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Utilization of Waste Plastic in Concrete Towards Sustainable Development: A Review

Rajat Saxena[a], Abhishek Jain[a] And Yash Agrawal[a]
[A](*Assistant Professor, Department Of Civil Engineering, Geetanjali Institute Of Technical Studies, Udaipur, India)*

ABSTRACT
In the present decade, one of the environmental issues in most regions of world is the existence of large number of bottles made from poly-ethylene terephthalate (PET) and huge quantities of plastic wastes deposited in domestic wastes and landfills. These plastic wastes are adversely effecting the environment and is a topic of serious concern for various concerned authorities. In spite of all efforts made to limit the use of plastic based products, their utility is increasing day by day and thus the amount of plastic waste generated is also increasing day by day. Various attempts were made through experimentation to check the feasibility of plastic waste to be use partially in concrete with respect to various properties of strength, workability, durability and ductility of concrete. This paper is aiming to give a over view of various studies conducted on utility of waste plastic material used in the concrete.

Highlights:
- Use of plastic waste in concrete in different forms is discussed.
- Effect of plastic waste on different properties of concrete is illustrated.
- Use of plastic waste exceptionally helpful to produce green sustainable concrete.
- Harmful effects of plastic waste are mentioned.

Abbreviations:
PET, polyethylene terephthalate; PP, polypropylene; PBW, plastic bag waste; RC, reference concrete; w/c ratio, water-cement ratio; STS, splitting tensile strength; NA, natural aggregate; IS, Indian standard.

Keywords: Concrete, plastic waste, compressive strength, flexural strength, splitting tensile strength, modulus of elasticity.

I. INTRODUCTION

In today's world, the utility of plastic based products is increasing day by day resulting in generation of more amount of plastic waste, leading to a waste disposal crisis [1]. Plastic is a polymer of hydrocarbon monomers, and is used frequently in everyday life in form of polythene bags, food packaging material, water bottles, containers, cutting boards, electrical appliances, furniture, vehicles, plastic beverage, margarine, shampoo and detergent bottles etc [2]. Plastic has become a necessary part of everybody's life in modern world [3]. Plastic based products are used in every part of the world and thus are increasing the amount of waste generation [4]. On an average about 10 millions of plastic bags are used and discarded every day in India's capital [5]. The world's annual consumption of plastic materials was about 5 million tons in the 1950's which has now increased to 100 million tons in recent times, resulting in more amount of generation of plastic waste [6]. Due to this plastic waste can be seen everywhere in every part of society [7].

The disposal of plastic waste in open environment leads to various environmental problems due to their low biodegradability and presence in large quantities which are disturbing the ecological balance of nature and is major cause of health hazards to living beings [8] [9] [10]. One of the logical methods for reduction of environmental impact by plastic wastes is the applicability of these materials in other industries [7].

Concrete industry seems to be the most appropriate industry which can consume huge amount of plastic waste [11]. The concrete consumption in India by various construction industries is around 370 million m^3 per year and it is expected to increase by 30 million m^3 every year [12]. Concrete in its simplest form requires three basic ingredients - cement (the binder), aggregates (ranging in size from fine to coarse) and water [13]. Concrete's constituent materials are available naturally in all parts of the world but with the increasing requirement of concrete in various construction industries, these materials are getting deficient day by day [14].

Thus both the problems- disposal of plastic waste and unavailability of concrete's constituent materials can be effectively managed by using the plastic waste in concrete [15].

Various properties of concrete like ductility and tensile strength can be improved by efficiently using plastic waste in concrete. Moreover using plastic waste in concrete decreases its weight also and thus buildings can be made more earthquake resistant by using plastic waste in concrete [16].

II. FRESH CONCRETE PROPERTIES CONTAINING PLASTIC WASTE

2.1 Workability

The property of fresh concrete which indicates the amount of useful internal work required to fully compact the concrete without bleeding or segregation in the finished product [17]. Workability depends on three main factors: proportion of cement-water paste, including paste admixtures, if any; consistency of the gradation and type of aggregate [18].

Usman *et al.* (2015) replaced the coarse aggregate in concrete specimens of M25 grade by plastic waste (polythene bags) in various percentages (0, 2, 5 and 7%) and determined the workability with the help of slump test. They reported that workability decreased with the increasing amount of plastic waste as replacement of coarse aggregate [5].

Table 1 Slump Values [5]

% Polythene	0	2	5	7
Slump (mm)	140	136	131	125

Albano *et al*. (2009) replaced sand in concrete with Polyethylene Terephthalate (PET) with two dfferent w/c ratio (0.50 and 0.60). Average sizes of the PET particles were 0.26 and 1.14 cm, named small and big, respectively. Fine aggregate (sand) was replaced with 10% and 20% by volume of PET with particle sizes of 0.26 and 1.14 cm and a 50/50 mix of both sizes. Workability was determined with the help of slump test. It was observed that for a fixed particle size, there was greater slump for the blends with 10% of recycled PET. The blends with PET with a 50/50 particle size gave higher values of slump compared to the blends with PET particles of 0.26 and 1.14 cm. PET effected the slump but it had more effect on slump when the w/c ratio increased [19].

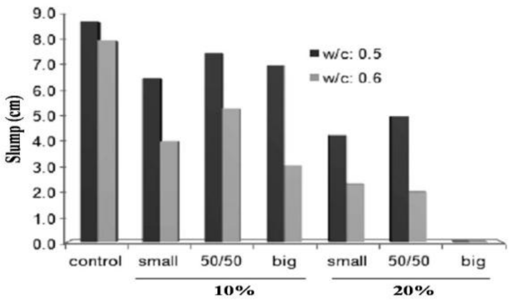

Fig. 1 Slump values of Concrete-PET blends at different water/cement ratios [19]

Ghernouti *et al*. (2011) used recycled plastic bag waste (PBW) material as replacement of fine aggregate (sand) in concrete in steps of 10%, 20%, 30% and 40%. They determined the influence of the plastic bag waste (PBW) on the workability of concrete by slump test and compared the workability with that of reference concrete (RC). They observed that fluidity of concrete improved with increasing amount of waste that was favourable for concrete. The plastic cannot absorb water; therefore, excess of water improved the workability [20].

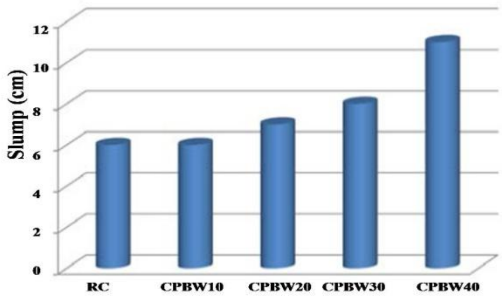

Fig. 2 Slump values of concrete containing plastic bag wastes in different percentages [20]

Bhogayata *et al*. (2012) used non-recycle polyethylene plastic bags in shredded form in concrete of M25 grade. The ordinary plastic bags having thickness of less than 20 microns were collected and shredded in form of fibres by two methods manually and by shredders [21]. Plastic fibers were introduced in different proportions from 0%, 0.3%, 0.6%, and 0.9% to 1.2% of the volume of concrete. Workability was determined by compaction factor as per guidelines of IS 1199 (1959) [22] and it was observed that it decreased with the increasing amount of waste with comparison to controlled concrete. The shredded fibres got well mixed and evenly sprayed in the mix and showed better workability in comparison to hand cut fibres. Beyond 0.6% addition in both form workability was reduced upto 30%.

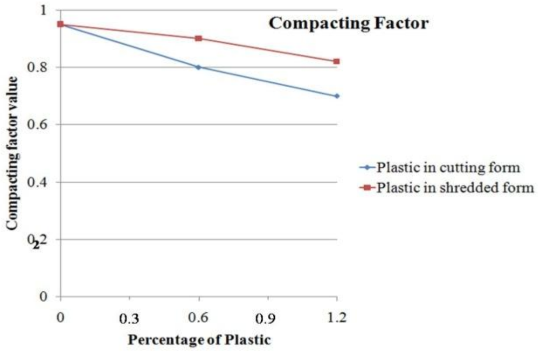

Fig. 3 Compaction factor test results of concrete containing plastic bags [21]

Kumar *et al*. (2014) used plastic bags in fibre form to replace cement in M25 grade concrete in various proportions 0.5%, 0.75% and 1.0% by weight of cement. Super-plasticizer of Sica company was used in 0.4% dose of weight of cement. Workability was determined by slump test and it was found that on addition of waste polythene, workability of concrete was reduced and slump loss increased with increase in dose of waste polythene. Slump value at 0%, 0.5%, 0.75% and 1.0% dose of polythene was found to be 118, 83, 64 and 27 mm respectively [14].

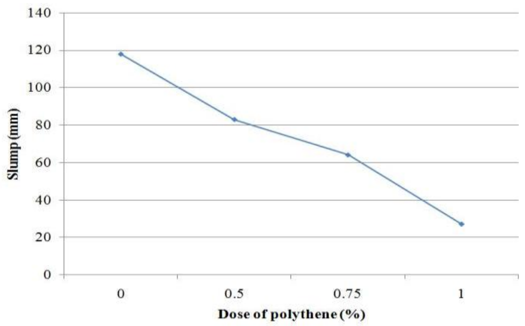

Fig. 4 Slump of concrete mix with varying dose of waste polythene [14]

Ismail and Hashmi (2008) used waste plastic containers, which mainly consisted of approximately 80% polyethylene and 20% polystyrene as sand replacement. Concrete specimens were prepared with 0%, 10%, 15%, and 20% replacement of sand with plastic waste and were named as Pl_1, Pl_2, Pl_3, and Pl_4 respectively. They determined workability with the help of slump test and found that the slump decreased sharply with increasing amount of waste plastic. The reductions of slump were 68.3%, 88.33%, and 95.33% for Pl_2, Pl_3, and Pl_4 respectively in comparison with reference concrete Pl_1 [23].

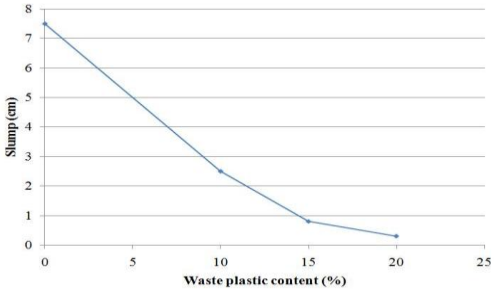

Fig. 5 Slump of waste plastic concrete [23]

III. HARDENEDCONCRETEPROPERTIES CONTAINING PLASTIC WASTE

3.1 Compressive Strength

Compressive strength is the maximum compressive stress that, under a gradually applied load, a given solid material can sustain without fracture. Compressive strength is calculated by dividing the maximum load by the original cross-sectional area of a specimen in a compression test as per guidelines of IS 516 (1959) [24]. The compressive strength of concrete is often used as the basis for making many decisions regarding the strength and serviceability of a concrete structure [25].

Usman *et al.* (2015) replaced the coarse aggregate in concrete specimens of M25 grade by plastic waste (polythene bags) in various percentages (0, 2, 5 and 7%) and determined the compressive strength. They reported the decrease in compressive strength of concrete specimens at 28 days. The 28 day average compressive strength at 0%, 2%, 5% and 7% replacement was found to be 26, 24, 21 and 19 N/mm^2 respectively [5].

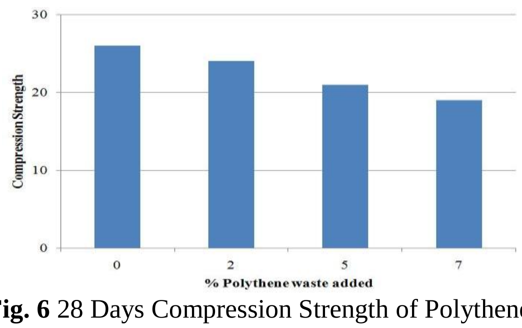

Fig. 6 28 Days Compression Strength of Polythene Waste Concrete [5]

Malak (2015) used wastes from polypropylene (PP) and polyethylene terephthalate (PET) as replacements of coarse aggregate in five different replacement levels 10%, 20%, 30%, 40% and 50% by volume of aggregates and carried out compressive strength test at 28 days. It was reported that the compressive strength of concrete containing 0% waste was 20 N/mm^2. With the increasing amount of plastic waste, it was found that compressive strength decreased. Compressive strength at 10%, 20%, 30%, 40% and 50% replacement level was found to be 13.46, 11.5, 9.36, 9.13 and 9.11 N/mm^2 respectively [9].

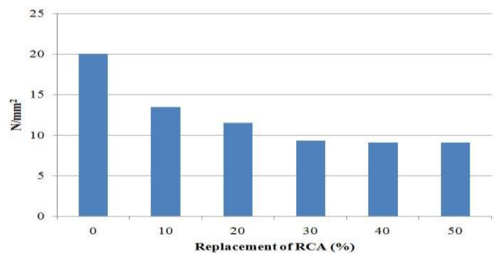

Fig. 7 28 Days Compression Strength [9]

Ramadevi and Manju (2012) used waste PET bottles in fibre form as the partial replacement of fine aggregate in M25 grade of concrete specimens with 0.45 w/c ratio in various percentages 0.5%, 1%, 2%, 4% and 6%. Mix design of M25 grade concrete was done in accordance with the guidelines of IS 456(2000) and IS 10262(2009) [26, 27]. An appreciable increase in the compressive strength was reported till 2% replacement of the fine aggregate with PET bottles fibres and then the compressive strength was found gradually reducing [28].

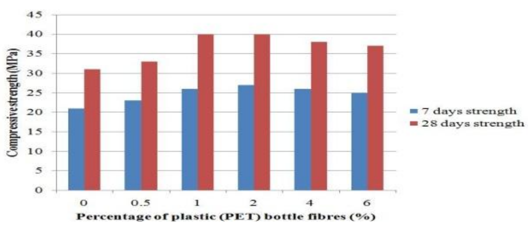

Fig. 8 Compressive Strength of Concrete Containing Waste PET Bottles [28]

Frigione (2010) used waste unwashed PET bottle (WPET) as replacement of fine aggregate. WPET was replaced by weight of 5% of fine aggregate in concrete. Compressive strength was determined at 28 days and 365 days and it was found that at 28 days it slightly decreased (not lower than 2%) when WPET was added in substitution of natural sand in comparison to reference concrete. The differences in compressive strength observed at 28 days were substantially identical to those measured at 365 days. The compressive strength at 28 and 365 days of WPET concrete were of 0.4–1.9% lower than the reference concretes [29].

Kim *et al.* (2010) used short fibres made from recycled PET within structural concrete. To verify the properties of recycled PET fibre reinforced concrete, it was compared with polypropylene (PP) fibre reinforced concrete for fibre volume fractions of 0.5%, 0.75%, and 1.0%. The recycled PET and PP fiber-reinforced specimens exhibited compressive strength decreases of 1–9% and 1–10%, respectively, compared to the non-reinforced specimens [30].

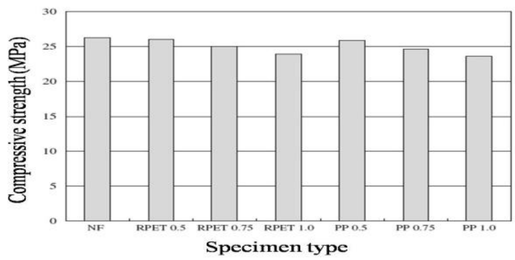

Fig. 9 Compressive Strength [30]

Albano *et al*. (2009) replaced sand in concrete with Polyethylene Terephthalate (PET) with two different w/c ratio (0.50 and 0.60). Average sizes of the PET particles were 0.26 and 1.14 cm, named small and big, respectively. Fine aggregate (sand) was replaced with 10% and 20% by volume of PET with particle sizes of 0.26 and 1.14 cm and a 50/50 mix of both sizes. PET-filled concrete blends show a decrease in compressive strength. It was observed that for both w/c ratios, the blends with 10% of PET of small or 50/50 mix particle sizes presented the better compressive strength when compared to the blends with greater content or bigger particle size. The blends with 20% of PET (big particle size) for both w/c ratios presented the lower compressive strength [19].

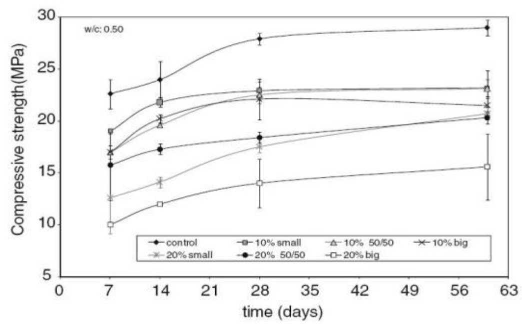

Fig. 10 Compressive Strength of Concrete with PET at w/c ratio 0.5 [19]

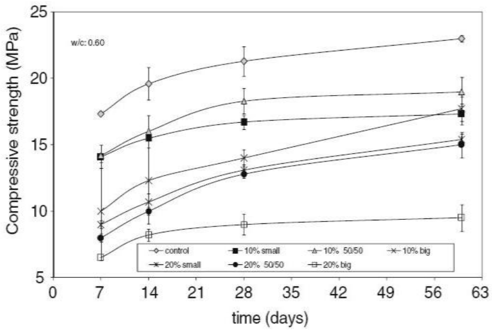

Fig. 11 Compressive Strength of Concrete with PET at w/c ratio 0.6 [19]

Kandasamy and Murugesan (2011) used polythene fibers (domestic waste plastic) at a dosage of 0.5% by weight of cement in M20 mix of concrete. Cubical and cylindrical specimens of M20 grade concrete were tested for compressive strength. It was observed that cube compressive strength of concrete in 7 days increased by 0.68% and in 28 days it increased by 5.12% in comparison with reference concrete and cylinder compressive strength of concrete in 28 days increased by 3.84% in comparison with reference concrete [31].

Table 2 Comparison of 7 days cube compressive strength test results [31]

Grade of concrete	Average Compressive Strength at 7 days (N/mm^2)		Increase in compressive strength of concrete by addition of fiber (C2-C1)/C1 × 100%
	Plain concrete, C1	**0.5% with fiber, C2**	
Sample 1	22.44	22.67	1.02
Sample 2	22.22	22.22	0.00
Sample 3	21.56	21.78	1.02

Table 3 Comparison of 28 days cube compressive strength test results [31]

Grade of concrete	Average Compressive Strength at 28 days (N/mm^2)		Increase in compressive strength of concrete by addition of fiber (C2-C1)/C1 × 100%
	Plain concrete, C1	**0.5% with fiber, C2**	
Sample 1	33.56	35.78	6.61
Sample 2	33.11	34.89	5.38
Sample 3	32.89	34.00	3.37

Table 4 Comparison of 28 days cylinder compressive strength test results [31]

Grade of concrete	Average Compressive Strength at 28 days (N/mm^2)		Increase in compressive strength of concrete by addition of fiber (C2-C1)/C1 × 100%
	Plain concrete, C1	**0.5% with fiber, C2**	
Sample 1	24.90	26.03	4.54
Sample 2	24.33	25.46	4.64
Sample 3	24.05	24.61	2.33

Ghernouti *et al*. (2011) used recycled plastic bag waste (PBW) material as replacement of fine aggregate (sand) in concrete in steps of 10%, 20%, 30% and 40%. They determined the influence of the plastic bag waste (PBW) on the compressive strength of concrete. They found that at replacement levels of 10% and 20%, compressive strength at 28 days decreased by 10% and 24 % respectively in comparison to reference concrete (RC) [20].

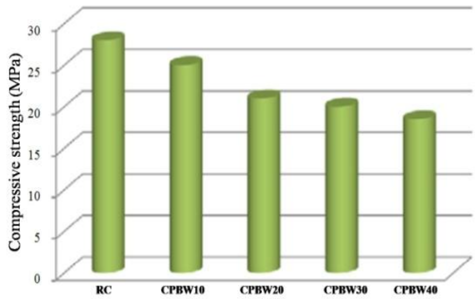

Fig. 12 Compressive Strength Test Results of Concrete Containing Plastic Bag Waste [20]

Bhogayata *et al*. (2012) used non-recycle polyethylene plastic bags in shredded form in concrete of M25 grade. The ordinary plastic bags having thickness of less than 20 microns were collected and shredded in form of fibres by two methods manually and by shredders. Plastic fibres were introduced in different proportions 0%, 0.3%, 0.6%, 0.9% and 1.2% of the volume of concrete. It was observed that compressive strength at 7 and 28 days decreased with the increasing amount of waste in concrete. The hand cut macro fibres showed greater strength loss, compared to shredded fibres. Beyond 0.6% of concrete volume of the fibres made from the plastic bags having thickness less than 20 microns reduced the strength nearly up to 30% and at 1.2% the strength reduced up to 50% compared to the controlled concrete [21].

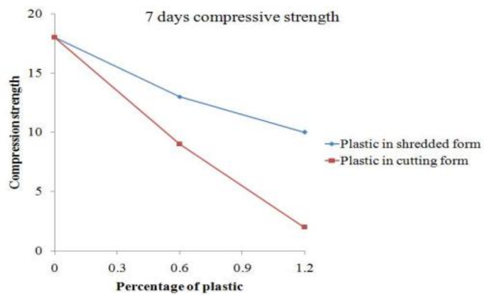

Fig. 13 7 Day Compressive Strength of Concrete Containing Plastic Waste [21]

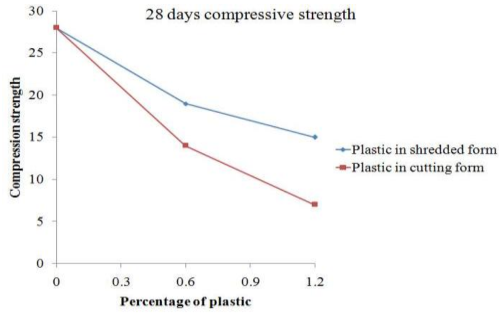

Fig. 14 28 Day Compressive Strength of Concrete Containing Plastic Waste [21]

Raghatate (2012) used plastic bags in fibre form in concrete mix of M20 grade with w/c ratio 0.45 in various percentages 0%, 0.2%, 0.4%, 0.6%, 0.8%, and 1%. Compressive strength at 7, 14 and 28 days was determined and it was found to be decreasing with the increasing amount of plastic bag fibres in concrete. Addition of 1 % of plastic in concrete caused about 20% reduction in strength after 28 days curing. It was found that 28 days compressive strength at 0%, 0.2%, 0.4%, 0.6%, 0.8%, and 1% addition of plastic bag fibres was 25.92, 23.2, 22.1, 20.26, 19.85 and 20.2 N/mm^2 respectively [32].

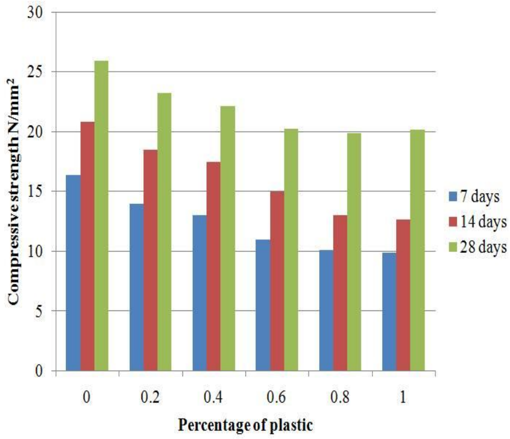

Fig. 15 Compressive Strength of Concrete Containing Plastic Bags [32]

Bhogayata et al. (2013) used metalized polythene waste bags (used in most of the food packaging industries) in shredded form in concrete. The metalized polythene waste bags were shredded to the macro pellet form of size 1mm×2mm approximately and were added in concrete in different proportions from 0%, 0.5%, and 1% to 1.5% of the volume of concrete. Fly ash was also added in different proportion like from 0% to 30%. Compressive strength was determined and it was found that the targeted mean compressive strength was 42 N/mm^2 for the controlled concrete. It was observed by them that the value of compressive strength decreased was negligible between additions of fibres from 0.5% to 1% in the concrete. When the plastic fibres were added in concrete up to 1.5% by volume the strength was reduced to 18.3 N/mm^2 by 56.43% compared to the controlled concrete. They noticed that addition of fly ash contributed to reduce the strength reduction within the limit of addition of plastic fibres up to 0.5% compared to the controlled concrete [33].

Kumar *et al*. (2014) used plastic bags in fibre form to replace cement in M25 grade concrete in various proportions 0.5%, 0.75% and 1.0% by weight of cement. Compressive strength was determined and it was found to be increasing with increasing amount of plastic bags up to 0.75% addition and thereafter it decreased, however the compressive strength at 1% waste polythene was more than the referral concrete. Compressive strength of concrete containing waste polythene was increased by 4.03%, 4.55% and 17.11% at 7, 28 and 56 days respectively at 0.75% dose of waste polythene and by 3.03%, 1.32% and 2.76% at 7, 28 and 56 d respectively at 0.5% dose of waste polythene [14].

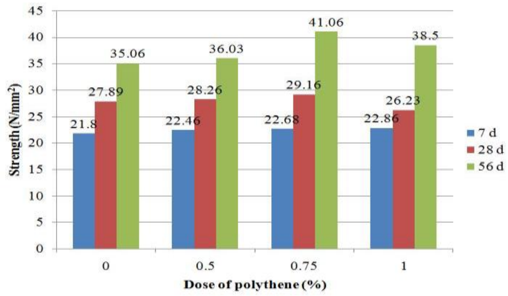

Fig. 16 Compressive strength of concrete with varying % of waste polythene [14]

3.2 Flexural Strength

It is also known as modulus of rupture and is defined as the stress in a material just before it yields in a flexure test and it represents the highest stress at its moment of rupture [34]. It characterizes the bending strength of unreinforced beams [35]. Flexure strength is one measure of tensile strength of concrete which is an important parameter for determining deflection and minimum flexural reinforcement [36]. Flexure strength is determined as per guidelines of IS 516 (1959) [24].

Malak (2015) used wastes from polypropylene (PP) and polyethylene terephthalate (PET) as replacements of coarse aggregate in five different replacement levels 10%, 20%, 30%, 40% and 50% by volume of aggregates and carried out flexural strength test at 28 days. It was reported that the flexural strength of concrete containing 0% waste was 53.4 N/mm^2. It was reported that the flexural strength increased when replacement was 10% and thereafter with the increasing amount of plastic waste, flexural strength decreased. Flexural strength at 10%, 20%, 30%, 40% and 50% replacement level was found to be 59.03, 51.07, 51.59, 49.28 and 48.32 N/mm^2 respectively [9].

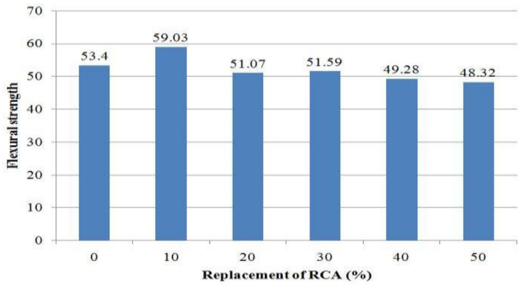

Fig. 17 Flexural Strength of concrete with varying % of waste plastic [9]

Ramadevi and Manju (2012) used waste PET bottles as the partial replacement of fine aggregate in M25 grade of concrete specimens with 0.45 w/c ratio in various percentages 0.5%, 1%, 2%, 4% and 6%. Mix design of M25 grade concrete was done in accordance with the guidelines of IS 456(2000) and IS 10262(2009) [26, 27]. The flexural strength of the specimens with replacement of the fine aggregate with the PET bottle fibres was found to be increasing gradually with the increase in the replacement percentage [28].

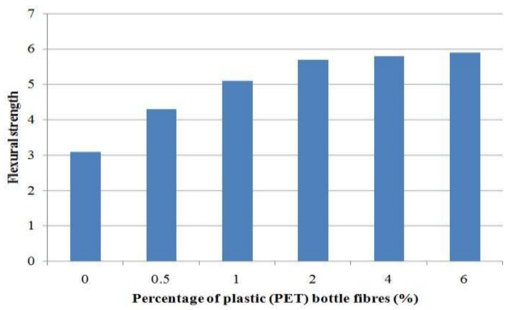

Fig. 18 28 Days Flexural Strength of Concrete Containing PET waste [28]

Ghernouti *et al.* (2011) used recycled plastic bag waste (PBW) material as replacement of fine aggregate (sand) in concrete in steps of 10%, 20%, 30% and 40%. Influence of the plastic bag waste (PBW) on the flexural strength of concrete was determined. Reduction was observed in the flexural strength according to the increase in percentage of plastic bag waste in the concrete in comparison to reference concrete [20].

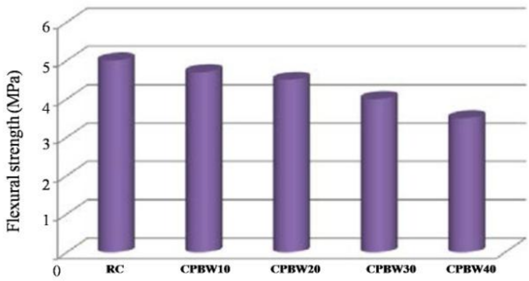

Fig. 19 Flexural Strength of Concrete Containing Plastic Bag Wastes [20]

Saikia and Brito (2014) used PET aggregates to replace natural aggregates of concrete in various percentages 5%, 10% and 15% in volume of natural aggregate (NA). NA were replaced by 3 type of PET aggregates- two were shredded and separated fractions of similar types of PET bottles and one was a heat-treated product of the same PET bottles. The shredded fractions were flaky with two sizes of particles, fine (PF) and coarse (PC). The heat-treated pellet-shaped product was called (PP). Flexural strength was determined after 28 days of curing. It was observed that as the amount of any type of PET-aggregate in concrete increased the flexural strength decreased in comparison to the reference concrete. At a given substitution level of the three types of aggregate, the decreasing trend can be arranged as: PP > PF > PC [37].

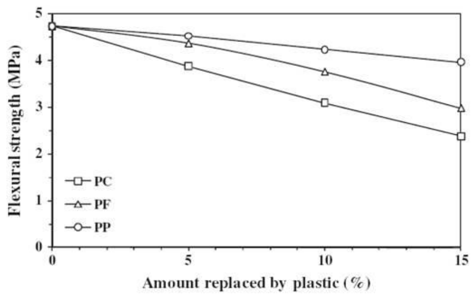

Fig. 20 Influence of various types of PET-aggregate on the flexural strength of concrete [37]

Ismail and Hashmi (2008) used waste plastic containers which mainly consisted of approximately 80% polyethylene and 20% polystyrene as sand replacement. Concrete specimens were prepared with 0%, 10%, 15%, and 20% replacement of sand with plastic waste and were named as Pl_1, Pl_2, Pl_3, and Pl_4 respectively. Flexural strength was determined and it was reported that the flexural strength of waste plastic concrete mixtures at each curing age decreased with the increasing amount of the waste plastic in concrete. Concrete mixture made of 20% waste plastic showed lowest flexural strength at 28 days, that is, 30.5% below the value of the reference concrete mixture [23].

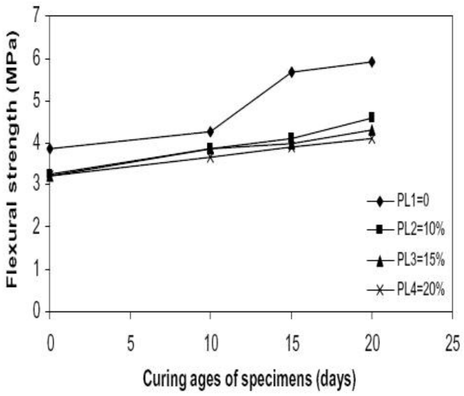

Fig. 21 Flexural strength [23]

3.3 Splitting Tensile Strength

Splitting tensile strength (STS) is one of the concrete mechanical properties that are used in structural design. It can be related to numerous parameters, which include compressive strength, water/binder (W/B) ratio and concrete age [38]. The concrete is not usually expected to resist the direct tension because of its low tensile strength and brittle nature [39]. However, the determination of tensile strength of concrete is necessary to determine the load at which the concrete members may crack. The cracking is a form of tension failure.

Usman *et al.* (2015) replaced the coarse aggregate in concrete specimens of M25 grade by plastic waste (polythene bags) in various percentages 0, 2, 5 and 7% and determined the split tensile strength as per guidelines of IS 5816:1999 [40]. Split tensile strength increased with increase in amount of plastic waste as replacement of coarse aggregate [5].

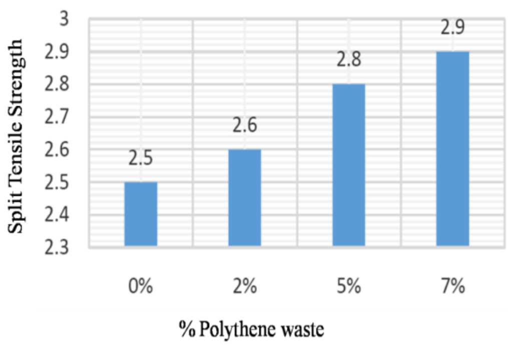

Fig. 22 Influence of Plastic Waste on Split tensile strength of Concrete [5]

Ramadevi and Manju (2012) used waste PET bottles in fibre form as the partial replacement of fine aggregate in M25 grade of concrete specimens with 0.45 w/c ratio in various percentages 0.5%, 1%, 2%, 4% and 6%. Mix design of M25 grade concrete was done in accordance with the guidelines of IS 456(2000) and IS 10262(2009) [26, 27]. The split tensile strength increased till the 2% replacement of the fine aggregate with PET bottle fibres and then decreased slightly with increase in the replacement of the fine aggregate [28].

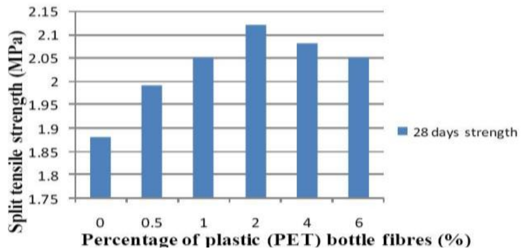

Fig. 23 Split Tensile Strength of Concrete Containing PET Waste [28]

Frigione (2010) used waste unwashed PET bottle (WPET) as replacement of fine aggregate. WPET was replaced by weight of 5% of fine aggregate in concrete. Split tensile strength was determined at 28 days and it was observed that at 28 days it slightly decreased (not lower than 2.5%) when WPET was added in substitution of natural sand in comparison to reference concrete. The tensile strength at 28 days of WPET concrete were of 1.6–2.4% lower than the reference concretes [29].

Albano *et al*. (2009) replaced sand in concrete with Polyethylene Terephthalate (PET) with two different w/c ratio (0.50 and 0.60). Average sizes of the PET particles were 0.26 and 1.14 cm, named small and big, respectively. Fine aggregate (sand) was replaced with 10% and 20% by volume of PET with particle sizes of 0.26 and 1.14 cm and a 50/50 mix of both sizes. They determined splitting tensile strength at 28 days of cure. For w/c ratio of 0.50 they found the decrease in the splitting tensile strength with respect to reference concrete which was independent of the size of the PET added. However, when the amount of recycled PET was 20%, the reduction in split tensile strength was more significant. For the w/c 0.60, the observation remained same as it was for w/c ratio of 0.50. The 50/50 mix particle size gave the smallest reduction in strength [19].

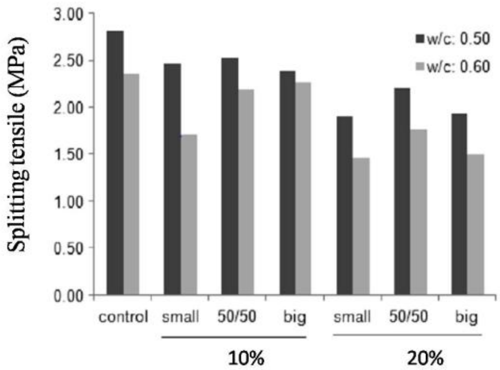

Fig. 24 Split Tensile Strength of Concrete Containing PET Waste [19]

Kandasamy and Murugesan (2011) used polythene fibers (domestic waste plastic) at a dosage of 0.5% by weight of cement in M20 mix of concrete. Cylindrical specimens of M20 grade concrete were tested by them for split tensile strength. It was observed that split tensile strength of concrete in 28 days increased by 1.63% in comparison with reference concrete.1.63% [31].

Table 5 Comparison of 28 days split tensile strength test results [31]

Grade of concrete	Average Split Tensile Strength at 28 days (N/mm^2)		Increase in compressive strength of concrete by addition of fiber (C2-C1)/C1 × 100%
	Plain concrete, C1	0.5% with fiber, C2	
Sample 1	2.90	2.97	2.41
Sample 2	2.83	2.90	2.47
Sample 3	2.83	2.83	0.00

Raghatate (2012) used plastic bags in fibre form in concrete mix of M20 grade for w/c ratio 0.45 in various percentages 0%, 0.2%, 0.4%, 0.6%, 0.8%, and 1%. The splitting tensile strength of concrete containing plastic bag fibres was determined at 28 days. Observation showed the improvement of tensile strength of concrete up to 0.8% addition of plastic and thereafter it decreased with the increasing amount of plastic bag fibres in concrete. 28 days split tensile strength at 0%, 0.2%, 0.4%, 0.6%, 0.8%, and 1% addition of plastic bag fibres was found to be 4.12, 4.38, 4.92, 5.16, 5.57 and 5.12 N/mm^2 respectively [32].

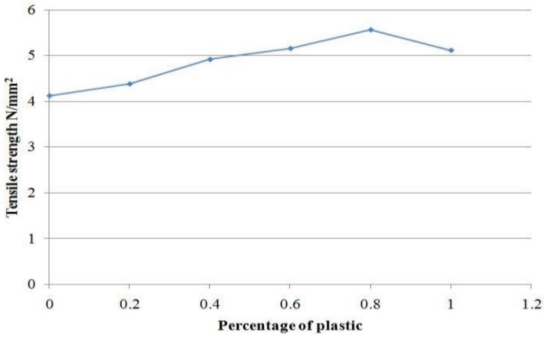

Fig. 25 Split Tensile Strength of Concrete Containing Plastic Bags [32]

Bhogayata *et al.* (2013) used metalized polythene waste bags (used in most of the food packaging industries) in shredded form in concrete. The metalized polythene waste bags were shredded to the macro pellet form of size 1mm×2mm approximately and were added in concrete in different proportions from 0%, 0.5%, and 1% to 1.5% of the volume of concrete. Fly ash was also added in different proportion like from 0% to 30%. Splitting tensile strength was determined and it was observed that the maximum split tensile strength of the specimen prepared with the controlled concrete was noticed as 3.96 N/mm^2, which reduced to 2.26 N/mm^2 by 43% when the plastic fibres were added in concrete up to 1.5% by volume of the mix. It was observed that the value of splitting tensile strength decreased was very less between additions of fibres from 0.5% to 1% in the concrete. It was also observed that addition of fly ash contributed in reduction of the strength within the limit of addition of plastic fibres up to 0.5% compared to the controlled concrete [33].

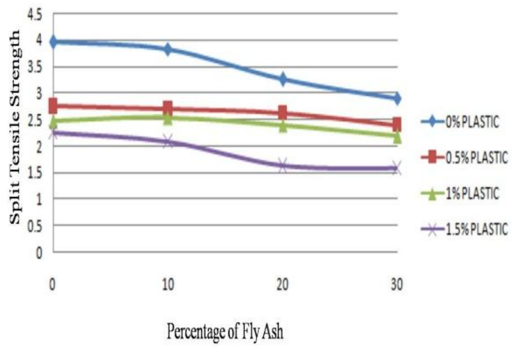

Fig. 26 Split tensile strength of concrete containing waste polythene bags [33]

Saikia and Brito (2014) used PET aggregates to replace natural aggregates of concrete in various percentages 5%, 10% and 15% in volume of natural aggregate (NA). NA were replaced by 3 type of PET aggregates- two were shredded and separated fractions of similar types of PET bottles and one was a heat-treated product of the same PET bottles. The shredded fractions were flaky with two sizes of particles, fine (PF) and coarse (PC). The heat-treated pellet-shaped product was called (PP). Split tensile strength was determined and it was observed that as the percentage of incorporated PET-aggregate increased, split tensile strength decreased. The maximum and minimum reductions in tensile strength were observed in concrete with PC and PP, respectively [37].

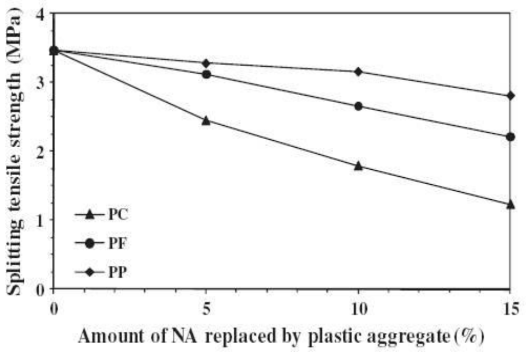

Fig. 27 Influence of PET-aggregate incorporation on the 28-day tensile splitting strength of concrete [37]

3.4 Modulus of Elasticity

It is an important mechanical parameter, defined as the ratio between normal stress to strain below the proportional limit of a material, and it is used to calculate the material's capability to distort elastically [41, 42]. The elastic modulus of concrete is an important parameter in reinforced concrete design and analysis. With the in- creased use of lightweight aggregates for structural concrete, this property holds greater importance [43].

Kim *et al.* (2010) used short fibres made from recycled PET within structural concrete. To verify the properties of recycled PET fibre reinforced concrete, it was compared with polypropylene (PP) fibre reinforced concrete for fibre volume fractions of 0.5%, 0.75%, and 1.0% [30]. Elastic modulus was determined as per ASTM C469 (1994) [44] and it was observed that the recycled PET and PP concrete specimens showed lower elastic modulus than those of the unreinforced specimens. Elastic modulus decreased with increasing fibre content in concrete.

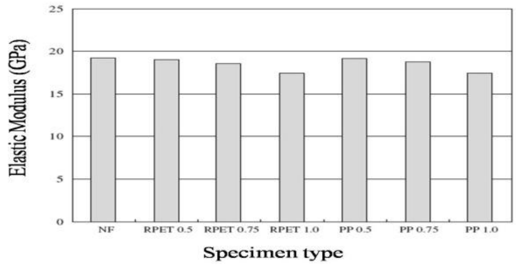

Fig. 28 Influence of PET on Elastic Modulus of Concrete [30]

Albano *et al*. (2009) replaced sand in concrete with Polyethylene Terephthalate (PET) with two different w/c ratio (0.50 and 0.60). Average sizes of the PET particles were 0.26 and 1.14 cm, named small and big, respectively. Fine aggregate (sand) was replaced with 10% and 20% by volume of PET with particle sizes of 0.26 and 1.14 cm and a 50/50 mix of both sizes. Modulus of elasticity was determined and it was observed that it decreased with the increasing amount of plastic waste for both the w/c ratios 0.5 and 0.6 but when the values of modulus were compared with respect to the w/c ratio, it was observed that for a w/c of 0.50 the values were higher. For a fixed particle size, a higher modulus was achieved with 10% of PET [19].

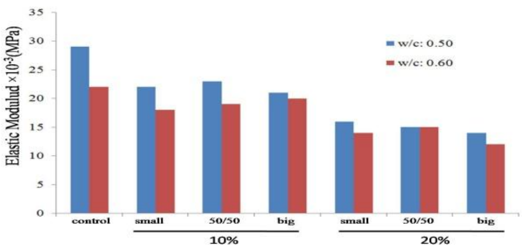

Fig. 29 Modulus of Elasticity [19]

Saikia and Brito (2014) used PET aggregates to replace natural aggregates of concrete in various percentages 5%, 10% and 15% in volume of natural aggregate (NA). NA were replaced by 3 type of PET aggregates- two were shredded and separated fractions of similar types of PET bottles and one was a heat-treated product of the same PET bottles. The shredded fractions were flaky with two sizes of particles, fine (PF) and coarse (PC). The heat-treated pellet-shaped product was called (PP). Modulus of elasticity was determined and it was observed that modulus of elasticity of concrete containing PET-aggregate was lower than that of the reference concrete. It decreased as the content of PET-aggregate increased. At a given substitution level of the three types of aggregate, the decreasing trend can be arranged as: PP > PF > PC [37].

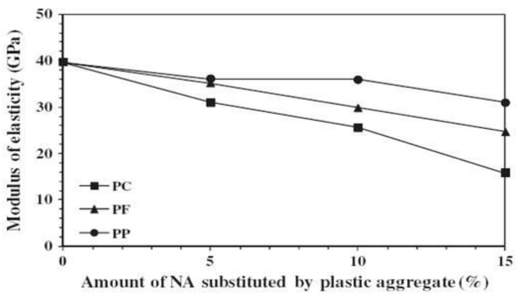

Fig. 30 Influence of various types of PET-aggregate on the modulus of elasticity of concrete [37]

Marzouk *et al.* (2007) used polyethylene terephthalate (PET) bottles to replace sand in concrete in various percentages 2%, 5%, 10%, 15%, 20%, 30%, 50%, 70% and 100%. Three types of PET aggregates were used – Type-A, Type-C and Type-D with maximum aggregate size 0.5, 0.2 ad 0.1 cm respectively. Elastic modulus was determined and it was found that modulus values decreased as the PET quantity increased. At 50% replacement of sand with PET bottled waste, they noted a 50% reduction in elastic modulus in comparison with the reference mortar (27.94 MPa) [45].

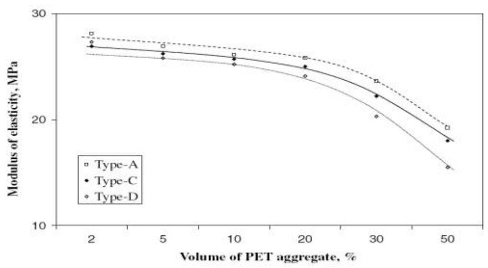

Fig. 31 Modulus of elasticity of composites vs. volume of PET aggregate [44]

IV. SUMMARY AND CONCLUSIONS

The use of plastic waste in concrete has been broadly investigated in recent years. This review paper has presented aspects on plastic waste and its usage in concrete, which could be summarized and concluded as:

1. According to prior test studies, it refers that plastic waste can be utilized in concrete up to certain limit without much effecting the properties of concrete.
2. Plastic waste has control on the workability property of concrete. Slump value and the compaction factor decreased with the increase in amount of plastic waste in concrete.
3. Different studies demonstrates that strength of concrete containing plastic waste were comparable to that of reference concrete up to certain limits.
4. Concrete produced by using plastic waste has durability properties comparable to that of reference concrete up to certain limits.
5. Use of plastic waste in concrete mix proved exceptionally helpful to produce green sustainable concrete.

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