iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** VI **Month of publication:** June 2025

DOI: https://doi.org/10.22214/ijraset.2025.72500

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue VI June 2025- Available at www.ijraset.com

A Step towards Sustainable Concrete by Replacing Plastic Waste in Concrete: A Summary of its Mechanical Properties

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Abstract: Plastics have become an essential part of our daily lives, and global plastic production has increased dramatically in the past 50 years. This has significantly increased the amount of plastic garbage produced. Researchers have recently been interested in using trash and recyclable plastics in concrete as an ecologically acceptable building material. Many publications have been published that describe the behaviour of concrete, containing waste and recovered plastic com ponents. However, information is scattered, and no one knows how plastic trash behaves as concrete materials. This research examines the use of plastic waste (PW) as aggregate or fibre in cement mortar and concrete manufacturing. The article reviewed the three most significant features of concrete: fresh properties, mechanical strength, and durability. PW and cement connections were also studied using microstructure analysis (scan electronic microscopy). The results showed that PW, as a fibre, enhanced mechanical performance, but PW, as a coarse aggregate, impaired concrete performance owing to poor bonding. The assessment also identified research needs to enhance the performance of PW-based concrete in the future.

Keywords: plastic waste; sustainable concrete; mechanical strength; durability and microstructure analysis.

I. INTRODUCTION

Cement, sand, coarse aggregate, water, and admixtures are used to make concrete. After water, concrete is the second most used material in the building construction [1–3].The quality of aggregates, which make up 65–80 percent of the total quantity of concrete, have a significant impact on concrete strength [4]. By the end of 2025, the global materials construction industry expected a 59 percent growth in aggregate demand [5]. Due tothe constant manufacture of concrete, natural resources are depleting, resulting in severe environmental consequences [6–9]. Fast economic growth and the emergence of a throw away culture, on the other hand, have resulted in challenges in garbage managing andits dumping. To address this difficult issue, scholars have started looking at possiblealternatives to replace natural aggregates and bindingmaterials [10–14]. Various research studies have been done recently to substitute natural aggregatewith waste by-products from manufacturing businesses, vehicles, and electrical items.Plastic's widespread usage and manufacturing reached a total of 359 million tons in 2018[15]. Acrylonitrile butadiene styrene (ABS) is a thick plastic composed of polycarbonateand acrylonitrile butadiene styrene [4]. As a result of its adaptability, flexibility, and durability, plastic is employed in variousparts of life,involving home and manufacturing usages. Due to its being lighter inweight than metal, plastic has gained prominence in electrical gadgets, packaging materials,and cars. However, as the world's population grows and industrialization accelerates,so does the production of plastic garbage, which presents a huge environmental challenge.

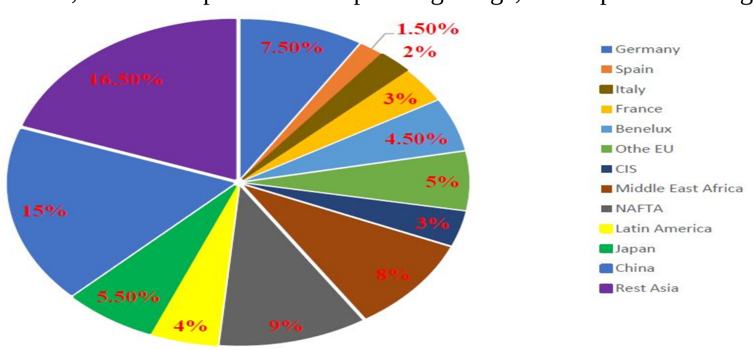

Figure 1. Global Production of Plastics: Data Source [17].

The review provides a compressive overview of the utilization of PW in concrete. The review concentrates on the main characteristics of concrete, such as fresh properties(slump flow and fresh density), strength properties (compressive strength (CMS), split tensile strength (STS) and flexural strength (FLS)) and durability (water absorption, dry shrinkage and carbonation depth).Microstructure analyses were also considered to study PW and paste bonding. The successful review provides a guideline for researchers to understand the behaviour of PE as a concrete ingredient.

II. PHYSICAL PROPERTIES

Most of the published research assessed the qualities of PW to be utilized in concrete. The physical qualities data of PW used by various researchers are organized in Table 1. It should be noted that PW has a near-zero absorption capacity, which will increase concrete flow ability. It is also worth noting that the researchers reported varied outcomes. Some of them are rather different. The apparent density, for example, ranges from 350 to 1315 kg/m^3.

Table 1. Properties of Plastic Waste (PW) Used in concrete.

Reference	[22]	[23]	[24]	[18]
Specificgravity	-	-	0.97	-
Water Absorption (%)	0.01	-	0%	0.13
Fineness Modulus	-	2.8	-	-
Moisture Content (%)	-	-	-	-
Apparent density(kg/m3)	560	350	-	1315
Specific surface(m2/kg)	1.67	450	-	-
Bulk Density (kg/m3)	-	-	620	261.4
Plastic Type	Polyethylene Terephthalate	Low Density Polyethylene	E-Waste	Polycarbonate

Bottles, laptops, LCDs, monitors, and printers were among the plastic garbage collected, and the kind of plastic recovered was acrylonitrile butadiene styrene plastic. The plastic aggregates in this research are made by going through four processing steps. The PW was first washed to remove any dust or clay particles. The E-waste plastic was then crushed in an electric crusher into tiny flakes or shredded particles in these cond phase. E-waste flakes were melted in a kiln in the third step. Acrylonitrile butadiene styrene plastic melts at roughly 105 degrees Celsius. Nevertheless, the kiln heat was raised to 200 degrees Celsius to assure optimal melting. Plastic flakes were melted and then chilled in water to make plastic rocks which were crushed to pebbles. Finally, plastic aggregates were created by crushing the plastic rocks. Figure 3depicts a schematic design of aggregate manufacture. Figure 4depicts the microstructure of plastic particles, which were non-uniform in shape and size. The non-uniform shape decreased the fluidity of concrete by increasing the friction among concrete constituents.

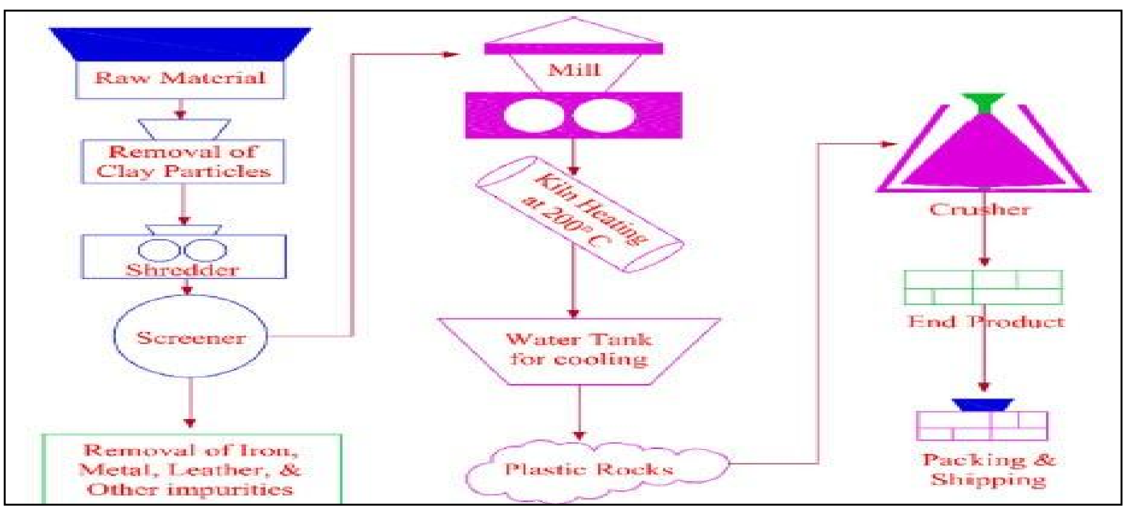

Figure2.Manufacturing Process of Plastic Aggregates :Used as per Elsevier Permission [24].

III. FRESH PROPERTIES

A. Workability

The slump values of different combinations of PW in concrete are shown in Table 2 and Figure 5. Figure 5shows that, as compared to the control concrete, the slump of concrete mixes decreased as the amount of fine plastic aggregate increased.

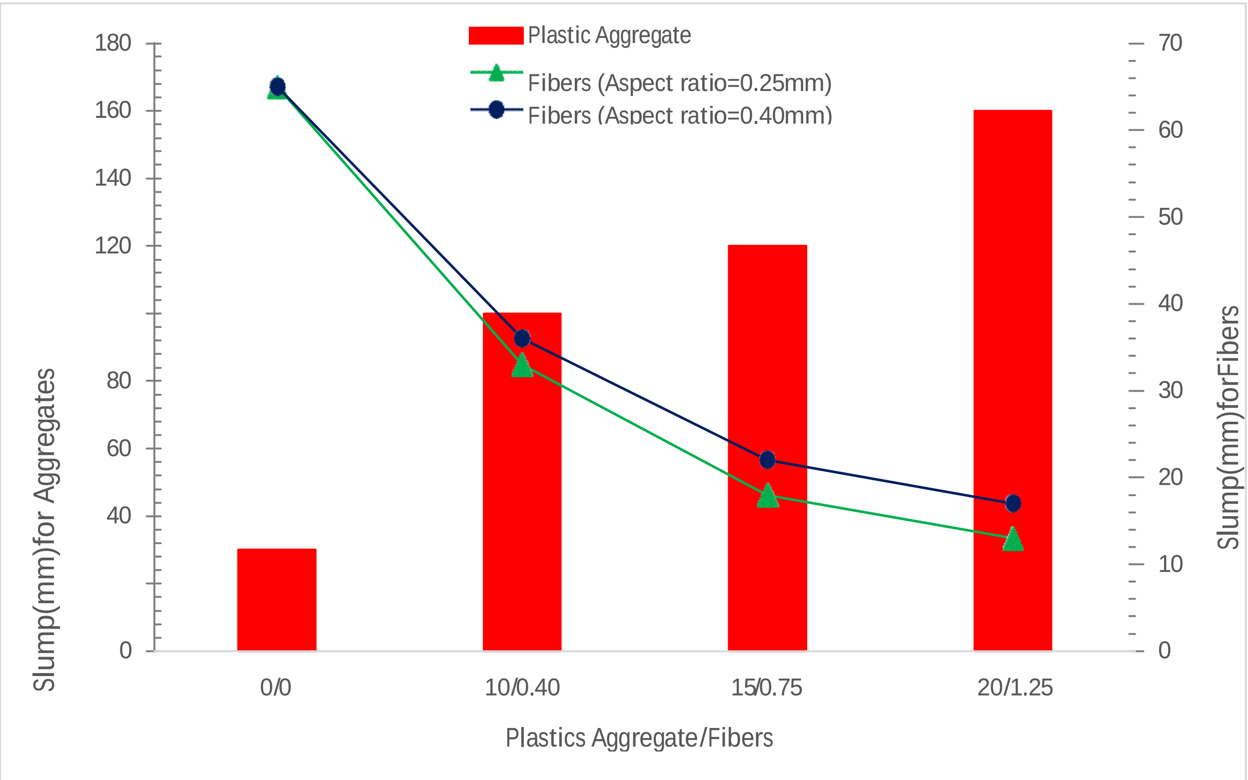

Figure3.Slump Flow: Data Source [24,26].

The slump values of different combinations of PW in concrete are shown in Table 2 and Figure 5. Figure 5 shows that, compared to the control concrete, the slump of concrete mixes decreased as the amount of fine plastic aggregate increased.

The decrease was observed regardless of type, and these results were consistent with those of previous research [27]. However, plastic waste used as fibres reduced the flowability of concrete. The reduction in flowability with fibres was due to their larger surface area, which required a greater quantity of paste to cover the surface [28,29]. Additionally, the fibres increased friction among concrete components, further reducing flowability.

Table 2 Slump values of different types of Plastic Used

Reference	Plastic Waste	Slump(mm)
[24]	0%,10%,15%and20%	30,100,120and160
[39]	Aspect ratio=2.5 0%,0.10%,0.25%and0.50%	120,100,80and60
	Aspect ratio=2.5 0%,0.10%,0.25%and0.50%	120,100,70and55
[40]	Plastic fibres (0.25 mm)0%,0.40%,0.75%and1.25%	65,33,18and13
	Plastic fibres (0.40 mm)0%,0.40%,0.75%and1.25%	65,36,22and17
[41]	0%,2%,4%,6%,8%and10%	132,126,102,80,52and14

IV. MECHANICAL STRENGTH

A. Compressive Strength (CMS)

Concrete's compressive strength (CMS) is one of its most essential and useful properties. Concrete is used as a building material to withstand compressive forces. CMS is also considered at sites where tensile, or shear strength is a primary concern. As a result, the CMS of concrete and cement mortar is a key characteristic that is carefully examined in nearly all research involving plastic aggregates.

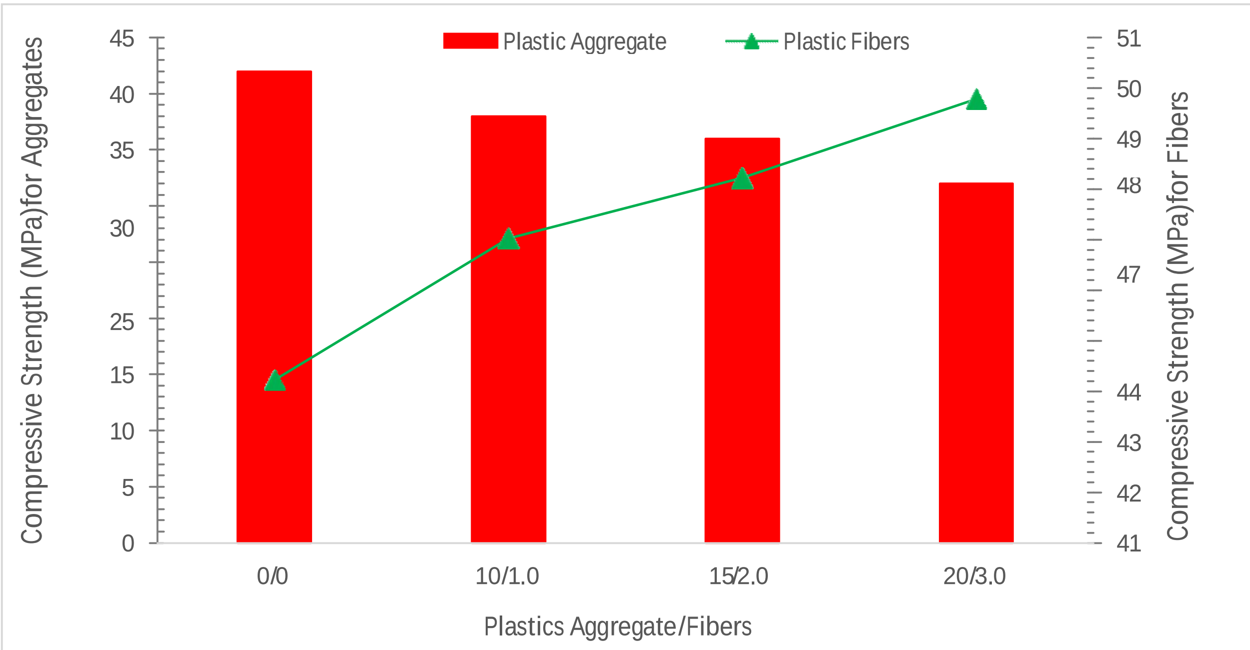

Figure4.CompressiveStrength:DataSource[24,26].

The CMS of concrete using PW as aggregate or fibres is shown in Figure 6 and Table 3. PW used as fibres increased the CMS of concrete, whereas PW used as aggregate reduced it.

Table 3. Summary of Compressive Strength (CMS).

Reference	Plastic Waste	Compressive Strength (MPa)
[49]	0%, 10%, 15%, 20% PC	7 Days: 21.5, 19.6, 18.16, 16.6 28 Days: 30.5, 27.5, 25.3, 26
[24]	0%, 10%, 15%, 20%	42,38,36 and 32
[25]	0%, 5%, 15%	WC 61.45, 70.25 and 65.21 OC 54.80, 66.17 and 59.77
[18]	0%, 7.5%, 15%	7 Days 33, 27 and 25 28 Days 37, 32 and 33 56 Days 45, 40 and 35

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
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Reference	Plastic Waste	Compressive Strength (MPa)
[39]	Aspect ratio = 2.5 0%, 0.10%, 0.25% and 0.50% Aspect ratio = 2.5 0%, 0.10%, 0.25% and 0.50%	16, 15, 14 and 13 16, 14, 13 and 12
[40]	Plastic fibers (0.25 mm): 0%, 0.40%, 0.75%, 1.25% Plastic fibers (0.40 mm): 0%, 0.40%, 0.75%, 1.25%	23.3, 24.1, 26.6 and 23.5 23.3, 26.2, 24.1,.23.4
[22]	0%, 10%, 20%, 30% and 50%	3 Days 22, 18, 15, 15 and 17 7 Days 26, 22, 20, 18and 16 14 Days 32, 29, 25, 17 and 16 28 Days 60, 58, 52, 42 and 40.
[53]	PVC: 0%, 2.5%, 5%, 10%, 20%	60 Days 32, 27, 20, 14 and 08 120 Days 40, 35, 22, 14 and 09
[54]	PP plastic volume fraction: 0%, 0.5%, 1.0%, 1.5%, 2.0%, 2.5%, 3.0%	7 Days 17, 18, 19, 16, 13, 12 and 11 28 Days 24, 23, 21, 20, 19, 18 and 18
[26]	0%, 1%, 2%, 3%	7 Days: 34.67, 36.00, 39.11, 41.78 14 Days: 38.36, 40.22, 43.78, 46.04 28 Days: 44.22, 47.02, 48.22, 49.78
[56]	0%, 5%, 10% and 15%	PP 3.7, 3.5, 3.4 and 3.0 PF 3.7, 3.6, 2.0 and 1.9
[23]	0%, 10%, 20%, 30%, 40%	28 Days 20, 25, 26, 22 and 21

OC = Oven Curing
WC = Water Curing
PF = Plastic Fine Aggregate or Plastic Flakes
PC = Plastic Coarse Aggregate
PVC = Polyvinyl Chloride
PP = Plastic Pellets

B. Flexural Strength (FLS)

Flexural strength is assessed in terms of stress and is defined as a material's capacity to withstand deformation under flexural loading stress (FLS).

The flexural strength (FLS) of concrete using PW as aggregate or fibres is shown in Figure 8 and Table 4. PW used as fibre enhanced the FLS of concrete, like its effect on compressive strength (CMS), while PW used as aggregate reduced it. The FLS ranged between 9 and 15 MPa. Differences in FLS between PW concrete and conventional concrete were minimal. The plastic waste did not form strong, interlocking bonds with the cement, as observed from the surfaces of the cracked samples [59]. The same reasoning applies to the behaviour of FLS as it does to the reductions in CMS, splitting tensile strength (STS), and modulus of elasticity caused by the incorporation of PET aggregate.

After failure, the reference specimen split into two parts, while concrete beams incorporating PET and plastic fibres did not. During testing, the PET-concrete beam and plastic fibres bridged the fracture, preventing brittle failure [58]. The increased ductility and post-crack flexural toughness resulted in mechanical properties—such as impact resistance—that were nearly comparable to those of concrete reinforced with polypropylene and high-modulus polyethylene fibres [60].

Concrete specimens containing 0.2–1.0% volume fractions of HDPE fibres, cut from scrap plastic containers, were tested. Results showed that 0.6% HDPE fibres could increase CMS, STS, FLS, and impact strengths by approximately 15%, 23%, 22%, and 200%, respectively, with only slight improvements observed when increasing fibre volume to 0.8% and 1.0% [61]. PET fibres were also found to improve FLS and mortar toughness [39]. Multiple researchers have reported that fibres enhance FLS by preventing crack propagation [62–66]. Even 0.75–1.25% HDPE fibres (by volume) maintained 30–40% of post-crack tensile strength relative to peak FLS capacity [40]. FLS improved with increasing PF content up to 1.75% by volume; however, higher concentrations led to strength reductions due to uneven PF distribution, although values remained higher than the control mix [43]. Similar findings have been reported for comparable PF types and contents [67].

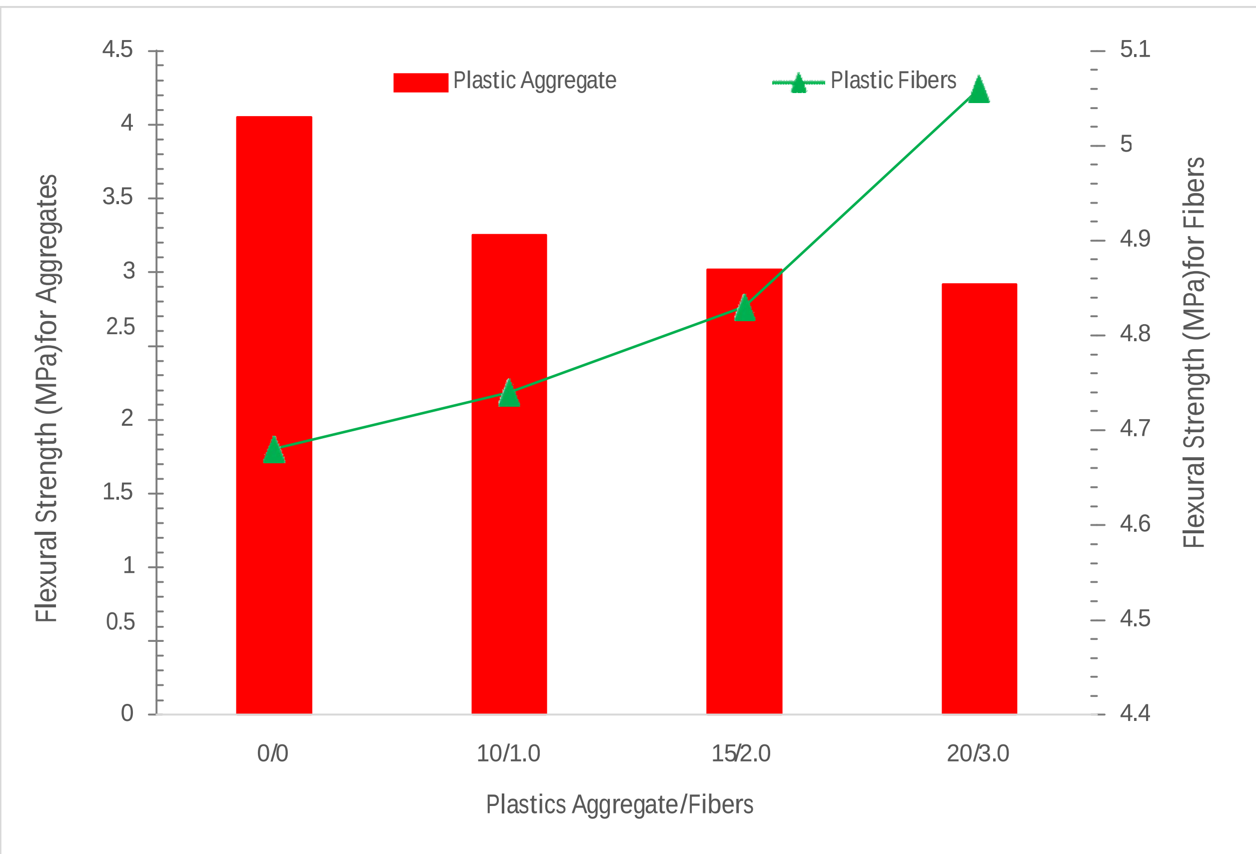

Figure5. Flexural Strength (FLS):Data Source[26,49].

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Table4. Summary of Flexural Strength (FLS).

Reference	Plastic waste	Flexure Strength (MPa)
[49]	PF 0%,10%,15%and20%PC 20%	7Days 2.35,2.12,2.17and1.72 28Days 4.05,3.25,3.03and2.92
[50]	0%,5%,15%and 25%	28Days 15.45,8.08,1.95and0.29
[22]	0%,10%,20%,30%and40%	3Days 6.0,4.5,4.5,4.6and4.4 7Days 6.5,5.5,5.0,4.8and4.5 14Days 7.5, 6.0, 6.0, 58 and 4.7 28Days 10.5, 8.5, 6.5,7 and 5.8
[51]	2mmfibers 0%,5%,10%,15%,20%,25%,30%,35%and40%	28Days 10.5,9.5, 8.5,7.5, 6.5, 6.4,6.3, 6.2 and6.1
[52]	0%,10%,20%,30%and40%	28Days 4.8,4.5,4.2,3.8and3.2
[53]	PVC 0%,2.5%,5%,10%and20%	60Days 7.0,5.8,5.3,5.0and2.0 120Days 7.0,5.8,4.1,5.0, 2.0
[41]	0%,2%,4%and6% 10%FlyAsh 0%,2%,4%and6%	28days 7.0,7.2,7.0and5.6 7.4,7.6,7.2and5.2
[54]	0%,0.1%,0.2%,0.3%,0.5%,0.7and1.0%	28Days 4.28,4.17,4.24,4.15,4.62,5.02and4.84

C. Split Tensile Strength (STS)

As mentioned earlier, one of the most important and practical properties of concrete is its compressive strength (CMS). Concrete is a structural material capable of withstanding compressive pressures. In areas where tensile or shear strength is critical, compressive strength is often used to estimate the required mechanical properties.

Table 5.Summary of Split Tensile Strength (STS).

Reference	Plastic Waste	Split Tensile Strength
[49]	PF: 0%, 10%, 15%, 20% PC	7 Days: 1.50, 1.46, 1.35, 1.29 28 Days: 2.02, 1.80, 1.73, 1.69
[24]	0%, 10%, 15%, 20%	28 Days WC 4.5,4.0,3.5and3.2
[25]	0%, 5%, 15%	WC: 3.85, 4.12, 4.22 OC: 3.23, 3.44, 4.19
[18]	0%, 7.5%, 15%	

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		28 Days 4.5,4.0,3.5and3.2
[39]	Aspect ratio=2.5 0%,0.10%,0.25%and0.50% Aspect ratio = 2.50. 10%, 0.25%and0.50%	1.4,1.6,2.1and2.2 1.4,2.0,2.3and2.4
[40]	Plastic fibres (0.25 mm): 0%, 0.40%, 0.75%, 1.25% Plastic fibres (0.40 mm): 0%, 0.40%, 0.75%, 1.25%	2.79,3.03,3.93and2.88 2.79,3.08,2.95and2.96

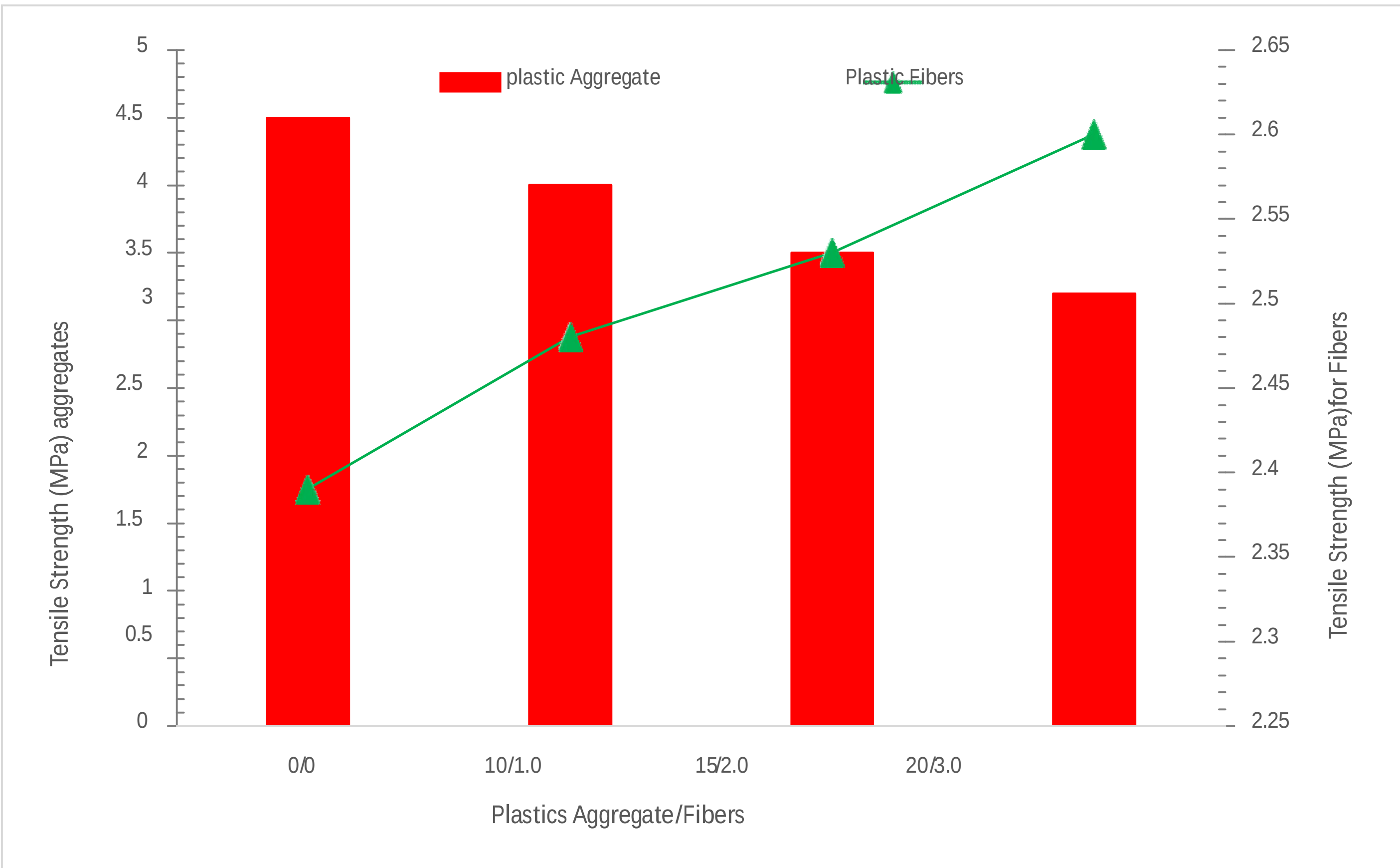

Figure6.Tensile Strength(STS):Data Source[24,26].

V. ENVIRONMENTAL IMPACTS

Plastics, synthetic fabrics, tires, rubber, and the plastic waste (PW) used in this study [92] are all products of the petrochemical industry. This type of waste significantly contributes to greenhouse gas emissions. The primary product of carbon compound oxidation during incineration is carbon dioxide (CO_2). Therefore, estimating carbon dioxide emissions based on the carbon content of burned waste is considered reasonable. In the literature, the most referenced method is the mass balance (or material balance) calculation approach. This method requires knowledge of the quantity of fossil carbon burned and the oxidation rate, which reflects the efficiency of incineration. The greenhouse gas emission factors for various types of PW during incineration are summarized in Table 6. According to research, the combustion of plastic waste emits a considerable amount of carbon dioxide. Incineration of polyethylene (PE) releases approximately 813 kg CO_2 equivalent per ton, while polypropylene (PP) emits around 812 kg CO_2 equivalent per ton. In contrast, the burning of polyvinyl chloride (PVC) produces the lowest amount of carbon dioxide among the three. Recycling plastic waste into concrete mixtures is considered one of the most effective strategies to reduce pollution caused by energy consumption, global warming, and waste disposal.

Table 6.Release of Corban Di oxide of Plastic: UsedasperElsevierPermission[92].

Plastics	CO2(%)	FossilCO_2	Oxidize	Corbon
PE	85.6%	100%	95%	813kgeqC/t
PP	85.5%	100%	95%	812kgeqC/t
PVC	40.1%	100%	95%	381kgeqC/t

VI. CONCLUSIONS

A comprehensive review of existing research on the performance of recycled waste plastic in concrete was conducted. The effects of recycled waste plastics, in the form of aggregate (fine or coarse) and fiber, on the fresh, mechanical, and durability properties of concrete were examined. The key conclusions are as follows:

- Flowability of concrete decreased with the inclusion of plastic fibers due to their larger surface area. However, an increase in flowability was observed when plastic waste was used as aggregate, attributed to its lower water absorption. Depending on particle form, size, surface roughness, water-cement ratio, and cement paste volume, the flowability of concrete may improve with increasing amounts of fine recycled plastic aggregate.
- Mechanical strength—including compressive, flexural, and tensile strength—decreased when plastic was used as aggregate. This reduction is primarily due to weak bonding between the plastic and cement paste. In contrast, plastic fibers enhanced mechanical strength by preventing crack propagation, like the effects observed with conventional fibers.
- Durability of concrete declined with the use of plastic aggregates, whereas plastic fibers improved durability. However, available data on the durability performance of concrete with plastic waste remains limited.
- Incorporating recycled plastic waste into concrete mixes is a promising strategy to mitigate environmental impacts, including pollution, energy use, waste disposal, and contributions to global warming.

VII. RECOMMENDATION

1) The weak bond between cement paste and plastic aggregate can potentially be enhanced using pozzolanic or filler materials. Therefore, this review recommends conducting detailed investigations on the behavior of plastic-based aggregates combined with pozzolanic or filler additives.

2) Chemical treatment using calcium hypochlorite ($Ca(ClO)_2$) has been shown to improve the bond between the cementitious matrix and plastic aggregates, as reported by Lee et al. [47]. However, due to the limited available data, further comprehensive studies are necessary.

3) The thermal properties and long-term durability of concrete containing plastic-based aggregates should be thoroughly examined before such materials are adopted in practical applications.

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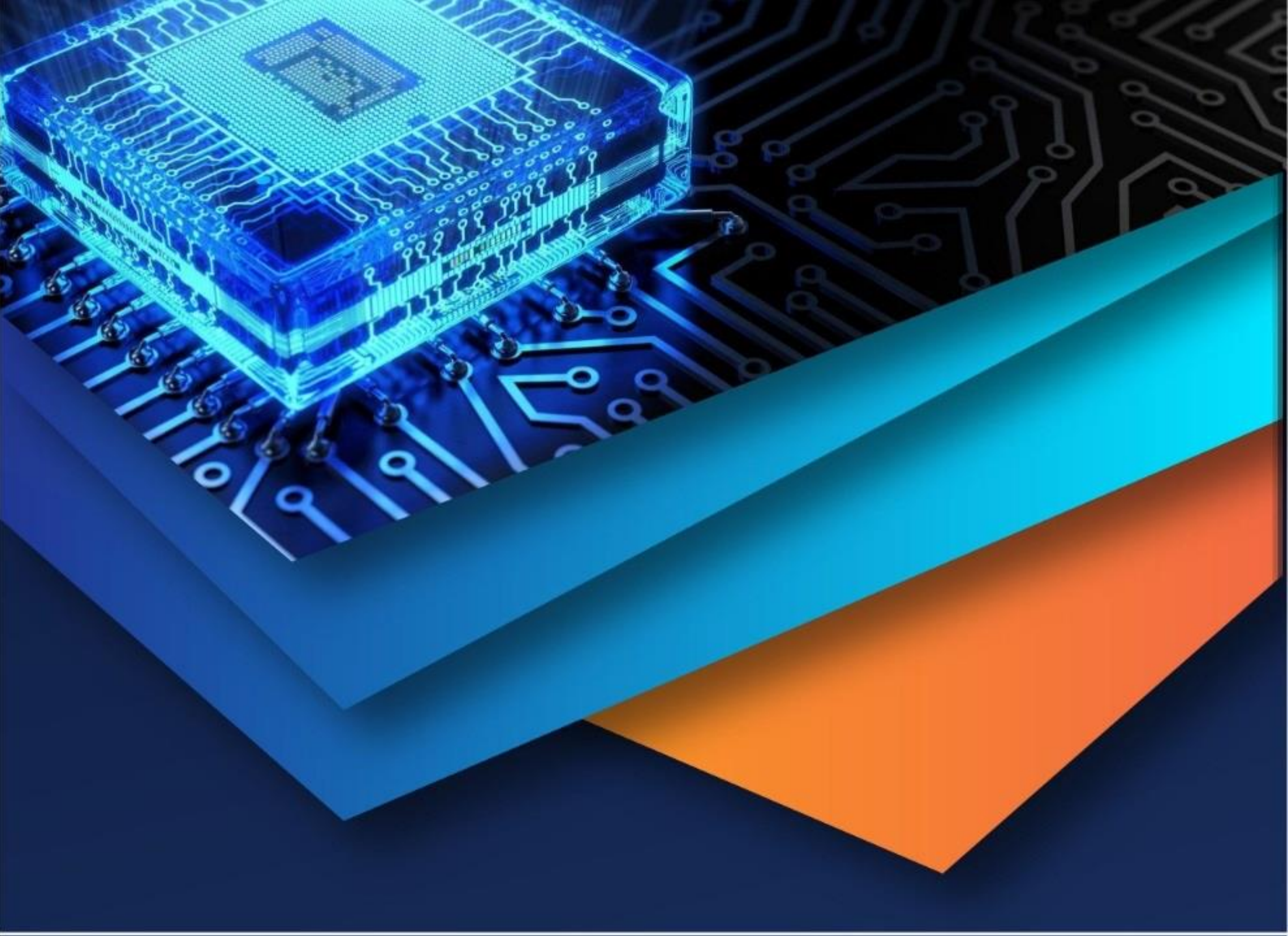

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