Utilization of Waste Plastic as Sustainable Material in Construction: A Review

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Abstract

The measure of plastic waste in municipal solid waste is expanding because of expansion in population, urbanization, advancement exercise. A major concern these days is the disposal of plastic wastes. These wastes are non-biodegradable in nature bringing about ecological illness and cleanliness problems. The reason for this study was to resolve the solid waste issues created by plastics. This paper present the plastic waste utilization in concrete for making concrete economical and light weight on the other hand it is viewed as the best ecological option for taking care of the issue of waste disposal. This paper shows a detailed review about utilization of waste plastic in concrete and mortar. The influence of recycled plastic concrete on fresh density, workability, dry density, compressive strength, flexural strength, splitting tensile strength, carbonation depth and ultra sonic pulse velocity is discussed in this paper.

Key words: plastic waste, sustainable, concrete, mortar, compressive strength, carbonation depth.

1. Introduction

A present day way of life, close by the headway of innovation, has inspired an increment in the sum and mode of waste being created [1]. Numerous waste generated today will stay in nature for hundreds and may be a large number of years [2]. Plastic, a standout amongst the hugest developments of twentieth century, plastic is a worldwide material [3]. Plastic waste “means any plastic discarded after use or after their intended use is over” [4] and is discover everywhere on the globe in recent years. A colossal progress within the consumption of plastic is found all over the arena in contemporary years (Figure 1), which additionally raises the creation of plastic-associated waste. The generation of waste plastics is expanding very rapidly [5]. Consumption of plastics in India is about 16.5 million tonnes in the year 2017-18[6]. India generate approximately about 15,342 ton of waste plastic per day [7]. The plastic waste is now a heavy environmental threat to modern civilisation. Plastic is composed of a number of poisonous chemical compounds, and for this reason plastic contaminates environment [8]. Plastic is a non-biodegradable fabric and researchers determined that the material can stay on this planet for 4500 years without degradation. Land-filling using plastic would mean keeping the unsafe fabric forever [9-10]. Plastics don't decay normally thus elective techniques should be executed [11].

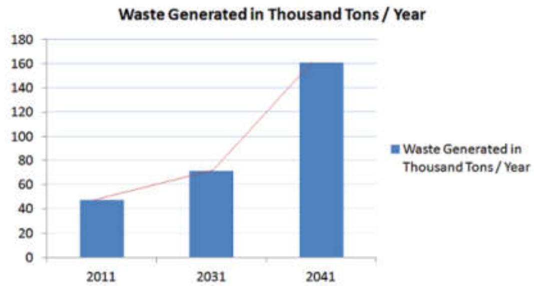


Figure 1. Plastic waste generation in thousand tons/year [8]

1.1 Plastic waste scenarios and its negative effects

Plastic is very commonly used material, quite often used form of plastic are carry baggage, cups, water bottle packing material etc. made up of polyethylene, polypropylene or polystyrene. Other molded plastic created from poly ethylene terepthalate (PET) and poly vinyl chloride (PVC). In 2007, a world's annual consumption of PET drink covers of roughly 10 million tons, which shows 250 milliards bottles approximately [12]. Waste PVC was gathered from residential waste, mineral water jugs, MasterCard's, toys, pipes and canals, electrical fittings, furniture, organizers and pens, restorative disposables and so forth. The utilization of plastics has expanded from 4000 tons/annum to 4 million tons/annum virtually 50 to 60% of the whole plastics are consumed for packing [13-16]. There are many uses of plastics as structural materials and road materials. Waste plastic utilize in road construction work it increased its resistance and performance [17]. Plastics will expand the softening point of the bitumen [18] in some cases it also increased its fatigue resistance [19-20]. Concrete is very commonly used structure material [21]. Its second just to water as the most used material in the planet [22] the concrete industry is famous to go away colossal environmental footstep on Planet Earth [23]. Concrete consumed by the development enterprise in India is around 370 million cum per year; it is anticipated to expand 30 million cum each 12 months [24-25]. Plastic waste also used in concrete construction work which is a better solution of disposal problem. The use of waste plastic modified concrete become more economic and reduces the plastic waste which is beneficial for an environment [26].

1.2 Types of plastic

Plastic is classified as thermoplastic and thermosetting materials (Table 1-4). The difference between these two types of plastics is that thermoplastics can be heated and shaped over and over again and thermosetting plastics can only be heated and shaped once.

Table 1. Thermoplastic and Thermosetting Resins [10]

S.no	Thermoplastic	Thermosetting
1	Polyethylene Teryphthalate (PET)	Bakelite
2	Polypropylene (PP)	Epoxy
3	Polyvinyl Acetate (PVA)	Melamine
4	Polyvinyl Chloride (PVC)	Polyester
5	Polystyrene (PS)	Polyurethane
6	Low Density Polyethylene (LDPE)	Urea – Formaldehyde
7	High Density Polyethylene (HDPE)	Alkyd

Table 2. Source of waste plastic [10]

S.no	Type of Plastic	Source of waste
1	Low Density Polyethylene (LDPE)	Carry bags, sacks, milk pouches, bin lining, cosmetic and detergent bottles
2	High Density Polyethylene (HDPE)	Carry bags, bottle caps, house hold articles etc.
3	Polyethylene Teryphthalate (PET)	Drinking water bottles etc
4	Polypropylene (PP)	Bottle caps and closures, wrappers of detergent, biscuit, vapours packets, microwave trays for readymade meal etc.,
5	Polystyrene (PS)	Yoghurt pots, clear egg packs, bottle caps. Foamed Polystyrene: food trays, egg boxes, disposable cups, protective packaging etc
6	Polyvinyl Chloride (PVC)	Mineral water bottles, credit cards, toys, pipes and gutters; electrical fittings, furniture, folders etc

Table 3. Rise of plastic consumption in India [27]

S.no	Year	Consumption (tonnes)
1	1996	61,000
2	2000	3,00,000
3	2001	4,00,000
4	2007	85,00,000
5	2017	1,78,00,000

Table 4. Types and quantities of plastics in municipal solid waste in the USA [28-29]

S.No	Type of plastic	Quantity (1000 tonnes)
1	Polyethylene terephthalate (PET)	1700
2	High density polyethylene (HDPE)	4120
3	Low density polyethylene (LDPE)	5010
4	Polypropylene (PP)	2580
5	Polystyrene (PS)	1990
6	Other	3130

Plastics creation additionally includes the utilization of conceivably unsafe chemicals, which are included as stabilizers or colorants. Many of these have not undergone an environmental risk assessment and their impact on human health and the environment is currently uncertain.

2. Properties of concrete containing plastic waste

2.1 Fresh concrete properties

Properties of concrete in its fresh state are important as a result of the influence the standard of the hardened concrete. Fresh concrete has distinctive properties which are required for development of solid structures. Properties of fresh concrete discussed below.

2.1.1 Slump test

The slump test is use to evaluate the workability of concrete. The slump test is viewed as a measure of the viscosity of the mix within the fresh state [30-31]. By means of slump test consistency of contemporary concrete can be discovered. Workability of concrete most often depends on the quantity of fines and properties of fine aggregate in it [32]. Ismail and Al-Hashmi [33] investigated that the slump was prone to decreasing sharply with increasing the waste plastic ratio (Table 5 and Figure 2). The reductions of slump were 68.3%, 88.33%, and 95.33% for (Pl) waste plastic mix Pl2, Pl3, and Pl4, respectively. In spite of the slump reduction, the waste plastic concrete mixtures have easy workability and are suitable for use in precast applications.

Table 5. Waste plastic concrete mixtures [33]

Symbol	Material					
(Pl) Waste plastic mix	Cement kg/m^3	Aggregate kg/m^3	sand kg/m^3	Waste plastic kg/m^3	Waste (%)	W/C or W/(C+WP)
Pl_1	380	1020	715	0	0	0.53
Pl_2	380	1020	643.5	71.5	10	0.53
Pl_3	380	1020	604.75	107.25	15	0.53
Pl_4	380	1020	572	143	20	0.53

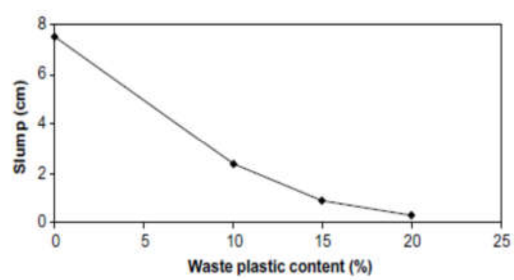


Figure 2. Slump of waste plastic concrete [33]

Tang and Nadeem [34] observed workability of concrete. The workability of Polystyrene aggregate concrete (PAC) is generally similar to the corresponding normal weight concrete showing a range of 55–65 mm slump.

Saikia and Brito [9] investigated the workability behaviour of concrete containing plastic aggregate. They give two perspectives on workability. They found majority of studies a lower slump value of fresh concrete due to the incorporation of several types of plastic aggregates they give reasons for the lower slump value of the concrete mix containing plastic aggregate are the sharp edges and angular particle size of plastic aggregate.
On other side an increase in the slump value due to the incorporation of plastic aggregate is also reported. Incorporation of plastic aggregates is as a result of the presence of extra free water within the mixes containing plastic.

Kou et al. [35] investigated workability of light weight aggregate concrete. River sand was partially replaced by poly vinyl chloride (PVC) plastic waste granules in percentages of 0%, 5%, 15%, 30% and 45% by volume (Table 6). Slump values were between 170 and 175mm, result indicates decrement of workability of light weight aggregate concrete. This was because of the precise shape and bigger sizes of the PVC granules when contrasted and waterway sand.

Table 6. Slump value of concrete mixtures [35]

Mix code	Suprplastizer L/M^3	Sand content kg/m^3	Pvc content kg/m^3	Slump (mm)	Visual inspection
P0	2.05	850	0	175	Consistent and homogeneous
P5	2.05	805	15	175	Consistent and homogeneous
P15	2.10	720	45	170	Homogeneous
P30	2.30	595	90	175	Homogeneous but less consistent
P45	2.70	470	135	170	Harsh with bleeding

2.1.2 Fresh density test

Gupta et al. [36] determined the density of concrete modified with plastic waste in form of polythene bag as fine aggregate replacement. They found that density decreases as the percentage replacement of fine aggregate with polythene waste increases. The density of concrete after 28 days curing of cubes (average of three specimen for each mix) containing polythene waste was observed as 2408 Kg/m^3, 2279 Kg/m^3, 1900 Kg/m^3, 1591 Kg/m^3 and 1455 Kg/m^3 at 0%, 5%, 10%, 15% and 20% replacement of fine aggregate respectively. The decrease in density may be due to the low density of plastic waste compared to sand.

Ismail and Al-Hashmi [33] reported that fresh density values of waste plastic concrete mixtures tend to decrease by 5%, 7%, and 8.7% for waste plastic Pl2, Pl3, and Pl4, respectively (Figure 3). This trend is also attributed to the density of the waste plastic being less than the sand which leads to a reduction in the fresh density.

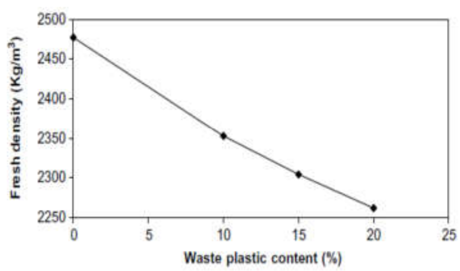


Figure 3. Fresh density of concrete containing plastic waste [33]

2.2 Hardened concrete properties

In this section, influence of waste plastic on hardened concrete properties; Dry density, compressive strength, flexural strength and split tensile strength test is discussed.

2.2.1 Dry density test

Ismail and Al-Hashmi, [33] investigated that dry density of waste plastic concrete combinations at each curing age are likely to diminish below values for the reference concrete combination (Figure 4).

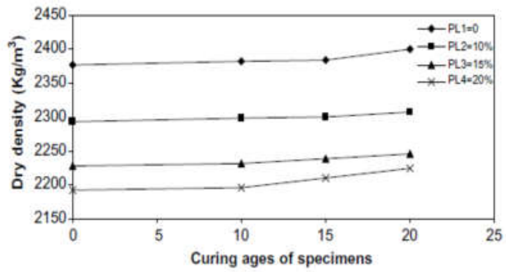


Figure 4. Variation of dry density of modified concrete with curing age [33]

2.2.2 Compressive strength

Compressive strength is an important parameter in evaluation of strength of concrete. Gupta et al. [36] observed the compressive strength of concrete containing polythene waste as partial replacement of fine aggregates for 0.45 w/c ratio at 7 and 28 days of curing. The compressive strength of concrete without polythene waste after 7 days of curing was observed 17.8 MPa which reduced to 1.6 MPa at 20% replacement of fine aggregate by plastic waste. The compressive strength after 28 days curing of cubes (average of three specimen for each mix) containing polythene waste was observed as 26.7 MPa, 23.1 MPa, 17.9 MPa, 10.5 MPa and 4.6 MPa at 0%, 5%, 10%, 15% and 20% replacement of fine aggregate respectively. The decrease in compressive strength may be due to (i) the reduction in bonding strength between the surfaces of plastic waste and cement paste (ii) the large particle size of the plastic waste, increasing the pores and cavities in the concrete.

Ismail and Al-Hashmi [33] investigated the effect of plastic waste ration on compressive strength of the mix. It was observed from the Figure 5 that increase in percentage of plastic waste ratio lead to decrease the value of compressive strength as compared to plain mixt at every curing age. This pattern can be attributed to the shrink in adhesive force between the outside of the waste plastic and the cement paste, as well as the particles size of the waste plastic increase.

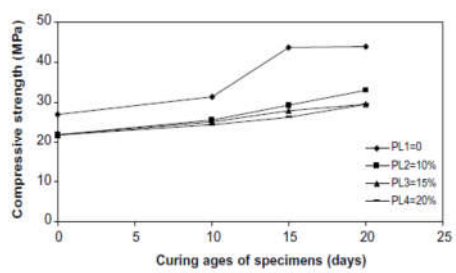


Figure 5. Compressive strength of concrete containing plastic waste [33]

Ramadevi and Manju [37] observed that the compressive strength increased up to 2% replacement of the fine aggregate with poly ethylene terepthalate (PET) bottle fibres and it gradually decreased for 4% and 6% replacements (Figure 6).

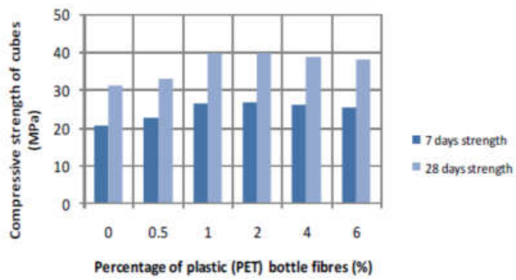


Figure 6. Variation of compressive strength with plastic fibres (%) [37]

Vanitha et al. [38] investigate the compressive strength of concrete, they found that up to 4% exchanging of waste plastics, there was a mild deviation of compressive force. Compressive strength value of the concrete mix decreased with the addition of waste plastics more than 4% of waste plastics. Best modifier content of waste plastics is found to be 4% for paver blocks and 2% for solid blocks (Figure 7-8).

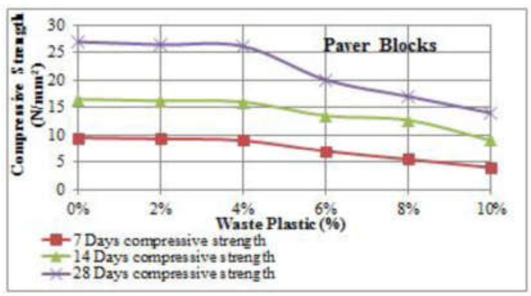


Figure 7. Variation of compressive strength with plastic waste (%) in Paver blocks [38]

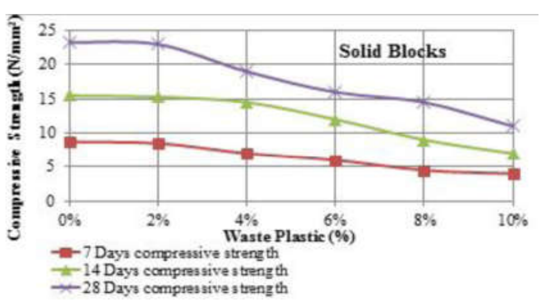


Figure 8. Variation of compressive strength with plastic waste (%) in solid blocks [38]

Akcaozoglu et al. [39] investigated compressive strength of the mixtures containing PET aggregates. ACI Committee definition states that compressive strength of a structural lightweight concrete at 28 days should be above 15–17 MPa (Table 7). Results shows that the compressive strength values at 28 days of the mortar specimens were quite higher than 17 MPa. It was seen from these outcomes that, the compressive strengths of the mixtures containing sand and PET together have been greater than the mixtures containing Polyethylene terephthalat (PET) without sand (Figure 9).

Table 7. Compressive strength (MPa) of mortar produced [39]

Mixture	1 day	3 day	7 day	28 day	90 days	180 day
M1	12.3	17.9	20.2	22.4	26.0	26.8
M2	6.8	13.8	20.3	26.5	27.8	28.8
M3	14.4	22.5	23.6	27.0	28.8	30.6
M4	8.4	15.4	21.9	28.3	29.6	31.1

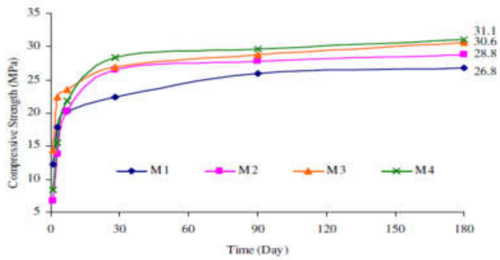


Figure 9. Compressive strength variation of plastic mortar [39]

Akcaozoglu et al. [40] observed compressive strength of concrete replaced waste PET as light weight aggregate with conventional aggregate. Five different mixtures were prepared for analyse the effect of waste plastic on concrete strength. Mixture was prepared by 30%, 40%, 50% and 60% waste plastic replacement with aggregate (Table 8). It is observed from results that the compressive strength of specimens decreased depending on increment of PET aggregate amount replaced with conventional aggregate.

Table 8. Compressive strength of concrete [40]

Mixture	Compressive strength (MPa)		
	7 days	28 days	90 days
M0	31.9	43.2	55.9
M1	18.4	25.3	26.9
M2	16.5	17.7	22.7
M3	14.9	16.6	19.7
M4	8.4	9.5	11.1

Kou et al. [35] investigated compressive strength of light weight aggregate concrete river sand was partially replaced by PVC plastic waste granules in percentages of 0%, 5%, 15%, 30% and 45% by volume. Results shows that compressive strengths of the LWAC were reduced with the increase in PVC granules content.

Hannawi et al. [41] reported compressive strength of mortar made of polycarbonate (PC) and Polyethylene terephthalat (PET) waste were used as partial replacement of natural aggregates. Different volume divisions of sand 3%, 10%, 20% and 50% are supplanted by the same volume of plastic. Result indicates that decrement in compressive strength when the plastic aggregates content increases (Figure 10).

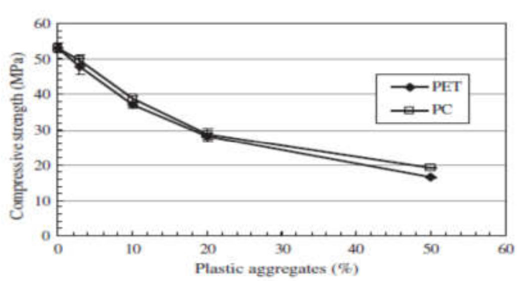


Figure 10. Compressive strength with plastic aggregate content [41]

2.2.3 Flexural strength

Ismail and Al-Hashmi [33] investigate flexural strength of concrete, result showed that the flexural Strength of waste plastic concrete mixtures at each curing age is inclined to diminish with the expand of the waste plastic ratio in these combinations. Concrete mixture made of 20% waste plastic has the lowest flexural strength at 28 days curing age (Figure 11).

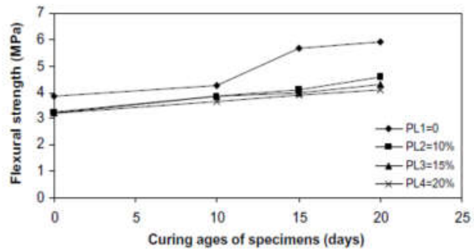


Figure 11. Flexural strength of concrete with waste plastic as aggregate [33]

Ganiron [42] reported the flexural strength of concrete use thermoplastic as fine aggregate result shows that during 7 to 21 days flexural strength of concrete increase rapidly but on the 28th days the specimen failed to reach the maximum strength of the concrete (Figure 12)

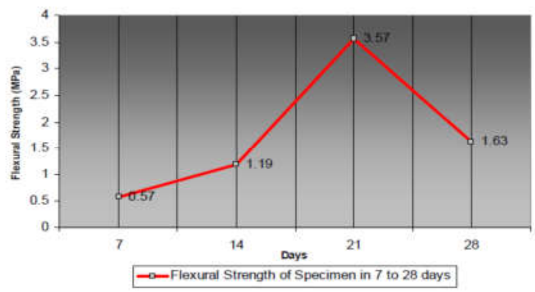


Figure 12. Flexural strength variation in modified concrete [42]

Ramadevi and Manju [37] observed that the flexural strength increased up to 4% replacement of fine aggregate with PET bottle fibres with no change at 6% replacement level (Figure 13).

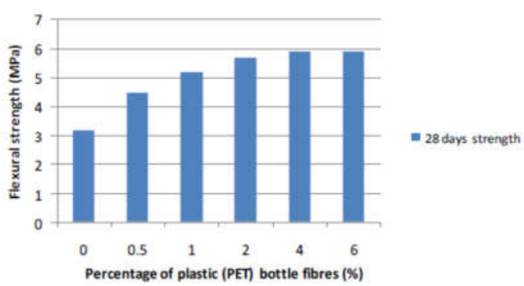


Figure 13. Flexural strength variation with plastic fibres (%) [37]

Akcaozoglu et al. [39] investigated flexural strength of mortar result indicate the flexural-tensile strength values containing only PET aggregate were close to the mortars containing PET and sand aggregate together (Table 9).

Table 9. Flexural strength of cement mortar [39]

Mixture	1 day	3 day	7 day	28 day	90 day	180 day

M1	2.2	3.9	4.4	4.7	5.8	6.7
M2	2.0	3.1	3.9	4.8	5.2	6.1
M3	2.9	4.2	4.5	4.8	5.7	6.8
M4	1.5	3.2	3.7	4.8	5.5	6.0

Hannawi et al. [41] reported flexural strength of mortar made of polycarbonate (PC) and polyethylene terephthalate (PET) waste are used as partial replacement of natural aggregates. Different volume divisions of sand 3%, 10%, 20% and 50% are supplanted by the same volume of plastic. The flexural strength values of waste plastic mixtures stay unchanged evaluating to manage mixture when the sand volume substituted with aggregates increases from 0% to 10% for PET mixtures and from 0% to 20% for PC mixtures (Figure 14).

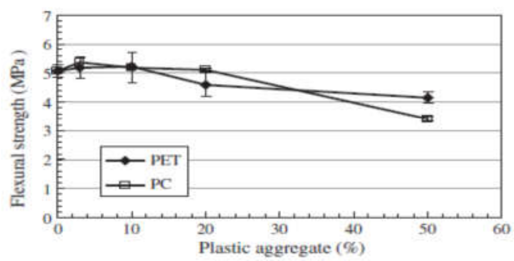


Figure 14. Evolution of the flexural strength with plastic aggregates content [41]

Rai et al. [43] investigated flexural strength of concrete using waste plastic with plasticizer, it was reported that flexural strength of waste plastic mix concrete decreases with the increase in percentage of plastic waste (Figure 15).

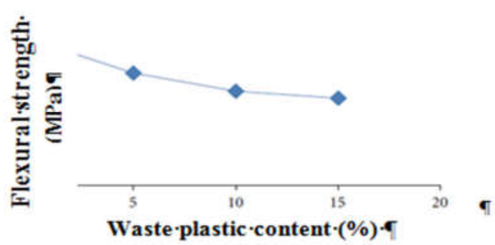


Figure 15. Flexural strength of concrete mix with varying percentage of waste plastic [43]

2.2.4 Split tensile strength test

Tensile strength is one of fundamental and essential property of concrete [44]. Splitting tests are popular test used for determining the tensile strength of concrete. Split tensile strength of concrete is generally discovered by testing plain concrete cylinders [45].

Ramadevi and Manju [37] investigated that the split tensile strength increased up to 2% replacement of the fine aggregate with PET bottle fibres and it steadily decreased for 4% and 6% replacements (Figure 16).

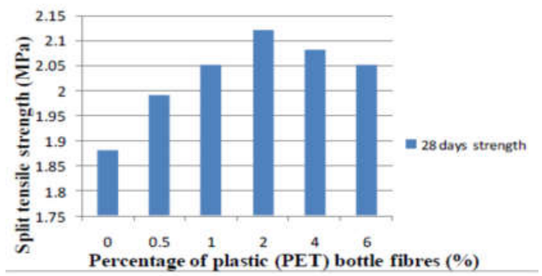


Figure 16. Variation of split tensile strength with plastic fibres (%) [37]

Albano et al. [46] investigated split tensile strength of concrete using waste pet bottles with different w/c ratio 0.5 and 0.6. Figure 17 showed reduction in split tensile strength with respect to traditional concrete for both w/c ratios.

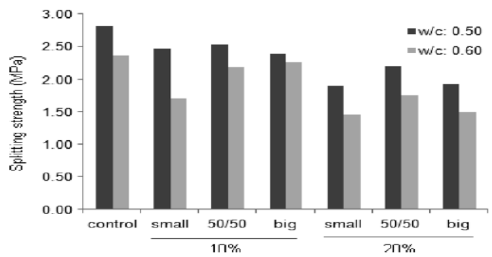


Figure 17. Splitting tensile strength of concrete-PET blends at different w/c ratios. [46]

Lakshmi and Nagan [47] investigated the split tensile strength of concrete utilize E-plastic waste in concrete as aggregate with varying percentage of 0% to 30% for M20 grade of concrete. Figure 18 shows decrease in strength when plastic percent is more than 20% in concrete.

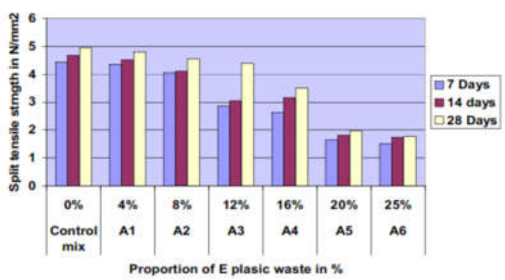


Figure 18. Variation of split tensile strength with E plastic waste [47]

Patil [48] observed the behaviour of concrete partially replaced with plastic waste. Five replacement levels 10%, 20%, 30%, 40% & 50% by volume of aggregates were used for the preparation of the concretes of polypropylene (PP) and polyethylene terephthalate (PET). Figure 19 showed decrement in tensile strength of concrete with increasing percentage of waste plastic.

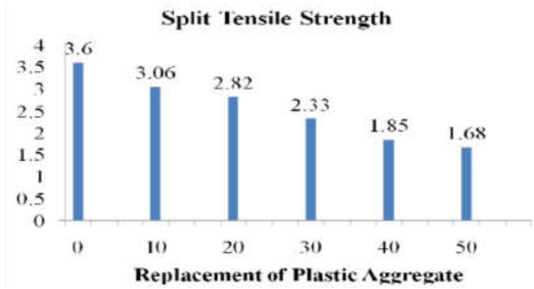


Figure 19. Tensile strength of concrete containing waste plastic [48]

2.2.5 Durability tests

Carbonation depth

Carbonation is a main reason for concrete structures disintegration [49]. Carbonation is generally perceived as a large cause of corrosion of reinforcement in concrete [50].
Akcaozoglu et al. [39] investigated carbonation depth of mortars prism (40x40x160 mm). Table 10 and Figure 20 shows that carbonation depths of mortars increased depending on increasing CO_2 amount penetrated into the samples which increased in time. It was understood from this result that, PET and sand aggregates used together did not combine with each other sufficiently.

Table 10. Carbonation depth (mm) of cement mortar [39]

Mixture	3 days	7 days	28 days	90 days	180 days
M1	0	0.3	1.2	4.3	5.0
M2	0	0.3	1.7	5.5	7.6
M3	0	0.0	1.4	4.8	5.9
M4	0	0.6	2.5	6.8	8.5

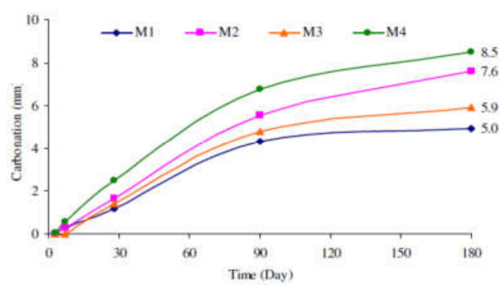


Figure 20. Variation in carbonation depth (mm) of cement mortar with days [39]

2.2.6 Ultra sonic pulse velocity test

Ultrasonic pulse velocity technique is famous non-destructive techniques used in the evaluation of concrete properties [51]. Ultrasonic pulse velocity is used to determine material properties, explore defects and investigate deterioration [52].

Akcaozoglu et al. [40] investigated the ultra sonic pulse velocity of concrete containing waste poly ethylene terepthalate (PET) as a light weight aggregate, on specimens with the dimensions of 500x500x100 mm (Table 11). Results indicate the ultrasonic wave velocity values of specimens decreased as the amount of waste PET lightweight aggregate (WPLA) increased in mixture.

Table 11. Ultra sonic wave velocity of concrete [40]

Mixture	Ultrasonic wave velocities km/s	
	28 days	90 days
M0	4.36	4.42
M1	3.46	3.40
M2	3.18	3.10
M3	2.89	2.94
M4	2.44	2.32

Albano et al. [46] investigated ultra sonic pulse velocity of concrete. Figure 21 showed decreased in ultra sonic pulse velocity, initially ultrasonic pulse velocity increase very rapidly but as time passes it decreases.

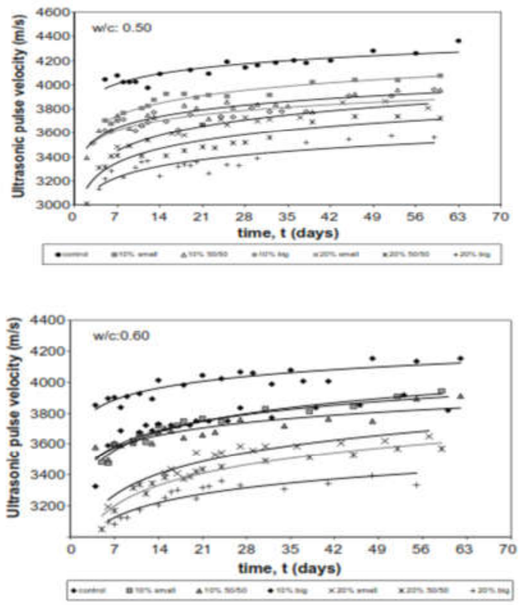


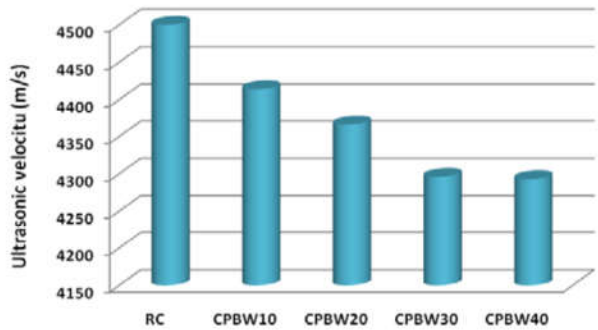
Figure 21. Ultrasonic pulse velocity versus curing age of Concrete-PET blends at different w/c ratio. [46]

Gavela et al. [53] investigated that the ultra sonic pulse velocity of concrete containing industrial wastes polypropylene (PP) and polyethylene terephthalate (PET) as aggregate. There have been two replacement levels, 20% and 30% by volume of aggregates (Table 12). When proportion of plastic waste increases in concrete decreased in ultra sonic pulse velocity was observed.

Table 12. Results of the ultrasonic pulse velocity testing [53]

	Velocity at 7d (cm/µsec)	Velocity at 28d (cm/µsec)
RM1	0.43	0.74
RM2	0.42	0.72
20%PP, w/c=0.5	0.41	0.63
20%PP, w/c=0.6	0.59	0.63
30%PP, w/c=0.5	0.35	0.49
20%PET, w/c=0.5	-	0.65
30%PET, w/c=0.6	-	0.54

Ghernouti et al. [54] observed ultra sonic pulse velocity of concrete containing recycled plastic bag waste as shown in Figure 22. Sand was replaced with plastic waste at varying percentage of 10%, 20%, 30% and 40%. Result showed that use of waste plastic bag reduces the ultra sonic pulse velocity of concrete.



RC=Reinforced concrete, **CPBW**= Concrete with plastic bag waste

Figure 22. Evaluation of ultrasonic velocity of all mixtures as function of content plastic bag wastes [54]

3. Conclusion

The utilization of plastic waste in concrete and mortar as a partial replacement of natural aggregates has been broadly investigated by various researcher in past years. This review paper has presented an assortment of aspects on utilization of plastic waste in various forms in concrete and mortar, which may possibly concise and concluded as:

- Density of concrete containing plastic waste decreases as the percentage replacement of fine aggregate with polythene waste increases .The decrease in density is due to the low density of plastic waste as compared to fine aggregate.
- Utilization of plastic waste in concrete results in the development of lightweight concrete.
- Reduction in workability of concrete ingress plastic has been observed and based on the observed values of slump, the concrete containing plastic waste is recommended to be used in R.C.C beams, slabs, and road construction works.
- With increase in replacement level of plastic waste in concrete, reduction in compressive, flexural and split tensile strength have been found.
- Carbonation depth of cement mortar increased when it mixed with plastic waste due to improper mixing of PET and fine aggregate.

Based on the test results it can be concluded that utilization of plastic waste as fine aggregate in concrete and mortar will reduce the accumulation of plastic waste and will protect the natural resources (river sand) for being more consumed and extracted. Hence, concrete modified with plastic waste will make environment cleaner and sustainable.

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