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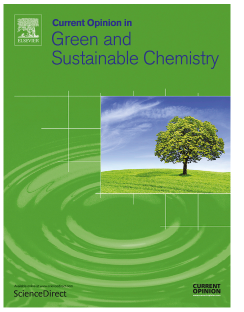

A critical review of the current progress of plastic waste recycling technology in structural materials

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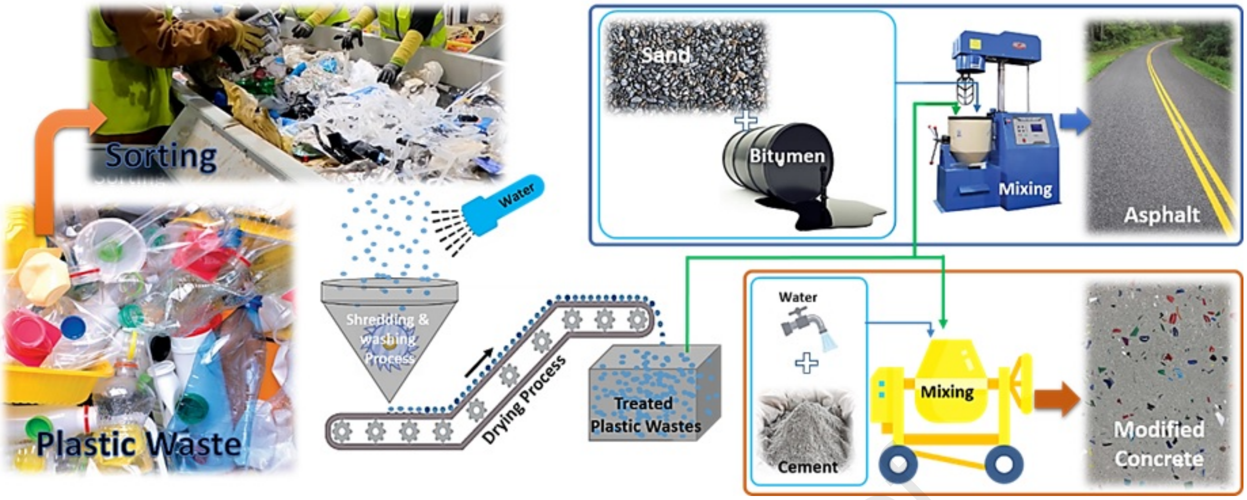
Sorting
Plastic Waste
Water
Shredding & washing Process
Drying Process
Treated Plastic Wastes
Sand
Bitumen
Mixing
Asphalt
Water
Cement
Mixing
Modified Concrete

A critical review of the current progress of plastic waste recycling technology in structural materials

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Abstract

One of the main environmentally threatening factors is plastic waste which generates in great quantity and causes severe damage to both inhabitants and the environment. Commonly, plastic waste generated on the land ends up in water bodies, resulting in detrimental solid impacts on the aquatics via poisoning and flooding the marine ecosystem. Exploring various approaches to convert plastic wastes into new products known as an efficient way to manage them and to enhance the sustainability of the environment, discussed in this article. Moreover, The limitation of the application of plastic waste for construction purposes is also considered. It is wind up that the usage of plastic waste for construction purposes will significantly rectify the sustainability of our environment and also be regarded as a trustworthy source of materials for applying in conventional materials such as concrete and asphalt.

Keywords: Construction materials; Recycling; Plastic waste; Sustainability; Environment.

Introduction

Due to the wide range of household and industry applications, polymeric materials have become an impartible component of our current lives [1]. Worldwide plastic production is estimated to be around 1.1 billion tons by 2050 [2]. Environmental Protection Agency reported that out of tons of plastic waste generated, only 7% is recycled annually. The records demonstrated that only 8% of the plastic is incinerated, and the remaining is landfilled. However, the high energy and cost of landfilling process lead to these wastes being released into water bodies [3,4]. Thermoset, thermoplastic, and elastomer plastic wastes are not easily degraded and could cause primary environmental contamination [5,6]. Therefore, proper plastic waste management is the key to solving environmental and sustainability issues. The traditional model uses resources based on the "take-make-consume-waste" strategy. It is essential to switch from the linear model to a generative and restorative model based on the circular economy idea. Standard waste management techniques for plastic materials include thermal breakdown, landfills, mechanical pulverisation, incineration, recycling, and microbiological decomposition (figure 1). The main remaining challenge in managing the waste plastic industry is the rapid and efficient identification and sorting of waste plastic mixtures [7].

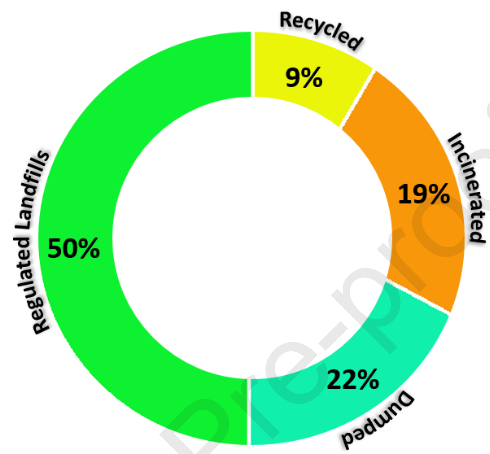

Figure 1. Global share of waste treatment and disposal according to the method.

Hence, plastic waste is generally tossed out in landfills and disposed of into the environment. Meanwhile, energy recycling of plastic waste is commonly employed by incineration, in which a significant amount of energy can be regenerated and used in different fields [8]. Among all those methods, recycling plastic waste can simultaneously provide an environmentally friendly and acceptable approach. Plastic waste recycling deals with the waste management process, which stacks up plastic waste materials, convert them to raw materials and employs them to produce other products. Disposing of plastic waste is the main advantage of recycling. Moreover, it also helps to minimise the demand for raw polymeric materials that can help to reduce global warming [4,5,8]. The plastic recycling process can be classified into primary, secondary, tertiary, and quaternary stages, according to the ASTM Standard D5033 [9]. Based on the mechanism of each process, plastic waste recycling can be categorised as chemical, mechanical, and biological recycling [6,10]. During catalytic and thermal processes in chemical recycling, plastic waste can be converted into value-added fuels/chemicals. Such a process is the primary method to decrease plastic waste, which is a significant source of environmental concern. Separation of the different materials is known as the other required process in the recycling of plastic waste. Density separation (densities-based), optical sorting (colours and peaks-based), Tribo electrostatic separation (effective surface work function-based), and flotation (surface properties based) are various separation techniques known in the field of plastic waste recycling [11]. One of the most powerful methods to eliminate the accumulation of contaminants in the environment induced by plastic waste is knowing the most desirable separation methods and recycling plastic waste. This review aims to discuss the latest state-of-the-art technology of chemical and mechanical plastic waste recycling techniques to decrease plastic waste accumulation in the environment. It is worth noting that the chemical recycling of plastic wastes is contingent on the polymer chains' degradation [3-5,10].

A variety of plastic wastes exist; polyethylene and polyethylene terephthalate (PET) is known as the most common ones. Scientists have found the recycling of plastic waste as a compelling path, and different recycling methods have been extensively proposed for such waste by the packaging industry. However, their use in the construction industry is not widespread. In fact, the construction industry is an important and favourable sector where plastic wastes add value and can be used for different applications, as it is the most significant industrial sector in various financial systems and the largest consumer of raw materials. Civil construction material can be obtained from plastic wastes in the form of bulk in asphalt and cementitious mixtures, insulation, filler, etc. Despite the great potential of plastic waste application in the construction sector, its usage and development are still quite limited [12-14]. Two critical economic drivers influence the viability of thermoplastic recycling. These are the price of the recycled polymer compared with virgin polymer and the cost of recycling compared with alternative forms of acceptable disposal. Additional issues are associated with variations in the quantity and quality of supply compared with virgin plastics. A lack of information about recycled plastics' availability, quality, and suitability for specific applications can also act as a disincentive to using recycled material [14]. This article reviews recent advances in plastic waste recycling methods and materials. Furthermore, polymeric waste materials in popular constructions, such as asphalt pavements and cementitious concrete, have been studied. Moreover, the use of waste materials to improve the performance of concrete and asphalt is also reviewed.

Recycling plastic wastes

Plastic materials are less recycled compared to other materials consumed in large quantities, such as glass, paper, ceramics, and aluminium [15,16]. Total plastic recycling is known as a complex technique due to its multistage processing, disposal and sorting, distribution, and use [17,18]. Plastic wastes can be recycled chemically, mechanically, or thermally (Table 1). In the initial stage, they need to be sorted, which is generally performed automatically by employing different technologies such as fluorescence, electrostatics, infrared, floatation, and spectroscopy. The physical degradation of plastic waste evolves through different processes, such as shredding and/or grinding, which are the main stages of mechanical recycling [19].

Table 1: The advantages and limitations of different plastic waste recycling methods

Methods	Advantages	Limitations	Ref.
Mechanical	• It is the most straightforward process for recycling metal matrix composites, and it is especially well-suited for fibre-reinforced polymers (FRP), where fibre breaking is accomplished through shredding. • The recycling facilities are simple and economical, using less energy and resources than chemical or physical recycling processes.	• The decreased melt viscosity is due to hydrolytic and thermal depolymerisation. • The generation of cyclic and linear oligomers affects the printability and dyeability of the final product.	[20,21]
Chemical	• The greater rates of the monomer with a shorter reaction time. • Higher potential for profitability through new materials application. • The most cost-effective approaches for high-performance recycling composites.	• The expensive investment in developing technical infrastructure/processes. • The feasibility of an industrial scale has not yet been completely established. • High temperatures and much energy are needed.	[22,23]

However, compared to the incineration process, mechanical recycling is described as inefficient due to its plastic waste mixtures' complexity; hence, most plastic wastes are incinerated [24,25]. But, based on the literature, the mechanical recycling technique is the most used plastic recycling technique due to its rapid process and efficiency. For the chemical recycling of plastic wastes, the polymer chains can be broken down and converted to their initial monomers that can be used instead of virgin raw materials in developing raw plastic materials.

Thermal recycling of waste plastic materials includes melting the plastic wastes by elevating their temperatures and then casting or injecting the molten into a mould to form products. Faraca and Astrup investigated the recycling capabilities of different plastic products such as polypropylene (PP), polyvinyl chloride (PVC), high-density polyethylene (HDPE), polyethylene terephthalate (PET), and polystyrene (PS) [26]. They reported that the intrinsic properties of plastics could affect their recycling potential. It is worth noting that recycled plastics indicated according to their commercial codes as; 1, 2, 3, 4, 5, 6, and 7, which means PET, HDPE, PVC, LDPE, PP, PS, and others, respectively. Figure 2 demonstrates the potential for sorting, reprocessing and recycling common plastics via mechanical or chemical methods. According to the studies, the sorting and reprocessing ability of the plastic materials mentioned in this category is more than 50%. Among them, PET exhibits low recyclability. Moreover, it is reported that recycling polyethylene and polypropylene will show greater value in energy consumption and their management systems.

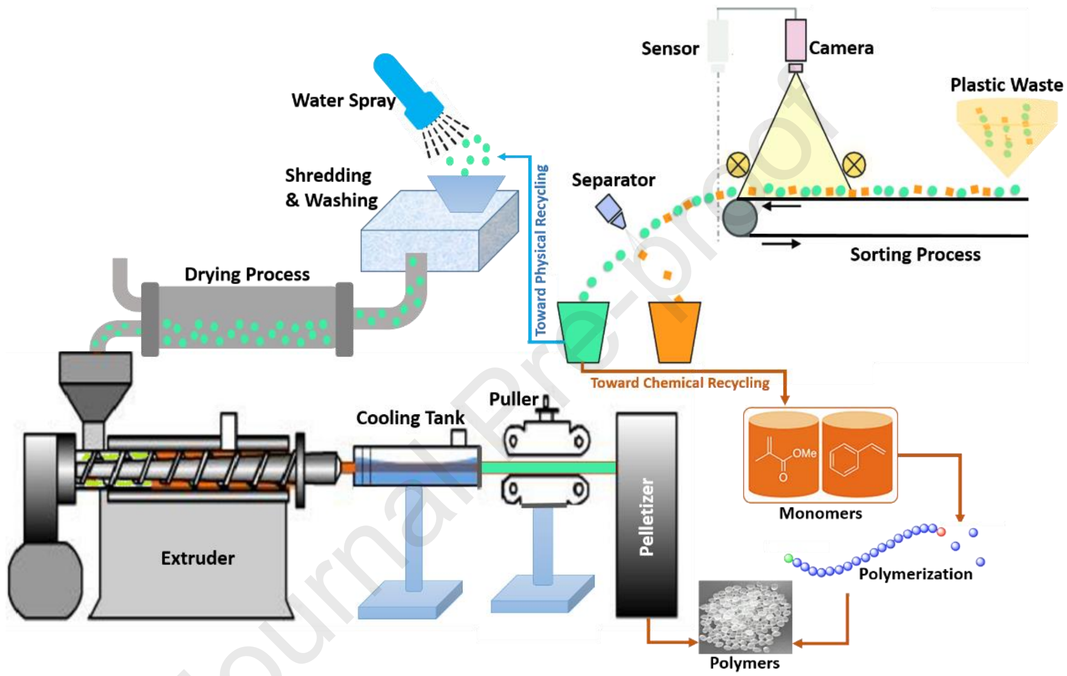

Figure 2. Schematic illustration of plastic waste recycling via mechanical and chemical methods.

Types of plastics and possible construction applications

One of the main backbones of every nation is the construction industry, which greatly contributes to its economy. Therefore, employing waste materials will significantly improve the sustainability of construction practices and processes. The major goal of the circular economy model is to maintain products and their constituent parts at their best levels of efficiency and value for the entirety of their intended lifecycles. Considerable reduction of waste plastic materials disposal in the marine environment will be achieved by employing the innovative sustainable use of plastic waste for construction applications. Therefore, alternative materials can be proposed to meet the great demand of the construction industry. However, durability and mechanical properties must comply with the intended application to use polymer wastes for construction purposes. Figure 3 represents the overview of using untreated polymer wastes in construction materials.

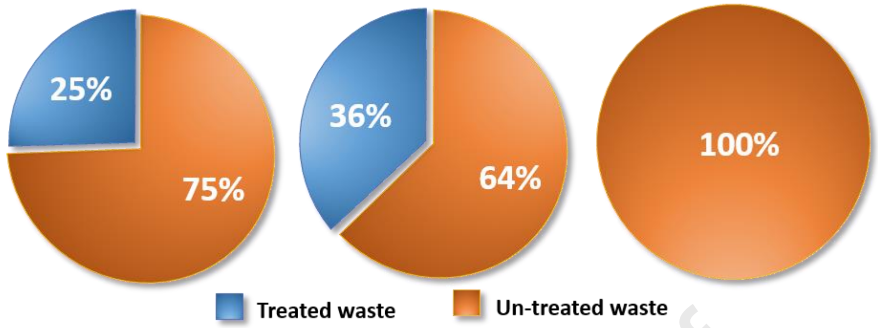

Figure 3. Overview of applying treated waste polymers in construction materials [27].

Moreover, such materials must be sustainable and cost-effective to be substituted over other types of materials. For example, some recycled non-biodegradable waste plastic bags have been used to produce wall and floor tiles with enhanced mechanical properties and lower flammability [28]. This study demonstrated that plastic bags, which are known as the primary contributor to water and soil pollution, can be converted into highly durable and lightweight products. Hama and Hilal [29] reported the properties of self-consolidating concrete (SCC) developed by incorporating fine aggregates of plastic wastes [19]. This research demonstrated that loading 12.5 W% of plastic aggregates to SCC enhanced its fresh properties, such as filling and passing ability. There is a variety of plastic wastes (Figure 4) which are generated according to their initial application, such as polypropylene (PP), polyethylene terephthalate (PET), polystyrene (PS), low-density polyethylene (LDPE), High-density polyethylene (HDPE), etc. Recent investigations show that most plastic wastes are composed of LDPE. However, PP and HDPE also showed a significant amount of similarity to that HDPE.

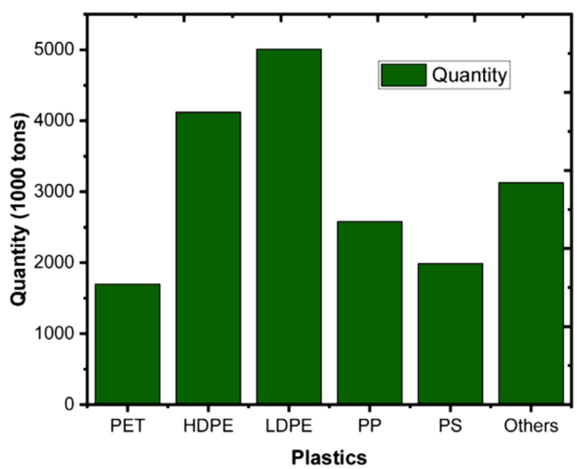

Figure 4. Different types of plastic wastes and their estimated quantities [30]

Khalid et al. investigated the performance of plastic wastes in fibre-reinforced concrete beams [20,31]. In their research, ring-shaped PET (Figure 5) was loaded into the concrete in order to improve its fracture energy, compressive strength, beam flexural strength, and splitting tensile. It also illustrated that the plastic fibres added to the concrete improved the mechanical behaviour of the beams concerning the first crack strength and load and showed almost no effect on the failure mode. Plastic wastes can be employed for indoor use and general engineering aside from the application for construction purposes. The use of PW as a replacement for aggregate in base and subbase construction for pavements has improved the pavement's shear, stiffness and bearing capacity [32]. Their study showed that incorporating PW lowers the stiffness, bearing capacity and resilient modulus of the blends; however, acceptable performance was still achieved. Plastic wastes can also be loaded into asphalt mixtures, similar to the utilisation of plastic waste for cementitious composites as an aggregate [33]. Based on the record, the amount of asphalt produced globally during each year for asphalt pavements in the form of a binder, waterproofing materials, or roofing or sealing has been estimated at 1.7 trillion metric tons [34,35]. Generally, asphalt pavement comprises 4 to 8 per cent of bitumen and aggregates, which are the most conventional material for paving roads due to their high durability and load-bearing properties. Modification with polymers is a common way to improve asphalt pavement performance. Recently, polymeric waste materials such as waste plastics and rubber have been evaluated as alternative polymeric materials for strengthening the performance of asphalt pavement. There are two different methods to load waste plastics or rubber into asphalt, which are known as; the wet process and the dry process. In the former process, the waste materials act as a modifier which are loaded into bitumen and mixed, resulting in preparation of a polymer-modified bitumen. In the later process, the plastic wastes act as aggregate or filler through the asphalt mixture, and the raw aggregate and filler can be substituted by these wastes [13,36].

The incorporation of plastic wastes in asphalt resulted in an enhancement in the crack and skid resistance of the pavement. Using plastic wastes as modifiers in the asphalt mixtures significantly improves stiffness and rutting resistance performance. Such increment in the performance of the plastic waste-modified asphalt might be attributed to the more excellent resistance of the matrix caused by the incorporation of the plastic waste. Moreover, a significant reduction in traffic noise was observed in the case of plastic waste incorporated asphalt. It is also reported that plastic wastes can be employed as a potential replacement for wood, blocks and bricks by using moulding processing [37].

Figure 5. Ring-shaped plastic fibres used for improved concrete beam performance [31]

Limitations to the application of plastic wastes

Some limitations in the use of plastic waste have been reported that inhibit its large-scale use, which can be summarised as

a) Varying composition: plastic wastes are made up of a variety of types and grades, which might be resulted in a non-isotropic performance while operating for construction purposes;
b) Harvesting: This is known as the major limitation of plastic waste before the recycling process;
c) Low density: This can result in some limitations where a higher modulus of elasticity and toughness is required;
d) Lack of understanding: limited understanding of the long-term performance of recycled plastics caused a limitation in the acceptance and the usage of the plastic wastes (PW) by the contractors;
e) Low surface energy: this leads to poor mechanical bonding while incorporating into the composites and significantly reduces the overall mechanical properties of the resulting composite;
f) Economic constraints: recycling some types of plastic requires costly advanced equipment that inhibits the recyclability of these types of plastic wastes;
g) Lack of standards: despite extensive investigations into the usage of plastic waste in cementitious composites, there is still no standard for applying plastic waste for construction purposes.

Summary and outlook

Plastics play an essential role in our daily lives, and the generation of plastic waste at the end of its use is unavoidable. Therefore, their employment in construction is a viable option that helps the proper management of plastic waste while rectifying the sustainability of the environment. This article has studied the current investigations that have been conducted on employing recycled plastic waste for construction purposes. The following conclusions can be summarised:

- Using plastic waste for construction can solve waste management problems and minimise using raw materials for construction purposes while supporting the sustainability of the circular economy.
- Using plastic waste for construction purposes leads to using these wastes for long-term applications compared to the short-term use in new products, which will result in the generation of new plastic waste.
- Plastic wastes can be used as an aggregate, binder, and fibre, making it a suitable replacement instead of all the components used in cementitious composites while providing the acceptable overall performance of the final composite.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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** of outstanding interest

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Declaration of interests

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