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Potential Applications of Different Forms of Recycled Plastics as Construction Materials—A Review †

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Abstract: The issue of waste plastic generation is a pressing global concern with several significant environmental, economic, and health implications. Various studies have explored the utilization of recycled plastics in construction, yet there is a notable gap in providing a comprehensive overview of recyclable plastic types, suitable recycling methodologies, and the range of products tailored to specific applications. Thus, the aim of the current literature review was to achieve a thorough review of the literature on the current use of recycled plastic as a construction material and its possible future applications. This was attained by targeting the highly reputable journals articles published during the last decade. Studies show the convenient recycling of thermoplastics due to their reversible nature. However, their durability and resistance to temperature are still points of concern. Recycled plastics are commonly used as replacements for aggregates in the manufacturing of cementitious composites as part of various research investigations. Efforts to tackle the issue of plastic waste include improving recycling infrastructure and encouraging the development of alternative materials.

Keywords: construction materials; plastic aggregates; plastic recycling; waste plastic

1. Introduction

Plastics have evolved as a vital commodity for daily human use [1]. Over the past few decades, there has been an exponential increase in the production of plastic materials [2]. Plastic production is expected to surpass 0.50 billion tons in 2025. Around 60% of plastic waste remains non-recycled [3]. Pakistan generated nearly 12 million tons of plastic waste in 2020, and the amount generated could reach up to 22 million tons in 2050 [4]. Plastics are versatile, lightweight, and durable, making them popular for various applications, from packaging to construction to electronics [5]. The generation of plastic waste is a global environmental concern characterized by the production and accumulation of plastic materials that have reached the end of their useful life. Globally, around 0.40 billion tons of plastic wastes are generated [6]. Some of the major contributors to plastic waste are single-use plastics, such as disposable bags, bottles, straws, and packaging [7].

The two distinct categories of polymers are thermoplastics and thermosetting plastics, which exhibit different behaviors when subjected to heat [8,9]. Thermoplastics can be reformed in to any shape after heating and are referred to as recyclable due to their reversable nature [10]. However, thermosetting plastics undergo chemical changes upon heating that result in a hardened rigid material, a process referred to as polymerization [11]. This irreversible behavior leads to their finalized form, which cannot be softened or reshaped without significant degradation [12]. Thermoplastics generally have lower mechanical strength and heat resistance and may soften or deform at elevated

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temperatures [13]. However, thermosetting plastics are known for their high mechanical strength and excellent heat resistance. They maintain their structural integrity at elevated temperatures [14].

Thermoplastics are widely used in applications such as packaging materials, automotive components, consumer goods, and 3D printing due to their recyclable and reprocessable nature [15], whereas thermosetting plastics are used in electrical insulators, aerospace components, automotive parts, and composite materials due to their durability and high levels of temperature resistance [16]. E-wastes, also referred as electronic wastes, originate from discarded or obsolete electronic and electrical devices, equipment, and components and are used in various forms in the construction industry [17]. These e-wastes are often recycled and incorporated into cementitious composites in the form of plastic aggregates [18,19]. Aggregates from recycled plastics have been utilized extensively as an ingredient by researchers for investigations of flexible pavements [20].

To the best of the authors' knowledge, a limited addressal of the utilization of recycled plastic in construction materials is reported. This review paper is therefore intended to document the current and potential applications of recycled plastics as construction materials, as documented in the existing literature. To attain this, research studies published in highly reputable journals over the past decade are thoroughly reviewed to gather all published information relating to the utilization of recycled plastic in the construction industry. Firstly, the generation of waste plastic is discussed. Then, recycling techniques for waste plastic are reviewed. Finally, the current applications of recycled plastic as construction materials are explored, and potential future applications are discussed.

2. Generation of Waste Plastic

Plastic waste generation varies by region, but it has been steadily increasing worldwide, affecting both developed and developing countries [21]. Plastic waste poses serious environmental challenges, littering landscapes and waterways and contributing to oceanic pollution [22]. Nonbiodegradable plastics affect the ecosystem through soil pollution, marine pollution, and air pollution [23]. Most plastics are non-biodegradable, and their conversion into microplastics takes centuries [24,25]. Additionally, these microplastics may percolate into marine environments, and their unpredictable nature can severely impact the ecosystem [26]. The unpredictable nature of plastics corresponds to the carcinogenic and hazardous chemicals which are incorporated during processing to obtain the desired properties [27,28]. Additionally, appropriate planning for plastic waste management and waste plastic recycling requires the realistic forecasting of plastic waste generation [29].

Figure 1 shows various types of thermoplastics and thermosetting plastics. Polyethylene and polypropylene are two of the most widely produced thermoplastics globally [30]. These polymers are used extensively in packaging, construction, automotive, and consumer goods [31]. Beyond commodity thermoplastics like PE, PP, and PVC, there are specialized thermoplastics, such as polycarbonate, polyethylene terephthalate (PET) and polyurethane, which are used in industries like the electronics, automotive, and aerospace industries [32]. On the other hand, thermosetting plastics are integral to the production of composite materials, including fiberglass, carbon fiber, and aramid fiber composites, which are used in the aerospace, automotive, and marine industries [33]. The global production of this type of plastic waste is influenced by the demand and consumption of plastic manufactured products.

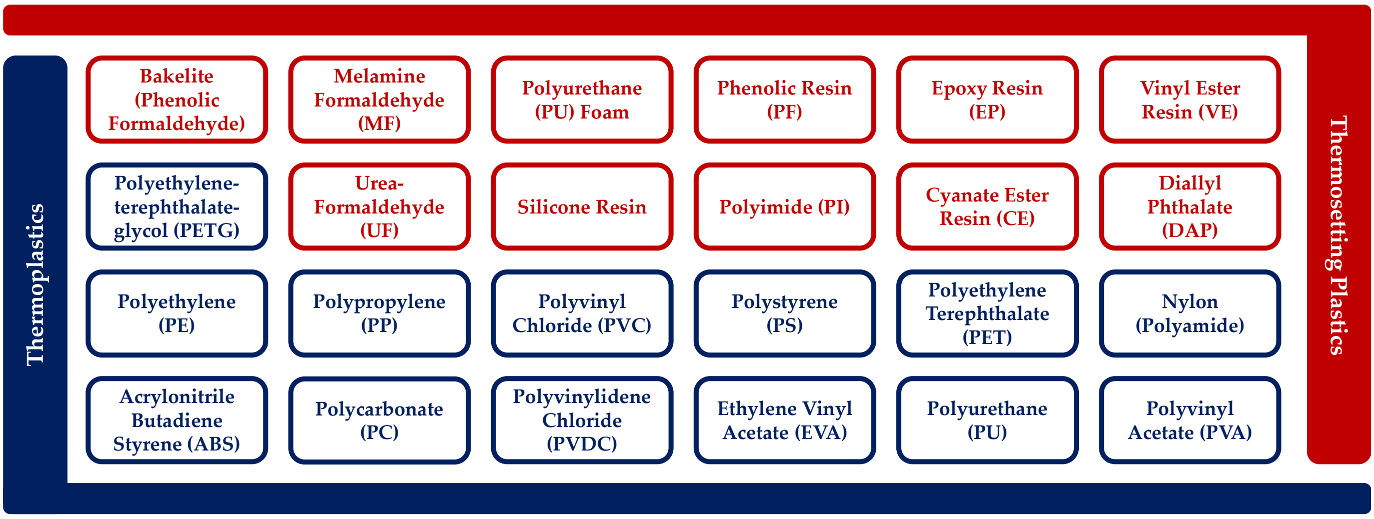

Figure 1. Types of thermoplastics and thermosetting plastics.

3. Waste Plastic Recycling Techniques

The recycling of waste plastics is an important aspect contributing to the circular economy [34]. The conversion of waste plastic to recycled plastic corresponds to different techniques based on the type of conversion and the requirements of the byproducts [35]. The most common techniques practiced for recycling waste plastics are presented in Table 1. The authors of [36] reviewed methods and challenges associated with the mechanical recycling of PET, PE, PP, PS, and PVC from the perspective of the circular economy. Mechanical recycling is particularly effective for plastics with similar properties, such as clean and well-separated plastic containers, but it also face challenges in terms of recycling mixed plastics, contamination issues, and the potential for material degradation during multiple recycling cycles [37]. Chemical recycling, including catalytic methods carried out under mild temperatures, are beneficial due to the simplicity of the processes and the lack of a need for extensive energy [38]. Also, the technique is favorable for mixed plastics, contaminated plastics, or plastics with complex structures which are challenging to recycle via mechanical recycling [39].

Table 1. Plastic waste recycling techniques.

Approach	Process	Ref.
Mechanical Recycling	The sorting, cleaning, shredding, and then melting waste plastic.	[36]
Chemical Recycling	The breakdown of plastic waste into its constituent molecules through chemical processing.	[39]
Thermal Recycling	The breakdown of plastic waste into its constituent molecules through heating at a high temperature.	[40]
Biological Recycling	The conversion of plastic waste into biomass or other useful products through microorganisms such as bacteria or fungi.	[41]

The thermal recycling of waste plastics has the advantage of reducing the volume of plastic waste, recovering energy, and potentially producing valuable fuels [42]. Thermal recycling is recommended for plastics with high calorific fractions and utilizes plastic as a fuel or raw material, remaining efficient and environmentally safe via ensuring proper design, monitoring, and regulation [40]. The authors of [41] reviewed recycling methods for PET waste plastic in which a biotechnological recycling approach using the enzymatic degradation of PET was compared with mechanical and chemical recycling approaches. Both conventional methods result in a lower quality of recycled plastic, in addition to economic and environmental costs. However, biotechnological techniques using engineered microorganisms can result in the production of valuable byproducts. The biological degradation or tertiary recycling technique completely breaks down waste plastic into its chemical component materials [43]. Based on the desired mechanical and durability properties, the adoption of recycling processes varies depending on the type of plastic waste stream to be recycled [44,45].

4. Application of Recycled Plastic as a Construction Material

The majority of the studies on recycled plastic from the perspective of construction materials use it in aggregates. The authors of [19] investigated the use of thermoset plastic as a 5% replacement for fine particles to develop eco-friendly cement mortar. It was observed that the composition resulted in the highest compressive strength, with a dense microstructure and a robust interfacial transition zone. The authors of [46] evaluated the composition of 50% sand and 50% high-density polyethylene (HDPE) to manufacture a sand–plastic composite intended to be used as floor tiles. It was revealed that low water absorption and sufficient adhesion increased interfacial bonding, leading to maximum compressive and flexural strength. The composite was recommended as a paving material in the non-traffic areas of public places. Table 2 shows various applications of plastic in the construction industry.

Table 2. Use of recycled plastic as a construction material.

Application	Composition	Modified Properties	Ref.
Eco-friendly cement mortar	5% thermoset waste as a replacement for fine particles	The highest compressive strength, a highly dense microstructure, and a robust interfacial transition zone.	[19]
Sand–plastic composites as floor tiles	50% sand and 50% HDPE	Maximum compressive and flexural strength due to sufficient adhesion, increased interfacial bonding, and low water absorption.	[46]
Wearing course of flexible pavement	Modified bitumen mix and processed waste plastic of about 5–10% by wt. of bitumen	Increased fatigue life and strength, ultimately enhancing the service life of pavement.	[47]
Pavement construction	0.5–3% HDPE and PP by weight of graded bitumen at a temperature range from 160 °C to 170 °C	A successful blending-in of the polymer strands in bitumen was observed. Stable polymer-modified bitumen was obtained using PP for pavement construction.	[48]

Pavement construction using plastic as a constituent has also gained attention in the recent decade. The authors of [47] used a modified bitumen mix containing the addition of waste plastic addition at 5-10% by weight of bitumen to evaluate its performance in a wearing course for flexible pavement. The results revealed a better service life in terms of increased strength and fatigue life. Another study was conducted [48] to evaluate the effects of the addition of HDPE and PP to bitumen. From 0.5% to 3% of HDPE and PP with an increment of 0.5% were replaced by weight of graded bitumen in a temperature range of 160 °C to 170 °C. As a result, the successful blending-in of the polymer strands in the bitumen was observed. Additionally, by using PP, a stable, polymer-modified bitumen was obtained for pavement construction.

5. Conclusions

This review paper focuses on the viable use of recycled plastics as construction materials, examining data extracted from relevant articles published in highly reputable journals over the past decade. This effort was made to compile pertinent published data concerning plastic recycling and its relevance for construction material applications. Based on this literature review, the conclusions are as follows:

1. The 2% annual growth rate of waste plastic is an alarming environmental challenge for Pakistan which needs to be addressed using an industrial-level recycling plan.
2. The decision to adopt a feasible recycling process majorly depends on the cost-effectiveness, the desired properties of the by-products, and environmental impacts.
3. Through obtaining recycled plastic with desirable mechanical and durability properties, waste plastic generation can benefit the construction industry by providing sustainable and resilient materials.
4. Future research studies should be oriented towards the properties-oriented process modification of recycling techniques to accelerate the large-scale transition of waste plastic into useful recycled plastic.

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