.69 | 99.31 | 0.00 | | [149] |
| PA, ABS, nylons PBT | 0.00 | 2.88 | 97.12 | 0.00 | | [142] |

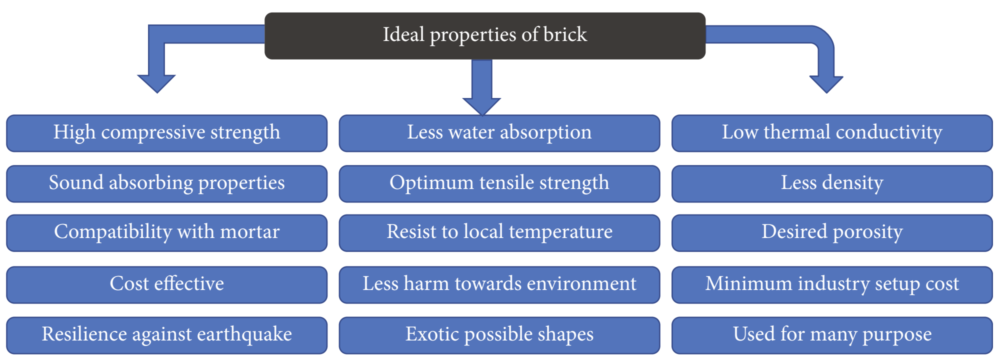


Figure 14: Ideal properties of bricks.

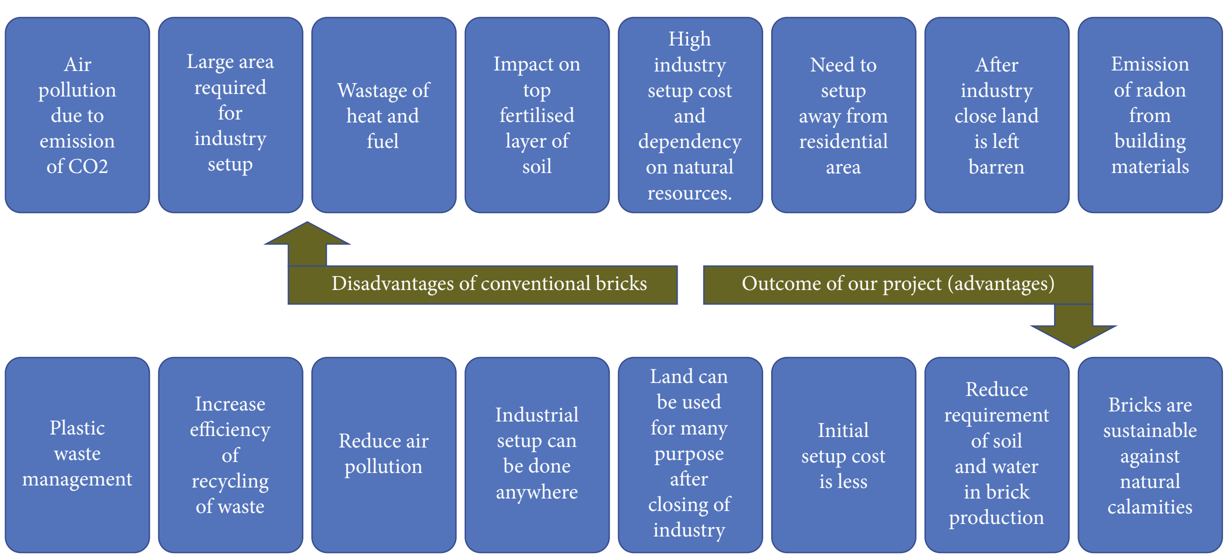


Figure 15: Comparison of the disadvantages of convention bricks over the outcome of the project.

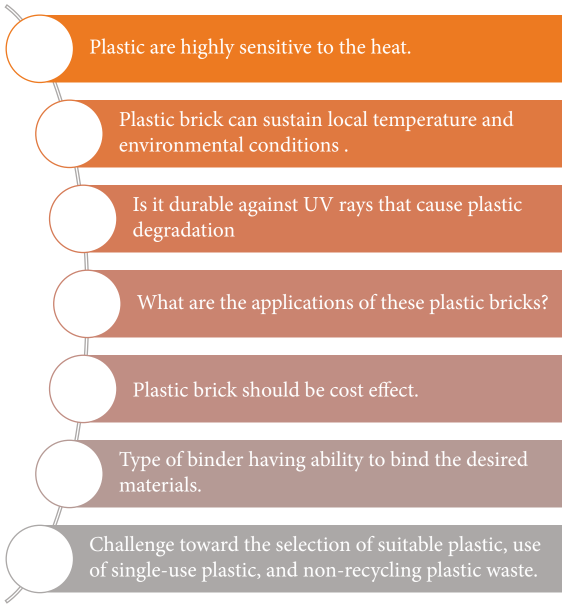


FIGURE 16: Challenges to the plastic bricks.

per resin is estimated as shown in Figure 13. Table 2 represents the comparative study of the physical characteristics of the plastic-containing bricks from the past research of the published work. The table contains the characteristics and properties of the brick such as compressive strength, water absorption, density, tensile strength, thermal conductivity, and porosity. All the properties are described with the help of several aspects such as the plastic type, plastic category, admixtures, and plastic content in the brick. This also helps to investigate the effect of variation in plastic content and type (resin) on the strength of the bricks. The review proposed the comparison of the properties of plastic brick with nonplastic brick from different research in the past. Properties are compared on the basis of their maximum and minimum values for the plastic content brick with the properties of control or reference brick (zero plastic waste brick).

Table 3 displays the many types of polymers, labeled according to the types of plastics, as well as the relative contributions of each type of plastic with different contents of moisture, carbon, volatile material, and ash into it and overall global contribution. There is also data for thermosetting plastic. All of the information was compiled from many published sources. These can effectively aid in a deeper understanding of plastic. Based on the literature review, the ideal properties of the bricks are shown in Figure 14. The outcome of the project over the disadvantages of the conventional brick is shown in Figure 15. Some of the challenges with plastic bricks are discussed in Figure 16. Research from MIT suggests that irradiated recycled plastic waste with concrete additives improves chemomechanical properties as well as lower the footprint of carbon [139, 140].

## 4. Conclusion and Future Work

The demand for plastics increases rapidly due to the wide increment in the population every year. These plastics are petroleum-based products on which the current world is fully dependent. Most packaging plastics are single-use and are nonrecyclable. Waste plastics affect serious environmental, ecological, economical, and health-related issues. These plastics are often in landfills, thrown in water bodies, or burned. Somehow, modern recycling techniques are not efficient to treat the plastic threat, as it is a problem not only in developing countries but also in developed countries. Plastic can pollute remote areas with no population.

The increasing population demands a large production of bricks and construction materials. Conventional bricks required high flame processing with a large quantity of fuel. The process emits a large quantity of carbon footprint. Some countries face a lack of natural resources to develop conventional bricks. Somewhere, resources to kiln bricks are costly, and the government of some regions also prohibits clay processing for the bricks. In such areas, plastic bricks can be an alternative solution. A plastic brick can reduce plastic waste and causes effective management of the plastic recycling system. Some studies show that waste plastics can be used as construction material for development. The plastic brick has an efficient effect on the nation's development activities with ecological, environmental, economic, and health considerations. Due to this high rate of production, it was decided to explore and carefully consider whether using waste plastic as an option to make bricks would be feasible. Due to this high rate of production, it was decided to explore and carefully consider whether using waste plastic as an option to make bricks would be feasible. It is necessary to evaluate the effects of adding plastic waste to the construction material from the viewpoints of physical properties and compressive strength. Studies on using plastic waste as a substitute material in the construction industry have gradually increased over the past years.

Many researchers are putting their efforts into the recycling of plastics by brick processing, but somehow, some gap is found in the wide production and further development. After so much research, the production and support of plastic bricks are still quiet. That needs to be further investigated. Most of the research is investigated with PET waste plastics contributing very little to overall plastic production. Studies should be required with others plastics for efficient processing. There is a large gap in the testing of characteristics of plastic bricks that is somehow missing in past research. Some gaps are found in the study on the effect of environmental factors on the properties and strength of plastic bricks. The microstructural investigation is still limited, while thermal conductivity is also discussed in the limited research work.

## Nomenclature

PET: Polyethylene terephthalates
PE: Polyethylene
HDPE: High-density polyethylene
LDPE: Low-density polyethylene
PS: Polystyrene
PVC: Polyvinyl chloride
PP: Polypropylene.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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