AN ANALYSIS OF THE STATE-OF-THE-ART IN PLASTIC SCRAP RECYCLING STRATEGIES FOR CONSTRUCTION COMPONENTS

Abstract

Plastic waste poses one of the primary dangers to the planet since it is produced in large quantities and seriously harms both the environment and human population. Plastic waste from land-based sources frequently finds its way into bodies of water, where it poisons and floods the marine ecology, harming aquatic organisms. Examining diverse methods to transform plastic trash into novel goods is recognized as an effective means of handling them and improving the welfare of the planet, as covered in this piece. Additionally, the restriction on the use of plastic waste for building is taken into account. It has been determined that using plastic waste for building will greatly improve the ecological balance and be recognized as a reliable supply of resources for use in more traditional components like concrete and asphalt.

Keywords: Circular economy, Recycling, Polymer composites, Sustainable construction.

Authors

Debargha Banerjee
Assistant Professor
Civil Engineering Department
JISCE, Kalyani, India.
debargha.banerjee@jiscollege.ac.in

Debasish Das
Assistant Professor
Civil Engineering Department
JISCE, Kalyani, India.

Uddipta Ghosh
Assistant Professor
Civil Engineering Department
JISCE, Kalyani, India.

Mayukh Mandal
UG Student
Civil Engineering Department
JISCE, Kalyani, India.

Debjit Chakraborty
UG Student
Civil Engineering Department
JISCE, Kalyani, India.

Subhadeep Barman
UG Student
Civil Engineering Department
JISCE, Kalyani, India.

Subhajit Ghosh
UG Student
Civil Engineering Department
JISCE, Kalyani, India.

Subham Mondal
UG Student
Civil Engineering Department
JISCE, Kalyani, India.

Md Emran Hossain
UG Student
Civil Engineering Department
JISCE, Kalyani, India.

I. INTRODUCTION

Polymers have grown into an integral part of our modern life due to their numerous domestic and industrial applications; Evode et al. [1]. By 2050, the amount of plastic produced globally is predicted to be over 1.1 billion tons; Lai and Lee [2]. According to data from the Environmental Protection Agency, just seven percent of the tons of plastic waste produced each year is reused. Statistics showed that just eight percent of plastic gets burned, with the remainder going to landfills. However, these contaminants end up being dumped into water bodies due to the land filling process's significant energy consumption and expense; (Yuan et al; Emenike et al) [3,4]. Debris made of thermoset, thermoplastic, and elastomer plastics are difficult to break down and may be the main source for ecological degradation; (Chen et al; Prajapati et al) [5, 6]. Thus, the solution to ecological and conservation issues lies in effective discarding of plastic disposal. The assets used by the conventional approach are determined by the "take make- consume-waste" method. A creative and regenerative paradigm built on the circular economy principle must replace the linear approach. Heating disintegration, garbage dumps, mechanical pulverization, combustion, reusing, and microbial degradation are common waste management strategies for plastic materials. The swift and effective detection and arranging of recyclable plastic mixes remains a key issue for handling the discarded plastic business; Pan et al [7]. In the meantime, burning plastic waste is a widespread method of recycling its energy, since it allows for the large regeneration of energy that can be applied to many industries; Astrup et al [8]. Of various techniques, reusing scrap plastic can offer a socially and ecologically appropriate solution at the same time. Reusing plastic debris relates to rubbish management, which gathers plastic waste items, transforms them into raw materials, and uses them to make other products. Recycling's primary benefit is the disposal of plastic waste.

The ASTM Standard D5033 divides the plastic reuse method into first, second, third-level, and fourth stages [9]. Waste plastic reclamation is capable of being divided into three categories based on the mechanisms involved in each process: chemical, mechanical, and biological recovering; Siwal et al [10]. Plastic waste can be transformed into valuable substances and energy using heat and catalyzed reprocessing techniques. The main way to reduce plastic waste—a major cause for ecological concern—is through a procedure like this one. The other necessary step in the reprocessing of plastic waste is splitting of the various elements. In the subject of recovering plastic waste, there are several methods of segregation that are recognized, including density classification, optical sorting, Tribo electrostatic segregation and buoyancy; Wu et al [11]. Understanding the best methods of sorting and reclaiming plastic waste are two of the most effective ways to stop the buildup of pollutants in the surroundings caused by plastic waste. This review seeks to address the most recent advancements in organic and structural plastic waste recycling methods in order to reduce the amount of plastic waste that ends up in the ecosystem.

There are many different types of recyclable plastics, but the most prevalent ones are polyethylene and polyethylene terephthalate (PET). Plastic debris recycling has been identified by researchers as a promising avenue, and the packaging industry has put up a number of recycling strategies for this kind of garbage. They aren't frequently used in building sector, though. Since the building trade is the greatest the client of natural resources and the primary market in various economic sectors, it is actually a favorable and crucial area where recyclable plastics add value and may be used for diverse uses. Plastic scraps can be used to make substantial asphalt and concrete mixtures, binder, soundproofing and other materials for civil works. Although plastic waste has a lot of promise for use in the building industry, its growth and utilization are currently extremely restricted; Damayanti et al [12]. The feasibility of reclaiming thermoplastics is influenced by two significant financial factors. These are the expenses of reprocessing in comparison to other approved methods of elimination and the price of regenerated polymerization compared to virgin polymer. Compared to virgin plastics, differences in the amount and standard availability are linked to further issues. The supply, consistency, and potential of reused plastic for certain uses can all be factors that discourage the use of reused materials; (Sony et al and Ahmed et al) [13,14]. This paper examines current developments in substances and techniques for recovering plastic waste. Additionally, research is done on polymeric recyclables used in common structures like concrete and asphalt pavements. Additionally, an investigation is conducted on the usage of debris to enhance the lifespan of asphalt and concrete.

II. REUSE OF LEFTOVER PLASTICS

Unlike to different substances that are utilized in extensive amounts, like glass, paper, ceramics, and aluminum, plastic products are less recyclable; (Awoyera et al.; Awoyera and Adesina) [15-16]. Because it involves multiple stages of preparation, screening, elimination, shipment, and utilize, entire reuse of plastic is recognized as a difficult technology; (Hahladakis and Iacovidou; Singh et al) [[17-18]. Plastic scraps are recyclable using mechanical, chemical, or thermal methods. They must first be separated, which is typically done automatically using a variety of techniques like spectroscopy, electrostatics, infrared, flotation, and fluorescence. The primary steps that involve mechanical recycling, splitting and/or crushing, are the procedures that lead to the physical breakdown of plastic material; (Serranti and Bonifazi; Khalid et al; Das et al) [19-21]. The intricacy of plastic debris combinations makes mechanical recycling ineffective when juxtaposed with combustion; as a result, the majority of plastic waste are burned (Shamsuyeva and Endres; Lee and Liew; Kho and Hssien; Aryan and Yadav) [22-25]. However, because of its quick processing time and effectiveness, the hands-on reusing method is the most popular plastic recycling method, according to the research. The chains of polymers discovered in plastic waste can be split down chemically to return to their original monomers, which can then be utilized to create fresh plastic components rather than virgin raw materials. Faraca and Astrup looked into how recyclable certain plastic goods were; (Eriksen and Astrup) [26]. Research indicates that the plastic elements listed in this group have a screening and recycling capacity greater than 50%. PET is one of them that is least recyclable. Furthermore, recycling polyethylene and polypropylene is expected to yield better results in terms of energy usage as well as administration methods.

III. DIFFERENT KINDS OF PLASTICS AND THEIR POTENTIAL USES IN CIVIL WORKS

Each country's building sector is one of its primary foundations and a major contributor to its GDP. As a result, using recyclables will greatly increase how sustainable constructing methods and procedures are. Maintaining items and their component parts at their highest levels of quality and effectiveness for the duration of their planned life spans is the key objective of the model known as the circular economy. The creative, environmentally friendly utilization of leftover plastic for construction uses will result in a significant decrease in the discharge of recyclable plastics in the oceans. As a result, substitute materials may be suggested to satisfy the high demand in the building sector. But mechanical qualities and longevity have to match the purpose of their use. In addition, these components have to be accessible and environmentally friendly in order to replace other kinds of resources. For instance, certain reprocessed non-biodegradable waste plastic bags have been utilized to make floor and wall tiles that are less flammable and have better durability; (Kazemi et al; De Camargo and Saron) [27, 28]. The characteristics of self-consolidating concrete (SCC) created by adding fine aggregates made from plastic waste were documented by Hama and Hilal [29]. According to current studies, LDPE makes up the majority of plastic waste. But PP and HDPE also revealed a notable degree of resemblance to that HDPE; Subramanian (2000) [30]. The effectiveness of plastic waste in fiber-reinforced beams made of concrete was studied by Khalid et al. In order to increase the concrete's breaking energy, compression strength, beam bending strength, and split extensible, researchers injected ring-shaped PET into the material. Additionally, it demonstrated how the addition of plastic fibers to the concrete enhanced the beams' reliability with regard to load and initial cracking power while having little to no impact on their collapse mechanism; Khalid et al [31]. The shear, firmness, and bending capacity of slabs have increased when PW is used in place of stone in base and sub-base design; (Henriksen et al; Serranti et al) [32, 33]. Bitumen and aggregates, considered the most common materials used to build roadways because of their outstanding resilience and carrying capabilities, typically make up 4 to 8% of the asphalt road surface. Adding plastics to an asphalt pavement is a typical method of improving its durability. Lately, other polymer substances for enhancing the efficiency of asphalt roads have been assessed, including waste polymers and rubber; (Hunter et al; Tejaswini et al.) [34, 35]. The wet technique and the method of drying are the two distinct ways that waste polymers or rubber can be loaded into asphalt. The leftovers function as an alter in the initial process, loading and mixing with bitumen to create bitumen that has been changed with polymers. During the subsequent procedure, the plastic wastes function as a supplement or aggregate in the asphalt mixture, and they can be used in place of raw aggregate and fillers; Song et al [36]. The addition of plastic debris to asphalt improved the pavement's resilience to cracking and skidding. The rigidity and durability against ruts performance of the asphalt mixtures are greatly enhanced by the use of plastic wastes as additives. The enhanced durability of the framework brought about by the addition of the plastic waste may be the source of this increase in the effectiveness of the asphalt treated with plastic waste. In addition, there was a noticeable decrease in road noise when asphalt with leftover plastic was used. Additionally, it has been suggested that by employing moulding treatment, leftover plastic may be used as a viable substitute for wood, blocks, and bricks; Bae et al [37].

Based on their physical characteristics and chemical makeup, plastics are divided into a number of categories. Depending on the ease of reprocessing and reuse, each kind has an own recycling pathway. The main categories of plastics and their usual recycling processes are broken down below.

Table 1: Plastic Identification Codes (Resin Codes)

Code	Plastic Type	Common Uses	Recycling Pathways
1	PET or PETE (Polyethylene Terephthalate)	Beverage bottles, food containers	Widely recycled; turned into fiber for carpets, clothing, containers, etc.
2	HDPE (High-Density Polyethylene)	Milk jugs, detergent bottles, piping	Widely recycled; used for plastic lumber, piping, new bottles.
3	PVC (Polyvinyl Chloride)	Pipes, clear food packaging, medical tubing	Rarely recycled; difficult due to chlorine content; may be downcycled or incinerated.
4	LDPE (Low-Density Polyethylene)	Plastic bags, film wrap, squeezable bottles	Limited recycling; often downcycled into bins, floor tiles, or lumber.
5	PP (Polypropylene)	Yogurt containers, straws, caps	Increasingly recycled; used for signal lights, battery cases, brooms.
6	PS (Polystyrene)	Disposable plates, cups, foam packaging (Styrofoam)	Poorly recycled; difficult and uneconomical; can be compacted and reused.
7	Other (e.g., PLA, polycarbonate, nylon)	Multi-layer packaging, electronics	Hard to recycle; usually ends up in landfills unless specialty processes are available

Recycling Pathways

1. Mechanical Recycling
   - Shredding, washing, melting, and remoulding into new products.
   - Common for PET, HDPE, and sometimes PP.

2. Chemical Recycling (Advanced Recycling)
   - Breaks plastic into its original monomers or other chemicals.
   - Suitable for complex or contaminated plastics like (PVC), (PS).

3. Energy Recovery
   - Incineration to generate energy.
   - Often used as a last resort for unrecyclable plastics.
4. Biological/Enzymatic Recycling
   - Emerging for specific types like PLA (bio-based plastics).
   - Still in development.

Discussion on standardization challenges, long-term durability, and lifecycle assessment (LCA) results of using plastics as construction materials:

Using plastics as construction materials brings both innovation and challenges. Here's a detailed discussion of the standardization challenges, long-term durability, and lifecycle assessment (LCA) results associated with their use:

1. **Standardization Challenges:** In the construction industry, plastics include a wide variety of materials with varying formulas and performance characteristics, such as PVC, HDPE, polycarbonate, and PU foam. This makes it more difficult to achieve consistent standards.

   Important Concerns

   Material Variability: It is challenging to create universal performance benchmarks since formulations differ greatly depending on additives, fillers, and production techniques.

   Unavailability of Uniform Testing Procedures: In contrast to more conventional materials like steel or concrete, plastics do not have widely accepted requirements for fire performance, mechanical strength, thermal expansion, or UV resistance.

   Recyclability Standards: The recycled content and recyclability of building materials made of plastic cannot be consistently measured or reported.

2. **Long Term Durability:** Although plastics provide advantages like inexpensive management and durability against corrosion, deterioration is a worry.

   Advantages

   Corrosion and Chemicals Resistance: Perfect for tough settings (e.g., coastal structures, wastewater-pipelines).

   Lightweight and Mouldable: Allows for creative designs and lowers installation and transportation-costs.

   Moisture Resistance: PVC and HDPE are two examples of plastics that do well in humid conditions.

   Issues

   UV Degradation: Extended exposure to sunshine can deteriorate some plastics, such as polyolefins, necessitating coatings or stabilisers.

   Creep and Deformation: Certain plastics may undergo persistent distortion as a result of prolonged static stress.

   Thermal Sensitivity: A lot of plastics are susceptible to deformation at elevated temperatures and have a lower point of melting.

   Microplastic Generation: Plastics have the potential to break down into microplastics as they growing older which could have negative effects on the environment and human health.

3. **Outcomes of Lifecycle Assessment (LCA):** From the mining and processing of raw materials to the disposal of end-of-life materials, lifecycle assessments analyse the effects on the environment. Plastics produce a range of outcomes:

   Good Results: Reduced Embodied Energy: Many polymers require less initial energy to manufacture than metals and concrete.

   Fuel and Emissions Savings: Insulation and windows made of lightweight plastic can lower the requirement for heating and cooling, which saves operating energy.

   Potential for Recyclability: With the right collection and processing, certain plastics—particularly thermoplastics—can be recycled.

   Negative Impacts

   End-of-Life Problems: Plastics frequently have no market for recycling and can end up in landfills or burned, which adds to pollution over time.

   Toxicity Risks: If improperly handled, some plastic additives (such as phthalates and flame retardants) can be harmful to human health and the environment.

Limitations

1. Because plastic waste comes in a range of sorts and levels, it may not function in an isotropic manner when used in building.
2. Certain situations where a greater degree of elastic properties and toughness is needed may be limited by low density.
3. Insufficient information about reused plastics' longevity resulted in restrictions on the builders' willingness to make use of leftover plastic.
4. Insufficient exterior energy considerably lowers the general strength of the final compound by causing inadequate structural bonding during incorporation.
5. Certain plastics cannot be recycled because doing so requires expensive, sophisticated technology, which limits the amount of plastic waste that can be recycled.
6. Furthermore, there is currently no regulation for using plastic waste in building, despite thorough research into its application in concrete composites.
7. Mechanical and structural limitations such as lower bond strength, deformation under load and thermal expansion.
8. Durability and aging associated with UV degradation, risk of fire and chemical sensitivity.
9. Issues related with bonding and compatibility.
10. Environmental risks because of releasing microplastics and toxic substances.

IV. CONCLUSIONS

Plastics are indispensable to our everyday existence, and as they are used up, trash made from plastic will inevitably be produced. As a result, using them in construction is a practical way to improve our ecological footprint and aid in proper handling of plastic waste. The current research on using waste plastic that has been repurposed for construction has been examined in this article. There are many benefits and major drawbacks to using plastic in building. For uses including piping, insulation, window frames, panels, and flooring, plastics are perfect because of their exceptional durability, resistance to corrosion, lightweight nature, and design flexibility. Their ability to withstand chemicals and moisture prolongs the life of buildings and lowers maintenance expenses.

However, issues with long-term durability, protection against fire, and sustainable development must be considered. Because they are made from non-renewable resources, plastics present problems with regard to recycling and disposal at the end of their useful lives. They also need to be carefully considered and mitigated because of their flammability and the emission of hazardous fumes during combustion. In a nutshell the usage of plastic products should be harmonised with environmental considerations, even though they can help create more inventive, economical, and efficient building techniques. To optimise the advantages while reducing the environmental effect, developments in recyclable and biodegradable plastics are crucial, as is a greater focus on circular economy principles.

A summary of the conclusions that follow is possible.
1. Utilizing plastic scraps for building can reduce the need for basic components and address issues with waste disposal while promoting the circular economy's longevity.
2. In contrast to their brief utilization in new items, the building sector uses plastic trash for over time uses, which results in the development of fresh plastic waste.
3. Plastic scraps are a good substitute for most of the ingredients used in cementitious materials, since they may be utilized as an aggregate, binder, and fiber while still maintaining a satisfactory level of ultimate composite effectiveness.

DECLARATIONS

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