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Potential of Different Forms of Recycled Plastic as Construction Material—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 research is to have a thorough review of literature about the current recycled plastic use as construction material and possible future application. This is attained by targeting the highly reputable journals articles published during last one decade. Studies show convenient recycling of thermoplastics due to their reversible nature. However, their durability and resistance to temperature is still a point of concern. Recycled plastics are commonly used as replacement of aggregates in 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

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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, which can 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]. Waste plastic generation 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]. One of the major contributors to plastic waste is single-use plastics, such as disposable bags, bottles, straws, and packaging [7].

The two distinct categories of polymers are thermoplastics and thermosetting plastics that exhibit different behaviors when subjected to heat [8,9]. Thermoplastics can be reformed in to any shape after heating and referred as recyclable due to their reversable nature [10]. However, thermosetting plastics undergo chemical changes upon heating that makes resulting in hardened rigid material and the process is referred as polymerization [11]. Their 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 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 used widely in applications like packaging materials, automotive components, consumer goods, and 3D printing due to their recyclable and reprocess able nature [15]. Whereas thermosetting plastics are used in electrical insulators, aerospace components, automotive parts, and composite materials due to their durability and high-temperature resistance [16]. E-wastes also referred as electronic wastes from the discarded or obsolete electronic and electrical devices, equipment, and components are used in various forms in the construction industry [17]. These e-wastes are often recycled and incorporated in cementitious composites in the forms 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 author's knowledge, limited addressal of recycled plastic utilization 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 existing literature. To attain this, researches published in highly reputable journals in last one decade are thoroughly reviewed to gather all published information related to recycled plastic utilization in construction industry. Firstly, waste plastic generation is discussed. Then, recycling techniques for waste plastic are reviewed. Finally, current application of recycled plastic as construction material is explored and potential application in future is 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, waterways, and contributing to oceanic pollution [22]. Nonbiodegradable plastics affects the ecosystem through soil pollution marine pollution and air pollution [23]. Most of the plastics are non-biodegradable and their conversion to microplastics takes centuries [24,25]. Additionally, these microplastics may percolate into marine environments and their unpredictable impacts 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 desired properties [27,28]. Additionally, appropriate planning for waste plastic management and waste plastic recycling needs 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 find extensive use in packaging, construction, automotive, and consumer goods [31]. Beyond the 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 electronics, automotive, and aerospace [32]. On the other hand, thermosetting plastics are integral in the production of composite materials, including fiberglass, carbon fiber, and aramid fiber composites, which are used in aerospace, automotive, and marine industries [33]. The global production of the type of plastic waste is influenced by demand and consumption of the plastic manufactured products.

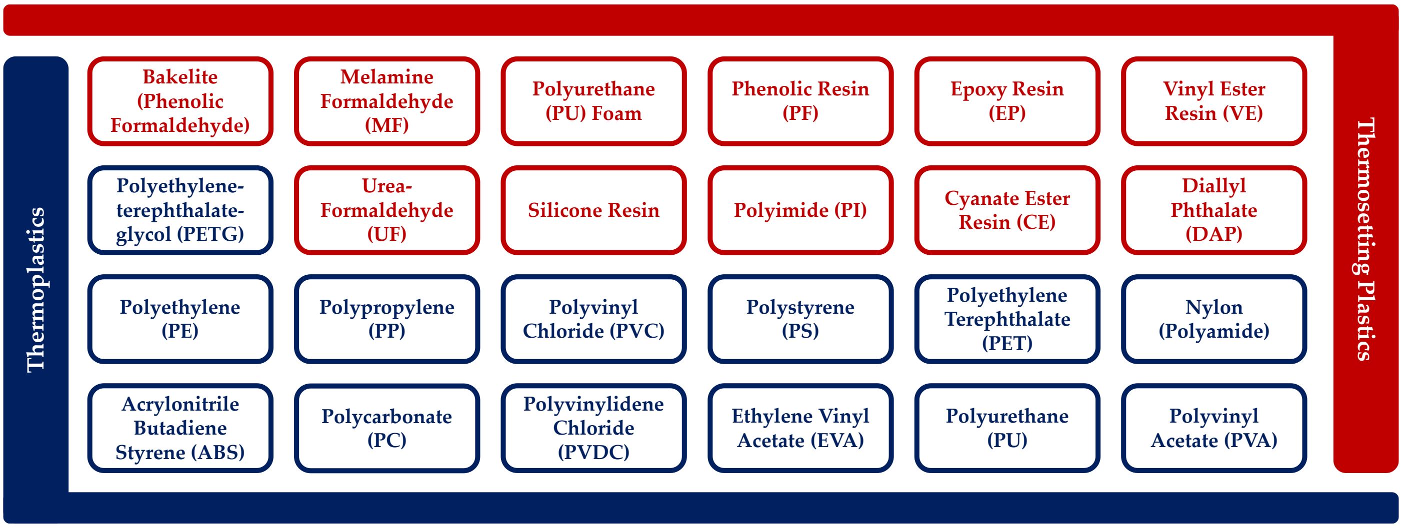

Figure 1. Types of thermoplastics and thermosetting plastics.

3. Waste Plastic Recycling Techniques

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

Table 1. Plastic waste recycling techniques.

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

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 that utilizes plastic as a fuel or raw material and remains efficient and environmentally safe by ensuring proper design, monitoring, and regulation [40]. Ref. [41] reviewed recycling methods for PET waste plastic in which biotechnological recycling approach using enzymatic degradation of PET was compared with mechanical and chemical recycling approaches. Both conventional methods result in lower quality of recycled plastic in addition to economic and environmental costs. However, biotechnological technique using engineered microorganisms can end up in to producing valuable byproducts. The biological degradation or tertiary recycling technique completely breaks down the waste plastic into 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 Construction Material

The majority of the studies on recycled plastic in perspective of construction material use it as aggregates. [19] investigated the use of thermoset plastic as 5% replacement of fine particles to develop eco-friendly cement mortar. It was observed that the composition resulted in highest compressive strength with dense microstructure and robust interfacial transition zone. [46] evaluated the composition of 50% sand and 50% high density polyethylene (HDPE) to manufacture 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 paving material in non-traffic areas of public places. Table 2 shows various applications of plastic in construction industry.

Table 2. Use of recycled plastic as construction material.

Application	Composition	Modified Properties	Ref.
Eco-friendly cement mortar	5% thermoset waste as replacement of fine particles	Highest compressive strength, highly dense microstructure and 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, 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 service life of pavement	[47]
Pavement construction	0.5–3% HDPE and PP by weight of graded bitumen at a temperature range of 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 constituent is also gaining attention in current decade. Ref. [47] used modified bitumen mix with waste plastic addition of 5-10% by weight of bitumen to evaluate its performance as wearing course of flexible pavement. The results revealed better service life in terms of increased strength and fatigue life. Another study was conducted by [48] to evaluate the effect of HDPE and PP addition in bitumen. 0.5% to 3% of HDPE and PP with an increment of 0.5% were replaced by weight of graded bitumen at a temperature range of 160 °C to 170 °C. As a result, successful blending-in of the polymer strands in bitumen was observed. Additionally, by using PP, a stable polymer modified bitumen was obtained for pavement construction.

4. Conclusions

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

1. 2% annual growth rate of waste plastic is an alarming environmental challenge for Pakistan which needs to dealt with industrial level recycling plan.
2. Decision to adopt feasible recycling process majorly depends on the cost-effectiveness, desired properties of the by-products and environmental impacts.
3. By obtaining recycled plastic with desired mechanical and durability properties, waste plastic generation can be worked out in the benefit of construction industry through sustainable and resilient materials.
4. Future researches should be oriented towards properties-oriented process modification in recycling techniques to accelerate the large-scale transition of waste plastic to useful recycled plastic.

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