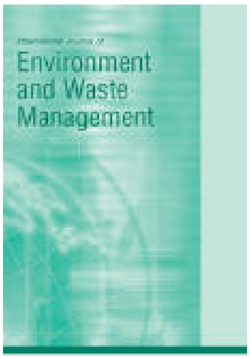

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Recycling of plastic waste as coarse aggregate in concrete for sustainable development

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Abstract: This paper presents a detailed experimental investigation to use plastic waste in concrete. Construction work uses a wide range of raw materials, most of which eventually ends up as landfill. That makes the construction industry one of the largest contributors to landfill waste and greenhouse emission like CO_2 worldwide. Experimental investigations were carried out to determine strength characteristics of concrete by replacing coarse aggregate with 10%, 15% and 20% processed plastic waste. Tests were conducted on concrete specimens to understand its behaviour under tensile, compressive and flexural loading conditions. Based on the experimental results, it was observed that 10% replacement of coarse aggregate with plastic waste aggregates provides the optimum results among all the conditions tested in this experiment. The concrete mix prepared using plastic waste can be used for mass concreting and low load-bearing structures.

Keywords: sustainable development; solid waste; non-biodegradable; plastic waste; concrete.

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1 Introduction

A modern lifestyle, alongside the advancement of technology, has led to an increase in the amount and type of waste being generated, leading to a waste disposal crisis. A polymeric product such as plastic is one of such materials. Plastic is being used on a daily basis both in industry and domestic purposes. Plastic materials are economical, lighter in weight, durable, easily transportable. However, plastic materials are non-biodegradable in nature. Humankind had generated 6.3 billion metric tons of plastic waste until the previous decade. Out of this, only 9% was recycled and 12% incinerated. The vast majority 79% was thrown away (Geyer et al., 2017). It is expected to generate four times more plastic waste over the next 30 years. According to CPCB (2013) report approximately 5.6 million tons per annum (TPA) of plastic waste is generated in the country, which will be a huge threat to the environment in future. According to a survey of CPCB, 8,500,000 tons of plastic bags were used in India in the year of 2007 (CPCB, 2013).

According to PPCB (2011), solid waste management (SWM) is a major problem for many urban local bodies (ULBs) in India, where urbanisation, industrialisation, and economic growth have resulted in increased municipal solid waste (MSW) generation per person. The Management of solid waste materials and their safe disposal is of major concern in today's world of the living. The importance is enhanced when it comes to polymeric products especially plastic. The prominent use of plastics and plastic material in the last 50 years can be correlated with plastics being inexpensive and durable.

However, problems arise with the very slow approximately negligible rate of degradation of plastic, which leads to certain interruptions in biological functions.

Government has taken steps towards the prevention of use of single-use plastic to control the waste in urban areas. Along with that reusing of plastic waste or recycled has been encouraged in recent years to control the production of new plastic products. Few of the steps towards this is using plastic waste in road construction work. The slow degradation of plastic work as a valuable property in concrete. Plastics cannot be recycled number of times as it loses its strength and finally ends up in landfills. One of its use is as aggregates in cement concrete to create light weight structures as plastic is lighter than stone aggregates. The construction process also involves energy expenditure and waste production. However, the current knowledge on the topics of energy consumption, waste production and its environmental impact in the construction process is very limited.

Struble and Godfrey (2004), did a comparison between the environmental impacts of the reinforced concrete beam and a steel beam (I-beam) for one cubic meter as shown in Table 1. The energy consumption includes both energies, construction and demolition energy. Torgal et al. (2012) used waste rubber from tyres and PET waste like bottles in concrete to study the properties and durability of concrete containing polymeric waste and concluded that use of rubber in concrete has various applications in earthquake resistance structures and noise reduction barrier while PET waste in concrete can be used in underwater to prevent erosion problems. Shubbar and Al-Shadeedi (2016) studied the utilisation of waste plastic bottles as fine aggregate in concrete and concluded that employing discarded plastic waste made of polyethylene terephthalate (PET) in concrete is an efficient approach to get rid of such waste. Elzafraney et al. (2005) studied the use of recycled plastic to develop an energy-efficient building. Ismail and Al-Hashmi (2008) studied the use of waste plastic in the concrete mixture as an aggregate replacement and concluded that compressive strength, as well as the flexural strength of all waste plastic concrete, tend to decrease with the increasing waste plastic ratio in the mixture. Ferreira et al. (2012) studied the influence of curing conditions on the mechanical performance of concrete containing a recycled plastic aggregate. Rahman et al. (2012) used recycled PUF and HDPE to study the compressive strength and density, they show that using PUF decreases the weight of concrete noticeably.

Recycling of low-density polyethylene saves approximately 56.5 million Btu/ton amount of energy and 1.98 ton of CO_2 equivalent/ton of waste greenhouse gas emission compared to its production from virgin raw materials (Vlachopoulos, 2009). Also, virgin polymers are produced in relatively few locations around the world, as a result, overall transportation, and energy cost increases. That is why recycling of plastic is widely used nowadays. According to Mitchell (2012), Embodied carbon and embodied energy for sand and gravel extraction is 4.28 kg/CO_2/ton and 8.3 KWh/ton respectively, which is very less compared to LDPE. However, recycled plastic aggregate used in the experiment is a waste product produced during the recycling of LDPE. So, the energy consumption and greenhouse gas emission during the production of this plastic aggregate are considered negligible. Therefore, the use of this plastic aggregate in concrete mix can be termed as sustainable development of concrete because it is emitting very less amount of greenhouse gas during the construction of concrete structures, consuming less amount of energy and most importantly, it uses a non-decomposable waste in its production.

Table 1 Environmental impact of reinforced concrete and steel beams

Impact	*Reinforced concrete*	*Steel*
Resources (kg)	3,743.3	2,076.67
Warming potential (kg equivalent CO_2)	763.98	994.44
Water pollution index	0.34	0.98
Air pollution index	2.01	2.46
Solid Waste generated (kg)	143.235	200.0
Energy consumed (GJ)	10.74	25.52

Concrete is a composite material composed of fine aggregates, coarse aggregates and cement paste which hardens with time. Cement is a powdery substance made with calcined lime and clay as major ingredients. Clay component of cement provides silica, alumina, and iron oxide, while calcined lime basically provides calcium oxide (Dunuweera and Rajapakse, 2018). Coarse aggregate are those aggregates which are retained on 4.75 mm IS sieve and containing only so much finer material as is permitted by the specification (IS 6461-1, 1972). Fine aggregates are those aggregate most of which passes 4.75 mm IS sieve and containing only so much coarser material as is permitted for various grading zones in the specification (IS 6461-1, 1972). This paper presents an optimum content of plastic as a coarse aggregate that can be used in concrete to recycle plastic bags and hence to reduce the environmental solid waste. One series of tests were conducted using sand and coarse aggregates for the concrete mix design of M20. Other tests were conducted by replacing the crushed stone with 10, 15 and 20% of plastic waste by volume. The results were compared with original mix design, i.e., without adding any plastic waste as coarse aggregate.

2 Materials and methods

Three replacement levels 10%, 15% and 20% by volume of coarse aggregates were used for the preparation of the concrete mix following IS 10262 (2009) because 100% replacement is not possible due to certain properties of plastic aggregate.

In the current investigation during mix design, Portland slag cement (PSC) was used. The specific gravity of the cement used for this study was determined using Le Chatelier flask and was found to be 2.99. The specific gravity of various materials used in the current study are presented in Table 2. Locally available river bed sand was used as fine primary aggregate in this study. The water absorption of the sand used in this study was found to be 1.2%. The specific gravity of fine aggregates was found to be 2.68. For concrete mix design usually, 9.5 mm to 37.5mm diameter coarse aggregates are used. Coarse aggregates can be obtained from primary, secondary or recycled sources. In this study, crushed stones of size below 20 mm were used as coarse aggregates. The water absorption test conducted by weighing the aggregates soaked in water for 24 hours was found to be 1.5%. The specific gravity of the coarse aggregate was found out by weighing the certain quantity of coarse aggregate within a wire basket inside and outside the water. One series of tests were conducted using 100% crushed stones of size below 20 mm as a coarse aggregate. For all other tests, crushed stone was replaced with the plastic waste of 10, 15 and 20% by volume. The specific gravity of coarse aggregates was found to be 2.84.

2.1 Recycled plastic

Processed plastic waste bags were used in the concrete mix design. Plastic waste is lighter than water; therefore, the specific gravity of waste plastic was determined using kerosene. The specific gravity of kerosene is 0.82. The specific gravity of recycled waste plastic used in the concrete mix design was found to be 0.95. Recycled plastic aggregates have a very big advantage over conventional aggregate as plastic is non-biodegradable, therefore, after the demolition of the structure made up of recycled plastic aggregate, it can still be used in further construction works. Nowadays recycled concrete aggregate of conventional aggregate is very famous in construction works, but this aggregate is contaminated from various sources while recycling of waste plastic aggregate remains as it is and gives equal strength and property on multiple times use as well.

Table 2 Specific gravity of the various materials used in the study

Material	*Specific gravity*
Cement	*2.99*
Fine aggregate (sand)	*2.68*
Coarse aggregate (stone chips)	*2.84*
Plastic coarse aggregate	*0.95*
Water	*1.00*

2.2 The process of plastic waste recycling

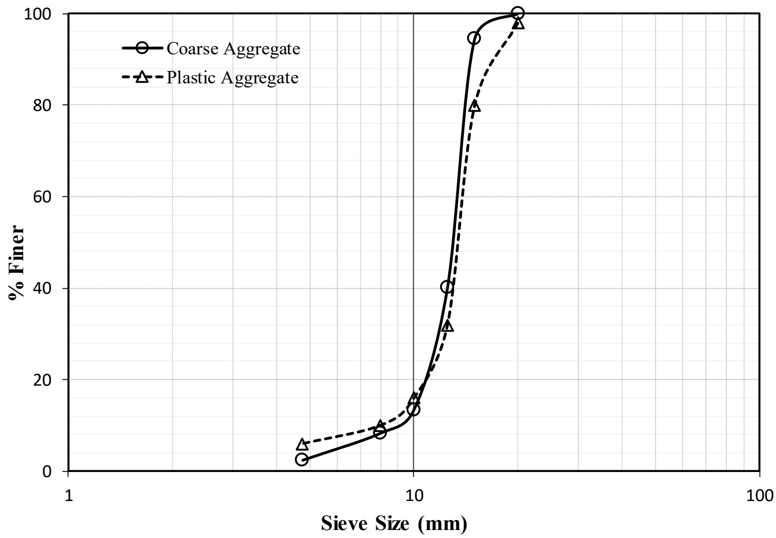
This paper focused only on the recycling process of LDPE type of plastic which can be recycled up to 4 times because after that the product becomes toxic. The whole process is divided into several steps. Initially, Plastic was collected from the various sources by waste pickers and then separated according to their types and properties. And these plastics were shredded into tiny pieces or flakes using a plastic cutting machine known as shredder machine to ease the further process. Then these flakes were washed properly in big tanks and kept for drying under the sun. After drying the shredded plastic were compressed by applying heat and pressure in a compressor machine to densify. The densified plastic wastes were formed to granules. These granules were then fed into the extrusion machine’s hopper where it pushed into the screw channel where these granules get heated up and compact as they advance down towards melting stage where it was pushed down towards various sieves or wire meshes such that long and continuous wires of plastic of specified diameter depending on the size of sieve fitted in machine, comes out from the machine. But some amount of molten plastic stuck on the other side of sieves and blocks its opening, so they must be cleaned after each cycle. This waste plastic produced was very hard and stiff, and could not be used in the further recycling process.

This hard plastic was being crushed into small pieces and was being used as coarse aggregate in the current investigation. The plastic wires that came out from the extruder machine were passed through a water channel where it was allowed to cool and harden. Then it was chopped by a chopper (cutter machine) to form pellets. A flow diagram with the picture explains the whole process of recycling of LDPE in Figure 1.

Figure 1 The process of recycling of plastic waste (see online version for colours)

The plastic coarse aggregates used for the experiment is non-uniform in shape and size and expressed as differently graded. So, gradation of aggregate is done by sieving through a set of standard sieves using sieving machine. The particle size distribution curve of plastic aggregates and normal aggregates is shown in Figure 2. It is found that the aggregate is uniformly graded with 12.5 to 15 mm size coarse plastic aggregates.

Figure 2 Particle size distribution of plastic coarse aggregate and conventional coarse aggregate



3 Tests performed

Series of tests were conducted to determine compressive strength, tensile strength, flexural strength, bond stress and ultrasonic pulse velocity (UPV) of concrete by replacing 10, 15 and 20% by volume of coarse aggregates by plastic waste. The targeted strength of the concrete mix design was 20 MPa, i.e., M20 grade of concrete. One series of test was conducted without using plastic waste as coarse aggregate. Table 3 presents the list of various tests conducted, the size of concrete specimens, curing time and the standard followed to conduct the tests.

Table 3 Tests performed on concrete

Sl. no.	*Test performed*	*IS code reference*	*Specimen size (in mm)*	*Curing condition*
1	Compressive test	IS 516 (1959)	Cube, 150 × 150 × 150	7, 28 days
2	Tensile splitting test	IS 5816 (1999)	Cylinder, D = 150, H = 300	7, 28 days
3	Pull out test	IS 2770-1 (1976)	Cube, 150 × 150 × 150	7, 28 days
4	Flexural strength test	IS 516 (1959)	Beam, 100 × 100 × 500	7, 28 days
5	Ultrasonic pulse velocity test	IS 13311-1 (1992)	Cube, 150 × 150 × 150	28 days

The experiments were conducted by replacing the conventional coarse aggregate with plastic aggregates by 10%, 15% and 20% by volume of coarse aggregate. The quantity of various material used for the design mix are shown in Table 4. The total quantity of material required for three cubical specimens of size 150 mm × 150 mm × 150 mm, two cylindrical specimens of diameter 150 mm and height 300 mm, two prism specimens of dimension 100 mm × 100 mm × 500 mm and one cube specimen of 150 mm × 150 mm × 150 mm used for bond strength test are presented in Table 4.

Table 4 Quantity of materials used in this study

Material	*M20*	*10% replacement*	*15% replacement*	*20% replacement*
Cement	12.22	12.22	12.22	12.22
Fine aggregate (sand)	26.78	26.78	26.78	26.78
Conventional coarse aggregate	39.16	35.27	33.31	31.38
Water	4.88	4.88	4.88	4.88
Coarse plastic aggregates	0	1.37	1.50	2.706

3.1 Compressive test

The compressive test is a qualitative test which measures the compressive force resistance or the crush resistance of a material and ability of the material to regain its original shape after a specified compressive force is applied. It is measured using a compressive strength testing machine. Cube or cylindrical samples are usually tested under a compression testing machine to obtain the compressive strength of concrete. To determine the compressive strength, cubes were cast using a design mix following IS 10262 (2009). For each mix six cubes of dimension 150 mm × 150 mm × 150 mm were cast. After seven days of curing inside the water bath, three cubes were tested to determine compressive strength using a universal compression testing machine. Similarly, another three cubes were tested after 28 days to determine its compressive load carrying capacity and the values were noted down. The procedure described in IS 516 (1959) was followed to carry out the test.

3.2 Split tensile test

Concrete is very weak in tension due to its brittle nature and cannot resist the tension. The tensile strength is one of the important properties of concrete. The tensile splitting test is usually carried out on cylindrical concrete specimens. The test was conducted using compressive strength testing machine. For each mix, six cylindrical specimens each of dimension 150 mm diameter and 300 mm long were prepared. After seven days of curing underwater, three specimens were tested, and the average strength was noted following IS 5816 (1999). Remaining specimens were tested after 28 days curing.

3.3 Pull out test

The force required to pull out the reinforcement bar inserted into the concrete specimen is measured by pull out test. It is a measure of bond strength between the reinforcement bar and the concrete. For each mix, three cubes of 150 mm × 150 mm × 150 mm were cast for pull-out test using 16 mm diameter reinforcement bars. The cubes were cast such a way that the reinforcement bar reached 10 mm from the bottom of the cube. After 28 days of curing underwater tests were conducted on the universal testing machine and corresponding bond stress was noted as per IS 2770-1 (1976).

3.4 Flexural strength test

Flexural strength is also known as modulus of rupture. Flexural strength test measures the direct tensile strength of the unreinforced concrete beams. Flexural strength test was conducted on hardened concrete. For each mix, six specimens of dimension 100 mm × 100 mm × 500 mm were prepared and tested in flexural strength testing machine. Flexural strength tests were carried out following IS 516 (1959) after 7 days and 28 days of curing the specimens underwater.

3.5 UPV test

UPV test is a non-destructive test to analyse the quality of the concrete. In this test, the strength and quality of concrete are assessed by measuring the velocity of the ultrasonic pulse passing through the structure and by measuring the time taken by the waves to pass through the structure being tested. A comparatively higher value of velocity is obtained if the structure is uniform in terms of density, consistency, and homogeneity while lower velocity may indicate the presence of voids in the structure. In the current investigation, the UPV test was performed after the 7 and 28 days of curing following IS 13311-1 (1992). The UPV test setup is shown in Figure 3.

Figure 3 UPV test being conducted on a concrete cube (see online version for colours)

4 Results and discussion

The various tests conducted using plastic waste as a replacement to coarse aggregate was compared with that of the tests conducted without using any plastic waste. The test results are presented in the following section.

The density of plastic aggregates is lesser than that of the density of normal coarse aggregate and there is a possibility of plastic aggregates segregation during the mixing process. To avoid the segregation of plastic aggregates, hand compaction was preferred than vibrator while preparing concrete cubes and cylinders with required w/c ratio for hydration of less workability. The procedure eliminates the probability of segregation. Higher w/c ratio required for the higher workability or when concrete is needed to be pumped, therefore, for such cases the mix with plastic aggregate is not suitable due to segregation issue.

The density of plastic aggregates is about 0.98, which is considerably lesser as compared to normal coarse aggregate, which have specific gravity of about 2.65, the reduction in weight of specimens with recycled plastic mix was noted. Table 5 presents the with weight comparison for various percentages of plastic waste.

Table 5 Weight of different concrete specimens used in the current study

Specimen	*Weight at 0% replacement*	*Weight at 10% replacement*	*Weight at 15% replacement*	*Weight at 20% replacement*
Cube (kg)	3.1	2.91	2.83	2.78
Cylinder (kg)	6.57	6.35	6.19	6.11
Prism (kg)	5.95	5.74	5.59	5.51

As explained earlier the current knowledge on the topics of energy consumption, waste production and its environmental impact in the construction process is very limited. In addition, the field need to be explored to understand the effect we are producing through the work we are presenting. The purpose of the current investigation was to find out the effect on the strength of the concrete with plastic waste utilisation as sustainable development. Torgal et al. (2012) reported a massive decrease in compressive as well as tensile strength of concrete after replacing aggregate with rubber waste, however, in the current study increased in tensile strength of concrete was observed when recycled plastic aggregate was used. Shubbar and Al-Shadeedi (2016) reported an increase in compressive, tensile and flexural strength of concrete with replacement of 2% by volume of fine aggregate with PET fibre, however, upon further increase in PET fibre content (4% and 6%), the concrete strength was noted to decrease. In the present study when test was conducted by 10% replacement of coarse aggregate with plastic aggregate, a decrease in compressive strength was observed whereas tensile and flexural strength was found to increase. Therefore, the strength of concrete specimen depends on the properties of material, test conditions the process followed. Ismail and Al-Hashmi (2008) reported arrest of propagation of micro cracks after introducing fibro form shape waste plastic in concrete. Rahman et al. (2012) reported a decrease in weight of specimen while replacing aggregate with HDPE and PUF in concrete. Similar observation was noted in the current investigation. The crack propagation delays or reduces after introduction of plastic aggregate in concrete and reduction of weight of specimen due to less specific gravity of plastic aggregate compared to conventional aggregate which helps in improving the tensile strength of concrete.

As the latest code for concrete design IS 10262 (2019), but the experimental investigation was carried out by following IS 10262 (2009). Hence, taking into consideration of the latest code the major difference between IS 10262 (2009, 2019) is found that, the 2019 version address the mix design for self-compacting concrete, high strength (greater than M65), concrete with fly ash, slag or GGBS as Cementitious material added in design along with few changes in design of low strength concrete.

IS 10262 (2019) proposes a new formula for calculation of target strength of concrete after 28 days of curing as follows:

$$f'_{ck} = f_{ck} + 1.65\,S$$

or

$$f'_{ck} = f_{ck} + X$$

whichever is higher.

Where

f'_{ck} target mean compressive strength at 28 days, in N/mm^2

f_{ck} characteristic compressive strength at 28 days, in N/mm^2

S standard deviation, in N/mm^2

X factor based on the grade of concrete.

The values for X and S are provided in the IS code.

After considering the latest code for changes in design calculation for target strength it has been found that there was no change in final target strength as the higher value among two formula has to be considered.

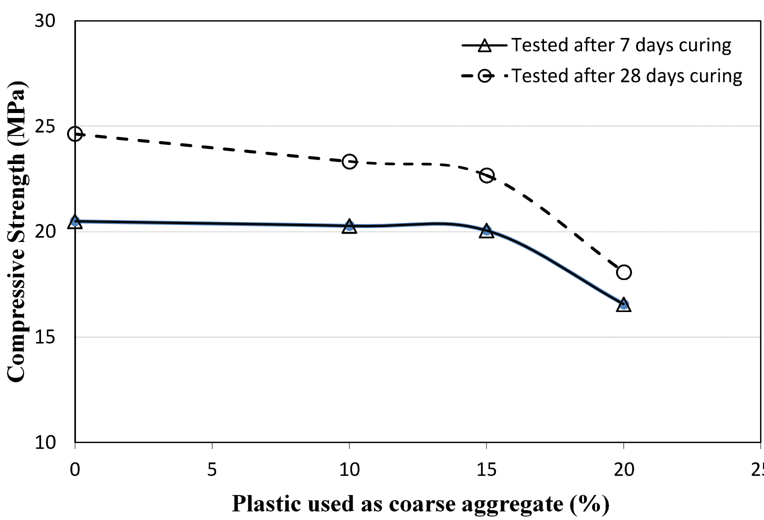
IS 10262 (2019) changed the volume of entrapped air percentage on nominal size of aggregate. Earlier for 20 mm size of nominal aggregate the value was 2% but in latest division the value is 0.5% of volume of concrete as a result of this change the total bulk volume of concrete will be increased and the quantity of every ingredient in the mix will be increased to a very small content which can be neglected as we take 10% extra of each item. IS 10262 (2019) also proposed a graph for assuming the w/c ratio, after considering the graph it has been found that it suggested for a w/c ratio of 0.44. but to avoid segregation of aggregates w/c ratio of 0.4 was considered in our design which is less than suggested by the latest code but was adequate according to surrounding conditions.

4.1 Effect on compressive strength of the concrete

The crack propagation during compression testing on a cube is shown in Figure 4. Figure 5 represents the effect of plastic content on the compressive strength of concrete after curing for 7 and 28 days. It was observed that the compressive strength after 7 days of curing was constant up to 15% replacement of coarse aggregate by plastic aggregate. Beyond 15% replacement of coarse aggregate by the plastic aggregate, the compressive strength of the concrete was found to decrease. However, for the tests conducted after 28 days curing, the compressive strength was found to decrease gradually. The plastic waste granules used in this investigation were found to be smoother, slippery and hydrophobic in nature, as a result, the Interfacial Transition Zone had lower strength and stiffness and the bonding between granules was weaker as compared to crushed stone aggregates, resulting in lower compressive strength. Therefore, the concrete with a lower percentage of plastic as coarse aggregate can be used in large construction projects. For lighter structures where the total amount of load is less, the high percentage of waste plastic can be used to replace conventional coarse aggregate. Use of hand compaction method instead of using vibrator was the reason behind lower of compressive strength of concrete specimen. Use of vibrator could cause segregation of plastic aggregate in the concrete mix. In order to compare between the conventional concrete mix and modified concrete mix, hand compaction was used in every specimen even without using (0%) plastic aggregate.

Figure 4 Compressive strength test of a concrete cube containing plastic aggregate (see online version for colours)

Figure 5 Compressive strength versus percentage of plastic as coarse aggregate (see online version for colours)



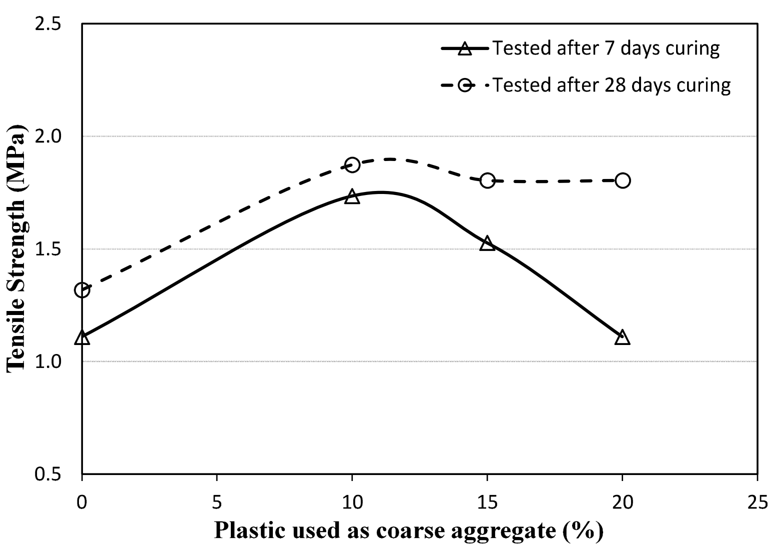
4.2 *Effect on tensile strength of the concrete*

The crack propagation during the tensile test on the cylindrical concrete specimen with and without recycled waste plastic is shown in Figure 6. The difference between the natures of crack propagation in two different types of concrete is clearly visible. In case of concrete with partial use of plastic aggregate, the width of crack was noted to be much lesser than that of concrete cylinder prepared without plastic waste. Figure 7 presents the change in tensile strength with various percentages of plastic waste used in concrete after curing for 7 and 28 days. It was noted that after 7 and 28 days curing, the tensile splitting strength for concrete with plastic waste increases up to 10% replacement. Beyond 10% replacement, the tensile splitting strength of concrete decreases gradually for 7 days cured concrete and remains constant for 28 days cured concrete. The reason for such behaviour may be the properties of plastic, adding plastic aggregate in concrete induces softening behaviour in concrete but because of difference in shape and stiffness of the plastic aggregate and its hydrophobic nature, adding more plastic than optimal value weakens its tensile strength too. Hence, the concrete with up to 10% of plastic replacement can be used as optimal value of the plastic aggregate in various construction purposes.

Figure 6 Crack in concrete cylinder, (a) with (b) without plastic waste as aggregates (see online version for colours)

(a) (b)

Figure 7 Variation of tensile strength with various amount of plastic as coarse aggregate



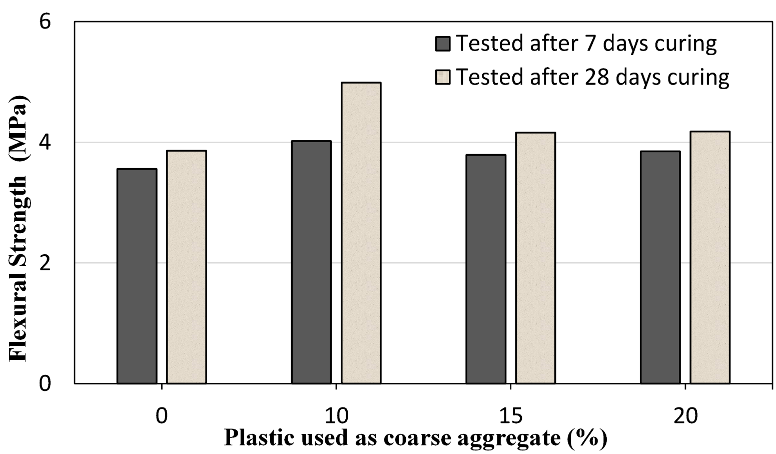
4.3 Effect on flexural strength of the concrete

Flexural strength is one of the measures of the tensile strength of concrete. It is measured to determine the force required to resist failure of an unreinforced concrete beam or slab by bending. The crack propagation in the specimen after failure is shown in Figure 8. Effect of plastic waste on flexural strength of concrete is shown in Figure 9. It was noted that flexural strength increases for 10% addition of plastic waste as compared to concrete without any plastic waste cured for 7 and 28 days. Beyond 10% replacement of coarse aggregate by plastic waste, the flexural strength decreases by some amount and was found to be constant for further increase in plastic content. The explanation for the loss of tensile strengths of concrete due to the incorporation of waste plastic aggregate applied to the flexural behaviour of concrete too.

Figure 8 Crack propagation in the concrete beam after flexural strength test, (a) with (b) without using waste plastic as coarse aggregates (see online version for colours)

(a) (b)

Figure 9 Flexural strength versus the percentage of plastic used as coarse aggregate (see online version for colours)

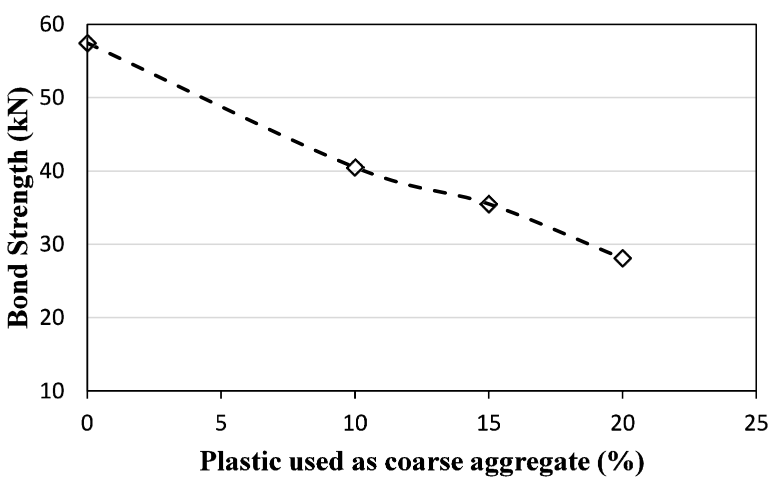


4.4 Effect on bond strength of concrete

Figure 10 represents the crack propagation in the specimen during loading and Figure 11 presents the bond stresses measured from pull out test with various percentages of plastic waste content in concrete. It was noted that the pull out strength of the concrete with various replacements of plastic decreases gradually and the maximum bond stress was obtained at 10% coarse aggregate replacement by plastic waste in concrete. The plastic waste granules used in this investigation were found to be hydrophobic, having a plane and angular shape with smooth characteristics which do not contribute to the strength of the concrete as does the natural coarse aggregates. Therefore, the bonding between granules was weaker as compared to crushed stone aggregates.

Figure 10 Crack propagation during pull out test (see online version for colours)

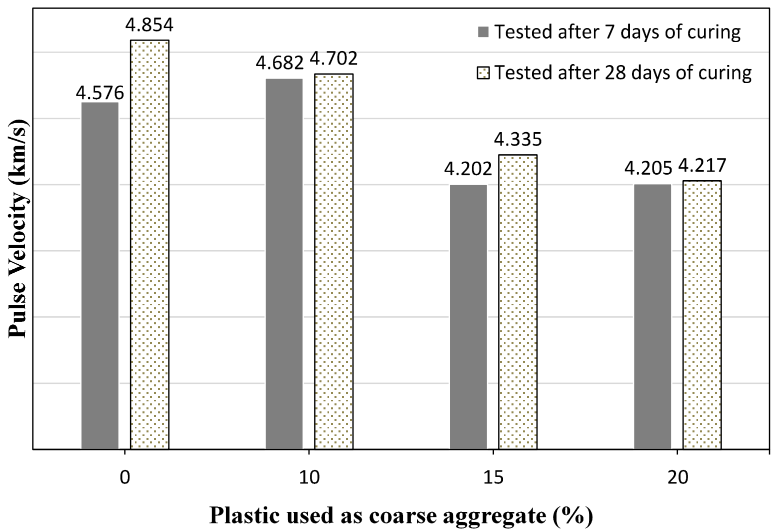
Figure 11 Bond strength versus the percentage of plastic used as coarse aggregates



4.5 Effect on UPV of concrete

The UPV is a non-destructive test to determine the strength of concrete. Figure 12 presents the variation of UPV with different percentages of plastic waste used in concrete. The UPV was found to decrease continuously with increase in plastic content in concrete. Therefore, the strength of the concrete tested for the investigation would be decreased with higher percentages of plastic content. The results indicated the rigidity of the material reduces. The explanation for such behaviour of concrete was the tiny gaps or pores in the Interfacial Transition Zone because of the lack of reaction between the cement paste and waste plastic aggregates.

Figure 12 Change in pulse velocity with various amount of plastic used as coarse aggregates



In the case of compressive and bond strength tests, the strength was noted to decrease monotonically with increase in plastic content, while for split tensile and flexure tests the strength was first observed to increase and then decreased. The possible reason for the above behaviour of concrete specimens could be due smoother, slippery and hydrophobic nature of plastic granules used in this study. Due to that, the Interfacial Transition Zone had lower strength and stiffness and the bonding between granules was weaker as compared to crushed stone aggregates. Replacing conventional coarse aggregate with plastic aggregate also induces some plastic property inside the concrete, which in turn lower the compressive and bond strength. For the same reason, the plastic behaviour of concrete, i.e., the split tensile strength and flexural strength of specimen was noted to increase as the quantity of plastic aggregate increases inside concrete increased. At higher plastic waste content, the concrete starts behaving more like a plastic material, therefore, the deformation of concrete under loading was noted much faster and small cracks were noted to develop without complete failure.

5 Conclusions

Following conclusions can be drawn from the above study

- The effect of compressive strength, tensile strength, flexural strength, bond stress and UPV of concrete specimen was investigated by replacing coarse aggregate with 10, 15 and 20% of plastic waste by volume.

- Compressive strength of the specimen was found to have negative effect with addition of plastic aggregate as it decreases with an increasing amount of plastic.
- The addition of plastic aggregate in concrete creates a plastic behaviour in concrete as a result tensile and flexural strength were observed to be maximum at 10% plastic replacement in concrete as compared to the conventional design.
- The bond stress decreases gradually with increase in percentage of plastic replacement and was observed to be maximum at 10% replacement of coarse aggregate with plastic waste among all replacement group.
- The strength of modified concrete mix, with an addition of plastic as coarse aggregate up to 10% with conventional aggregate was within the permissible limit, in this case the permissible limit is the design strength of specimen (in our case 20 MPa for compressive strength).

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