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A review on the application of plastic waste in the reinforced concrete structures

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Abstract. Concrete is the most significant material in the construction industry which is required to construct several facilities like roads, buildings, and bridges etc. which leads to the economic development of a country. But now days, in view of sustainable development and environmental problems, plastic waste management is one of the major environmental issues due to its non-biodegradable nature which allows it to stay in the landfills until they are cleaned up. To overcome all these concerns, plastic waste may be used as a substitute of natural fine and coarse aggregate in concrete and a valuable solution to utilize the plastic items which causes several problems. In order to, present study is focused on the affecting properties of concrete as workability, compressive strength, and tensile strength of concrete with using plastic waste and without using plastic waste. Based on the detailed literature, it was observed that the plastic waste is not affecting the quality and consistency of concrete. However, as the number of PVC particles in the mixture increased, the drying shrinkage values decreased and the inclusion of plastic flakes can mitigate drying shrinkage cracking which leads the higher durability of concrete. Based on the comprehensive literature, it was also observed that the plastic aggregate found to be suitable for low and medium strength concrete. However, the investigation on the application of plastic aggregate in the high strength concrete is found limited. It was concluded that the optimum percentage of the plastic aggregate was found about 20%.

Keywords: compressive strength; concrete; plastic waste; tensile strength; workability

1. Introduction

Plastic waste products may be used as an alternate to natural construction resources thereby reducing their scarcity, and further plastic waste management has become a serious concern in the country. According to previous studies, the plastic waste industry has boomed due to its application in the construction sector (Raghatate 2012). The yearly use of plastic materials worldwide has risen to approximately 0.1 billion tonnes in recent years (Sambhaji 2016, Siddique *et al.* 2008). Due to their extended degradation period, plastic wastes has found application in the construction sector to reduce its ill effects (Harini and Ramana 2015). Concrete is crucial to the successful application of these materials in the building. The major outcome is to look at the strength qualities of fine and coarse aggregate that has been partially replaced with plastic. Syed (2018) highlights those non-biodegradable materials like plastic products and scrap tyres are harmful to the environment.

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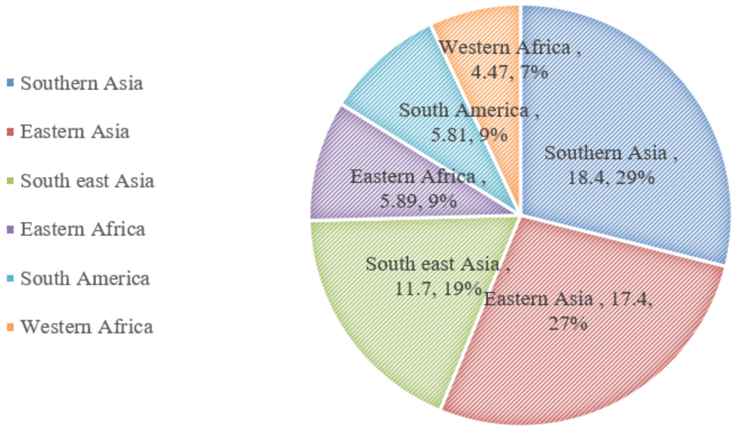

Fig. 1 Major plastic generators as per specific regions in the world

E-waste has the potential to pollute both the soil and the groundwater. If waste products cannot be avoided, finding a new use for them in another process is preferable to disposal of them. To enhance the mechanical properties of concrete and its cost saving several plastic aggregates, like polystyrene foam wastes, High-density polyethylene (HDPE), Polyethylene terephthalate (PET), and other plastic materials, were explored. In all over the world, southern Asia and eastern Asia generate the large portion of plastic waste (Lebreton and Andrady 2019), see Fig. 1.

The production of plastics was approximately 6.3 billion tonnes between 1950 and 2018, with 9% being recycled and the remaining 12% being burned and waste generation globally represented in Fig. 1 (Karthikeyan *et al.* 2019). Only around a quarter of the plastic consumed in India is recycled, whereas the unexpended were getting disposed of in landfills. This massive volume of plastic waste will undoubtedly end up in the ecosystem. The cost of building and upkeep of pavements rises in tandem with the rate of development. As a consequence, engineers and designers have been searching for new ways to employ plastic wastes in concrete paver blocks. The use of plastic waste in concrete pavement makes it less susceptible to rutting, extremely durable and environmentally friendly and also cost effective (Vanitha *et al.* 2015).

Recycling of polyethylene terephthalate in polymer concrete helps in saving energy and in partially solving a solid waste problem caused by plastics. In a comparison, reinforced plastic concrete beam demonstrated superior strength and increase the ductility when compared to reinforced Portland cement concrete beam. Plastic concrete beam requires less cover for the tensile reinforcing steel due to their inherent high flexural strength, low permeability and exceptional chemical resistance (Rebeiz *et al.* 1994). Conversely, sand-plastic waste blocks are prone to melting at higher temperatures and are capable of bearing lower loads only. Therefore, they have limited use in areas where paving blocks are not subjected to the higher temperature and higher load intensity, (Awodiji *et al.* 2021). Past experimental studies have shown that the use of waste plastic to heated aggregate enhances its strength, has higher water resistance, and has long-lasting performance because of coat forming over aggregates using plastic waste. The use of plastic in conjunction with bitumen in road building has two fold advantages as extending the life and smoothness of the road and further making it eco-friendly (Chavan 2013). Plastic debris is added to bitumen as a modifier to improve some of the bitumen's qualities. It was also observed that the roads constructed with scrap plastic found to be better in comparison to traditional roads. Also, noticed that the e-plastic

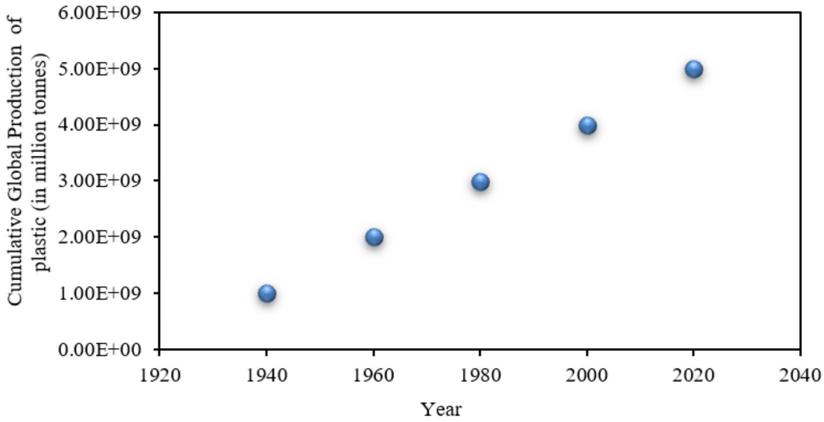

Fig. 2 World annual of plastic production

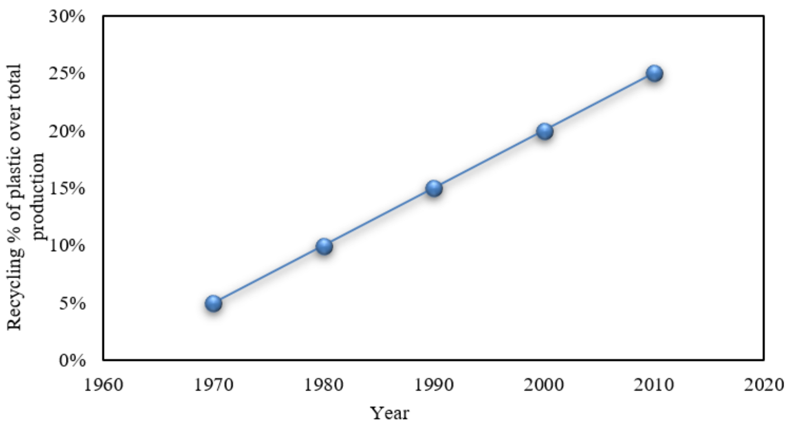

Fig. 3 Recycling rate of plastic waste over production (Geyer *et al.* 2017)

garbage is one of the world's fastest-growing waste in developing countries. However, it is more harmful to the environment and as per data e-plastic generated in 2014 was almost 41.8 million metric tonnes (Balde *et al.* 2015). In 2018, it is expected that the amount of e-waste produced would reach 50 million metric tonnes (Balde *et al.* 2015) and plastic production increasing rate as per decades shown in Fig. 2 and against the production of recycled rate is very less is also shown in Fig. 3. Rebeiz and Fowler (1993) and Abdel-Fattah and El-Hawary (1999) concluded that the ductility of polymer concrete was found to be more as compared to ordinary cement concrete. The structural behaviour of polymer concrete reinforced with steel bars and fibre also influences the load-deflection and moment- curvature curves. Additionally, need to account for the impact of thermal cycle on the tensile bond strength of thin polymer overlays applied to portland cement concrete slabs.

2. Plastic waste

Plastic waste is a major problem all over the world. It increases daily because of its abundance

Table 1 Different types of plastic and its properties (Khan *et al.* 2019)

Type of plastic	Properties	Density range (g/ml)	Common sources
Polyethylene terephthalate (PET)	Tough, rigid, shatter-resistant softens when heated	1.38-1.39	Soda, water, juice, and cooking oil bottles
High-density polyethylene (HDPE)	Semi-rigid, tough, and flexible	0.95-0.97	Bleach bottles, milk jugs, and water jugs
Polyvinyl chloride (PVC)	Semi-rigid, strong, glossy	1.16-1.35	Bottles of detergent, shampoo bottles, shrink warp, and pipes
Low-density polypropylene (LDPE)	Flexible, moisture-proof, not crinkly	0.92-0.94	Sandwich bags, garbage bags
Polypropylene (PP)	Semi-rigid, non-glossy	0.90-0.91	Screw-on caps, margarine tubes
Polystyrene (PS)	Brittle, sometimes glossy, often	1.05-1.07	Styrofoam, egg cartons, take-out

use, though the small amounts are landfilled and recycled but the remaining large quantity is disposed of as waste into the marine. The waste is generated from houses, hospitals, factories, educational institutes, etc. its production rate has increased since 1950 and the plastic waste recycling rate increases at a very low rate as compared to the production rate, see Fig. 2. In order to reduce plastic waste, its utilization in construction materials like fine and coarse aggregates to be increased (Geyer *et al.* 2017).

It's important to note that recycling rates can vary significantly as per different regions. Some developed countries have higher recycling rates compared to others, but even those rates often fall below 30%. As shown in Fig. 3, it has been demonstrated that recycling rate of plastic waste increasing year by year but it is not sufficient to eliminate the harmful effect of plastic waste on the environment.

2.1 Different types of plastic and their uses

Plastic wastes as a supplement of aggregates in concrete production can be found in different forms, see Table 1. As the utilization of plastic waste in concrete, most significant properties of plastics are their longevity and endurance and require minimal maintenance which results the better performance of concrete. Polymethyle metacrylate and polystyrene have higher tensile modulus, tensile strength and yield strength which is more suitable plastic for concrete construction (Almohana *et al.* 2022) and different type of plastic waste is shown in Fig. 4.

Plastic waste can be used as a substitute of natural aggregate, however there are some merits and demerits of plastic aggregates in term of production. In view of merits, environmental benefits with reducing the demand of natural aggregate and utilizing the waste as building material with avoiding landfill and solid waste management. The light weight and less energy consumption as compare to natural aggregate which is processed by mining, crushing and transportation are the demerits. In the structural component, plastic aggregate may be degrade by which reduce the bearing capacity. Also, it reduces the strength of concrete and depends on specific production, quality control and intended application.

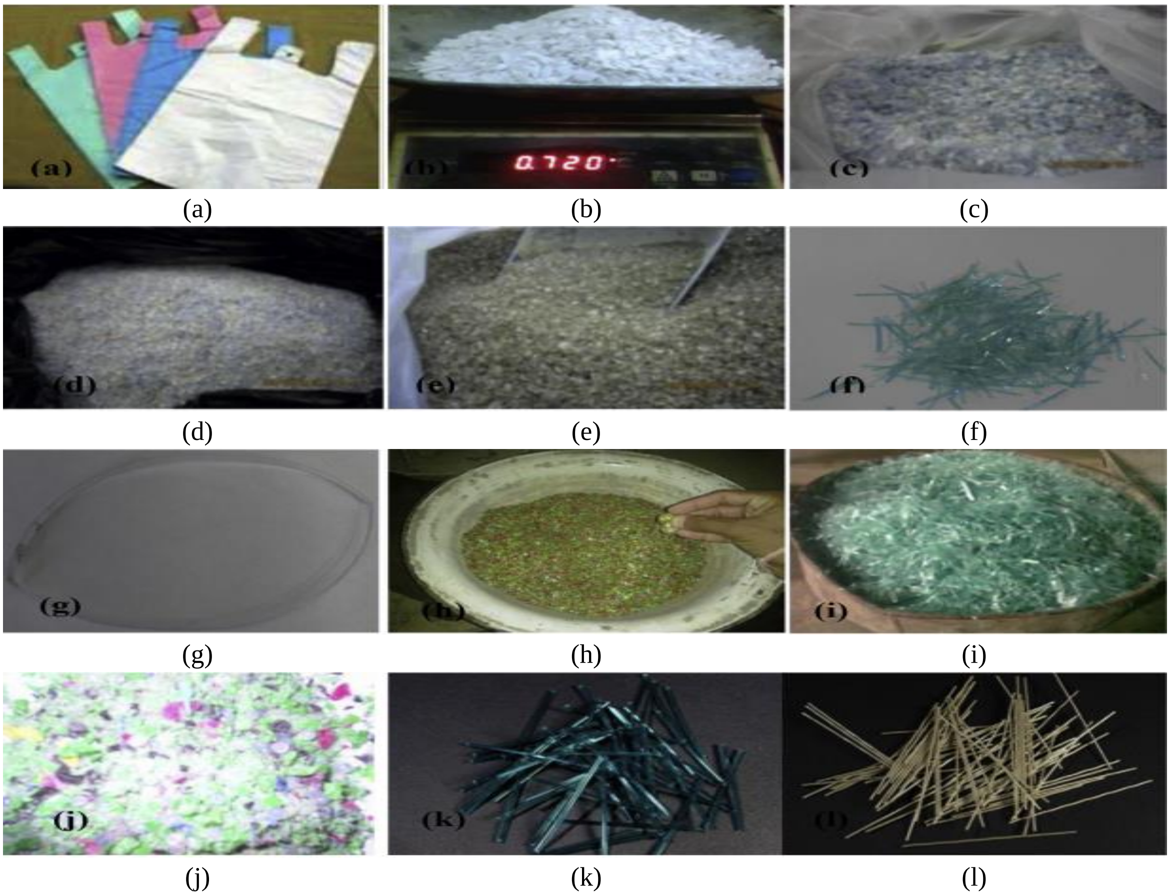

Fig. 4 Different forms of waste plastic (a) Polyethylene, (b) Crushed waste plastic, (c) PET-aggregates (Polyethylene terephthalate), (d) and (e) PET aggregate, (f) Short laminar fiber, (g) Sample of 'O' fiber, (h) Shredded fiber, (i) Hand Cut fiber, (j) Granulated Plastic, (k) Polyethylene terephthalate and (l) polyethylene terephthalate

3. Mechanical properties of plastic waste

HDPE fibers largely improved concrete serviceability by reducing cracking induced from drying shrinkage and water permeability, as well as providing post-cracking flexural ductility (Pesic *et al.* 2016). When PET fibers were used as reinforcement for concrete, the concrete's tensile strength improved (Foti 2013). It was also noticed from scanning electron microscopic (SEM) examination that the PET aggregate and cement paste were well bonded. It absorbs less water than other materials. As a result of PET fibres, enhancement in tensile strength was observed and it also make good bond compare to other plastic fibres lead to less water absorption. As per another study by Bulut and Şahin (2017), e-plastic as unsaturated polyester resin with different ratios as 0, 5, 15 and 25% was incorporated as a part of filling material along with quartz and gravel to create polymer concrete. Conversely as the ratio of e-plastic increased, the compressive, flexural and splitting tensile strength values decreased but the ductility improved. Based on experimental findings, the optimal resin ratio was determined to be 15% while the ideal e-plastic ratio was 5%.

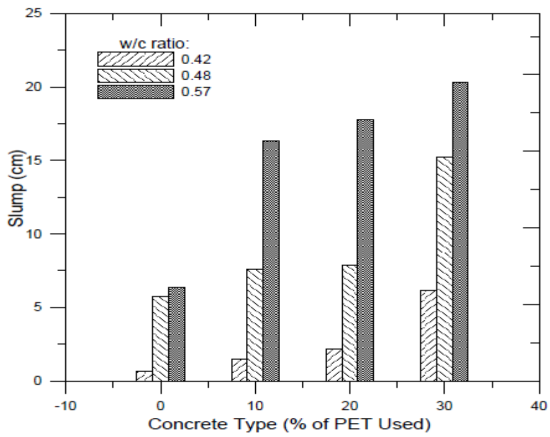

Fig. 5 Slump variation with concrete type at various w/c ratios (Islam and Dipta 2018)

4. Use of plastic waste into concrete

Using plastic waste as a supplement to fine and coarse aggregates, a reduction in concrete strength was observed, however, the use of plastic waste for non-structural concrete may be encouraged due to higher workable mix and waste utilization. In this section concrete's fresh, mechanical, and durability characteristics were studied incorporating plastic waste. When plastics are added to concrete, the compressive strength of the concrete tends to decrease. Nevertheless, researchers have studied the negative effect which can be mitigated by incorporating suitable mineral admixtures. Additionally, chemically treated plastics, such as those treated with alkaline bleach (bleach+NaOH) have been found to enhance the performance of plastic fiber reinforced concrete. On the other hand, the workability of concrete that contains waste plastic initially improves. However, as the amount of waste plastic increases, the workability starts to decrease (Sharma and Pal 2002). In another study by Hama and Hilal (2019), it has been found that due to difference in specific gravity of plastic and natural aggregates, volumetric design method is more suitable for mix design and signifies that shape and content of plastic aggregate affect the workability. Round shape aggregates increase the workability due to less friction with cement particles but angular shape plastic aggregates decrease the slump value and density of concrete.

4.1 Workability of concrete with plastic waste

In this section, the workability of concrete using plastic wastes by different investigators are reported. In previous studies it has been observed that the plastic used as aggregate has smooth surface and lower water absorption value, hence as the ratio of plastic increases, workability improves (Ali *et al.* 2021, Harini and Ramana 2015, Adejumo and Jibrin 2007). Arivalagan (2016) examined workability in terms of the slump in their study. On substituting fines with plastic waste by 5, 10, 15 and 20%, the slump values of that concrete mix are 26 mm, 21 mm, 17 mm, and 13 mm respectively. Similarly, higher slump values were obtained while using PET aggregates (Islam and Dipta 2018, Meherier and Islam 2016). For 30% PET aggregate and 0.57 w/c ratio, the highest slump value was obtained, see Fig. 5 (Islam and Dipta 2018). Yildirim and Duygun (2017) used plastic waste as fines substituent for 5, 10 and 15%, and found that while using higher plastic waste content, the consistency of the mix was increased due to the presence of non-absorbent substance in the form of waste electrical cable rubber (WECR).

4.2 Mechanical characteristics of concrete with plastic waste aggregates

The mechanical characteristics of plastic waste concrete are discussed in this section. Karthikeyan *et al.* (2019) performed strength tests at 3, 7, 14, and 28 days using10% plastic waste substituent, the compressive strength was 9.5, 15, 21, and 26 N/mm^2 respectively. The split tensile at 3, 7, 14, and 28 days with 10% replacement was found to be 1.07, 1.5, 2, and 2.5 N/mm^2 respectively. Flexural strength is enhanced by 2.5, 3.5, 4.2, and 4.5 N/mm^2 after 28 days of 10% replacement. When the amount of plastic is increased, there are noticeable reductions in compressive strength. In the study of Khajuria and Sharma (2019), plastic was added to concrete in proportions of 0, 2.5, 5, 7.5, and 10% in place of coarse aggregate. During the experiment, it was found that adding 2.5% PCA (Plastic Coarse Aggregate) to concrete boosts compressive strength initially, but that adding higher amount of PCA reduces strength. At 2.5% PCA, the compressive strength is at its highest. When compared to other strengths, the cylinder's tensile strength is superior. The outcome of flexural strength is comparable to that of compressive strength. Lakshmi and Nagan (2010) compared the compressive and splitting tensile strength of concrete with and without E-plastic waste coarse aggregate. Mechanical strength was significantly lowered when the e-plastic content was greater than 20%. Raghatate (2012) has been determined that the influence of plastic particles in concrete leads to a decrease its compressive strength. The research findings indicate that when concrete is supplemented with 1% plastic, there is a significant reduction, i.e., 20% in its overall strength. Also, the study further revealed that the addition of 0.8% plastic waste to the concrete resulted in an increase in its strength. This implies that the concrete gains strength with this particular plastic content. However, it should be noted that exceeding the threshold of 0.8% plastic to a decline in the strength of the concrete.

Conversely, according to Sudharsan and Balamurugan (2017) an increase in strength was observed for 20% replacement level of recycled plastic waste. Sambhaji (2016) concluded that the plastic aggregate concrete has the best flexural strength up to 10% plastic aggregate for 7 days and 28 days. A reduction in compressive strength of 14.89% was observed for 20% plastic aggregate in concrete. Harini and Ramana (2015) used silica fume as a cement substituent to raise the compressive strength of the mix for partial replacement of plastic at 5%, 10%, and 15%. Because the particle size of silica fume is so minute, it fills in the small spaces in the concrete, increasing the concrete's strength. Using 15% silica fume in concrete mix containing 20% plastic waste content enhanced the compressive strength by 22.5%. On partially replacing fines with 6% plastic, tensile strength increases, however, when plastic is substituted with more than 6% of the fine aggregate, tensile strength decreases. A reduction in density was observed as the quantity of plastic waste in concrete was increased. Sarwe (2014) investigated waste plastic concrete has lower compressive strength, however, for 0.4% waste plastic, desired compressive strength can be achieved. It was concluded that cube compressive strength using both steel fibre and waste plastic was much better. With only 0.6% waste plastic and 0.3% steel fibre, the compressive strength is higher.

According to Subramani (2015), in comparison to controlled concrete specimens, the mechanical strength of concrete containing plastic aggregate was comparative. When the plastic concentration reached more than 20% as a coarse aggregate, however, the strength was considerably reduced. Mahesh *et al.* (2016) found that addition of plastic waste reduces early strength of concrete but 28 days strength was found to be increasing. When a higher percentage of plastics, such as 6% in this case, is added, the 7 days strength is shown to be lower when compared to conventional concrete. There is no significant difference in split tensile strength with age for low plastic waste content (2-4%). Adding plastic waste reduced the density of concrete due to its lower specific gravity than sand. Therefore, for low strength applications the use of plastic waste can be a viable option. Chen *et al.* (2015) explored the utilization of HDPE for fine aggregate substituent. For 10% replacement, a 15% strength reduction was observed as compared to the reference mix. Significant enhancement in tensile strength for 10, 20, and 30% substituents were observed. Additional tests were carried out to observe the plastic aggregate influence on concrete's thermal properties. Substantial reduction in heat absorption whereas reasonable reduction in heat transfer was observed. Chaudhary *et al.* (2014) have utilized LDPE as a sand replacement and reported that inclusion of LDPE enhanced mechanical properties of mix up to 0.8% replacement. Significant enhancement of 35% and 17% in compressive and splitting tensile strength respectively was observed. Thorneycroft *et al.* (2018) studied that using waste plastic as fines in structural concrete mixtures for up to 10% by volume substituent, may salvage 820 million tons of sand. The mechanical strength reduction in concrete mix containing plastic waste is primarily due to the weaker interfacial bond within the plastic and concrete matrix. Because failure propagates in tension in concrete, a poor bond around plastic particles reduces compressive and tensile strength. The best overall performance was obtained by employing graded PET plastic waste with comparative size distribution as fines and a 10% volume substituent. Using to 5 percent replacement of fine aggregate with PET waste, enhanced strength characteristics were observed (Rahmani *et al.* 2013). However, splitting tensile strength shows a decreasing trend with increase in PET waste because plastic waste has smooth surface which ultimately results in reduction of bond strength (Rahmani *et al.* 2013). Khalid *et al.* (2018) investigated mechanical characteristics to explore the plausible use of synthetic fibers in concrete. It was concluded that increase in fiber content enhances tensile strength of concrete. No significant effect on bending behaviour of concrete beams was observed on adding RPET-5% or RPET-10%. The strength to initial crack was increased by 32.3% for concrete beams containing RPET-10%. Bag *et al.* (2020) investigated the impact on concrete strength due to the fine plastic waste. For early strength, the compressive strength was comparative for up to 15% with the reference mix. For higher replacement levels, reduction in early age compressive strength was observed. The gradual drop in strength was observed at 28 days age of concrete. After 7 days of curing, a negligible effect was found for the tensile strength of plastic waste concrete. Flexural strength did not alter in a clear pattern. Till 15% plastic waste substituent as fines, no significant change in splitting tensile strength was observed. For higher plastic waste content, the reduction in strength was nearly 18%. As a result, concrete containing up to 15% plastic substitution may be used in a wide range of construction projects. After 7 days curing, substituent of 10% plastic waste resulted in a 10% drop in flexural strength. The flexural strength remained constant as the plastic component was increased. However, after 28 days of curing, it was shown that adding 10% plastic trash increased flexural strength by 10%. Sangal (2018) found that utilization of PET bottles as fines in concrete, the compressive and splitting tensile strength increased. For 1%, 3%, 5%, and 10% of plastic bags as fines in concrete, the compressive strength deteriorate on increasing plastic content, while enhancement in tensile strength was observed. On the increasing percentage of polyvinyl chloride pipes, the strength increases. If fines are replaced with plastic chairs in concrete mix for 1, 3, 5, and 10%, the concrete gets stronger. For low plastic seats percentage, compressive and tensile strength were marginally increased and then decreased for higher plastic seats percentage. Tafheem *et al.* (2018) concluded that PET (10%) concrete has higher compressive strength than HDPE (10%) concrete, but it does not grow. For 10% HDPE and 5% PET+5% HDPE concrete specimens' reduction in splitting tensile strength were 37% and 7%, respectively, and conversely for 10% PET concrete, the strength enhancement was 21%. Conclusively, PET plastic was found to have higher tensile strength than HDPE plastic. As a result, it is suggested to add PET plastic to concrete mix to increase its strain carrying ability. The concrete reinforced with HDPE plastic fiber shows increase in mechanical properties for up to 3.5% HDPE inclusions (Malagavelli 2011).

Concrete is weak in tension, so as to increase the tensile strength, the reinforcement is provided. Average stress-strain relationships of reinforced concrete can be studied using tension stiffening factor ension stiffening is a phenomenon that demonstrates how well concrete can bear tension across cracks, consequently enhancing the stiffness of a reinforced concrete structure before the reinforcement reaches its yield point. This effect mainly stems from the activation of bonds at the interface between the steel and concrete. Various factors come into play when considering tension stiffening, including the reinforcement ratio, the arrangement and diameter of the reinforcement bars, concrete shrinkage and the brittleness of the concrete matrix. Several empirical equations exist to assess tension stiffening (Choi and Cheung 1996, Noh and Choi 2006). The aspect ratio has significant influence on fiber reinforced concrete, generally up to aspect ratio of 50 an increasing trend has been observed in strength of concrete and beyond 50 aspect ratio strength was found in decreasing order (Prahallada and Prakash 2013). Umasabor and Daniel (2020) showed that concrete mix with 5% PET by weight replacement had higher compressive strength. Lower flexural strength of concrete containing PET aggregate was observed than control mix. Comparable results were reported by Azhdarpour *et al.* (2016) and suggested PET replacement as fine aggregate up to 10% only, substitution greater than 10% shows reduction in all strength parameters. Ullah Khan and Ayub (2020) employed fibers and strips of PET plastic as a flexural and shear reinforcement in the beam to enhance ductility and strength capacity of beam. 1% volume fraction of fibers or strips of PET plastic were used in the beam. For beams with flexural failure, a maximum 13 percent enhancement in load capacity for the beams was observed for mix with PET fibers and strips (Kalpana *et al.* 2020). Using E-waste up to 25%, the tensile strength of concrete was enhanced (Santhanam and Anbuarasu 2020). Application of E-waste can be found in high strength concrete where mechanical characteristics of concrete containing 0, 8, 12 and 16 percent E-waste as coarse aggregate was found higher.

4.3 Durability properties of concrete with plastic waste

Various researchers studied concrete durability parameters with plastic waste, are discussed in this section. According to previous literature, an increasing quantity of PET waste used to supplement fine and coarse aggregate increases wear resistance by up to 20% and this increase in abrasion resistance could be due to PET waste's high toughness and abrasion resistance (Chodankar and Savoikar 2021, Saikia and De Brito 2014, Saxena *et al.* 2020). Ullah *et al.* (2021) found that incorporating E-waste aggregate in concrete decreases the reduction of compressive strength after being exposed to alternating wetting and drying cycles when compared to the control mix. When 10% E-waste aggregate is used, the compressive strength loss is half that of the control mix. For plastic waste aggregate replacement ratios of 15% and 20%, even greater results were obtained. Due to its low water absorption capacity, E-waste aggregate has significant decline in sorptivity value in the capillary water absorption test (29 percent reduction for 20 percent E-waste content). Silva *et al.* (2013) concluded that incorporation of PET waste in concrete as aggregate exhibited greater carbonation depths and chloride migration coefficient than those of the control mix. However, it shows a lower drying shrinkage value (Elango 2018). The acid attack resistance and sulphate attack resistance of concrete were also reduced as a result of increased integration of the plastic waste as fine aggregate (up to 20%) in concrete (Won *et al.* 2010). Recycled PET fiber reinforced concrete shows lower resistance against sulphate attack as compared to plain concrete (Almeshal *et al.* 2020). Ultra-Sonic Pulse velocity decreased with an increase in PET waste because the inclusion of PET as sand has negative impact on concrete's porosity (Balasubramanian *et al.* 2021). However, inclusion of Waste Glass Powder (WGP) as cement replacement can enhance chloride penetration resistance. Mix containing 5% WEP+20% WGP and 10% WEP+0% WGP shows lower values of total charge passed 2766 and 2963 coloumbs respectively as compared to control mix in which 3500 coloumbs charge passed (Balasubramanian *et al.* 2021). Combined replacement of cement with waste glass powder (5-20%) and coarse aggregate (5-15%) with waste e-plastic performed better in slump value test. A summary of concrete properties with plastic waste by different studies is shown in Table 2. It was observed that the adequate replacement value of plastic waste (fine and coarse aggregate) to enhance the properties of concrete lead to better utilisation of plastic waste without degrading other properties. Table 2 reveal that the performance of plastics in the such as workability and mechanical strength which is an important to design the concrete mix.

5. Conclusions

Sustainability considerations in construction processes and materials have become critical for the construction industry's existence. Alternatives to traditional construction materials have been investigated for decades around the world. One such alternative to an ordinary fine and coarse aggregate in concrete is waste plastic. Because of the various sources of plastic creation, more studies could be conducted to make the conclusions more viable for researchers and the building sector and to develop a more sustainable concrete. The goal of this study is to assess existing studies on the effects of plastic trash on concrete qualities such as workability, compressive strength, tensile strength, and flexural strength.

- On the basis of the previous studies, it was observed that the use of plastic waste as the replacement for fine and coarse aggregate will increase the workability of the mix due to the ability of plastic not to absorb the water. Therefore, this non-absorbing property of plastic increases the workability of concrete. PET type plastic is the most common type of plastic waste, and it will increase the workability of concrete at 5% replacement of fine aggregate.
- After doing a detailed literature study, it was discovered that the compressive strength of concrete is affected by various factors i.e., types of plastic, size of the plastic, and types of replacement like fine and coarse. The compressive strength does not increase always with the increase in plastic waste. Though, a previous study revealed that the use of 15-20% PVC as a fine aggregate and 20% e-plastic as a coarse aggregate will result in an increment in the compressive strength. On the other hand, the use of 5% PET as a fine aggregate also resulted in an increment in the compressive strength. But further increment in the proportion of PET and HDPE as a fine aggregate i.e. up to 20% and 10% will result in a decrement in the strength value. The main reason for the same can be the decrement in the bonding of cement with the plastic waste (i.e., added more than 20%). While it gets increased due to the addition of silica fume as a replacement of cement from 10-15%.
- Another important finding of the study is that the tensile strength of the mix also gets increased with an addition of 5% PET-type plastic waste as a fine aggregate. Though, in order to get a better result, the size of plastic should be matched with the replaced aggregate.

Table 2 Replacement quantity of plastic and its effect on strength

Properties	Replacement of plastic as a		Effect
	Fine aggregate	Coarse aggregate	
Workability	5% PET	-	Increase
	-	0-30% PET	Increase
	5%-15% WECR	-	Increase
Compressive strength	-	2.50%	Increase
	-	20% e-plastic	Increase
	20% PET	-	Decrease
	10% HDPE	-	Decrease
	15-20% PVC	-	Increase
Tensile strength	-	2.50%	Increase
	-	20% e-plastic	Increase
	6% PET	-	Increase
	20% HDPE	-	Increase
	15% waste bags	-	Constant
	15-20% PVC	-	Increase
Flexural strength	-	2.50%	Increase
	10% PET	-	Increase
	10% waste bags	-	Increase

Note: PET=Polyethylene terephthalate, WECR=waste electric cable rubber, HDPE=High-density polyethylene, PVC=Polyvinyl chloride, e-plastic=electronic plastic

- The utilization of 10%PET and 10% waste bags as a fine aggregate in concrete mix will increase the flexural strength of the concrete.
- Another critical observation of the present study is the use of Polyethylene terephthalate (PET) waste as a replacement for fine aggregate in the range of 5-10% gives better results in the fresh and hardened properties of concrete. While utilization of 10% PET plastic waste in concrete will be an aid as compared to 10% HDPE plastic waste as PET plastic has more tensile strength than HDPE plastic. It is concluded that the PET plastic waste concrete may be used, where the requirement of tensile strength is more than compressive strength in a structure. PET plastic is also used as a fiber in the reinforced concrete beam to enhance the flexural and shear capacity.
- It was observed that abrasion resistance of concrete increases with an increase in the replacement of fine aggregate and coarse aggregate by up to 20% PET waste.
- The use of PET waste in concrete results in higher carbonation depth, higher chloride migration, lower water absorption, lower sulphate resistance, and lower acid resistance.

For the future perspective, different plastic waste can be utilized individually or in a combined manner in different proportions as the replacement of fine and coarse aggregate. Besides this, an attempt can be made for utilizing different plastic waste materials without subjecting them to any treatment i.e., heating, or chemical as these may also raise the environmental-related concern again.

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