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Evaluation of Some Beneficial Environmental Impacts and Enhanced Thermal Properties Resulting from Waste Plastic Integration into Concrete

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ABSTRACT

The burgeoning issue of plastic waste, exacerbated by urbanization and pollution, has emerged as a global concern. A novel approach to address this problem involves the recycling of waste plastics and their incorporation into concrete, thereby promoting sustainability and environmental responsibility. This study offers a comprehensive review of the effects of integrating plastic waste into concrete to enhance its thermal properties. The findings reveal that the inclusion of waste plastics considerably reduces the thermal conductivity of concrete, augments its thermal resistance, and optimizes its thermal diffusivity. Moreover, the utilization of plastic waste in concrete yields environmental advantages, such as the mitigation of detrimental impacts on marine and terrestrial ecosystems resulting from plastic pollution. This research contributes to the expanding body of literature on sustainable concrete production and waste plastic recycling, providing valuable insights for the development of eco-friendly construction materials.

1. INTRODUCTION

In recent decades, the global construction industry has undergone a paradigm shift towards adopting novel concepts and environmentally-friendly approaches that prioritize ecological and sustainability considerations. This transition is essential, as the building sector is a significant consumer of construction materials and natural resources [1]. Sustainable concrete has emerged as one of these innovative ideas, providing a viable alternative to conventional concrete [2].

Sustainable concrete functions similarly to conventional concrete, yet it possesses enhanced characteristics, such as improved mechanical properties and functional performance, due to the incorporation of alternative materials into the mix. This results in increased cost-effectiveness, durability, and reduced environmental impact [3, 4]. By strategically substituting certain proportions of cement, sand, superplasticizer, or other vital concrete components, significant improvements in toughness, workability, mechanical properties, sustainability, and cost-effectiveness may be achieved [5].

Many researchers have explored the use of waste materials or depleted substances in concrete mix designs as a replacement for cement, superplasticizer, and sand, yielding various positive effects [6-11]. These benefits include reducing the accumulation of natural waste on land, rivers, seas, and oceans; minimizing the adverse impacts of various waste categories on animals, plants, and fish; decreasing environmental pollution; improving air quality; mitigating hazardous particulate matter in the air; and reducing the budget required for recycling, treating, and processing solid waste in landfills.

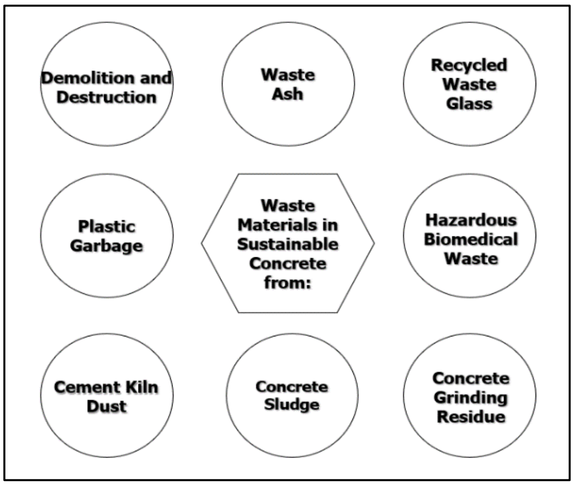

Figure 1. Suitable types of wastes that can replace some materials in sustainable concrete [12-15]

Figure 2. Some facts and valuable impacts of taking plastic recycling into account [16]

However, not all waste materials may be suitable for incorporation into concrete while maintaining practical and functional mechanical properties. The most appropriate waste materials that can be used in the concrete mix are presented in Figure 1. Waste plastics (or plastic garbage), as indicated in Figure 1, are commonly integrated into concrete. Recycling waste plastics offers both environmental and economic benefits, as shown in Figure 2.

Numerous studies [17-23] have investigated the significant impacts of incorporating plastic waste into concrete mixes on mechanical properties, durability, and workability. They have found that the careful addition of plastic waste can result in an array of positive effects, improving various mechanical features such as toughness, compressive strength, splitting tensile strength, impact strength, Young's modulus/modulus of elasticity, ductility, and water permeability. Additionally, these authors have noted that incorporating waste plastic in concrete can lead to increased sustainability and a considerable reduction in plastic waste accumulation, which would otherwise adversely impact the environment.

Conversely, other researchers [3, 24-26] have identified several benefits that can be achieved when substituting certain proportions of waste plastic in concrete, including enhanced energy performance and thermal properties, specifically thermal conductivity, thermal resistance, thermal insulation, thermal stability, and fire resistance. They suggest that improvements in thermal resistance could render concrete an excellent insulating material, significantly reducing cooling and heating load requirements during summer and winter due to minimized heat transfer and thermal energy losses. Consequently, construction projects incorporating concrete with waste plastic additives could provide greater thermal stability.

Moreover, some studies [12, 27] have highlighted the potential for improved economic feasibility and cost-effectiveness by reducing the need for expensive materials in the concrete mix design process for specialized construction purposes. This reduction could lead to decreased budget requirements for large-scale construction projects, such as skyscrapers, infrastructure facilities, and utility-scale buildings [4, 28, 29].

Despite efforts to recycle, incinerate, or dispose of plastics, the volume of plastic waste continues to increase rapidly due to global population growth. It is projected that in the coming decades, plastic waste will become a considerable challenge, necessitating extensive efforts and international cooperation to address this escalating issue, as depicted in Figure 3.

In light of these findings, this paper aims to provide a comprehensive review of the thermal properties, mechanical features, environmental impacts, and economic profitability of concrete mixes containing waste plastic. It addresses knowledge gaps in the existing literature and offers critical recommendations for sustainable construction practices.

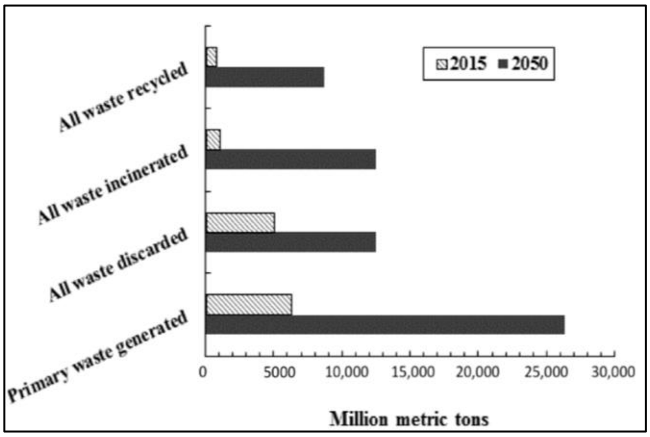

Figure 3. Different treatment approaches for waste plastic according to past (2015) and expected (2050) projections [29]

2. INTRINSIC PROPERTIES OF PLASTIC MATERIAL AND PLASTIC WASTE

This section will offer two major knowledge contributions:

(1) Fundamental features of plastics;

(2) Functional advantages of plastic waste incorporation into the concrete mix.

2.1 General properties of plastics

Plastic is a form of polymer that, while soft, may be shaped and sized as required, much like synthetic fibers, and, when firm, may be used to manufacture long-lasting objects. The word "plastic" comes from the Greek word "plastikos", which means "to mold," and it is utilized to refer to a wide variety of synthetic or semi-synthetic organic polymers. The word "plastic" was derived from the word "Plastikos". It is well known that many forms of plastics each exhibit their own unique set of chemical and physical properties [30-34]. Plastic is used to manufacture a wide variety of items, including but not limited to chairs, tables, buckets, toys, and balls. Vital characteristics of plastics include the following features Shrivastava [35]:

- They are chemically stable, and they have less weight.
- They are adaptable to a wide range of forms and dimensions.
- They have lower thermal conductivity and higher insulation properties.
- They have superior resistance to impact and do not rust.
- They are characterized by considerable levels of see-throughness and durability.
- Their dimensions are not stable, and deformation occurs readily.
- They work in an affordable process.

2.2 Benefits of using waste plastics in concrete

Particularly for large-scale construction projects, applying waste plastic replacement is quite helpful in lowering the original capital cost of the concrete. Additionally, implementing plastic waste to manufacture concrete can increase sustainability and decrease pollution, relying on some substitution percentages of concrete that range between 0% and 99% or utilizing a full-substitution proportion (100%) in some cases [36-38].

Aggregate/sand/cement substitution with plastic in concrete can modify some necessary mechanical characteristics. It can improve its thermal performance by enhancing thermal resistance and reducing fire resistance [5, 39-43].

3. FAVORITE IMPACTS OF WASTE PLASTIC INTEGRATION INTO CONCRETE ON WORKABILITY

Poonyakan et al. [44] undertook an experimental analysis through which valuable influences of waste plastic use in concrete on thermal conductivity and other parameters were addressed. The scholars classified some common plastic wastes that can be engaged in the concrete mix, especially polyethylene terephthalate, low-density polyethylene, high-density polyethylene, and polypropylene.

According to their experimental work, the outcomes proved that polyethylene terephthalate, low-density polyethylene, high-density polyethylene, and polypropylene should be replaced in concrete at optimal and suitable replacement ratios of 50%, 10%, and 5%, respectively. Hence, better concrete thermal and mechanical properties could be guaranteed. Those essential characteristics contain bulk density, workability, splitting tensile stress, compressive strength, and thermal conductivity. Meanwhile, their outcomes affirmed that when low-density polyethylene with a replacement percentage of roughly 30%, the new concrete mix could have significantly low thermal conductivity.

Figure 4. RPA categories used to substitute natural coarse aggregates: (a) Granules, (b) Fibers, (c) Black flakes, (d) Mixed flakes and (e) White flakes [5]

Basha et al. [5] guided an analytical work exploring the leading advantages and dominant benefits of using waste plastic in concrete. Three distinct types of recycled plastic were utilized to prepare a specimen set of concrete employing various replacement ratios. They applied compressive strength tests and estimated the thermal and mechanical properties of the new concrete specimens. According to their experimental research, they found that a concrete mix with 100% of recovered waste plastic aggregate obtained compressive stresses of 17 MPa and densities of 1,500 kg/m^3. Further, results emphasized that harnessing 25% recycled waste plastic produced a density of 2,000 kg/m^3 and a compressive stress of 35 MPa. What's more, their work asserted that raising the recycled waste plastic percentage could lessen concrete's bond strength, flexural stress, and elastic modulus. Concerning the impact of plastic waste on concrete's thermal properties, it was determined that the thermal conductivity of conventional concrete was 1.7 W/m.K. On the other hand, the thermal conductivity of concrete made using waste plastic ranged from 0.5 to 1.1 W/m.K. Figure 4 illustrates Recycled Plastic Aggregate (RPA) varieties used in their analysis.

Concurrently, Bhogayata and Arora [45] published a manuscript discussing the critical added values of recycled plastic fiber incorporation and styrene-butadiene rubber latex addition into concrete on modifying its workability and other vital mechanical features. To determine the combined effect of Recycled Plastic Fiber (RPF) and Styrene Butadiene Rubber (SBR) latex, fresh and cured conventional concrete sorts were tested. The scholars reported that the effects of combining RPF and SBR latex on concrete are rarely investigated, despite the fact that conventional concrete incorporating recycled plastics and polymer modifiers like SBR latex has been estimated to some extent. Therefore, their research was led to determine the best proportions of RPW and SBR latex and to assess their impacts on the new concrete mix characteristics. Workability, chloride ingress, acid and sulfate resistance, water sorptivity, splitting tensile strength, impact strength, flexure strength, and compressive strength were tested. SBR latex was added to the concrete at a concentration of 0-20% by weight of cement. The average RPF length was 20 mm, and the average RPF diameter was 0.4 mm. The RPF was added to the mixture at a volumetric ratio between 0% and 2%. Improvements in cracking resistance, flexure resistance, and reduced rate of chemical and water infiltration were observed in both fresh and hardened specimens of modified concrete that had some ratios of RPF and SBR latex. All parameters of the concrete mixes were enhanced by adding 1% RPF with a unit volume of concrete and 15% SBR latex by the weight of the cement. The research also confirmed how to make sustainable concrete with improved qualities by using waste plastics.

Abu-Saleem et al. [46] carried out an analytical research process, evaluating the crucial influences of recycled plastic waste integration into concrete on its workability and further important properties when it is employed for kerb applications. Polyethylene Terephthalate (PET), High-Density Polyethylene (HDPE), and Polypropylene (PP) were the recycled plastic wastes used in their work. Compressive strength, indirect tensile strength, flexural strength, and static chord modulus of elasticity were among the mechanical properties evaluated. Furthermore, the scientists tested other mechanical features, including fresh concrete properties, namely workability, fresh density, and air content, besides durability properties like water absorption, water sorptivity, abrasion resistance, and drying shrinkage. Examining the microstructures of the samples required using a Scanning Electron Microscope (SEM). Although the use of plastic aggregate in concrete decreased its fresh density and overall workability, the results proved that utilizing plastic waste as a partial replacement for natural coarse aggregate by up to 20%

could help satisfy kerb design requirements without negatively impacting strength. When compared to the control mix, abrasion resistance was elevated when PET and PP were substituted for up to 20%. When compared to the control mix, PET's drying shrinkage was satisfactory. The microstructural study revealed that PET-containing mixes had higher bond strength than HDPE and PP.

Fonseca et al. [47] administrated an analysis in which the mechanical behavior and workability of asphalt concrete were inspected and surveyed after the plastic waste replacement in this concrete category was considered. The scholars remarked that plastic garbage can be put to good use when combined with bitumen in the asphalt concrete production process. They added that this polymer could enhance some asphalt concrete's mechanical properties without adversely impacting its workability or other mechanical features. Their study was set out addressing these concerns for four distinct forms of plastic garbage by introducing varying amounts of plastic via the dry process and contrasting the resulting mixture to one that did not contain any plastic at all. The workability and mechanical behavior of the examined materials were evaluated using a group of laboratory tests, including volumetric parameter evaluation, the Marshall, gyratory compactor, and indirect tensile tests, repetitive four-point bending estimations, and repetitive compression. It was found that while asphalt concrete became less workable after being mixed with plastic waste, it was still manageable. Meantime, plastic waste made asphalt concrete more flexible. The material's stiffness values were sufficient for use as a pavement surface layer. The asphalt composites tested affirmed satisfactory resistance to fatigue cracking. Although the performance varied with plastic types and amounts, overall, the addition of plastic waste in this concrete helped boost resistance to permanent deformation.

4. PREFERABLE EFFECTS OF WASTE PLASTIC ON CONCRETE'S MECHANICAL PROPERTIES

Before discussing and highlighting various substantial influences of waste plastics on concrete's mechanical properties, it is vital to remark that utilizing waste plastics in concrete does not only provide favorable enhancements to the concrete's features, as the following articles will prove, but it does also offer multiple ecological and profitable rationales pertaining to better sustainability and promoted price feasibility of the new concrete mix compared with traditional concrete sorts. At the same moment, using plastic wastes in concrete, as various scholars claimed, would bring valuable improvements in the concrete's thermal effectiveness and energy stability.

The studies [48-50] shed light on the influences of waste plastic particles added to the concrete mix on making favorable amendments and enhancements of its mechanical properties, namely compressive strength and critical failure load.

In addition, other investigators [51-54] touched on the enhancements in the values of splitting tensile strength, bulk specific gravity, and absorption capacity. They discovered that utilizing some percentages of waste plastics would fulfil considerable amendments in those mechanical properties, helping make concrete more practical, durable, robust, and reliable for different construction applications that demand higher strength under challenging operating environments. The significant benefits accomplished by integrating some categories of plastic waste in concrete to foster its sustainability and effectiveness based on mechanical properties are explained in Table 1.

Table 1. The major mechanical characteristics of sustainable concrete utilise some plastic waste Jacob-Vaillancourt and Sorelli [55]

Plastic Materials	Tensile Strength (MPa)	Modulus of Elasticity (MPa)	Thermal Conductivity (W/mK)
Polyethylene Terephthalate	55 to 80	2.1 to 3.1	0.150
Polyethylene	18 to 30	0.6 to 1.4	0.330 to 0.520
Polyvinyl Chloride	50 to 60	2.7 to 3.0	0.170 to 0.210
Polypropylene	25 to 40	1.3 to 1.8	0.120
Polystyrene	30 to 55	3.1 to 3.3	0.105

Another mechanical property was investigated by some researchers, including the Ultrasonic Pulse Velocity (UPV). This parameter in concrete is necessary to locate its property and structure pertaining to voids and cracking that may adversely manipulate concrete performance [56-61].

Babafemi et al. [29] reported that implementing plastic wastes in concrete would minimize UPV, as described in Figure 5.

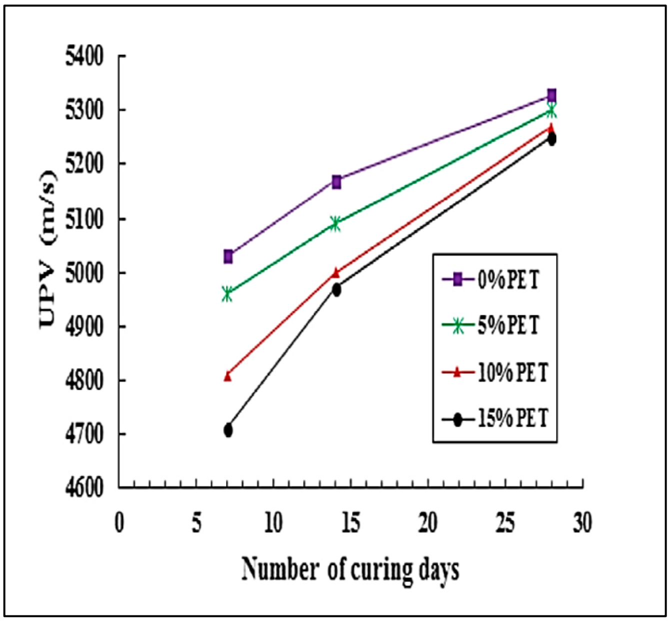

Figure 5. UPV assessment of concrete containing different ratios of polyethylene terephthalate [62]

Taherkhani and Arshadi [63] administrated a comparative analysis determining the mechanical properties of asphalt concrete before and after adding waste polyethylene terephthalate. The scholars mentioned that while some research publications have been executed on polyethylene terephthalate (PET)-modified asphaltic materials, they had mixed results and other issues, reflected in the lack of thorough experimental analyses that assessed the effect of PET particle size. Hence, their study evaluated how different amounts of waste PET and particle sizes could influence multiple asphalt concrete engineering features. Marshall, Indirect Tensile Strength (ITS), moisture damage, and dynamic creep tests were conducted on specimens of the mixes with ground waste

PET contents of 0%, 2%, 4%, 6%, 8%, and 10% (by the weight of asphalt binder). Coarse-graded PET consisted of particles between 1.18 and 2.36 mm in size, whereas fine-graded PET had particles between 0.297 and 0.595 mm in size. The sensitivity of dry and conditioned samples to moisture damage was tested using the ITS method. At 40 degrees Celsius and a stress level of 300 kPa, dynamic creep tests were conducted. Based on their experimental work, the results revealed that the Marshall quotient was maximized at around 4% of PET content for both coarse- and fine-graded PET particles and thereafter falls with further increases in PET concentration. Their empirical analysis also proved that the combination with 2% PET content had the highest ITS and resistance against moisture damage for fine and coarse PET particles. Outputs from dynamic creep tests showed that as PET percentage increased, permanent deformation resistance would diminish. Outcomes from combinations of concrete with coarse and fine PET particles emphasized that the latter provided superior performance.

Ullah et al. [64] guided experimental research, exploring the addition of specific plastic waste categories on asphalt concrete's mechanical behavior and properties. The scholars explained that when it comes to the functionality and longevity of flexible pavement, coarse aggregate is one of the most important components of asphalt concrete. Thus, they located how various physical and mechanical qualities could be affected by including waste plastic aggregates in the asphalt mix. Plastic waste was gathered from dumps, separated into two distinct types of polyethylene (LDPE and HDPE). Then, they were shredded into aggregates of the necessary particle size. In various percentages (5%, 15%, and 25%), these synthetic aggregates were substituted for natural ones. The results showed that the density of the asphalt mixture was lowered due to an increase in air spaces caused by the addition of both types of plastic trash. Partial substitution of natural aggregates with LDPE and HDPE boosted stability and flow characteristics by up to 15%. Rut depth was also lowest in LDPE-25 samples, followed by HDPE-25. When compared to the control sample, the HDPE-15 sample's robust modulus value increased by 168.5%, making it the highest. Plastic particles also increased the asphalt's dynamic modulus. For all samples, nevertheless, higher frequencies were accompanied by decreasing dynamic modulus values.

5. INFLUENCES OF PLASTIC WASTES ON CONCRETE'S THERMAL PROPERTIES

This section presents two critical aspects linked to the influences of plastic wastes on concrete's thermal properties. Those two aspects include the following:

(1) Table of literature review summarizing major investigation findings of plastic waste influence on concrete's thermal effectiveness.

(2) Overview and discussions on vital relevances and rationales of waste plastics impact on concrete's energy performance.

5.1 Literature review analysis related to waste plastic incorporation impact on concrete's thermal properties

Considering a table format, databases were investigated and gathered to collect vital information that include various research publications and peer-reviewed articles to provide additional experimental validation and proofs of waste plastic's influence on concrete's thermal properties.

These research publications focused mainly on addressing crucial relevances and vital influences of incorporating various types and sorts of waste plastic materials into the current concrete mix design to produce a new mixture with enhanced thermal features and offer high energy-efficient concrete that can serve in facilities and small and large-scale buildings.

Those thermal characteristics include:

A- Thermal insulation aspects of the new concrete mix,
B- Its thermal stability,
C- Consumption of cooling and heating energy requirements in summer and winter, respectively,
D- The potential of the new building to save the excessive electrical bill due to the large heat transfer across the facility envelope,
E- Other thermal energy performance parameters that could be optimized for better concrete's thermal effectiveness.

Table 2 indicates these aspects that are discussed and highlighted using various peer-reviewed paper.

Table 2. The leading values and significance of waste plastic incorporation into concrete (mainly thermal properties)

Name of Authors	Year	Title	Type of Thermal Properties	The ratio of Waste Plastic Substitution	Other Aspects Discussed
Almeshal et al. [65]	2020a	Use of recycled plastic as fine aggregate in cementitious composites: A review	Thermal conductivity, besides the resistance to fire properties	N/A	Pollution, environmental effects, and recycling of waste plastics
Almeshal et al. [66]	2020b	Eco-friendly concrete containing recycled plastic as partial replacement for sand	Thermal diffusivity and fire resistance	0%, 10%, 20%, 30%, 40%, and 50%	Sustainability and ecological impact
Bamigboye et al. [67]	2021	Evaluation of eco-friendly concrete having waste PET as fine aggregates	Thermal insulation and thermal conductivity	10% to 40%	Environmental impact and sustainability
Záleská et al. [68]	2018	Structural, mechanical and hygrothermal properties of lightweight concrete based on the application of waste plastics	Thermal insulation, thermal conductivity, and thermal resistance	50%	Sustainability and ecological impact
Akçaözoğlu et al. [69]	2013	Thermal conductivity, compressive strength and ultrasonic wave velocity of cementitious composite containing waste PET light-weight aggregate (WPLA)	Thermal insulation, thermal conductivity, and thermal resistance	30%, 40%, 50%, and 60% waste PET aggregate	Recycling, sustainability, and environmentally friendly concrete

Name of Authors	Year	Title	Type of Thermal Properties	The ratio of Waste Plastic Substitution	Other Aspects Discussed
Adesina [70]	2021	Overview of the influence of waste materials on the thermal conductivity of cementitious composites	Thermal resistivity, thermal conductivity, thermal insulation, and thermal density	0 to 50%	Environmentally friendly concrete, recycling, and sustainability
Khalil and Mahdi [71]	2020	Some properties of sustainable concrete with mixed plastic waste aggregate	Thermal conductivity	15, 25, and 45%	Ecological pollution, recycling, and sustainability
Poonyakan et al. [44]	2018	Potential use of plastic wastes for low thermal conductivity concrete	Thermal resistance, thermal conductivity, thermal insulation, and thermal density	5, 10, 30, and 50%	Green construction, sustainability, ecological pollution, and recycling
Gu and Ozbakkaloglu [72]	2016	Use of recycled plastics in concrete: A critical review	Thermal conductivity	N/A	Recycled plastic, Fresh concrete properties
Li et al. [73]	2020	Functions and impacts of plastic/rubber wastes as eco-friendly aggregate in concrete–A review.	Thermal conductivity	N/A	Eco-friendly aggregate, plastic aggregate, waste recycling
Bahij et al. [74]	2020	Fresh and hardened properties of concrete containing different forms of plastic waste–A review.	Thermal insulation, thermal conductivity	N/A	Modified concrete, solid waste plastic, mechanical properties
Ghorbani et al. [75]	2022	Thermal and mechanical characteristics of recycled concrete aggregates mixed with plastic wastes: Experimental investigation and mathematical modeling	Thermal conductivity	10%	Recycled waste materials, waste plastic
Ahmed et al. [76]	2022	Thermal conductivity and hardened behavior of eco-friendly concrete incorporating waste polypropylene as fine aggregate.	Thermal conductivity	0%, 8%, 16%, 24%, 32%, and 40%	Workability, dry density, compressive strength
Al Mohsin et al. [77]	2020	Improving Thermal Properties of Concrete Using Waste of Recycled Plastic.	Thermal conductivity	25%	Waste, recycled plastic, resources
Záleská et al. [78]	2017	Thermal properties of light-weight concrete with waste polypropylene aggregate.	Thermal diffusivity, thermal conductivity	10, 20, 30, 40, and 50%.	Composite materials, Thermodynamic states and processes
Hussein et al. [79]	2017	Thermal properties of light-weight concrete with waste polypropylene aggregate.	Thermal conductivity	2.5%, 5%, 7.5%, 10%, 12.5% and 15%	Workability tests, dry densities
Belmokaddem et al. [80]	2020	Mechanical and physical properties and morphology of concrete containing plastic waste as aggregate.	Thermal insulation	25%, 50% and 75%	Environmental impact, lightweight concrete

5.2 Overview of concrete's thermal properties considering the engagement of waste plastic in the mix

Halim et al. [81] led a research process inspecting critical variant roles of plastic wastes in adjusting the thermal characteristics of concrete. The scientists selected leftover polyethylene terephthalate plastic to involve in concrete aggregate and estimated some thermal features of the new design mix. Defined waste plastic replacement percentages for concrete in laboratories were 0%, 5%, 15%, and 25%. Relying on their experimental work, they concluded that adding more waste plastic (like polyethylene terephthalate) to concrete could dramatically alter its mechanical and thermal characteristics. Besides, concrete's capability for thermal insulation was enhanced, and its thermal conductivity declined when the waste-plastic ratio was large.

Moreover, experimental findings obtained from some scholars demonstrated that concrete might be engaged in multiple practical construction settings thanks to the addition of waste plastic and amended thermal insulation [82-88].

Bahij et al. [74] executed an analytical procedure classifying various thermal, fresh, acoustical, and mechanical properties of concrete when waste plastic is incorporated. The authors carried out a thorough overview. Their extensive review purpose was to locate crucial relevances of plastic waste integration into concrete and the corresponding modifications that could occur to the concrete's properties. Referring to their thorough overview, it was determined that while waste plastics are less biodegradable and non-degradable compared with other materials, incorporating them in concrete could alleviate its harmful ecological influences. Additionally, their extensive review confirmed that utilizing waste plastic in concrete could lessen the material's thermal conductivity. Knowing that low-density polyethylene, polypropylene, and high-density polyethylene have thermal conductivities of 0.35, 0.23, and 0.43 W/m.K, respectively. In comparison, the density of typical concrete varies from 1.34 to 2.92 W/m.K. Furthermore, their outputs revealed that the thickness, temperature gradient, surface area, and plastic features and types could impact the thermal merits of concrete whose cement/ aggregate/ sand is substituted via waste plastics. Those thermal features could alter the category of concrete that incorporates waste plastic according to the heat transfer features.

Thorneycroft et al. [89] directed an analysis identifying the viable traits of concrete when waste plastic substitutes for some of its sand. Because there is a significant amount of waste plastic in landfills (40% of waste plastic is left in various landfills in India), implementing this idea could achieve significant advantages and critical rationales for both concrete and nature. Neglecting waste plastic management has serious negative effects on the ecosystem. They suggested using waste plastic in concrete to handle these ecological affairs. On top of that, they administered an experimental estimation process on eleven concrete examples, defining the quantity of sand replaced by waste plastic, the size of the particles, the chemical makeup, aspect ratios, and individual components of the plastic material.

Their analytical outcomes revealed that concrete's strength was not significantly affected by substituting 10% of the sand in concrete with recycled waste plastic. However, it was discovered that compressive and tensile strengths would decrease as the replacement of waste plastic rose. On the other side, they confirmed that replacing some concrete elements with waste plastic alternatives could be a financially viable solution that could save approximately 820 million tons of sand annually, given the impacts of using waste plastic in concrete [90, 91].

5.3 Comments on the publications and paper gathered on waste plastic effect on concrete's thermal properties

To provide a conclusion and a summary of the critical contributions and relevant outcomes obtained from the experimental analysis of waste plastic's influence on concrete's thermal properties, it can be observed, from those articles, that the utilization of waste plastic in concrete resulted in multiple advantages, crucial traits, and positive features that can be invested and accomplished in different concrete types to help enhance their thermal performance. It is vital to mention that various scholars pointed out that incorporating plastics into concrete could fulfil better thermal insulation features, enhanced thermal stability, and a significant reduction in the electrical bill required for cooling and heating in summer and winter, respectively.

The reason for those substantial observations and positive properties is due to the significant potential of plastics in minimizing the heat transfer rate and thermal loss.

6. IMPACTS OF PLASTIC WASTES ON CONCRETE DURABILITY

While there are various authors in the available literature who addressed the importance and relevance of plastic waste influence in enhancing concrete's durability, it is essential to separate their findings into three critical classifications based on the topic they cover, which comprise:

(1) Modifications in Mechanical Properties;
(2) Enhancements in Thermal Properties;
(3) Changes in the Microstructure.

6.1 Waste plastic modifications on concrete's mechanical properties

Hilal et al. [92] executed an analytical work identifying major enhancements in the mechanical properties of concrete after adding waste plastics. The researchers clarified that waste disposal of Low-Density Polyethylene (LDP) and ceramics has elevated per annum, contributing to remarkable pollution degrees. As a result, recycling these materials into concrete can help improve the long-term viability of this building material. Thus, the purpose of their experimental study was to analyze the performance of Self-Compacting Concrete (SCC) consisting of particular LDP quantities. Six different concrete compositions were developed, varying in the amount of LDP used as fine aggregate (0, 6, 12, 18, 24, and 30% by volume) and the percentage of waste ceramic powder (30% by weight) used in place of cement. New properties (fresh density, segregation analysis, H2/H1 ratio, slump flow diameter, V-funnel, and T500 slump flow time) and old properties (dry density, ultrasonic pulse velocity, compressive and flexural strengths) make up the experimental parameters. Dry density and compressive strength were measured, but only after the samples were heated to 25 and 800°C for 3 hours. After being heated to 800°C, both the dry density and compressive strength with 30% LDP fell by 4.9 and 37.17%, respectively. It was emphasized that both the unheated and heated mixtures had sufficient compressive strength rates for structural use.

Singh et al. [93] studied the impact of waste plastic incorporation into the concrete design mix. Their research looked at how incorporating recycled polyethylene into asphalt could modify the binder and concrete's physical characteristics. According to Indian standards, four asphalt concrete mixtures were made, each with a different percentage of shredded polyethylene material. The aggregate was heated, and then hot asphalt binder and shredded polyethylene were added (in the same order) to coat the aggregate thoroughly. The mechanical and volumetric properties of the loose mixes were evaluated after being compressed. In addition, both short and long-term aging of compacted specimens were performed. Dynamic shear rheometry was used to examine the rheological parameters of the binder isolated from the aged and control mixes. The Marshall strength, flow, and volumetric properties were all enhanced in mixtures with shredded polyethylene. It was determined that the recovered asphalt binder had enhanced complex modulus values and reduced phase angle values throughout a wide frequency range after polyethylene was added to the mixture.

Al-Hadithi and Al-Ani [94] directed an experimental process classifying some contributions of waste plastic addition into the concrete mix. They claimed that sustainability is now the primary focus in the building sector. As one of the most vital materials in modern construction projects across the globe, concrete raises a number of concerns regarding its long-term viability. Finding new sustainable solutions is essential in light of the need to reduce pollution, natural resource depletion, and industrial waste.

In this context, Ahmad et al. [95] pointed out the percentage of international plastic waste production according to the country, which is depicted in Figure 6.

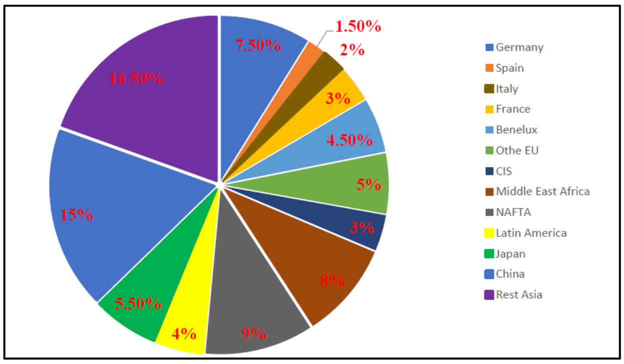

Figure 6. Global production of plastics [95]

Al-Hadithi and Al-Ani [94] added that the plastics sector around the world has expanded greatly in recent decades. Polyethylene terephthalate (PET) is one of the most common types of plastic found in consumer goods. This plastic is collected in large quantities from used water and beverage containers. Hence, their research intended to examine the viability of using shredded PET bottles as fine aggregate to replace some of the natural sand used in the production of High-Performance Concrete (HPC). Their experimental investigation was conducted to test HPC with and without plastic waste aggregate, evaluating and contrasting their respective properties. To make High-Performance Concrete more effective, they replaced some of the cement with PET-aggregate and some of the natural sand with different percentages of each (0%, 2.5%, 5%, and 7.5% by volume of the sand). Then, they added superplasticizer (SP) and silica fume (SF) (10% by weight). The slump was reduced to 68.75% at 7.5% replacement, indicating that fresh concrete containing PET-aggregate was less workable. Ultrasonic pulse velocity, bulk density, and water absorption were somewhat reduced with an increase in PET particles in the tests. Nonetheless, the static modulus of elasticity of HPC was found to be unaffected. Static modulus data showed a similar pattern, with values dropping for M2.5, M5, and M7.5 by 6.85%, 7.43%, and 10.18%, respectively. The use of flaky PET-aggregates in place of fine aggregate bridged the gap between the cracked concrete slabs, preventing the slabs from falling apart.

Figure 7 indicates global plastic waste production depending on the type of industry.

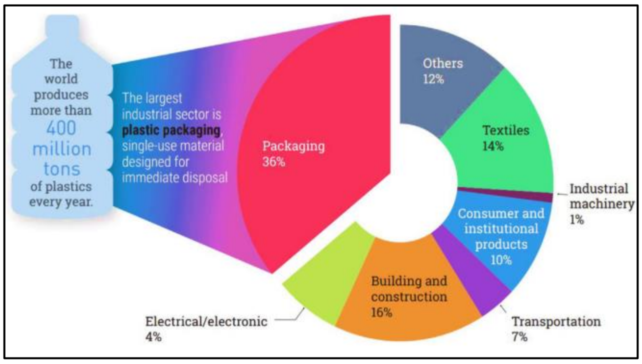

Figure 7. Worldwide plastic waste generation referring to the type of industry [42]

6.2 Waste plastic enhancements of concrete's thermal properties

Jacob-Vaillancourt and Sorelli [55] managed an emprical laboratory work in which the critical thermal properties in concrete were assessed after the addition of waste plastic. Additionally, their research estimated some vital mechanical properties of the new concrete mix. Those authors mentioned that the problem of plastic waste had become an urgent aspect, necessitating the development of new recycling strategies. They investigated the viability of using recycled plastics from actual post-consumer streams as a substitute for fine aggregate in concrete. Depending on the time of year, different Plastic Aggregates (PAG) were produced after being sorted in Material Recovery Facilities (MRFs). The concrete composites were characterized by their thermal conductivity, compressive strength, post-cracking compressive strength, toughness indices, density, and water absorption rate. The crucial PAG material parameter controlling concrete characteristics was figured out with the help of correlation tables. The quality of the concrete is examined concerning factors like the percentage of replacement, the type of PAG used, the amount of impurity, and the passing of time. The presented results suggested that producing eco-responsible construction materials with improved thermal insulation and water absorption by the use of concrete composite with PAG from post-consumer waste was a probable process.

Rohden et al. [96] conducted a research procedure detecting the impact of recycling waste plastic on high-strength concrete's thermal properties and mechanical behavior. To predict the change in thermal characteristics and the mitigation of concrete spalling when it is driven to heat, the authors utilized a thermal test of concrete incorporating waste plastic and exposed the concrete specimens to a thermal load of roughly 600°C. Additionally, they estimated the mechanical features of concrete that had been modified with waste plastics. Their experimental work confirmed that adding polypropylene fibers and plastic waste could significantly minimize the spalling of concrete after higher thermal exposure. Moreover, the experimental results proved that melting plastic waste and polypropylene fibers allowed for the release of internal pressure in concrete. Further, the results illustrated that employing waste plastic reduced concrete's deterioration when subjected to high thermal loads. Therefore, it can be deduced that utilizing plastic waste and polypropylene fibers could improve the mechanical and thermal qualities of concrete when compared to reference concrete.

Furthermore, some scholars [97-107] explained, in their experimental work, that integrating some categories of plastic wastes in concrete could accomplish advanced thermal stability and optimum mechanical performance under significant thermal loading.

6.3 Waste plastic effects on the concrete's microstructure

Ahmad et al. [17] led a study exploring the critical influences of waste plastic integration into concrete on its microstructure features. They mentioned that in the past 50 years, plastic production worldwide had elevated dramatically as the material has become ubiquitous in modern life. The result was a massive rise in the amount of trash and waste made out of plastic. Concrete made from recycled rubbish and plastics has attracted much attention from scientists as a potentially sustainable building material. There is a plethora of literature detailing the performance of concrete made from recycled materials and municipal solid waste. Nevertheless, data is dispersed, and it is unknown how plastic waste acts as a concrete substitute and could influence its microstructure. Hence, their study analyzed the feasibility of using Plastic Waste (PW) as an aggregate or fiber in the production of cement mortar and concrete. Their work discussed the fresh characteristics, mechanical strength, and durability of concrete.

At the same time, microstructure analysis was recorded via Scan Electronic Microscopy (SEM) to examine PW and cement connections. Their outcomes demonstrated that PW improved mechanical performance as a fiber. Unfortunately, degraded concrete performance could be noted as a coarse aggregate due to weak microstructural bonding between concrete molecules. Their research also highlighted areas for future study to help improve the performance of PW-based concrete and overcome this microstructure problem. Figure 8 describes an SEM image of plastic waste involvement in the concrete mix according to an Elsevier Permission.

Jain et al. [108] published a research article estimating the microstructural properties connected with a concrete mix that comprises shredded waste plastics. They expressed that global plastic waste accumulation became a challenging ecological obstacle that should be treated. Their current research attempted to use plastic bag shreds as an addition to concrete. In their study, the effects of incorporating waste plastic bags into concrete at varying percentages (0, 0.5, 1, 2, 3 and 5%) were analyzed. They carried out some tests to predict the new microstructure and determine the new concrete's workability, density, compressive and flexural strength, water permeability, static and dynamic modulus of elasticity, and abrasion resistance. It was discovered that waste plastic bags impeded the fresh concrete's flow and diminished the concrete's hardened properties. Additionally, there was a notable elevation in abrasion resistance in the waste plastic concrete samples. The optical microscope was also used to examine the microstructure. The data as a whole suggested that non-structural uses were feasible for the waste plastic concrete.

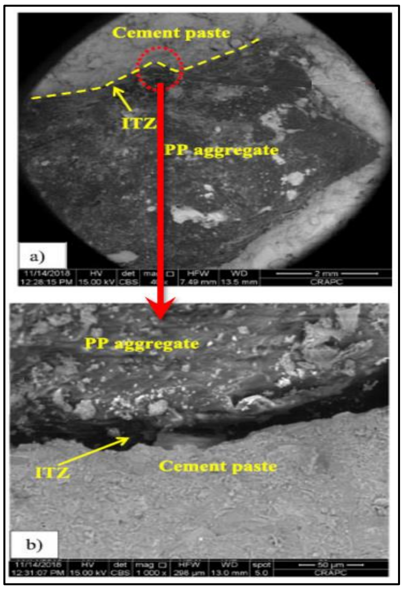

Figure 8. SEM image of plastic waste involvement in the concrete mix (Elsevier Permission) [17]

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

This research is guided to fill some knowledge gaps associated with the useful merits of adding waste plastics into concrete to fulfil some amendments and elaborations on its mechanical and thermal properties. It depends on a broad review to collect secondary information from diverse articles and publications that consider the importance and benefits of using waste plastics in concrete on its thermal properties besides its mechanical characteristics. Relying on the results attained by the literature, these inferences are possible:

(1) Recycled waste plastics are vital when incorporated into concrete as they could help achieve more sustainability aspects and environmentally friendly characteristics and reduce pollution.

(2) Some practical impacts could be fulfilled when different ratios of waste plastics are used in concrete, such as various elaborations in its thermal properties, including thermal conductivity, thermal insulation, thermal resistance, thermal diffusivity, and thermal stability.

(3) Achieving all these thermal properties in concrete would make buildings more cost-effective and facilitate the reduction of the winter and summer electrical bills required for warming up and air conditioning, respectively.

(4) Waste plastics can bring some vital enhancements in mechanical properties, making concrete more robust, reliable, and durable to serve longer lifespans.

7.2 Recommendations

Based on the outcomes attained from the broad review led in this paper, this article proposes some vital recommendations and key suggestions that could be adopted to enhance the integration of waste glass in concrete. These research recommendations include the following:

(1) To modify sustainability and ecological measures in construction standards and building codes to encourage civil engineers and project managers to use waste plastic in construction by making some substitutions in the new concrete mix.

(2) To urge researchers and engineers to conduct further analytical works and laboratory inspections to help provide more validation and expanded pieces of evidence on various valuable roles of plastic waste addition in concrete and its impacts on concrete's mechanical and thermal features.

(3) To carry out further empirical investigations connected with the incorporation of Polycarbonate (PC), Acrylonitrile-Butadiene-Styrene (ABS), Polyethylene Terephthalate (PETE/ PET), and Acrylic or Polymethyl Methacrylate (PMMA) into the concrete mix and validate the new concrete mix properties.

(4) To assess other waste plastic impacts on concrete properties, not mentioned explicitly and deeply in the global literature, like acoustic and rheological properties.

(5) To legislate highly sustainable laws and regulations that motivate and persuade project managers to integrate specific proportions of waste plastics in concrete.

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