

Recycling Plastic Waste into Eco-Friendly Concrete: A State of the Art Review

Kawa A. Ahmed^{1,*}, Amad Nori Abdulqudos²

¹Department of Environmental Science, Faculty of Science, University of Zakho, Duhok, Kurdistan Region-Iraq
(kawa.ahmed@visitor.uoz.edu.krd)

²Department of Energy Engineering, Technical College of Engineering, Duhok polytechnic University, Kurdistan Region Iraq
(Amad.abdulqudos@dpu.edu.krd)

Corresponding Author* kawa.ahmed@visitor.uoz.edu.krd

Abstract

The world plastic waste crisis and the tremendous environmental impacts of concrete production using traditional methods require waste management and building practices to be innovative marriages. This review critically examines the recovery of plastic waste in concrete, concentrating on its twin potential to help stem plastic contamination and build the construction industry lower in carbon emissions. The method utilizes many different forms of waste plastics, including Polyethylene Terephthalate (PET) and High-Density Polyethylene (HDPE), to produce a concrete mixture that brings great environmental benefits: It can keep plastic out of landfills and our oceans, and it reduces the greenhouse gases released during cement production. The review examines advances in the development of plastic-modified concrete: These improvements include enhanced mechanical properties such as increased durability, thermal insulation, and lower material density. It also examines environmental trade-offs including potential long-term effects and problems in recycling plastic-enhanced concrete. In addition, the paper identifies technical hurdles such as maintaining material strength and workability; it concludes with regulatory obstacles to the large-scale adoption of plastic-enhanced concrete. The paper uses a detailed analysis of case studies and actual practices to examine the practical feasibility of this new material in a variety of construction contexts. It ends with strategic recommendations for future research and policy development, stressing the need to establish regulations and standard frameworks to encourage the use of plastic-enhanced concrete. Ultimately, this review advocates for the larger acceptance of plastic-laden concrete as one piece in the puzzle of sustainable construction: one way to tackle a spiraling global plastic waste crisis that also meets broader environmental goals.

Keywords: Plastic, Waste, Building, Recycling, Management, Contamination.

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I. INTRODUCTION

The world is now facing an ecological crisis which has escalated to the extent of being one major environmental problem in 21st century [1]. Plastic Waste (PW) refers to any discarded materials of plastic, including single-utilize-materials, and other product of plastic, that are no longer in utilize and end up in ocean, landfills, or as a garbage in the environment [2]. Every year our planet produces over 330 million tons of plastic. In spite efforts to manage such waste, however, a staggering 8 million tons end up in oceans[3]. This accumulation of plastic waste has many wider implications, and it seriously affects marine life, water quality and ecological processes on land [3]. Due to the resistance of plastic to breaking down properly in a biogeochemical cycle it is only able to continue increasing such problems which have never before occurred [4]. Recycled plastic refers to plastic that has been re-created and processed from plastic waste to produce new products or materials. Even after collecting the plastics there is a process that includes

sorting, washing, shredding and melting them back into form, to be reused as raw components [5].

Recycling, often cited as a solution, is still insufficiently widespread and faces many problems [6]. These include the complexity of recycling different types of plastics and the lack of purity; economic success is also questionable [6]. Furthermore, the infrastructure for recycling is highly uneven, with many regions having neither the facilities nor the incentives needed to effectively manage plastic waste [7]. As a result, most of it goes either into landfills or into incinerators, both of which have massive environmental implications [7]. Additionally, the construction industry is one of the thirstiest industries in the world in terms of natural resources, energy, water, and is a major cause of the carbon dioxide problem [8]. While concrete is the most widely used material in construction today, it comes at great environmental cost [9]. Cement, which is essential in the production of concrete, is responsible for about 8% of all CO₂ emissions worldwide [10]. This figure alone indicates how much the construction industry contributes to today's

atmospheric burden of greenhouse gases [10]. Given those factors, combining plastic waste with concrete is a promising strategy [11]. This idea has a double benefit: firstly, as a way to divert plastic away from landfills and oceans, and secondly it has much less carbon dioxide content than when producing concrete [11]. Yet it is important to realize that many previous attempts to utilize waste materials in construction have met with only limited success [12]. These problems include technical difficulties involved in getting the properties of the material to meet industry standards, as well as resistance from market forces and obstacles in regulation [12]. In addition, the environmental consequences of incorporating non-biodegradable plastics into durable materials such as concrete are another major issue which has held up progress towards waste-based products in mainstream construction [13].

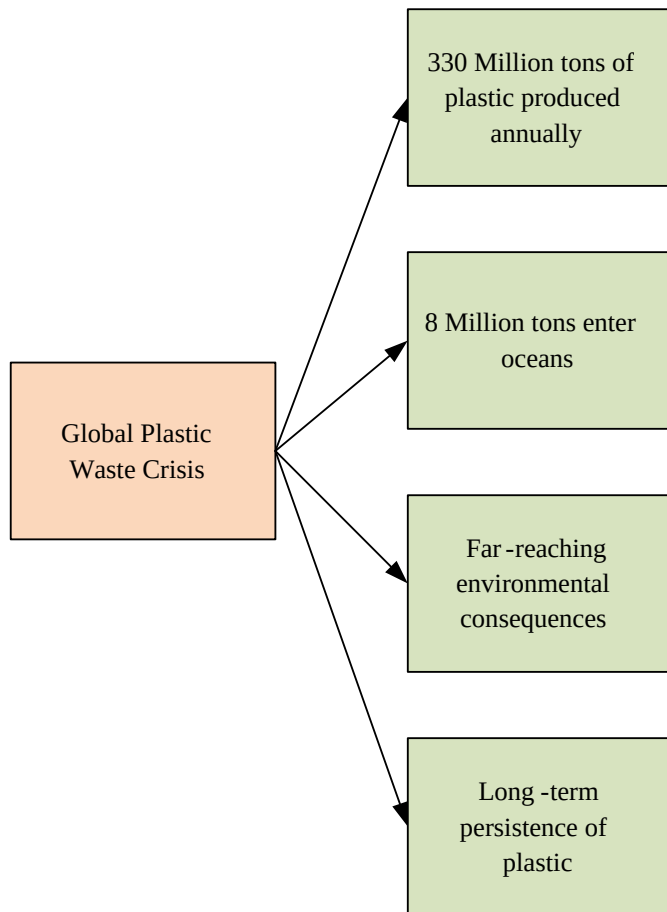


Fig 1. Global plastic waste crisis [3].

In particular, this review study examines the combination of plastic waste and concrete from three different but complementary angles: environmental challenges in the global plastic waste crisis for ecosystems and us human health are briefly reviewed; the environmental problems which ordinary concrete presents are clearly set out; how creatively to incorporate plastic waste into concrete is explained, such as types for incorporation methods and environmental benefits followed by a life cycle assessment.

II. ENVIRONMENTAL IMPACT OF PLASTIC WASTE

Plastic waste is an environmentally hazardous, causing damage to ecosystems and wildlife as well as human populations [14]. Arguably the most visible impact of plastic that it has been made rubbish, however is the piles on trash that has been in our natural habitats as well oceans [4]. The polluted waters from murky canals to oily ponds and rivers spewing wastewater densities as much or more than 400,000 parts per million not only look sickening but they are also killing dogs who dive into them without releasing the toxic that lurks beneath [4]. Plastic debris is mistaken for food by many marine animals, including birds, fish and some mammals this consumption can result in blockages, starvation or death [15].

Moreover, larger plastic pieces ranging from abandoned fishing nets to decreasing hunks may trap animals and in turn cause injury or immobilization leading paradoxically by drowning [15].

Beyond the individual animal level, plastic ingestion by marine life is a global ecological threat [16]. The plastic in the form of small particles gets into different levels of food chain when it breaks down. Because they are small, (less than 5 mm) microplastics can be ingested by everything from plankton all the way up to fish and humans [17]. These microplastics are ingested by larger predators, accumulate in fish, bird and mammal bodies where they can physically damage tissues or cells as biocides, serve at trophic transfer of chemicals to higher levels, be toxic [17]. While humans eating microplastic-contaminated seafood is hardly an issue with the same global impact as it could be critical from a public health perspective if large amounts of these toxins can build up in your body [18].

In addition to immediate harm it inflicts on wildlife, plastic waste acts as a primary driver of the greater environmental decline [14]. The main issue with plastics is they last for a very long time in the environment, which makes it much more difficult to clean them up, and means plastic waste can build up over years or centuries contaminating soil, waterways and oceans over that period [14]. Although some of the plastics will degrade over time, they are resistant to natural degradation processes and can be reduced in size into ever smaller fragments, but not all conditions completely decomposed plastic that breaks to produce small particles [19]. And when plastics do break down, many release toxic chemicals such as Bisphenol A (BPA) and phthalates that may be absorbed by the soil or end up in our food chain, posing further risks to human health [19].

Plastic waste also has a large carbon footprint impact on global warming [20]. Plastic production is very energy intensive, depending almost entirely on fossil fuels mainly petroleum and natural gas [20]. Production and incineration of plastic is thought to contribute around 3.8% of global greenhouse gas emissions, a number that looks likely to grow as more and more plastics are made [21]. In addition, as the plastics break down in nature they can emit methane and ethylene powerful greenhouse gases linked to climate change [21]. The plastic and climate link this nexus between plastic waste generation and climate change means that efforts to reduce the environmental impacts of plastics must take a more holistic approach than just response, moving beyond managing the end of life fate of plastics [22].

Plastic waste is harmful to the environment and human communities [22]. Poor waste management is often seen in developing countries; and can cause plastic to accumulate both on the streets, flooding cities or along natural areas causing pollution, sea polluting but concealing valuable livelihoods among fishermen); with ability to be wind-borne while may provide hiding/headquarter of pests (like rats that might spread-zoonosis)[7]. The consequent burning of the plastic waste a quite usual practice in places where correct disposal structure is missing such as informal landfills, household backyards or when open-burning be closer to home for everyone breathing it naturally releases dangerous fumes like dioxins and furans that could turn into respiratory problems, skin-irritation on short-term bases but also more serious health circumstances including cancer [23]. Also, plastic waste in waterbodies clogs drainage systems causing floods and the spread of communicable diseases [23].

The omnipresence of plastic waste and its widespread environmental consequences necessitate immediate action on a local level that is further executed many steps up at the global scale [23]. Efforts to limit plastic use and enhance waste management are paramount, but they have yet to be met with more profound systemic changes around consumption patterns, the structure of production in green alternatives for conventional plastics development as well as supportive policy instruments [24]. Only the plastic waste environmental crisis and save our planet for future generations can be address when we implement a comprehensive, multi-faceted approach to recycling [24].

A. Current disposal methods and their limitations

Plastic waste is a persistent problem, and the existing techniques of disposing plastic are insufficient by all means to provide sustainable solutions [14]. Plastic waste is primarily landfilled, incinerated or recycled and each of these options have specific environmental problems which might justify the development of new routes for plastic recycling in a more robust way [14].

Plastic waste disposal the landfilling is the most usual path for plastic-waste assassination, more evident in countries that has an available land [25]. Unfortunately, landfills are not the right way to solve our plastic waste problem [25]. When plastic waste ends up in a landfill, it is often buried and can take hundreds of years to break down if at all [26]. This can occur while the plastic is in direct contact with soil and groundwater, leaching dangerous chemicals that enter natural eco-systems (and ultimately might endanger human health) [26]. In addition, landfills are one of the largest sources of methane, a powerful greenhouse gas that causes global warming [27]. As landfills can take only so much and plastic waste is increasing in volume every year, this kind of tackle will not help us in the long run [27].

Incineration, another widely used disposal method, consists of burning plastic waste to reduce its size and produce energy [28]. Although it can reduce the plastic waste sent to landfills, however imperfectly [28]. Incineration releases dioxins, furans and heavy metals into the atmosphere which are harmful to people's lives [28]. Furthermore, the energy created through plastic incineration is anything but renewable because it means burning carbon-based materials [29]. While incineration results

in a volume reduction (i.e. waste becomes smaller), it does little to address the causes for continued plastic production and its disposal culture, nor contribute towards any kind of sustainable, circular economy [29].

Plastic modified concrete refers to concrete type that replaces conventional constituents, such as aggregates or binders, with waste plastic to improve specific characteristics or to encourage sustainable building. By decreasing the dependence on natural resources, it provides an approach to process plastic, which is waste [30].

While recycling is frequently positioned as the most sustainable option for disposal of plastic waste, it carries with a very low glass ceiling [31]. At present, the world recycles very little of its plastic; only about 9% of all plastics waste has been recycled [32]. Some of the reasons for this are very simply logistical in nature e.g., recycling different kinds of plastic often requires more complicated processes than other types, and plastics tend to be mixed with non-recyclable items sometimes [32]. Furthermore, plastic can degrade in the recycling process and must be melted down for it to work a costly option. And so, much of the plastic collected for recycling gets “downcycled” to lower-quality goods or is ultimately disposed in landfills or incinerators [32].

The constraints of these regular techniques for transfer emphasize the requirement for a more unified method in plastic waste administration [33]. This relates not just to upgrading waste management infrastructure, and increasing recycling rates but also involves reducing plastic production/consumption, sustainable alternatives for plastics as we use today & circular economy (where all materials are reused/recycled at highest possible rate) [33]. Given likely constraints on current and future waste management infrastructures, innovative breakthroughs must be improved upon in reducing environmental plastic flows by material science (e.g., use of biodegradable plastics) as well as substantial systemic changes throughout all stages from production to consumption and disposal. Number equations consecutively [33].

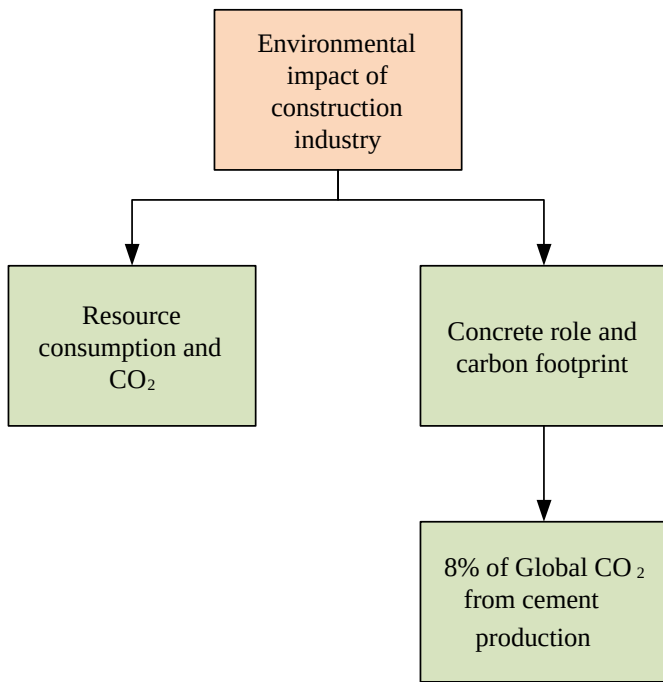


Figure 2. Environmental impact of construction industry [34, 35].

III. CONCRETE: AN ENVIRONMENTAL PERSPECTIVE

A. The Carbon Footprint of Traditional Concrete

Concrete is the most consumed man-made material on Earth and its omnipresence only underscores how it has been instrumental in molding our world of skyscrapers, expressways crisscrossing huge landmasses [36]. But behind this sheen of industrial strength is a huge environmental burden, and the production of concrete accounts for some of the most significant global greenhouse gas emissions [36].

Cement production (especially Portland cement) involves the calcination of limestone, CaCO_3 at elevated temperatures since it has a stable phase below that may release large amounts of CO_2 into atmosphere [37]. Cement production is responsible for around 8% of global CO_2 emissions, and per tons produced about one ton of the potent greenhouse gas, carbon dioxide (CO_2), is released [37]. The figure is even more shocking because global cement demand just keeps on growing with rapid urbanization, population growth and infrastructure buildout in emerging markets [37].

Concrete also has a footprint in other pollution CO_2 emissions from concrete massive amounts of energy largely from fossil fuels are also needed in the production process [10]. The high energy use of the cement production is another significant point in their overall global warming potential [10]. In addition, extracting and transporting limestone, sand or gravel for concrete production magnifies the resource depletion connected with its manufacture [10]. This often results in deforestation, extinction of species, and an increase on use the energy that then cascades into larger scale habitat destruction and general biodiversity loss [10].

Concrete is water-intensive, needing lots of it for mixing processes and curing during the manufacturing process [38]. In

areas where accessible freshwater is a global cost, the competing demands of energy and concrete production are likely to render concerted policy efforts at decarbonization both environmentally damaging and socially destabilizing [38]. Additionally, water especially use in concrete production may contain restricted chemicals which whenever disposal improperly could potentially cause environmental pollution [38].

However, the environmental consequences of conventional concrete go into its life cycle [39]. Over the lifetime of concrete structures, maintenance, repair and eventual demolition contribute to the environmental footprint [39]. Crushed concrete eventually creates construction and demolition waste, where a substantial amount of it remains in landfills creating one more issue to the difficulties for governmental agencies dealing with landfill management issues [12]. Although a portion of this waste is recyclable into new concrete aggregate, recycling itself requires energy and often produces lower quality recycled materials (so called downcycling) [12].

Due to the mounting environmental issues, even construction industry is understanding that it now has a responsibility in reducing concrete carbon footprint [40]. But the question is how to strike a balance between what appears useful for building infrastructure and using it in an environmentally friendly manner, given its direct influence on global warming. This has led to a significant increase in research activity focusing on the use of alternative materials and methodologies that can potentially mitigate or minimize the carbon emissions associated with concrete production, while maintaining its structural integrity and performance.

B. Need for Sustainable Alternatives in the Construction Industry

It can be seen nowadays that the construction industry is at a crossroads, as increased demands from an ever-expanding worldwide population intersect with urgent environmental challenges [41]. With the expansion of cities and infrastructure, it is an industry that faces a challenge like no other how to build for the future without building at all [41]. The solution is to start moving in adopting sustainable alternatives which adheres with minimizing the environmental footprint of construction practices and simultaneously fulfills the current requirements [41].

A limitation of traditional construction methods has been the demand for more sustainable materials, particularly in a market under pressure from an increasingly hostile natural environment [42]. Concrete (the wavy band in the middle) is at core of our struggle, as it making belches out loads of greenhouse gases while eating away resources and damaging land [42]. The continued use of these materials in the industry, with a better understanding and documentation of their environmental impact highlights the necessity for transformative solutions that marry construction practices to true sustainability [42].

Sustainable building materials provide a way to help improve traditional environmentally unfriendly construction practices [43]. With the possible to greatly reduce carbon emissions and natural resources, these materials (often from renewable sources or waste products) provide an

environmentally friendly alternative for we humans who must build a better future [43]. These materials are developed based on technological innovation and some due to the regulatory pressures, in other words by following international green building codes [43].

Plastic-reinforced concrete is one of the most viable alternatives and has been entering into practice [44]. This novel building material adds a double advantage of recycling the plastic waste to minimize pollution, and reducing carbon footprint caused by concrete making [44]. It is impressive that with only some portion of the traditional aggregates in concrete being replaced by recycled plastic, it can readily qualify as construction material: where such structural demands dictate use but opportunities to minimize waste and conserve resources are pursued [44].

Plastic-aggregate concrete represents the circular economy in construction [45]. By re-purposing our waste into new building materials, this method effectively closes the loop on material use and removes reliance from virgin resources while also dramatically reducing overall waste [45]. The construction industry could undergo substantial changes if circular economy principles were fully embraced making the sector more resilient, resource efficient and environmentally friendly [45].

However, the adoption of new materials often necessitates changes to building codes and standards as well developing testing and certification processes for safety measures towards their performance [46]. There might also be economic concerns, in that sustainable materials are likely to come with a higher upfront price tag than their traditional counterparts [46]. There must be cooperation among industry stakeholders such as architects, engineers, manufacturers and policymakers in setting the stage for sustainable construction methods to take off [46].

Sustainability in the construction sector is therefore considered a necessity not only environmentally, but also strategically [47]. The construction sector must find a way to respond, adapt and innovate as governments worldwide implement new rules on carbon emissions production and resource consumption [47]. Addressing these needs, and delivering them in an environmentally responsible manner can be achieved by the implementation of sustainable materials such as plastic-fortified concrete [47].

Ultimately, the construction industry cannot afford to continue relying on conventional materials such as concrete going forward [48]. On the one hand, concrete production results in environmental challenges, and on the other increasing demand for infrastructure makes clear a necessity of transformation towards sustainable construction [48]. This sort of thinking has an impact not just on the industry, but also directly contributes towards a more sustainable future which is why our involvement in doing so is crucial to ensuring that plastic waste does to continue unchecked [48]. In building a low-carbon future, the construction sector has an opportunity to make best practice business as usual and demonstrate that sustainable buildings will be infrastructure of future [49].

IV. PLASTIC WASTE IN CONCRETE: A REVOLUTIONARY APPROACH

A. Types of Plastic Waste Used in Concrete

Replacing our environmental liabilities with a part of the materials that use for construction on this scale is revolutionary in sustainable building practices [50]. Different plastic waste materials have been investigated for their potential in improving the properties of concrete, and each offered some additional benefits to the composite material [51]. Polyethylene Terephthalate (PET), High-Density Polyethylene (HDPE) and polystyrene are among the most commonly used plastics in this innovative approach [52].

Polyethylene Terephthalate (PET) is one type of plastic waste that a lot of people may be familiar with, as it typically used to produce beverage bottles and food containers [52]. Because of its strength, rigidity and moisture resistance PET can be introduced in concrete [53]. PET is usually ground into $<1\mu\text{m}$ particles or shredded in flakes, and then used as aggregate for concrete [53]. They can replace a certain percentage of the fine aggregates such as sand in concrete mix [53]. When PET is added into concrete, it has been reported that the presence of this polymer in concrete could enhance thermal and insulation properties compared to conventional lightweight concretes due to its low density [53]. PET modified concrete also offers improved resistance to chemical attack and increased durability, especially in areas with corrosive agents [54].

High Density Polyethylene (HDPE) is a more common plastic waste material applied in the forms of, for example, plastic bottles and geomembranes [55]. High strength to density ratio and good chemical resistance are among the qualities of HDPE which make it interesting for concrete applications [55]. Like PET, HDPE can be shredded into small particles or fibers to come into the concrete mix [55]. And despite some early concerns about the brittleness of reinforced concrete, HDPE-modified mixes have more flexibility and are less susceptible to cracking than steel-reinforced options due in part to a plastic fiber that carries stress over a broad cross-section [56]. This property is especially useful in case of concrete structures which are subject to dynamic loading or thermal expansion and contraction [56]. Furthermore, HDPE has a low water absorption rate, which minimizes the permeability of concrete and in turn increases its longevity [57].

Polystyrene is a highly workable lightweight thermoplastic (the same plastic as that in foam "space age" planes but with no air or gas to make it spongy), and can be used very useful for making concrete [58]. For example, in the context of lightweight concrete production, Expanded Polystyrene (EPS) is employed as a replacement for conventional aggregates [59]. For non-load bearing applications, the compressive strengths of EPS-modified concrete were acceptable as it had obvious quality reductions with a considerable lessening in weight [60]. This concrete is especially appropriate for use in precast and pre-molded concrete elements, isolation panels or lightweight building blocks [60]. By blending in polystyrene, a step can be taken to lighten the mass of concrete works and improve its thermal insulation capabilities which will aid greatly towards retaining energy within buildings [61].

Consequently, each of these plastic waste types contributes unique benefits to concrete and enables a diverse palette of material properties that can be tailored [61]. By leveraging the distinct properties of PET, HDPE and polystyrene, researchers and engineers can optimize concrete mixes to fulfill specific performance requirements whilst becoming more environmentally sustainable in response to plastic waste.

Usage of sustainable recycled plastics such as Polyethylene Terephthalate (PET) and High-Density Polyethylene (HDPE) in concrete provides new avenues of opportunities for more sustainable construction practices [51]. But these materials equally brought about various challenges since it is a concern that they should only be adopted into concrete mixes if its performance is not compromised [51]. The first challenge among them is the compatibility of the plastics with the cementitious matrix. It is pertinent to note that, due to the hydrophobic property of plastics, it interacts relatively less with the cement paste which is hydrophilic, and this leads to poor interfacial bonding [51]. This mismatch results in deleterious consequences on the mechanical performance of the concrete [51]. More importantly, the difference in the thermal expansion coefficients between plastics and the cement matrix brings about new problems; the plastic materials expand more than the cement when the temperature changes [62]. Such disparity gives rise to micro cracks and delamination adjustments in regards to time which hampers the durability of the concrete [62]. Approaches like surface modifications by chemical etching, mechanical roughening, or by using coupling agents might be promising for enhancement of the adhesion between plastics and cement [62]. Furthermore, the addition of fine mineral fillers or additional cementitious materials may help to increase the compatibility of plastics with the cement matrix [62].

The presence of plastics in cement also enhances or impairs its mechanical properties [63]. Since plastics are usually less stiff and strong than normal aggregates, the overall compressive and tensile strength of the composite could drop [63]. The decrease here is relatively greater (higher fraction of aggregates replaced) compared to the other substitutions made in the mix [63]. Moreover, irregular shapes and sizes of recycled plastic particles tend to increase porosity and void inside concrete matrix [64]. This porosity reduces the strength of the whole but also reduces the durability of the material. Unlike other plastics, PET and a few others can become brittle under certain conditions, for example, freeze-thaw or long-term loading that can result in the cracking and premature failure of these roads [64]. It is important to focus the durability and long-term performance of concrete when using recycled plastics as fine aggregates in concrete [64]. For instance, PET is vulnerable to chemical degradation in alkaline condition, which is common in cement-based matrices [65]. Such degradation can result in a loss of the material properties and, ultimately, damage to the composite over time. Additionally, plastics are less stable when exposed to heat than traditional materials in concrete [65]. This thermal instability could affect the structural integrity of concrete in high temperature exposed applications. Moreover, the poor adhesion of plastics to the cement leaves the entrance of water that accelerates the chemical degeneration and, in a reinforced system, provoke the steel reinforcement corrosion [65].

These difficulties continue on into the processing and mixing stages too. The inconsistent density and particle place properties of the recycled plastics can make it difficult to uniformly disperse the plastic into the concrete matrix. Such non-uniformity will segregate during mixing and placing and will reduce the uniformity of the material and its performance. Plastics also influence workability because they do not absorb water as traditional aggregates do. As a result, the maximum water-cement ratio can increase or decrease and also changes of the water-cement ratio or the addition of admixtures are necessary to get the desired consistency and time-behavior after setting. Moreover, recycled plastics frequently show residual contamination (pigments, additives or other polymeric pollutant) that can hinder the hydration and affect the chemical stability of the concrete [3,4].

B. Mechanisms and Processes

The plastic fibers are usually made from HDPE or PET and they increase the tensile strength, crack resistance benefiting durability of the concrete [66]. They act like a micro-reinforcement by helping to spread the load of stress more evenly across the concrete, therefore decreasing its chances of snapping under high loading conditions [66]. However, advantages lie in their use as for upon exposure to temperature fluctuations or dynamic loads, the fibers absorb and dissipate energy hence prolonging the building's life span [66]. In particular, plastic fibers can improve the energy absorption capacity of concrete because they will be much more effective when heavy loads or impacts are applied to a structure [67].

In 2022 research paper was published entitled "An investigation of the use of plastic waste as aggregate in concrete" and researcher used plastic waste in 6 different percentages from 5- 25%, because of its high sound absorption and low thermal conductivity, concrete that contained plastic waste can be utilized to improve the life quality of the concrete. Mechanical properties of concrete such as compressive strength is decrease from 36.63 (Mpa) to 17.26 (Mpa) when adding 25% of PW. Also, researcher stated that as the percentage of plastic waste increased in concrete the sound intensity (sound level) decreased from 65.5 (db) to 43.3 (db) and thermal conductivity decreased to $1.85 \text{ W.m}^{-1}.\text{K}^{-1}$ [9]. Also, another research was published and researcher conducted research on experiment to see how positively disposal plastic properties can be put to use as an aggregate. They replaced 10%, 15% and 20% of both fine and coarse aggregate elements in their experiment with plastic implemented fiber as an alternative material for the same purpose. In addition, they added steel fiber to the concrete. Their study shows that the strength of the material is decreased, but they recommend its use as an eco-friendly and resource-saving means [68]. In 2017 the researcher tested to find out what benefits reusing plastic waste as coarse aggregate in concrete could bring. They have tested mechanical properties in Concrete in which plastic aggregates are incorporated. They have used 10%, 15% and 20% respectively as their three percentages of plastic aggregates. A little decrease in strength was found and 15% replacement is the ideal percentage revealed [69].

According to pilot project in infrastructure, plastic enhanced concrete has been used. India's Plastic Roads utilized Plastic-filled asphalt and concrete for more than 33,000 kilometers of

roads in India plastic waste modified bitumen enhances road strength, lowers maintenance costs, and provides an easy answer to recycle huge quantities of plastic waste [70]. Also, Zwolle in the Netherlands has the world's first bike path made almost completely of recycled plastic. The plastic walkway is the latest demonstration of an emerging trend, with fewer cities and enterprises producing goods to be used once, but rather building a closed-loop economy in which all products are reused and nothing is wasted. KWS, the Dutch asphalt lead, developed the path. The road sections are modular and prefabricated, can be installed in weeks with minimal maintenance needed, which lowers life-cycle costs and road disruption [71].

According to large scale application, concrete that contained plastic has given effective in several large-scale structural applications. For example, Residential Projects in Construction companies in Dubai used plastic aggregates in concrete blocks to provide cost-effective housing. This helped lower the total mass of constructions, while still passing local building standards; thus, allowing for expansive rooming developments [72]. Also, Indonesia's plastic bridges- In rural Indonesia, concrete mixtures for small bridges incorporated plastic waste. It provided various advantages like high tensile strength, less cost of construction, making it a cost-effective option for locations where it is difficult to transport heavy material [73].

Polystyrene beads, which are one type of plastic waste can serve as filler materials that modify concrete properties to be used for more specific applications [74]. Usually these fillers are light in weight and can substitute for a portion of the normal aggregates in concrete, giving rise to material that has less specific gravity but with reasonably good compressive strength [74]. Polystyrene-based fillers in concrete: Polymethyl methacrylate can be an excellent alternative as polystyrene is typically added to concrete where weight reduction (precast walls, building blocks and insulation) applications are needed [58]. Polystyrene-modified concrete is also light weight, which offers better thermal insulation to the building and keeping its energy consumption at a lower level contributing again towards sustainable construction [58].

However, the process is beset with challenges in integrating plastic waste into concrete [75]. Work on the compatibility between plastic and a cement matrix, workability reduction potential, long-term durability of concrete modified with plastics is still under investigation [75]. Nevertheless, technological innovations in material science and concrete technology have been providing improved performance to plastic-incorporated concretes making these materials a potential alternative as sustainable concretes [76].

Using plastic waste in concrete is a good step towards sustainability of construction materials [77]. Researchers and engineers are developing novel concrete mixes that incorporate some of the unique properties of plastic waste, not only mitigating the environmental effect of these structures but also providing performance boosts [12, 75, 78]. With technology advancing, plastic-modified concrete has the potential to revolutionize into a regularized construction material and can be part of creating more sustainable & resilient built environment [79].

C. Environmental Benefits

Utilizing plastic waste in concrete is a sustainable development strategy that can tackle various important concerns about waste management, conservation of resources and climate change mitigation making the environmental benefits multifaceted [80]. Probably the biggest benefit is that it prevents plastic from being put into landfills, oceans or incinerators [80]. Integrating plastic in concrete helps combat the increasing issue of plastic pollution by preventing this waste from these disposal methods and converting it into a useful construction material [80].

Plastic waste not only helps in combating waste need but also assist in conserving the natural resources [81]. Natural aggregates, whether that be sand and gravel or crushed rock, are the primary materials for concrete production but they are limited in supply [81]. The mining, extraction and processing of these materials has a heavy environmental footprint, with habitat destruction, water use and energy costs [82]. Reducing the need for virgin materials and lessening environmental impact of concrete production could be achieved by partially replacing these natural aggregates with plastic waste [82]. The effort to use fewer materials in a sustainable manner reflects part of the circular economy limiting waste and using resources efficiently [82].

The other significant environmental value of plastic-infused concrete is its ability to decrease the carbon footprint during construction [83]. Cement is the main component of concrete, and while it underpins much of today's society, the process that creates cement emits CO₂ a lot of it about 8% of all global emissions [84]. Using plastic waste to partially replace concrete not only means that less cement is needed, but also makes it possible as per requirement of carbon emissions from concrete itself [84]. Also, the lightweight properties of some polystyrene-modified concretes can help save energy during transportation and construction, all helping to reduce carbon footprint [85].

The combined environmental advantages of incorporating plastic waste into concrete are undeniable and represent a potential sustainable response to some of the most pressing contemporary environmental problems [86]. If the construction industry is to lower its negative impact on the environment, plastic-enhanced concrete could potentially represent a new avenue towards a better built environment which is sustainable by design and more resilient in effect [86]. This novel approach not only solves the crisis of plastic waste but also meets the wider targets of sustainable development and climate change mitigation by converting waste into a resource [87].

V. COMPARATIVE ENVIRONMENTAL ANALYSIS

A. Life Cycle Assessment (LCA) of Plastic-Enhanced Concrete

For determining how beneficial plastic-enhanced concrete actually is for the environment, a method like Life Cycle Assessment (LCA) is indispensable [88]. This way of viewing the total effects on the environment checks out each stage in a products life—from extraction to processing at origin, loading station to factory, use and eventual scrap heap [88]. When applied to concrete, LCA offers extensive evaluation that

includes everything through trash benefits to use [88]. Crushing any illusions about the suitability of waste materials, this is an ecological death sentence for waste disposal in disguise [88].

Concrete that is high in cement, as the traditional stuff has been for many years now, inherently incurs a massive carbon footprint [89]. Cement is responsible for around 8% of global CO₂ emissions, largely from the energy-intensive calcination of limestone and combustion of fossil fuels within the cement production process [89]. In addition to carbon emissions, the removal of raw materials like sand and gravel is a source for resource depletion, habitat destruction as well as considerable energy consumption [89]. The entire life cycle of regular concrete is no angel when it comes to its environmental footprint [89].

Plastic-improved concrete, on the other hand is a potential solution that adds recycled plastic-waste into the cement mixture [51]. As a result, this mod will not only take care of the environmental problems linked to popsicle melting but also neutralizes some off-farming effects which in use bring traditional concrete production [51]. While plastic waste partially replaces natural aggregates, virgin raw materials get no demand relief for this reuse [51]. Consequently, this replacement has the potential to reduce resource extraction and related environmental contamination [51].

In addition, further research shows that the use of plastic waste in concrete helps us save energy and reduce carbon emissions [10, 90, 91]. Initial processing of the plastic waste initially requires energy; however, it consumes less overall than what is required for production of traditional aggregates [12].

Cement content is also significantly reduced with a reduction or elimination of plastic fillers and fibers, which are significant sources of CO₂ emissions [12]. The LCA clearly shows that, in many cases at least partial or even better total replacement of conventional concrete by plastic-enhanced one correspond to lower global environmental burden (especially to the greenhouse gas savings and material) per tons compared to pure [92].

However, the LCA also reveals problems linked to plastic-improved concrete [93]. That is, how long the material itself lasts and disintegrate which ends with release of micro-plastics from its debris during that process, must be balanced by killing tens or hundreds of thousands of years to billions upon use a non-biodegradable resource in something like construction [93]. Ultimately, these factors highlight the critical need for continued research and innovation to achieve maximal environmental sustainability of plastic modified concrete not reached before so that it can reach its true potential as a sustainable alternative to traditional cementitious materials.

B. Reduction in Carbon Footprint

Adding plastic waste to the concrete mix primarily reduces CO₂ emissions by reducing reliance on cement, which is easily one of the most carbon-intensive portions of producing this type of construction material [94]. Cement production accounts for approximately 900 kg of CO₂ emissions per ton produced, and is a very significant contributor to global carbon dioxide levels [95].

Studies and micro scale uses have shown that blending plastic waste into concrete could slash the cement ratio by 20%, translating directly to a proportional reduction in CO₂ emissions [96]. In one analysis related to PET-enhanced concrete, authors showed that a 15% replacement of fine aggregates with hopelessly mixed particles allowed decreasing the global carbon footprint by 12% [97]. Additionally, the implementation of HDPE fibers as a reinforcement material has led to lessening steel reinforcement necessity contributing towards decreased carbon footprint by avoiding high energy consumption in complete life cycle from production of steel [98].

A subtler way that utilizing plastics in concrete can help reduce the carbon footprint is through plastic-enhanced concretes' low weight aspect [99]. Materials such as Expanded Polystyrene (EPS) can lower concrete density, in addition to reducing energy consumption from transportation and construction [74]. To a large extent, the reduction in transportation energy cuts down on overall CO₂ emissions especially important for high-quantity construction projects like these where materials moving make up an unusually big part of the carbon footprint [100].

As a result of this reduction, the overall carbon footprint of plastic-enhanced concrete may be decreased up to 30% as compared with ordinary concrete depending upon type and mix design which could beneficially impact Life Cycle Assessment for any structural system [100]. This substantial decrease demonstrates the promise that plastic-filled concrete could play a significant role in reducing carbon-associated greenhouse gas emissions and contributing to climate change by construction industry collectively transitioning towards more environmentally sustainable building methods [100].

C. Long-Term Environmental Impact

The advantages of using plastic waste in concrete as opposed to just recycling them extend beyond reduced carbon footprints and resource lifespans [90]. What makes plastic-reinforced concrete so exciting is that it recycles waste a secondary raw material instead of being extracted from virgin resources, reducing burden on our planet and helping to keep the loop close [90]. It is a recycling solution for plastic waste, which would otherwise remain in the environment for hundreds of years, tackling both the problem of plastic pollution and reducing pressure on virgin materials while allowing resource use to be sustainable [101]. But the problems arising from that plastic-enhanced concrete could prove difficult to solve in terms of long-term environmental impacts [101]. More importantly, the long-term emission pathways of microplastics into water and air especially when such concrete materials degrade should be a matter for scrutiny [102].

Using plastic in concrete improves ductility and decreases weight; however, the long-term eco-environmental and technical impacts of this combo are uncertain [103]. This is not without problems though, microplastics could be released through wear or degradation in the environment [103]. These could impact ecosystems and human health. This may be less significant if it is encapsulated in the concrete matrix, but additional testing, e.g., leaching studies, is needed to determine and control this hazard [103]. Another concern is durability, as trade-offs may arise with plastic-modified concrete which may

lose some of its compressive strength and exposure to environmental factors, such as salts or moisture, which can impact the bond between the plastic and the cementitious matrix [51]. These challenges can be mitigated by process optimization of most mixtures and surface treatments. One problem recycling plastic-modified concrete is separating materials [51]. On the other hand, selective crushing or recycling as aggregate can fulfill the aspect of circular economy, but up-to-date technology/methodology is still needed [51]. A cradle-to-cradle evaluation indicates that replacing conventional aggregates with recycled plastic lowers the environmental impacts of material generation and waste disposal [51]. On the one hand, worries over longevity and microplastic emissions from synthetic materials point to the necessity of an integrated approach to lifecycle management [104]. Overall, additional research is needed to overcome microplastics mitigation, compatibility, and to develop recycling technologies, which are essential for the long-term sustainability of plastic-modified concrete [104].

Introducing plastic in concrete can be advantageous for both the reuse of this material that has global environmental impact as well as improving the properties of concrete; however, a concern mentioned in this paper is related to possible long-term negative effects of incorporated plastic due to microplastic release and degradation of plastic in long term effect and hence, their environmental impact [64]. However, the endurance of one type of plastic in concrete is limited; being exposed to atmospheric variables such as ultraviolet radiation, moisture and heat may break it down over time [64]. Throughout this process, the degradation could create microplastics, and these microplastics could then migrate to a nearby environment such as the ground or water systems [64]. How much is released depends on the specific type of plastic, the size of the plastic, its surface area, and the physical conditions in the environment where it breaks down [64].

To mitigate these concerns, several options can be pursued. Chemically stabilized or UV resistant plastics can reduce degradation, and encapsulation of plastics in coatings can decrease exposure to degrading environmental agents [105]. The improvement of recycling technologies for end-of-life plastic-concrete composites is another key aspect needed to avoid the release of microplastics that can occur during disposal or demolition of these composites [105]. It will be important to perform more experimental and modeling studies to be able to quantitatively assess the plastic degradation rates when embedded in concrete and exposed to changing environmental conditions [105]. Such studies should also examine pathways and risk of potential microplastic release along with steps to mitigate microplastic release [106]. In recognizing these issues and providing strategies to mitigate them, this research ultimately makes a case for further work, on the basis that plastic-leveraged concrete must contribute to the broader agenda surrounding sustainability and other environmental targets over the longer term [106].

At its end of life, the recycling or disposal of these materials has to be planned in a way that ensures plastic waste is not re-introduced into our environment [107]. This may go a step further in its environmental credentials, if left over plastic enhanced concrete can be efficiently recycled and perhaps even used as part of new mixtures [107]. Across current research and

innovation, integrating plastics into concrete offers the promise of a stronger environmental footprint for new construction that's both durable enough to last through every potential climate change threat world face.

VI. CHALLENGES AND LIMITATIONS

A. Technical and Environmental Challenges

Though promising, concrete and plastic waste also comes with technical challenges to tackle, both from a construction standpoint along through environmental perspectives [108]. The much larger technical challenge was to ensure that the plastic enhanced concrete met tough strength and durability standards for normal construction purposes [108]. The presence of plastic elements, especially when as supplementary aggregate or fibers to reinforced are apparent enough in the modification of mechanical properties from its concrete due [109]. Despite some studies have demonstrated that plastic-modified concrete can provide adequate compressive and tensile strength, the latter properties usually depend on price and quantity of aggregate used [62]. An example of this is if too much plasticizer is added where it might reduce the bonding within the cement matrix, making that batch deleterious or dangerous to depend on for structural stability [62].

Concrete is designed to endure numerous environmental factors for extended durations, including moisture exposure over a range of temperatures and chemical attacks [110]. The durability of plastic-enhanced concrete in these conditions over the long term is still being actively researched [110]. One of the biggest problems associated with incorporating plastics into concrete also regard environmental concerns [110]. Perhaps the most significant issue is that it encourages utilize of non-biodegradable plastic waste and in so doing reduces pressure on landfill immediately opens up a new avenue for incidental release into the environment [111]. For example, the use of plastic waste may release microplastics into the environment over time with long-term concrete aging or due to mechanical wear and tear [111].

The addition of plastic also makes a more involved process in the manufacturing as it must be distributed uniformly across mix so that achieved all relevant attributes are well developed [112]. Moreover, the variability in plastic waste due to different polymer types, contamination levels and physical forms makes production methods hard to standardize [113]. These challenges serve to reinforce the growth and innovation required for plastic waste in concrete, overcoming the technical barriers which limit its swift transition towards large scale implementation [113].

B. Regulatory and Standardization Challenges

This standard has been considered for quite some time, however a unified specification relating to how plastic waste is integrated into concrete does not exist at present in our field [114]. For the time being, most building codes and standards are written with typical materials in mind rather than considering more unconventional additives like plastic waste [114]. This lack of regulations makes it difficult to certify the safety, effectiveness or environmental benefits of recycled plastic in concrete [114].

For manufacturers and builders that means there is no clear set of rules regarding what kinds/amounts of plastic waste can be utilized in concrete [115]. They are not certain about the quality control processes that must be followed in producing concrete with plastic modifications, which maintain its structural and environmental requirements [115]. In a perfect world, standardized testing protocols would establish whether these materials are living up to their environmental promise and thus educate engineers (and architects) about what it is that they too could in good conscience readily specify for use in building construction [115]. Less reliable regulation means increased exposure for the environment to suffer [115].

Concrete containing recycled plastic has the possibility of cutting down global waste, but it also demands proper handling [116]. As the field of plastic-enhanced concrete remains largely unregulated, it will be important for regulatory oversight to accompany what is hoped could become a valuable use for discarded plastics so that this beneficial compound does not seed new environmental problems (e.g., harmful substance leaching or release of microplastics) [116].

This requires the creation of standards and guidelines urgently needed to enable wide commercialization that approach systematically all interesting aspects around use plastic waste in concrete [114]. These standards must apply throughout the lifecycle of a material from selection and processing of plastic waste, to production, use and final disposal in composite concrete with added plastics [114]. Doing so will require an industry-wide effort across all from material scientists to engineers, policy makers and environmental organizations [114].

C. Potential Environmental Hazards

Although the environmental benefits for plastic-modified concrete include a reduction in waste and support resource conservation, both some potential impacts need to be managed [117]. Microplastics: leading concern If concrete containing plastic waste degrades over time or is processed, there are chances that fact can be released in the environment as fine granular particles [118]. The danger is that those microplastics have interacted with soil, bodies of water and even the air [118].

Plastic waste, also trapped in the concrete, has an environmental risk of undesired substances leaching [25]. Other plastics include additives like plasticizers, flame retardants and stabilizers which can leach out under certain conditions [25]. This can in turn impact the environment, as fugitive emissions would release toxic substances from the concrete matrix that could potentially contaminate soil and water and pose a risk to human health [25]. The end of life implications of such leaching are also largely unknown, underscoring the importance for future studies to investigate how plastic outcomes from concrete-enhanced over time [119].

Compared with ordinary pure concrete, the end of life treatment for plastic reinforced concrete is also an associated tricky question. It is critical to develop environmentally safe and sustainable decommissioning strategies for plastic-reinforced concrete, as the possibility of environmental contamination especially during demolition, recycling or disposal stages remain high [120].

VII. FUTURE OPPORTUNITIES AND INNOVATIONS

A. Advancing Technologies

The construction industry is faced with a dilemma in the midst of its efforts to fight climate change and improve resource efficiency with new technologies opening up more opportunities for plastic waste applications in what has become the most widely-used building material across all continents [121]. Not only are these advances boosting the performance of plastic-modified concrete, but they also determine a new range of applications where this system is increasingly appealing for sustainable construction [121].

Now, one of the most exciting advancements is in the composition of cement starting from a matrix produced by Nano-engineered plastics [122]. Researchers are using this phenomenon to create plastic modifiers that can dramatically augment the mechanical properties of concrete by controlling and altering plastics materials at nanoscale size [122]. Incorporating Nano-plastics can, for example, improve the adhesion between cement matrix and plastic particles which makes concrete stronger and more durable [122]. And by including unique functionality in the application, such as adding water penetration and thermal insulation resistance of Nano additives to increase service life contribution also plays an important role for low environmental impact [122]. Another innovative nature is self-healing concrete with plastic microcapsules [123]. Self-healing concrete defined as a concrete that is designed to seal its cracks autonomously, through either the release of prefilled healing agents or the revival of dormant chemical processes [124]. These repair materials are encapsulated in microcapsules which consist of biodegradable plastics and will be opened during cracks appear on concrete [123]. These healing agents then react with the surrounding materials and fill up all those gaps, thus "healing" concrete and make sure not getting any worse [123]. In addition to increasing the service life of existing concrete structures, this technology also eliminates or significantly reduces future maintenance and repair requirements resulting in an overall improvement in construction projects environmental footprint [125].

3D printing offers new possibilities for plastics used in concrete, to advancements in the technology [126]. The material freedom of 3D-printed concrete enables the inclusion of a wide range of plastics, from recycled plastic aggregates and fibers to achieve micro-scale features in final prints [126]. The technology makes it conceivable to create complex, tailor-made structures swiftly and with minimal material waste making available more opportunities for application in sustainable construction principles [126]. And, being able to 3D print some of the concrete with plastics could mean creating lighter and more efficient building components that reduce energy use and material volume [126].

Biodegradable polymers made from renewable resources such as corn starch, sugarcane can be applied here to generate eco-friendly concrete admixtures [127]. These bio-based plastics can not only provide an alternative to fossil fuel materials but also the ability for full biodegradability at end of life in concrete, all helping reduce environmental impact [127].

These emerging technologies are coalescing to evolve plastic-enhanced concrete from a niche material into the cornerstone of sustainable construction [128]. Developing technologies such as these are not just striding in ecological engineering, they have the potential to revolutionize construction by taking plastic waste that is otherwise a global challenge and making it an environmental solution for future buildings [128].

B. Policy and Regulatory Strategies

The Recovery Plan: The widespread adoption of plastic-enhanced concrete is a market intervention requiring supportive policies and regulations that encourage innovation yet protect our environment and public health [108]. At the moment, not having clear details and guidance for how to utilize plastic waste in construction is one of the biggest obstacles that are limiting its wider adoption [108]. These gaps stay largely addressed if we do not come up with a comprehensive set of policies and regulations [108]. Most importantly, there was a need of some international standards that could manage the uses of plastic waste in concrete.

Plastic waste used in concrete, governments and regulatory authorities could encourage the use of plastic waste in concrete by recommending incentives to the stakeholders including construction industries, material producers and recyclers [129]. Such incentives could take the form of tax breaks, grants, or subsidies for the use of environmental technologies and practices [129]. For example, it can provide incentives for innovative processing methods and research into the optimal mix for concrete with plastic waste through financial support. The industry itself can also be spurred on by public recognition programs for companies working with sustainable materials [129].

To enhance both scalability and safety, transparent and enforceable regulations must be put in place to ensure that plastic waste integrated into construction materials is treated uniformly [130]. Such standards need to cover important aspects like the kind of plastic waste, its quality and processing along with performance parameters of concrete with plastic contents [130]. Having regulatory guidelines would guarantee consistency, reliability, and structural integrity of applications which will help create trust among stakeholders [130].

The synergy of these two elements can form a conducive ecosystem for plastic waste recycling in concrete. For instance, legislation requiring recycling quotas with penalties for non-compliance encourages a circular economy [131]. These policies can be further enhanced by collaboration among the policy makers, domain experts, researchers and all the other stake holders to make them more in consonance with the sustainability intentions while being practical to execute [131].

To foster the large-scale implementation of advancements in using plastic waste in concrete, supportive policies are essential [75]. Governments can encourage sustainable marine practices as well as implement regulations that help standardize processes and speed up the transition to greener, more innovative construction practices [75].

Plastic waste with some exceptions of polymer and properties could be successful designed in this way when quality

standards to define the acceptable types/plastics/ volumes, specifications for conducting tests on a certain level of substance performance ability combined with measures ensure environmental protection are presented [86]. Common international standards can reduce confusion for manufacturers, builders and regulators about the safety and reliability of plastic-modified concrete no matter where it is used in different regions or markets [86]. Creating incentives for recycled plastics use in construction would be another good step on the part of governments [132]. This may come in the form of tax credits, grants or industry subsidies for businesses that adopt plastic waste as part of their concrete admixtures and/or invests in new forms such as Fiber-Reinforced Polymer (FRP) technology [132]. Fiber-reinforced polymers are described as composites comprised of a polymer matrix with embedded fibers that confer strength and durability [133]. Incentives such as this have the potential to speed up uptake and help drive further innovation research into sustainable construction practices by removing some of the financial barriers that world face [132].

Plastic-Enhanced Concrete (PEC) brings scope and scale promise to the construction industry but comes with a cost challenge at scale [134]. The economics, from where the materials are sourced to where the final product is produced, needs to be contemplated [134]. The cost of raw materials is one of the most important factors. By incorporating plastic waste into concrete, it can help lessen dependence on normal aggregates like sand and gravel, which in turn are undergoing excessive extraction that makes them costly [51]. But using plastic waste in concrete involves resource-intensive activities like collecting, sorting, cleaning and processing plastic [51]. The production cost can be even higher, if advanced treatments are applied such as chemical modifications to improve cement bonding [51]. Production lines for existing concrete plants may need to be upgraded or replaced to accommodate mixes that have been modified with these plastics, which for smaller firms could be a capital barrier to entry [135]. In terms of the workforce, unique worker and engineer training to work with PEC could be costlier in the short term but ultimately result in improved efficiency in the long term [135]. Although these initial investments are costly, the ultimate returns from PEC should surpass its price tag. Improved robustness and environmental enervators resistance may lower the need for repairs and maintenance with the potential for lifecycle cost benefits [135].

Furthermore, as the technology becomes more mature and the production of PEC ramps up, economies of scale may contribute to reduce the costs per unit and PEC may become more and more attractive in comparison with conventional concrete [136]. Likewise, economic feasibility of PEC is also conditional on policy & market dynamics. Some of the costs could be offset by government incentives for sustainable construction (e.g. subsidies for recycling initiatives or tax breaks for green building projects) [136]. Simultaneously, the sustainability penalty associated with the business as usual approach to conventional cement production high carbon emissions makes PEC an appealing option in light of increasing regulatory pressures, and incoming carbon pricing, along with burgeoning associated commercial opportunities [137]. A comparison of costs goes a step further in evaluating the

feasibility. Specifically, PEC is expected to cost upwards of 10–20% more than conventional concrete in the early approximation, but due to the need for better plastic processing and infrastructure upgrades and cleansing of micro doses [138]. As an example, normal concrete is around \$100 /m³ [139]. Part of the cost is mitigated over the life of the product, as data from lifecycle analyses suggests PEC has potentially 15% higher cost-effectiveness over 20 years due to lower maintenance inputs [139]. Production scale is more difficult; however, it would benefit volume processing and standardization potentially allowing lower unit costs [139]. Will small firms pay more to enter the market, perhaps for infrastructure upgrades (about \$50,000-100,000 per facility) to play ball; however, subsidies and incentives for green construction may help.

Furthermore, regulation on plastic waste management needs firmer measures in place if recycled plastics are to be used as feedstock for building applications [140]. Although there are initial high barriers to entry, government policies that encourage the retrieval and separation of plastic waste could salvage not just environmental costs but drive the growth of a new industry reliant on plastics also [140]. In addition, regulations could be used to promote the consumption of plastics bio-based and bio-degradable in construction at large by setting a new frame to foster circularity for this sector while supporting broader bio-economy goals based on reduce fossil fuel dependency driven minimization of environmental performances [140].

C. Circular Economy in Construction

Integrating plastic waste into concrete is an important move along the road to a circular economy for the construction sector: a system where materials are continuously re-used, and recycled with minimum wastage and requirement of virgin resources [141]. One of the pivotal moves in this vision towards a circular economy comes from utilizing plastic-enhanced concrete to turn waste into an asset and completing that cycle back on material use [141]. In any kind of circular building economy, plastic waste is not considered a by-product which should be disposed of [142]. This reduces the demand for virgin natural aggregates, preserves resources and decreases environmental footprints of construction projects as well [142].

Additionally, burning plastic hazard to the environment and it may reduce all the litter in our landfill's food value (since recycling is a simply better use of scrap plastic) [143]. Consequently, this aligns with the tenets of sustainability and environmental protection to promote resource recovery and waste reduction [143]. By addressing global issues such as plastic pollution and resource depletion in a practical sense, it aims to hone material applications that can help move the construction sector towards sustainability using efficient technologies [144]. On the road ahead, further development and adoption of plastic-enhanced concrete could be key to building a circular economy in construction [144]. Plastic waste will weave itself into the fabric of our future built environment so that it does not come between us and a better world where there is no wastage, conservation restored over natural resources use & minimized environmental footprint wherever we humans reach [145]. It is a vision so tangible; The only way forward in construction to create the circular economy needed for a more sustainable future [145].

VIII. CONCLUSION

Plastic waste used as a component in concrete is an attractive option to help this, with the dual aims of simultaneously resolving issues around pollution and sustainable construction. As this review has shown, the enduring persistence of plastics in the environment within a rising global plastic waste crisis requires novel ways for managing wastes. On the other hand, construction (as one of the biggest carbon emitters and depletes open to change) desperately needs sustainable materials that help lessen their environmental burden. In reality the idea of incorporating plastic waste into concrete, is not only ecologically justified but technically feasible as well. Various plastics like PET, and HDPE have been successfully used as constituent materials in concrete mixtures to provide features of superior thermal properties, low material density and higher resistance under certain circumstances. If such developments continue, it may be that plastic-infused concrete represents a two for one impact solution: reducing the significant and pervasive planetary introduction of this type of waste while also mitigating some portion of cement's similarly vast carbon burden. But the path to plastic-enhanced concrete becoming a material that sees everyday use is, not surprisingly, bumpy. Limitations, both technical (e.g., how to guarantee the material longevity and strength for years) as well as environmental ones (potential release of microplastics), must be very carefully considered before implementations. The market for waste plastic reinforced concrete is still in its nascent stage, with a lack of guidance and regulation which would need to be adopted before the widespread commercialization of these materials. Nonetheless, the positive potential of plastic-charred concrete is massive. This material was found to have the potential for significantly improving global sustainability targets by using alternatives from traditional, resource-intensive aggregates and a lower carbon footprint. Unpacking recycled plastics is further supported by the premise of a circular economy, where materials are looped back into products and disallowed as waste overall. Ultimately, the path to plastic-enriched concrete becoming a staple in construction lies ahead and will be paved with additional research, creativity, and regulation for implementation but if it comes through fruition at any scale all this could contribute towards an industrial revolution within civil engineering sectors as well as promoting cleaner waste management;; And as the processes are fine-tuned and hurdles overcome, plastic waste might be transformed into a resource that can help create an undeniably better future. A victory from this effort could well serve as a model for other industries showing that environmental stewardship and technical ingenuity are not mutually exclusive in offering solutions to some of the most crucial problems facing our planet today.

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