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Review Article

EFFECT OF REPLACING NATURAL AGGREGATE WITH PLASTIC AGGREGATE ON THE MECHANICAL PROPERTIES OF CONCRETE-REVIEW

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Abstract

Humans are consuming vast quantities of plastic across various types, leading to significant challenges in decomposition and the subsequent generation of extensive plastic waste, posing a significant threat to the environment. To address this issue, researchers are actively exploring methods to minimize plastic waste and mitigate its widespread impact by incorporating it into concrete. This not only enhances concrete's durability but also reduces costs. This paper provides an overview of published research on the utilization of waste plastic in concrete. It reviews the efforts of numerous researchers in valorizing plastic waste in concrete, exploring different forms such as partial replacement of fine and coarse aggregate, as well as fibers, and examines their effects on the fresh, mechanical, and durability properties of concrete. The research findings indicate promising possibilities for recycling plastic waste in concrete. However, there is scope to investigate the combined utilization of plastic as both aggregate and fiber in concrete, potentially enabling the recovery of additional quantities of plastic waste. Furthermore, the study emphasizes the importance of employing scanning electron microscopy (SEM) to analyze changes occurring within the concrete.

Keywords: mechanical properties, durability, polyethylene terephthalate, scanning electron microscopy

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1. INTRODUCTION

Given the inorganic characteristics of plastic waste (PW), environmental harm has ensued, manifesting as water, air, and soil pollution, contributing to the spread of diseases and adversely impacting human health. The production of plastic has witnessed a substantial surge, escalating the amount of tonnes increased from 1.5 million in 1950 to an astonishing 359 million in 2018. [1, 2] and to 390.7 million tons in 2021 [3], A considerable portion of this quantity is utilized in manufacturing single-use plastic products, thereby giving rise to the accumulation of plastic waste. Since these materials do not undergo organic degradation or chemical interactions with the environment, they represent a substantial global environmental hazard[4] . For example, plastic bags need what It takes about 1,000 years to decompose in nature [5]. Numerous research studies have explored ways to leverage plastic waste, particularly in the construction sector, where rising plastic consumption and litter production are linked to population growth. Researchers introduced a quantity of recycled polypropylene (RPP) into concrete, comparing its performance with asphalt concrete (AC) and Portland cement concrete (PCC). The findings revealed that RPP demonstrated stiffness and flexural strength surpassing that of AC by three times and PCC by five times[6],In a separate study, a different team incorporated polyethylene terephthalate (PET) Bottles into recycled aggregate concrete (RAC). The tensile strength at cleavage, modulus of elasticity,ductility development all showed significant improvement in the results of the RAC experiments. [7].In recent years, a number of researches related to reducing the negative effects of these wastes have been conducted. They were used instead of natural aggregates [8, 9] and were also used as industrial fibers [10] to strengthen and improve concrete and concrete mixes like polypropylene fibers (PP) [11, 12], (PET) [13, 14], high-density polyethylene (HDPE) [15, 16], nylon fibers [17, 18]. The objective of this research is to mitigate the presence of plastic waste in the surroundings by presenting a comprehensive overview, derived from several literature sources, of the various kinds of plastic trash, its incorporation into concrete, and the resulting effects on the material.

There are essentially two types of plastic waste: plastic fibre and plastic particulate, that use in traditional concrete, where plastic waste is obtained by collecting and cleaning the used plastic materials, after which comes the cutting stage either using a paper shredder [19, 20], or manually [21], or using a CD cutter apparatus [22]. We get Reinforced Plastic Waste Fiber Concrete (RPWFC) by adding plastic waste as fibers in the concrete mortar [23], while we call the Reinforced Plastic Waste Aggregate (RPWAC) by substituting a quantity of naturally occurring large or small particles used in construction with coarse or fine waste plastic aggregate [24, 25], with regard to the method of preparing each of them (RPWFC-RPWAC) it is same as ordinary concrete in mixing, casting, and curing.

This paper delves into the various methods employed by researchers worldwide for incorporating plastic waste into concrete and analyzes its impact on concrete performance. The overarching goal is to mitigate plastic waste in the environment, thereby contributing to sustainable development efforts aimed at waste reduction

2. EFFECT OF PW ON FRESH CONCRETE

2.1 Workability

Workability serves as a measure of the concrete's ease of mixing and is deemed a critical property in the formulation of mixtures. Numerous factors influence workability, such as the water percentage in the mixture, temperature, mixing time and method, aggregate grading, cement content, as well as the presence of chemical and mineral additives.

2.1.1 Influence of PWA on Workability

The research used plastic garbage as a substitute for fine aggregate and found that as the amount of waste grew, its durability decreased accordingly [26],A similar observation was noted when substituting fine aggregate with varying percentages of PET and PE. The optimal replacement ratios were determined to be 10 for PET and 5 for PE, respectively [8].The workability is influenced by the surface shape of the utilized fibers. Three variations of PET were employed as a partial replacement of aggregates, the findings indicated enhanced workability and a reduced water-cement ratio when employing the semi-spherical form with a smooth surface of PET. In contrast, the other two forms (angular and non-uniform) diminished workability and required additional water[27].

2.1.2 Influence of PWF on Workability

Various proportions of plastic fibers ranging from 0 to 30, 50, 70, 90, and 110 were introduced into the mixture. The optimal aspect ratio was identified as 50, demonstrating the highest level of increased workability [28], It has been noticed that the workability increases significantly when adding PET fibers to the concrete mixture by 0.05 and decreases when the percentage is increased [29].A group of researchers put quantities of high-density polyethylene (HDPE) in proportions starting from 0% to 6% in the mixture. They found that workability improves and increases when it reaches 2% and begins to decrease when this proportion is exceeded [30]. The workability improved when added a percentage of fly ash to the polypropylene fibers, and the workability began to decrease by increase the percentage of the polypropylene fibers [31].We can conclude from the foregoing the versatility of the mortar decreases as the proportion of fibres increases. Table.1 shows us a summary of some above-mentioned studies that related to workability.

Table 1. Summary of some studies in workability

Studied Properties	**Type**	**PW Percentage (%)**				**Substituted Materials**	**Effect (%)**	
		Aggregate		Fiber				
Workability, Flexural strength, Compressive strength, Density, Toughness, [26]	PE and PS	10	Of FA	-		FA	-68.3	
		15					-88.33	
		20					-95.33	
Compressive strength, Workability, Density, Water absorption, [8]	PET PP	5	Of FA	-		FA	-8.3	-16.7
		10					-41.6	+25
		15					-83.3	-8.3
		20					-100	+8.3
		25					-100	+25
Density, Modulus of elasticity, Water absorption, Workability, Porosity, Compressive strength, [31]	PP	-		0.05	Of TM	-	0	
				0.1			-5.8	
				0.2			-17.6	

Notes: (FA) Fine Aggregate, (TM) Total Mixture, (+) (-) indicate to Increase and Decrease respectively, All values are results compared to Conventional Concrete

2.2 Density

Density, measured in kilograms per cubic meter (kg/m³), It stands as a fundamental property of concrete, influencing its strength, hardness, and durability.

2.2.1 Influence of PWA on Density

Upon replacing fine aggregate with 1%, 2%, 4%, and 8% of PET, the density exhibited a decrease of 0.5%, 2.8%, 7.3%, and 9% respectively. This trend is likely attributed to the fact that the specific gravity of the plastic aggregate is 13.75% lighter than that of the fine aggregate.[32]. A group of researchers found a decrease in fresh density when they replaced 5% and 10% of sand aggregate with plastic waste. They attributed this to the fact that the density of plastic waste is 70% less than the density of sand aggregate [33], and this was confirmed by a previous study that replacing plastic waste with fine aggregate has a positive effect on density [26].Observations during the replacement process indicated a correlation: as the rate of replacement increased, there was a simultaneous decrease in density and an increase in fragility[34].

2.2.2 Influence of PWF on Density

Eight samples, each with varying percentages of plastic waste (0, 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75), were tested. Additionally, alternatives to cement, Materials that include 20% fly ash and 10% silica fume were included. The findings demonstrated that the incorporation of more fibre has an adverse effect on both the rigidity and fresh characteristics of concrete, evident in the decreased densities across all eight samples [35]. Recycled low-density polyethylene waste fibers were integrated into the self-compacting concrete mix at varying proportions from 0.5 to 3.5. Density tests were performed on the samples, revealing that an incremental increase in (LDPE) fibers had an observable effect on density, leading to a gradual decrease[36]. The impact of incorporating PET fibers of varying lengths (1, 2, 3 cm) was examined at concentrations of 0.5 and 1. The findings indicated an inverse relationship between density and the percentage increase in plastic fibers [37]. Table.2 shows some of the above-mentioned studies related to density.

Table 2. Summary of some studies in density

Studied Properties	**Type**	**PW Percentage (%)**				**Substituted Materials**	**Effect (%)**
		Aggregate		Fiber			
Workability, Density, Compressive strength, Split tensile strength, [32]	PET	1	Of FA	-		FA	-0.15
		2					-2.35
		4					-6.5
		8					-8.8
Density, Slump, Compressive strength, Flexural strength, [33],	-	5	Of FA	-		FA	-5
		10					-8.7
		15					-10.75
Compressive strength, Slump, Density, Flexural, Tensile strength, Abrasion, [37].	PET	-		0.5	Of TM	-	-1
				1			-2.1

3. Effect of PW on Hardened Concrete

3.1 Compressive strength

This strength signifies the concrete's capacity to withstand axial loads leading to distortion and fracture. Hence, understanding to determine the effect of adding plastic garbage to the combination components, concrete that contains it must have a high compressive strength.

3.1.1 Influence of PWA on compressive strength

Someone studied the effect of adding quantities of plastic waste in different proportions, he replaced an amount of fine sand with proportions of this waste (5, 10, 20) %, tests revealed the fraction is increased, there is a corresponding drop in compressive strength., as the value was respectively, (39, 37, 32) [38], The same results were reached when ripping PET bottles and using as alternative offine and coarse aggregate separately in varying proportions (5, 10, 15, 20) %, the compressive strength decreased at 20% of coarse aggregate after 28 days curing from 26.7 to 6.9 and 5.4 MPa for fine aggregate, which indicates a weak bond between the waste and the slurry[39], While the using of recycled polypropylene and polyethylene terephthalate as a substitute for fine aggregate in different percentages in the mixture (5, 10, 15, 20)%, caused increase in compressive strength from 37.8 to 39.99 and 38. 25 when adding PET at a rate of (5 and 10)%, respectively, it began to decrease for the rest of the percentages and for the percentages of the second type as well [8]. 12%, 17%, and 22% of the coarse stone aggregate have been substituted with electronic waste from plastic aggregate and concluded that compressive strength was reduced regard withordinary concrete and attributed this to weak bonds and increased porosity[40], this is what some researchers concluded when they replaced fine aggregate with waste plastic, because plastic has weak bonds with the concrete mixture and voids will form in this case. They did not recommend this use in building structural structures, but rather in paving, facades and roads [41].

Some had a different opinion, they used plastic waste as place of fine aggregate in different proportions, and applied a compression experiment on cubic samples after 28 days, and it was found that the compressive strength increased over that of regular concrete, and that 15% was the best replacement ratio in terms of strength, as it increased from 27 for traditional to 31 MPa for concrete that contains that percentage of waste [42]. Plastic waste from various sources is used substituted of fine aggregate, such as CD, PET and a plastic water bottle in different proportions. After testing, he noticed that the samples deformed more than regular concrete and a drop in compressive strength as the proportion of plastic increases, especially large-sized particles [24].When converting PET waste into fine granules, replacing sand with it in concrete at a rate ranging from 1% to 8%, and comparing it to concrete that does not contain plastic particles, It was discovered that while plastic strength grows, it does so gradually content until it reaches a noticeable increase of 2%, which is Maximum strength, then begins to decrease until it reaches the minimum at 8% [32].

3.1.2 Influence of PWF on compressive strength

When metalized plastic waste (MPW) covering food items was cut into varying lengths of fibers (5, 10, 20) and combined them with concrete in proportions ranging from 0 to 2% of the total volume of the mixture, experiments showed that the compressive strength was not affected significantly, but rather slightly, as this addition had no direct effect on the strength [43]. The influence of adding plastic bag waste fibers to self-compacting concrete with lengths of (2, 4, 6 cm) was studied, experiments were conducted on samples and compared to a sample containing recycled polypropylene fibers and a sample that did not contain waste fibers, it was noted that the compressive strength increased by 7 to 13%. The largest percentage of fibers was 2 cm long, we can conclude that the length to diameter ratio does not affect this force [44]. Some of researchers tested samples containing different percentages of plastic banner fiber waste (0, 0.25, 0.5, 1, 2) % of the total volume, It was discovered that concrete can reach a maximum compressive strength of 1%, with an estimated increase of 4.95%, and the percentage was 0.25% the lowest compressive strength for ordinary concrete, where the decrease value reached 16.5%, when they tested the cube containing 2%, they found that the strength decreased again by 8.38%. Concluded from this study that adding plastic waste fibers does not show any noticeable or significant effect [45]. Another group cut the polyethylene terephthalate waste and used it in the mixture at a ratio of (0,0.5) % and an aspect ratio of (2.5,3), it was found that in both cases there was a slight decrease in the compressive strength, and that the more we exceeded that percentage, the more the compressive strength began to gradually decrease [46].

Twelve concrete mixtures were manufactured, six of which contained ordinary Portland cement and the remaining six contained palm oil fuel ash with a proportion of 20% Portland cement. These samples contained mineral plastic waste fibers 20 mm long in proportions between 0 and 1.25%, it was found that the compressive strength dropped at early ages for both species, and this force was greater in POFA than in OPC after the test was performed on day 91 [47]. someone shredded waste plastic bags using a special device, obtained waste plastic shredded fibers, and incorporated them into the concrete mixture in different proportions (0, 0.5, 1, 2, 3, 5) %, he evaluated the compressive strength after days of curing, it found that there was a very slight decrease in that strength for the ratios (0.5, 1) and a noticeable gradual decline for the remaining ratios, he concluded that by increasing WPSF ratio, the strength decreases [48]. The effect of adding MPW to concrete and incorporating natural zeolite or silica fume into the mixture was evaluated. The comparison conducted in two stages. first stage compared the concrete that did not contain MPW fibers with the rest of the samples, and it was reported that its compressive strength deteriorated, with highest proportion of decrease reaching 25%. As for the second stage, in concrete containing MPW fibers in proportions (0.5, 1), silica fume on the one hand, 7.5%, and natural zeolite, on the other hand, 15%, the first showed a noticeable superiority in compression strength on zeolite content [49]. Waste PET bottles added in different proportions in aspect ratio (L/D = 40, 60, 80). After experiments and comparison with regular it was discovered that the addition of fibres to concrete reduced its compressive strength, and it is likely that this decrease is due to the weakness of the plastic material in compression. Conversely, out of the three values, 60 was the greatest result for the strength of compressive resistance, and the lowest pressure value was for the mixture with a ratio of 80 [35].We can see by Table 3. a summary of some of the above-mentioned studies in the field of compressive strength.

Table 3. Summary of some studies in compressive strength

Studied Properties	Type	PW Percentage (%)				Properties Of Fiber (mm)	Substituted Materials	Effect (%)
		Aggregate		Fiber				
Workability, Density, Compressive strength, Modules of elasticity, Impact bending, [38],	Polycarbomate	5	Of FA	-		-	FA	-7.14
		10						-12
		20						-23.8
Compressive strength, Impact resistance, Energy absorption, Resistance temperature, [39]	PET	20	Of FA, CA	-		-	FA CA	-79.8 -74
Compressive strength, Flexural strength, Tensile strength, [40]	Electronic Plastic Waste	12	Of CA	-		-	CA	-3
		17						-17.4
		22						-24
Density, compressive, Flexural strength, [42]	Electronic Plastic Waste	10	Of FA	-		-	FA	+5.5
		15						+14.8
		20						+8
Slump, Compressive strength, Splitting strength, Modulus of rupture, Modulus of elasticity, [45]	Banner Waste Plastic	-		0.25	Of TM	L=40 D=0.5	-	-16.5
				0.5				-1
				1				+5
				2				-8.4
Compressive strength, Impact resistance, Energy absorption, [48]	Non-Metalized Waste Polythene Bags	-		0.5	Of concrete volume	L=15-30 W= 3-5	-	-2.25
				1				-14.23
				2				-40
				3				-73.8
				5				-84.64
Consistency, Density, Compressive strength, Splitting tensile strength, [35]	PET	-		0.25	Of concrete volume	L/D=40	-	-11.8
						L/D=60		-33.33
						L/D=80		-41.6

Note: (CA) Coarse Aggregate

3.2 Splitting tensile strength

The splitting tensile strength may be characterised by the ability of prismatic or cylindrical concrete to tolerate failure when subjected to tensile forces perpendicular to its longitudinal axis.

3.2.1 Influence of PWA on Splitting Tensile Strength

Certain researchers ground glass waste and incorporated it as a substitute for cement at a 15% rate. Additionally, they introduced plastic waste as coarse aggregate in varying proportions (25%, 50%, 75%, 100%) and conducted experiments on samples aged 60 days. When comparing the splitting tensile strength to the reference sample, they saw a decrease. The lowest percentage drop was 25%, or 19%, while the largest decrease in percentage was 100%, or 43.6% [50]. Additionally, PET waste was integrated into the concrete mixture as a partially as a replacement for(FN) at proportions (0, 25, 50) %, with variations relative of (W/C) at (40, 45, 55). 153 specimens underwent testing, comprising both cylindrical and cubic specimens. The findings indicated a decline in splitting tensile strength with the escalating presence of PET waste. This decrease may be attributed to the concurrent reduction in compressive strength [51].

By employing plastic electronic waste as a partial substitute for coarse aggregate in mortar, with proportions varying from 10% to 50%, it was observed that the splitting tensile strength exhibited a gradual decrease with an augmentation in plastic content. The most substantial percentage decrease was approximately 47.5% at the highest proportion, while the minimum percentage decrease amounted to 7.8% at the lowest proportion, as determined through examination [52]. Polyethylene terephthalate waste was used in mortar by partially replacing natural aggregate with that waste, at a specific rate of 7.5% and 15%, prepared samples in those proportions and applied high temperatures to them for approximately an hour, at 600 degrees and 800 degrees Celsius, and after cooling the samples, conducted their evaluation on them, It was discovered that the PET-containing materials have a low splitting tensile strength [53].An investigation of the effects of electronic plastic trash on concrete was the goal of a study team and assess the potential benefits of incorporating marble dust into the mixture at different proportions (0%, 5%, 10%, 15%) relative to the volume of cement. To achieve this, they processed the waste into three groups (a = 0-5, b = 5-10, c = 10-14) mm to emulate aggregate characteristics, with the intention of replacing natural aggregate at percentages of (0, 10, 20, 30, 40%). Following treatment and 28 days after pouring, they examined the samples and noticed that tensile strength of samples including waste decreased by percentages ranging from 11% for a 10% waste proportion to 21% for a 40% waste proportion. Interestingly, they noted that samples containing both waste and marble dust exhibited minimal decreases in tensile strength, approaching values close to traditional concrete. The researchers concluded that as the proportion of marble dust increased, the reduction in tensile decreased further, reaching as low as 1% for a 10% waste and 15% dust proportion [54]. Research was conducted to examine the impact of blending plastic waste and recycled glass powder with concrete. The hybrid aggregate was used to partially replace the coarse aggregate in proportions ranging from 10 to 50, resulting in a non-significant reduction in tensile division strength when compared to conventional concrete. The findings indicated that this mixture is advantageous and economically feasible for concrete paths for pedestrians [55].

A researcher explored the impact of incorporating polypropylene plastic waste into concrete at varying proportions (0%, 10%, 20%, 30%). This waste served as an alternative to natural aggregate in the first group and clay brick aggregate in the second group. Both groups received two different water-to-cement (W/C) ratios: 0.45 at first and 0.55 afterward. Test results from both groups revealed a notable enhancement in splitting tensile strength with the inclusion of 10% polypropylene plastic waste, regardless of the water-to-cement ratio. The first group showed the most rise, with a W/C ratio of 0.45, reaching 14.5. However, when the percentage of plastic waste rose, the strength at which it splits began to decline. As a recommendation, the study suggests utilizing a 10% recycled polypropylene in combination with either stone aggregate or clay brick aggregate for optimal results [56].

3.2.2. Influence of PWA on splitting tensile strength

Waste plastic polyethylene fibers after manually cutting them into two lengths (5-12//20-35) were used and conducted a test 7 days after casting on nine samples, eight contained different percentages of fibers (0.1, 0.2,0.3, 0.4) compared with the ninth reference sample that without fibers, the result was raised in the split tensile strength, especially at ratio of 0.3, where the highest increase was recorded at 3.21,with an increase in the amount of plastic, the strength begins to decrease gradually [57].

Also experiments conducted on samples that contained waste fibers from polyethylene terephthalate bottles and compared their effect on their shape and percentage on concrete. First shape was obtained by cutting PET bottles into rings with a width of 5 and 10 mm, a diameter of 60 mm, second shape by shredder the bottles into different shapes, regular sizes of 10-15 mm, with ratios ranging from (0-1.5) % for both shapes. After examination and evaluation, the splitting tensile strength exhibited an increase alongside the escalating percentage of PET fibers in the samples featuring a ring shape. The maximum increase was observed at 35.7% for a width of 10 mm with a 1.25% ratio, signifying the optimal percentage for ring-shaped samples with both widths. Conversely, for the samples featuring an irregular shape, the tensile strength started to gradually decrease with the augmentation of fiber percentage.[58]. Tensile strength on hybrid concrete was tested, where they added basalt fibers that are attached at 18 mm between the melt and waste polypropylene fibers in different lengths (6, 12, 19, 30) mm at a total rate of 0.3%, and replaced 20% of the cement with fly ash, 30% of natural aggregate with recycled aggregate. After comparison, it was noticed tensile strength increased when using polypropylene with a length of (19, 30), while it decreased at the remaining two lengths. The highest percentage of increase was 13.3% and the largest percentage of decrease was 45.5% [59].

When use several types of plastic waste fibers, including high-density polyethylene, polyethylene terephthalate, low-density polyethylene, and polypropylene in different proportions in the concrete mixture then test the samples after a certain age we will notice a decrease in splitting tensile strength [60]. A group of researchers melted plastic waste, molded it, then stretched it so they obtained plastic waste fibers, cut it into pieces with a size ranging from 10-40 mm and a fixed diameter of 0.4 mm. They added it to the mixture in proportions that ranged from 0 to 2% of the total volume, they modified the mixture by put styrene butadiene rubber in proportions starting from 0% and ending with 20% of the cement weight, conducted their tests on the samples after 28 days, and the splitting tensile strength increased for all percentages, while the maximum percentage increase was 47% for the sample containing 1% plastic waste and 15% SBR. This research has shown the effectiveness and importance of adding SBR to the concrete mixture [61].

The researchers appeared at that as the fibers of PW increase, the tensileincreases. They verified this when they cut PET bottles into fibers of specific lengths and sizes and combined with concrete in proportions (0.5, 1, 1.5) %, then tested the samples after specific days and found that the strength increased by 9.1% ,15.5% and 23.6%, respectively, compared to ordinary concrete [62]. Hybrid fibers, comprising polypropylene waste fibers with a length of 6 mm and basalt fibers with a length of 18 mm, were incorporated into concrete in varying proportions. Testing the splitting tensile strength revealed a significant enhancement in samples containing the hybrid fibers. The sample containing solely waste polypropylene fibers, without basalt, achieved the highest value at 4.55 MPa[63].Finally, we will summarize in Table 4. some of the studies we mentioned regarding splitting tensile strength.

Table 4. Summary of some studies in splitting tensile strength

Studied Properties	**Type**	**PW Percentage (%)**				**Properties Of Fiber (mm)**		**Substituted Materials**	**Effect (%)**	
		Aggregate		Fiber						
Density, Compressive strength, Water absorption, Splitting tensile, Flexural, Thermal conductivity, [50]	HDPE	25	Of CA	-		-		CA	-19	
		50							-32.9	
		75							-41.1	
		100							-43.6	
Workability, Density, Compressive strength, Tensile, Flexural, [52]	PET	10	Of CA	-		-		CA	-7.8	
		20							-32.6	
		30							-27.9	
		40							-39.1	
		50							-47.5	
Slump, , , Tensile, Modulus of elasticity, Density, Modulus of rupture, Compressive strength [56]	Waste Polypropylene	10	Of CA	-		-		CA	+14.5	
		20							-9.7	
		30							-11.6	
Workability, Compressive strength, Splitting tensile strength, Flexural, [58]	Waste Plastic Bags	-		0.1	Of Concrete Volume	L1=5-12	L2=20-35	-	+3.7	+3.7
				0.2					+1.7	+1.7
				0.3					+0.7	+7
				0.4					-8.3	-6.3
Tensile strength, Compressive, Pull-out strength, [58]	PET	-		0.25	Of Concrete Volume	Width=5 D= 60	Width=10 D= 60	-	+11.36	+10.7
				0.5					+16.9	+16.9
				1.75					+22.1	+25.65
				1					+26.3	+35
				1.25					+25.65	+35.7
				1.5					+13.3	+25.65
Slump, Compressive strength, Flexural, Tensile, Elastic modulus, [59]	Baselt + Waste Polypropylene	-		0.3	Of Concrete	18 + 6		-	-45.5	
						18 + 12			-33.9	
						18 + 19			+13.3	
						18 + 30			+8.1	

3.3 Flexural strength

Flexural strength indicates the ability of concrete to bear bending loads applied to prismatic elements such as beams and the absence of cracks or fractures in the sample, as it determines the degree of safety of concrete in structural applications.

3.3.1 Influence of PWA on Flexural Strength

A group cut electronic plastic waste from household appliances, old electronic equipment, and chips into 20 mm size and mixed them with concrete in different proportions (0, 8, 12, 16) % of coarse aggregate. They replaced 20% of the cement volume with fly ash, then casted the samples, when tested it after (7, 14, and 28) days it was noticed that flexural strength increased with increase percentage of plastic waste, as the highest value was recorded at 4.9 MPa for the 16% on the 28th day of curing [64].Six variations of concrete mixtures, incorporating varying amounts, employing leftover Bakelite plastic as an interim concrete replacement (a thermosetting plastic), underwent testing. It was reported that flexural strength reduced from 3.73 to 2.55 in comparison to the normal sample at a replacement rate of 10%. This decline in strength is attributed to the weaker bonds formed between the plastic waste and the concrete constituents. However, the inclusion of Bakelite in the concrete effectively mitigated crack formation in the beams [65]. A study on concrete that compresses itself was conducted, which included substituting a portion of the aggregate with waste polyethylene terephthalate obtained from bags at various percentages (0, 10, 20, 30, 50) relative to the weight of the sand. The test results, conducted at intervals of (3, 7, 14, 28) days, demonstrated a clear inverse correlation between flexural strength and the waste aggregate. As the percentage of PET increased, the flexural strength decreased, attributed to the reduced strength of the waste material [66].

In 2019, the global estimate for electronic plastic waste production reached approximately 51 million tons, with only 9.1% undergoing recycling. Recognizing the significance of addressing this issue, researchers explored the use of electronic plastic waste in concrete production to create an environmentally friendly alternative. This approach aims to diminish the decomposition of electronic plastic waste in soil, concurrently reducing pollution. In their study, the researchers substituted waste electronic plastics for coarse aggregate at proportions of (0, 5.5, 11, 16.5) % and utilized M sand (artificial sand derived from crushing rocks and stones) instead of natural sand. Experimental analysis on beam samples revealed a gradual increase in flexural strength from 5.24 to 5.37 at a replacement rate of 11%. However, this strength subsequently declined to 3.92 with a replacement rate of 16.5% [67]. Experiments were conducted on high-strength concrete incorporating (HDPE) plastic waste. Plastic vegetable boxes were collected, shredded into small pieces, and sieved to achieve sizes comparable to coarse aggregate. Four beams were tested, with three of them containing varying amounts of HDPE at replacement ratios of (10, 20, 30) % of natural aggregate, alongside a reference sample devoid of plastic waste. Silica foam was also employed as a partial replacement for cement. The results indicated a reduction in flexural strength with an increase in plastic content, and the sample with a 30% replacement showed cracks similar to the reference sample [68].

In this study used three types of plastic waste separately (low-density polyethylene, polypropylene, high-density polyethylene) in proportions of 10%, 20%, and 30% of stone aggregate, grade of concrete used was M20.With increasing plastic waste, the flexural strength showed a decrease for each due to the existing fragility of the contacting area between the plastic aggregate and the mortar. Sample containing 10% LDPE and the 30% PP were closest to the reference sample, as the percentage of decrease was 5.7%[69]. Another group behaved a new experiment with introducing plastic waste into gypsum boards, used fine gypsum granules, and ratio of water to gypsum was 0.8, they combined flat round plastic cable waste with a granular size of 3 mm into the mixture in proportions of 60%, 70%, and 80% of aggregate, then conducted their tests on the samples after 28 day and compared it with the traditional sample with 0% contain waste, they found flexural strength began to decrease. The highest value of flexural strength among the three percentages was the bend, which contained 70% in contrast to the percentage of 60% which gave the lowest value. While they emphasized the possibility of increasing this strength if a layer of cardboard is used in the manufacture of composite materials, thus the analyzed materials can provide a suitable alternative to gypsum boards[70].

3.3.2 Influence of PWF on flexural strength

A team of researchers started by obtaining rolls of plastic sheets, subsequently utilizing a designated machine to slit them into fibers measuring 20 mm and 50 mm in length. Following this, the researchers categorized the samples into two groups for testing. The first group included samples with 20 mm fibers at different percentages (0.5%, 1%, 1.5%) of the mixture volume, while the second group consisted of fibers with a length of 50 mm in the same proportions. Additionally, a reference sample without plastic was included for comparative purposes. Notably, the researchers observed a concurrent increase in flexural strength as both the length and percentage of plastic in the mixture rose. The most substantial percentage increase, reaching 84%, was noted in the sample featuring 50 mm fibers and a 1.5% plastic content, respectively[71]. Also converted domestic plastic waste into fibers. They cut them into one pattern, 30 mm long, 4 mm wide, and 0.3 thick, specific gravity was 1.12, and they placed them in the concrete mix in proportions ranging from (0-2) %. They poured it into molds and used a hammer with a tamping plate to compact them, it was obtained samples of concrete under the name Roller-compacted concrete. Through experimentation, it was shown that flexural strength increases with the increase of plastic waste up to 1%, after which it begins to decrease gradually. Highest percentage increase reached 17.86% compared to the normal sample [72]. Another researcher conducted tests on concrete reinforced with waste plastic fibers to ascertain how these fibres' length, breadth, and mixing ratio affect the concrete's hardness characteristics. First, they collected waste plastic bottles and turned it into plastic wire using a specialized device, then cut this wire into different lengths. (30,50,70) and (2,4,6) mm wide. The experiments were managed in three batches, first batch fixed the length and width and changed the percentage (0.3, 0.45, 0.6%), second batch the variable was width while ratio and length were constant, as for the third batch, the constant was the length and the variable were width, ratio. After 56 days, evaluated the samples and compared each batch separately, it was reached flexural strength increased in all samples compared to the traditional ones, as the ratio 0.45, the length 70 mm, and the width 2 mm, were the highest, which reaching 26%, 29%, and 33%, respectively [73].

When mixed percentages ranging from (0-4) % of low-density polyethylene waste fibers (which obtained it by placing the plastic in a machine to cut it into small pieces then melting these pieces under certain temperatures and extracting it in the form of a plastic wire by passing the plastic melted with a special device and cutting these wires into fibers of selected lengths. In this study, the length was 20 mm and the diameter was 1.5 mm) with the concrete mixture, The flexural strength experienced a slight decrease compared to the control concrete. Despite the marginal impact of incorporating plastic fibers on flexural strength, it serves to mitigate potential cracks and enhances flexural toughness when compared to the reference specimen [74]. Two types of polypropylene fibers were combined: the first type is virgin PP, while the second is RPP, which is recycled polypropylene that obtained it from plastic waste. The percentages of fibers used in the mixture were 0.25, 0.50, 0.75, and 1%, and the percentages of the two types of fibers were for some of them, PP:RPP = 100:0, 75:25, 50:50, 25:75, and 0:100. Testing revealed a minor reduction in flexural strength across all samples compared to the control sample. However, these results remained within acceptable standards, suggesting the potential use of plastic waste for environmentally friendly concrete. Optimal fiber ratio was meagered to be 0.75 for all polypropylene (PP) to recycled polypropylene (RPP) ratios [75]. An experimental study was conducted on samples incorporating waste plastic bottles cut into 15 mm fibers using a plastic cutting machine. These samples were compared based on fiber distribution. The first group featured homogeneously distributed plastic fibers, while the second group placed them in the tension zone. Outcome indicated that tension zone exhibited superior performance in terms of bending strength compared to the homogeneously distributed area. The optimal percentage for plastic fiber waste was determined to be 1% [76],

Recycled nylon fibers also had a noticeable impact on concrete, as they added it to the mixture in proportions ranging between (0.05-1) % and showed a noticeable improvement in flexural strength, the best rise value reached 24.2 times that of control concrete with a ratio considered optimal of 0.75%. This also increases cracking resistance [17].Table 5. shows a summary of some previous studies related to flexural strength.

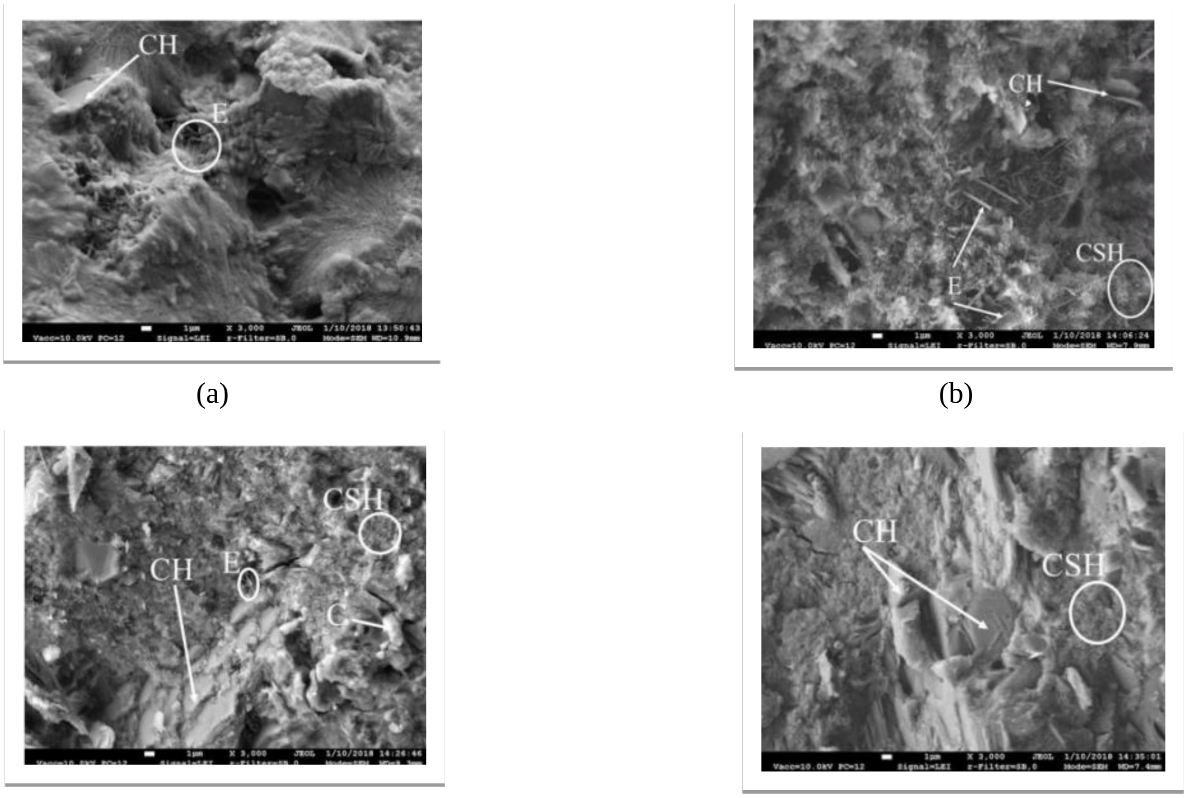
Table 5. Summary of some studies in flexural strength

Studied Properties	Type	PW Percentage (%)				Properties Of Fiber (mm)	Substituted Materials	Effect (%)		
		Aggregate		Fiber						
Slump, Compressive strength, Flexural, Split, [64]	Electronic plastic waste	8	Of CA	-		Size(20mm)	CA	+7		
		12						+11.6		
		16						+14		
Compressive strength, Split, Modulus of rupture, Durability, Shear behaviour, [65]	Bakelite plastic waste	2	Of CA	-		-	CA	-21.18		
		4						-26.27		
		6						-21.18		
		8						-16		
		10						-31.6		
Workability, Compressive, Thermal strength, Tensile, Flexural, [67]	Electronic plastic waste	5.5	Of CA	-		Size(20mm)	CA	+1.14		
		11						+2.5		
		16.5						-25.2		
Slump, Compressive strength, Flexural, Split tensile strength, Durability, [69]	LDPE PP HDPE	10	Of CA	-		-	CA	-5.71	-11.4	-7.4
		20						-20	-25.7	-15
		30						-40	-5.71	-25.7
Flexural strength, Plastic shrinkage, [71]	Recycled Plastic Roll	-		0.5	Of Mixture volume	L=20 L=50	-	+18.35	+6.3	
				1				+36.7	+48.8	
				1.5				+35.7	84.5	
Density, Modulus of elasticity, Compressive strength, Flexural strength, Absorption, [72]	Waste Domestic Plastic	-		0.5	Of Mixture volume	Length=30 Width=4 Thickness=0.3	-	+6.1		
				1				+17.86		
				1.5				+5.5		
				2				-9.3		
Compressive strength, Flexural, Plastic shrinkage, [74]	LDPE	-		1	Of Mixture volume	L=20 D=1.5	-	-3.88		
				3				-9.4		
				4				-4.7		

4. SCANNING ELECTRON MICROSCOPY (SEM)

When adding two types of plastic waste in different proportions. The first type, A, is high-density polyethylene, while the other, B, is low-density polyethylene, and conducting an SEM analysis, it was revealed that there are several minerals portlandite, ettringite, calcite, and hydro calcium silicate in all samples, as Fig 1-a show us the presence of portlandite crystals clearly, while ettringite is small in the form of needles in the pores. As for fig 1-b, which contains 5% of type A waste, the ettringite crystals clearly appear, while the portlandite becomes fewer and smaller in size, in addition to the presence of CSH. In the case of the presence of 10% of type B waste, the ettringite becomes rarely observed, and the size and number of portlandite crystals becomes larger and appears in this stage calcite in small proportions with a previous presence of CSH, as in Fig 1-c. As for Fig 1-d, which represents the addition of 10% of each type, we notice a complete absence of ettringite and the presence of portlandite in abundance and clarity, with the abundant presence of CSH in addition to the lack of pores. We can notice through This type of tests how quickly the plastic waste hydrates the cement [77].Another group also reported the importance of the SEM test because it gives an accurate description and a clear picture of what happens inside the sample after the test. They demonstrated how heat affected self-compacting concrete samples with varying amounts of (PET). They exposed samples to a temperature of T600 and compared them with samples were not exposed to heat T30 and both samples were placed under table microscope 3030plus. By looking at Fig 2-a (80X), which represents sample T30, we can observe combine the PET aggregate with slurry and form a smooth surface, while if we look at Fig 2-b (1500X) we notice the roughness of the non-PET side and the smoothness of the other side that Integrated with plastic, this reduces the properties of concrete due to weak friction force. Moving to the sample exposed to heat T600, we notice from Fig 2-c (30X) the appearance of pits resulting from the melting of plastic as a result of the heat. Also, the pits appear very clear in Fig 2-d (250X), the result will cause the building material to weaken, which could be detrimental, than the sample T30 due to the absence of CHS and evaporation of PET [78].

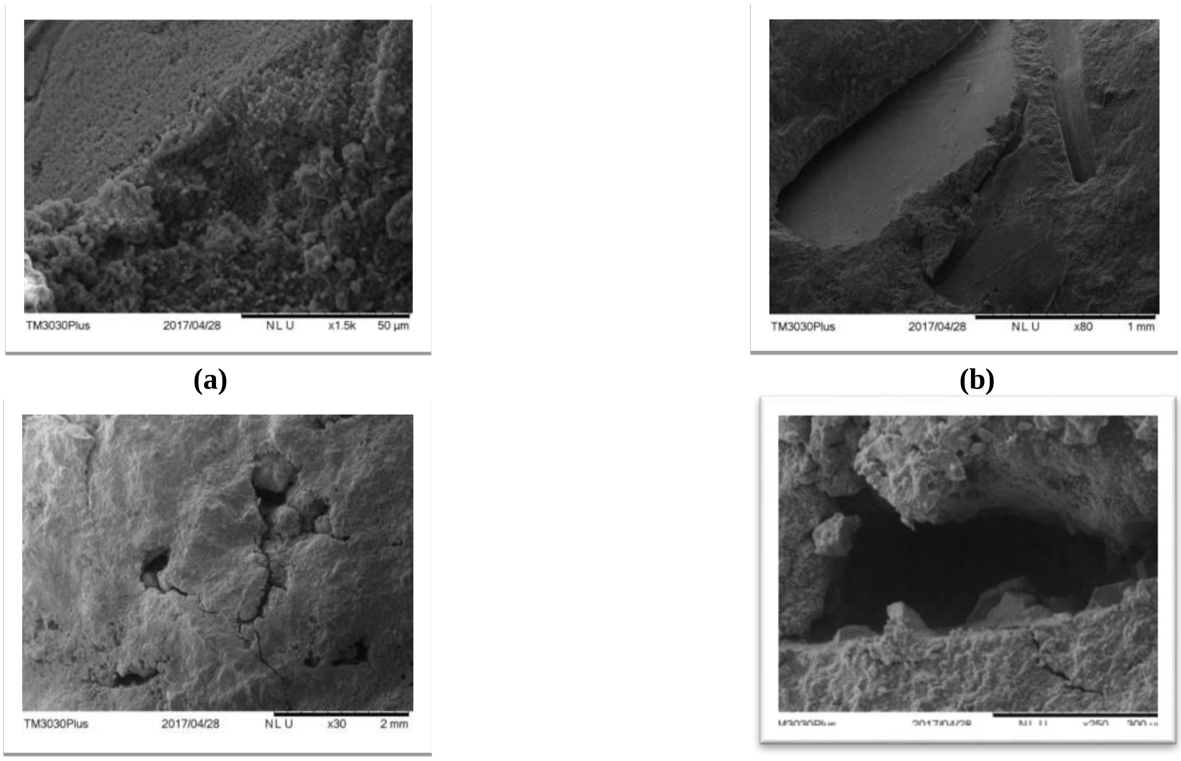
Scanning electron microscope was testing on three samples containing different types of plastic waste with 20% replacement rates. The first contained PET, the second HDPE, and the third recycled PP. They wanted from this test to verify the strength of the bond between this waste and the mortar. As we can see from the Fig3-a strong bonding due to the rough surface of PET, and thus the frictional forces are large, unlike the other two Fig 3-b-c, where voids clearly appear as a result of the loss of moisture, we can detect weak bonds between the slurry and the two types of waste (HDPE-PP) due to their smooth surfaces, so this result explains the results of previous experimental in current study, as the samples that Waste bottles have a higher compressive resistance than the other two types [79].



(a) (b)

(c) (d)

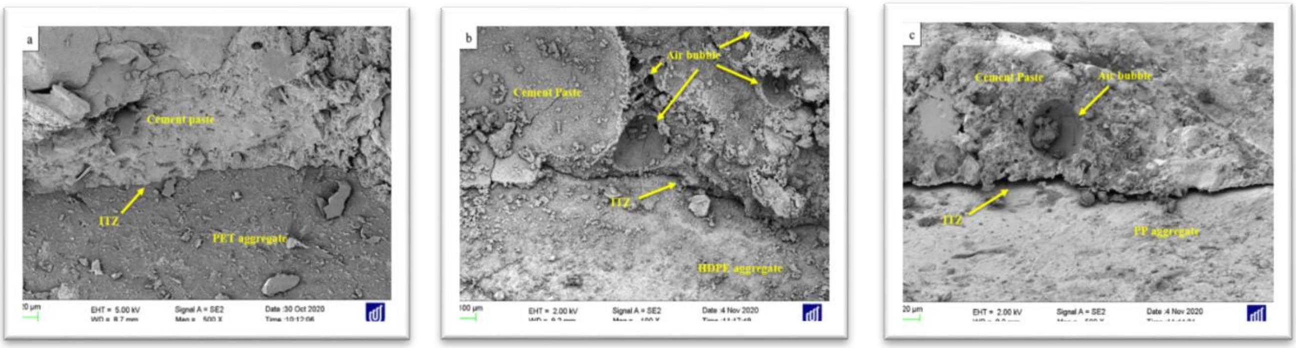
Fig. 1. Scanning electron microscope: a) Conventional Sample, b) 5% of A Waste, c) 10% of B Waste, d) 10% Of Each AB Waste, [77]



(a) **(b)**

(b) (d)

Fig 2. Scanning electron microscope under temperature: a) T30 (30X), b) T30 (1500X), c) T600 (30X), d) T600 (250X), [78]



a) b) (c)

Fig 3. Scanning electron microscope for different types of plastic waste: a) PET, b) HDPE, c) PP, [79]

5. CONCLUSIONS

We can summaries the impact of plastic waste fibres, both aggregate and fibre, on the characteristics of concrete from the previously described research:

With regard to the workability of samples containing PWA, it was found that it decreases with increasing waste content and that the shape has a positive effect on it. the perfect replacement rate for PET aggregate is 10%.

For PWF samples, the best aspect ratio to increase workability is 50. For PET fibers, an addition rate of 0.05% was optimal and 2% for HDPE.

The inclusion of plastic waste aggregate (PWA) in concrete results in reduced density, making the concrete lighter. The specific gravity of PWA is 13.75 times lighter than that of fine aggregate. Consequently, the increased presence of plastic in the mixture has a detrimental impact on both PWA and PWF.

Compressive strength exhibited an increase in some studies, with a consensus among researchers identifying a 2% replacement rate of PET as an optimal percentage for plastic waste aggregate (PWA). Conversely, other studies reported a reduction in strength with rise proportion of plastic aggregate in mixture. Additionally, for plastic waste fiber (PWF), the compressive strength increased by 2 cm when using the ideal length and by 1% at the recommended replacement ratio.

Regarding the split tensile strength of PWA, it was low, but it increased when a percentage of marble dust was used. As for polypropylene, the percentage of 10% was what was recommended to be present in the mixture alongside the clay bricks. As for the samples containing PWF, they showed a noticeable improvement in tensile strength in most forms waste plastic, PET with a circular shape had a significant effect on the tensile strength as in the hybrid fiber samples

The SEM test is one of the important tests that must be included in any research because it informs us about the behavior of materials and gives us a clear picture of the concrete's reaction to the surrounding factors, the way plastic waste is placed, and the extent of its integration with the cement mortar.

List of abbreviations:

PW:	Plastic Waste.
PWA:	Plastic Waste Aggregate.
PWF:	Plastic Waste Fiber
PET:	Polyethylene Terephthalate
HDPE:	High-Density Polyethylene
LDPE:	High-Density Polyethylene
PP:	Polypropylene
CA:	Coarse Aggregate
FA:	Fine Aggregate
TM:	Total Mix

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