JOURNAL OF ADVANCED ENGINEERING AND INNOVATION
Volume 1, Issue 2, December 2023 | 69-75
https://doi.org/10.54518/jaei.1.2.2023.1236

Recent Advances in Plastic Waste Utilization for Sustainable Concrete Development

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ABSTRACT

The increasing amount of plastic waste is a major challenge in environmental management and encourages the development of more sustainable construction materials. One widely researched alternative is the use of plastic waste as an ingredient in environmentally friendly concrete. This study aims to examine the effect of plastic waste use on concrete characteristics through a Systematic Literature Review (SLR) approach. Data were collected from scientific articles indexed in Google Scholar and published in the last five years. Literature that met the selection criteria was analyzed descriptively and comparatively, focusing on the type of plastic waste, mixture composition, testing methods, and changes in concrete properties, including workability, density, compressive strength, and water absorption. The results of the study indicate that the use of plastic waste can reduce the use of natural aggregates and provide environmental benefits by reducing the volume of plastic waste. The use of plastic waste at low to moderate levels can still produce concrete characteristics that meet the needs of certain applications, while higher levels tend to reduce workability, compressive strength, and durability due to the weak bond between plastic particles and cement paste. This study shows that plastic waste has potential as an alternative material in the development of environmentally friendly concrete, while still paying attention to the optimization of mixture composition and material quality control.

Keywords: *Concrete, Green Concrete, Plastic Waste, Recycled Materials, Sustainable.*

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ARTICLE HISTORY
Received : July 15, 2023
Final Revised : August 20, 2023
Accepted : October 26, 2023
Published : December 30, 2023

1. | INTRODUCTION

The increase in plastic consumption in various sectors has led to the accumulation of waste that is increasingly difficult to manage due to its non-biodegradable nature. Plastic is one of the most common types of solid waste generated due to population growth, urbanization, and industrial activity. This condition causes various environmental problems, such as pollution of land and water bodies, and an increase in the volume of waste in landfills. Therefore, developing technology to utilize plastic waste into materials with added value is one approach that supports the concept of a circular economy and sustainable development (Babafemi et al., 2018; Alhazmi & Al-Hashmi, 2020). On the other hand, the construction industry is one sector that consumes large amounts of natural resources, especially fine and coarse aggregates as the main ingredients of concrete. The high demand for construction materials has led to the continued exploitation of natural resources, potentially causing environmental impacts.

This condition has encouraged various studies on the use of recycled materials as substitutes or as concrete mixes without reducing its structural function. One material that has received widespread attention is plastic waste due to its abundant availability, relatively low density, and good resistance to environmental degradation (Babafemi et al., 2018). The concept of environmentally friendly concrete (green concrete) has developed as a solution to reduce the consumption of natural materials while increasing the utilization of solid waste. In recent years, plastic waste has been utilized as a partial replacement for fine aggregate, coarse aggregate, and as a fiber additive in concrete mixes. Various studies have shown that the use of plastic waste can reduce the specific gravity of concrete, resulting in lighter concrete. Furthermore, the use of plastic waste also has the potential to improve thermal and acoustic insulation properties, thus adding value to certain construction applications (Babafemi et al., 2018).

However, the addition of plastic waste also affects the characteristics of both fresh and hardened concrete. Several studies have reported that increasing the plastic waste content tends to decrease the slump value due to the plastic's hydrophobic surface and low water absorption capacity (Babafemi et al., 2018). Furthermore, the interfacial bond between cement paste and plastic particles is generally weaker than that of natural aggregates, which can lead to a decrease in compressive strength if the substitution content is too high. The magnitude of this effect is influenced by the type of plastic, particle size, material shape, mixing method, and percentage used in the concrete mix (Sohail et al., 2018).

Several studies published between 2018 and 2022 indicate that the use of low percentages of plastic waste can still produce mechanical characteristics that meet the requirements for various non-structural and semi-structural applications. However, the available research results still show significant variation due to differences in plastic type, mix composition, material processing methods, and testing procedures used (Toussaint et al.,2019). This situation indicates that a comprehensive evaluation of the effect of plastic waste on the physical and mechanical properties of concrete is still needed as a basis for developing more sustainable construction materials (Babafemi et al., 2018).

Based on this description, this study aims to examine the use of plastic waste as an environmentally friendly concrete admixture through a systematic review of various research results published between 2018 and 2022. The study focuses on the effect of adding plastic waste on the workability, density, compressive strength, and general characteristics of concrete as a basis for identifying the potential application of recycled materials in the development of more sustainable concrete.

2. | RESEARCH METHOD

This study uses the Systematic Literature Review (SLR) method or literature study that aims to identify, evaluate, and synthesize research results regarding the use of plastic waste as an environmentally friendly concrete mixture. The research stage begins with the formulation of a topic and research questions that focus on the effect of plastic waste use on concrete characteristic (Ahmad et al., 2022). Next, a literature search was conducted through the Google Scholar database using the keywords plastic waste concrete, recycled plastic concrete, green concrete, plastic aggregate concrete, sustainable concrete, and plastic fiber reinforced concrete. The obtained literature was then selected based on inclusion criteria, namely research articles published in the period 2018–2022, available in full text form, published in national and international scientific journals that have gone through a peer-reviewed process, and directly discussing the use of plastic waste as a substitute for aggregate, mixture, or reinforcing material in concrete.

Meanwhile, articles published before 2018, did not have clear methodological information, were in the form of short proceedings, or were not relevant to the research objectives were excluded from the analysis process. All literature that meets the criteria is then systematically evaluated by extracting information regarding the type of plastic waste used, mixture composition, testing methods, and concrete performance parameters including workability, density, compressive strength, and water absorption (Abu-Saleem et al., 2021). The collected data is then compared and analyzed descriptively-comparatively to identify trends in research results, similarities and differences in findings, and to formulate a scientific synthesis regarding the potential use of plastic waste as an alternative material for environmentally friendly concrete that supports the concept of sustainable construction.

3. | RESULTS AND DISCUSSION

A literature synthesis indicates that the use of plastic waste as a concrete admixture is a rapidly growing innovation supporting sustainable construction concepts. Based on various studies published between 2018 and 2022, plastic waste has been utilized in various forms, such as shredded particles, fibers, and granules, which serve as partial substitutes for fine aggregate, coarse aggregate, or as additives in concrete mixes. The most commonly used plastics include polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP), and polyvinyl chloride (PVC) (Singh & Demirsöz, 2022). Utilizing these materials not only aims to reduce the volume of waste ending up in landfills but also to reduce the exploitation of natural aggregates as the primary raw material for concrete (Babafemi et al., 2018; Awoyera & Adesina, 2020).

Most studies indicate that the addition of plastic waste has a direct impact on the properties of fresh concrete. Workability generally decreases as the percentage of plastic waste in the mixture increases. This phenomenon is caused by the hydrophobic nature of plastic surfaces, making them less able to absorb water like mineral aggregates. Furthermore, the irregular shape of plastic particles increases interparticle friction during the mixing process. As a result, the concrete mixture becomes stiffer, requiring adjustments to the water-cement ratio and the use of admixtures to ensure the slump remains within construction requirements. However, at relatively low concentrations, the decrease in workability remains within an acceptable range, allowing the casting process to proceed without significant segregation (Babafemi et al., 2018)

Another characteristic that consistently changes is the concrete's density. Nearly all studies report that concrete containing plastic waste has a lower density than normal concrete. This occurs because the density of plastic is much lower than that of natural aggregate. This decrease in density offers the advantage of reducing the dead load on the structure and increasing the potential for lightweight concrete to be used for certain applications. Furthermore, several studies report that the presence of plastic particles can improve heat and sound insulation, making the material more suitable for buildings requiring energy efficiency. However, the reduction in density must also be balanced with an evaluation of mechanical properties to ensure the concrete quality continues to meet design requirements (Zhang et al., 2022).

Compressive strength is the most frequently analyzed parameter in research on plastic waste-based concrete. Based on a review of various publications, a general trend indicates that increasing the plastic waste content leads to a decrease in concrete's compressive strength. This decrease is primarily due to a weak bond between the plastic surface and the cement paste, resulting in the formation of a less dense interfacial transition zone (ITZ). Furthermore, the elastic properties of plastic differ from those of mineral aggregates, resulting in less even stress distribution during loading. Nevertheless, most studies also indicate that the use of low levels of plastic waste can still maintain compressive strength at a level acceptable for non-structural and even some semi-structural applications (Farina et al., 2022). This indicates that the substitution rate plays a crucial role in the successful use of plastic waste in concrete (Babafemi et al., 2018; Awoyera & Adesina, 2020; Ahmad et al., 2022).

In addition to compressive strength, several studies have also evaluated other mechanical properties such as splitting tensile strength, flexural strength, and modulus of elasticity. The results show a similar trend, with a decrease in values when the percentage of plastic waste increases significantly. However, when plastic waste is used in the form of fibers of a certain size, several studies report increased resistance to crack propagation and the ability to absorb energy before failure (Signorini & Volpini, 2021). This indicates that the physical form of plastic waste is as important as the percentage used. Therefore, optimizing particle size, material form, and mixing method are factors that need to be considered in the development of environmentally friendly concrete based on plastic waste (Babafemi et al., 2018; Ahmad et al., 2022).

4. | CONCLUSION

A literature review has shown that plastic waste has significant potential for use as an environmentally friendly concrete admixture to support sustainable construction. A synthesis of various studies has shown that the use of plastic waste can reduce the consumption of natural aggregates and provide a value-added waste management alternative. The addition of plastic waste generally decreases the workability, density, and compressive strength of concrete as the percentage of the mixture increases. However, the use of low to moderate levels of plastic waste can still produce concrete that meets the requirements for various non-structural and some semi-structural applications. The differences in characteristics reported in each study are influenced by the type of plastic, particle size, material form, mix composition, and mixing and curing methods. Therefore, optimizing mix design is a crucial factor in achieving a balance between mechanical performance and environmental benefits. Overall, the use of plastic waste as a concrete admixture represents a promising innovation for reducing environmental pollution while increasing the efficiency of natural resource use. Further research should focus on developing technologies to enhance the bond between plastic and cement paste, evaluating long-term durability, and developing technical standards to support the broader application of this material in the construction industry.

Acknowledgment

We gratefully acknowledge the contributions of individuals who supported the completion of this article.

Funding Information

This research did not receive any funding.

Conflict of Interest Statement

The authors declare that there is no conflict of interest.

Ethical Approval and Originality Statement

Ethical approval was obtained for this study. The manuscript represents original work and has not been previously published, nor is it under consideration by another journal.

Data Disclosure Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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