

## Research

# Studies on partial replacement of waste high density polyethylene (HDPE) and polypropylene (PP) plastic with fine aggregate (FA) on mechanical, durability and thermal properties of M30 and M40 grade concrete

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## Abstract

The aim of the present paper is to incorporate two different waste plastic materials that is High-Density Polyethylene (HDPE) and Poly-Propylene (PP), were replaced with Fine Aggregate (FA) at a 10% by 2.5% increment. The widespread formation of HDPE and PP waste plastics has become a major environmental issue, endangering ecosystems and human health. Traditional disposal techniques, such as landfills and incineration, lead to pollution and resource depletion. Incorporating these polymers into concrete provides a long-term solution that reduces environmental effect while improving material qualities. The Different tests conducted are compressive strength (3, 7, 28 and 60 days) (150 × 150 × 150 mm), flexural strength (3, 7, 28 and 60 days) (100 × 100 × 500 mm), acid attack (28, 56 and 90 days) (100 × 100 × 100 mm), sulphate attack (28, 56 and 90 days) (100 × 100 × 100 mm), and thermal conductivity (180 mm dia x 20 mm thick). The compressive strengths of 40.52 MPa and 38.41 MPa for PP and HDPE material were observed in M30-grade concrete, respectively. Similarly, for M40-grade concrete, 43.6 MPa and 41.8 MPa are for PP and HDPE material, respectively. The optimum percentages of 5% and 7.5 for PP and HDPE material, respectively, can be replaced in concrete for flexural strength in both M30 and M40 grades. The least percentage loss in acid attack was observed at 28 days for both HDPE and PP material, but for 56 days and 90 days, the percentage loss of weight was significantly less (< 5%). The sulphate attack for both M30 and M40 grade concrete showed less than 10% percentage loss in weight after 90 days. Thermal conductivity (k) was also reduced by 30–35% for both HDPE and PP material, with 10% replacement in concrete for M30 and M40 grades. The use of Waste HDPE and PP material can be used to improve the mechanical, durability & thermal property of M30 and M40 grade concrete under controlled conditions.

**Keywords** High Density Polyethylene (HDPE) · Polypropylene (PP) · Compressive strength · Flexural strength · Acid attack · Sulphate attack · Thermal conductivity

## Abbreviations

HDPE	High-density polyethylene
PP	Poly-propylene
FA	Fine aggregate
K	Thermal conductivity
P	Load

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A	Area
W/C	Water/cement
B	Width
D	Depth (mm)
Q	Heat flow rate in the specimen
$T_h$	Temperature of Hot plate
$T_c$	Temperature of cold plate
L	Specimen thickness

## 1 Introduction

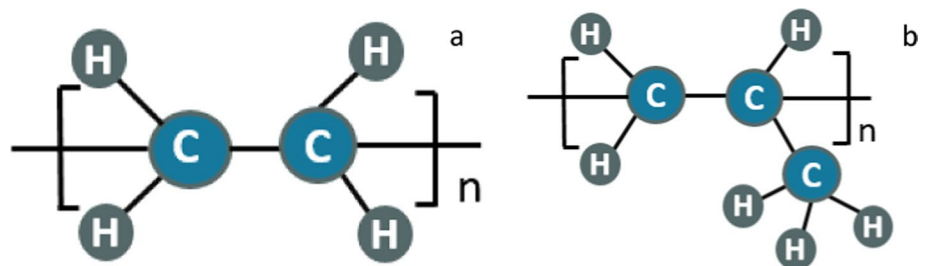
India is one of the 12 countries which are responsible for 52% of the waste plastic mismanaged in the world. Nearly 6.8cr tonnes of waste plastic will be dumped in the dumping sites by the end of this year (2023), by Earth Action (EA) report 2023 [1]. Polyethylene (PE) and polypropylene (PP) are thermoplastics classified as polyolefins. While they are closely related, there are some distinguishing features that separate them unique. It should be noted that the particular traits and attributes of each will differ based on its manufacturing techniques and its grades from supplier. There is much availability of polyethylene then polypropylene according to its production. Both PE and PP material is widely used in several industries such as consumer goods, automotive parts and for packing materials. Both PE and PP is a polymer which consist of repetitive ethylene (-CH<sub>2</sub>-CH<sub>2</sub>-) and propylene (-CH<sub>2</sub>-CH (CH<sub>3</sub>)-) monomers which is derived from petroleum respectively as shown in Fig. 1.

When PP is compared with PE, PP has high strength and stiffness because of this property it can be incorporated in concrete to improve its physical and mechanical properties [2, 3, 24, 40–43]. The density of PP is 0.90 g/m<sup>3</sup>–0.91 g/m<sup>3</sup> & PE is 0.91 g/m<sup>3</sup>–0.94 g/m<sup>3</sup> [4]. When PE was replaced in concrete as coarse aggregate (CA) its workability was reduced by 50mm when PE was replaced from 5 to 15% with water to cement ratio as 0.42 [10, 18, 23]. In an experimental evaluation it was observed that a constant value of slump 90mm was observed for different water to cement ratio of 0.45, 0.55 and 0.6. But, it resulted in reduction of compressive strength 40% when PE was replaced from 0 to 50% and the rate of compressive strength was reduced from 70 to 22% when PE was replaced from 50 to 100% [13, 16]. An optimum percentage of 0–20% was recommend to be partially replaced with fine aggregate in concrete as the compressive strength was increased from 27 Mpa to 42 MPa by [6, 7, 10, 12, 16, 18, 23]. Another study stated that when PE is replaced from 0 to 5% there is a reduction in compressive strength by 3 Mpa [23]. It was even recommend that M35 grade of concrete is desirable with PE-10 [23] they have achieved a compressive strength of 38 Mpa. [6] Observed 35 Mpa strength for PE-5 concrete but as the percentage of PE was increased to 12.5% its compressive strength by 20%. [20] For 0–50% and 50–100% replacement of PE in concrete after 28days the compressive strength was reduced by 52% and 57% respectively.

Splitting tensile strength for 28 days showed a decrease in compressive strength when PE was replaced from 0 to 15% [7, 10, 23]. When 5% PE was replaced in concrete it showed a highest tensile strength of 3.4 MPa which was observed to be 31% increase when compared with conventional concrete [23]. As the percentage of PE was replaced from 5 to 15% there was a reduction in tensile strength by 18% [23]. Similarly from other study the tensile strength was reduced by 8% and 28% when PE was replaced from 0–5% to 5–7.5% respectively [6]. When PE was increased from 7.5% to 10% the tensile strength was increased by 26% but as the percentage of PE was increased to 15% its tensile strength was reduced by 23% [6].

As we know that PE has a flexural strength of 10–50 MPa which can help in improving flexural property of concrete and the same was observed that when 15% PE was replaced in concrete it showed the highest flexural strength than

Fig. 1 a HD-PE b PP



conventional concrete [6, 12, 18, 19]. For 10% PE the flexural strength of 6 MPa was observed which 56% increase when compared with conventional concrete [23]. When same PE was replaced by 15% a slight reduction in strength by 1.5 MPa was observed [23]. The same pattern of flexural strength was even observed by different researcher [6]. When PE was replaced from 0 to 5% there was no change in the strength but when it was replaced from 5 to 10% an increase in strength by 54% was observed [6]. Similarly as the percentage of PE was still further increased from 10 to 15% there was a reduction in strength by 28% [6].

The elastic constant of material i.e., young's modulus/modulus of elasticity (E) was decreased with increase in PE material. As the percentage of PE was increased from 0 to 15%, its E was reduced by 75% [5, 11, 14, 20, 23]. The density of PE-FA concrete was decreased when recycled PE was increased. It was observed the density was reduced by 20% when PE was increased from 0 to 60% [7, 20].

Durability properties of concrete were also evaluated to understand its behaviour. Water absorption of PE conventional concrete was increased by increased from 5 to 10% with the increase in recycled PE from 0 to 15% [23]. The rapid chloride penetration test stated that the chloride ion penetration (CIP) was in from 2000 to 4000 Columbs [15, 23]. As the PE content increased from 0 to 15% its CIP was reduced from 4250 to 2700 columbs which was 36% reduction [23]. The Ultrasonic Pulse Velocity (UPV) test was conducted on the concrete specimens cured from 28 to 90days with 15% addition of PE in concrete till 60% in concrete and it was observed that there was a slight reduction in UPV [20]. Similarly thermal conductivity (K) was also performed on the same specimens and it was observed that K value was reduced from 2 W/m·K to 1.1 W/m·K from 0 to 60% PE at 7 days of curing [8, 9, 17, 20–22].

The widespread formation of HDPE and PP waste plastics has become a major environmental issue, endangering ecosystems and human health. Traditional disposal techniques, such as landfills and incineration, lead to pollution and resource depletion. Incorporating these polymers into concrete provides a long-term solution that reduces environmental effect while improving material qualities. However, there is minimal study on the ideal replacement proportion of HDPE and PP waste plastics in concrete mixtures, especially in higher-grade concrete such as M30 and M40.

The objectives of the present paper are: It is use to determine the optimal replacement percentage of HDPE and PP waste plastics in M30 and M40 grade concrete mixes, balancing environmental sustainability and structural performance. To assess the mechanical properties (compressive strength, flexural strength, and tensile strength) of concrete specimens containing varying percentages (2.5–10%) of HDPE and PP waste plastics. Investigate the durability characteristics (such as resistance to acid attack, sulphate attack and rapid chloride permeability test) of plastic-modified concrete to ensure long-term performance. To determine the thermal property of concrete by conducting thermal conductivity test. To develop guidelines and recommendations for the practical implementation of HDPE and PP waste plastic incorporation in M30 and M40 grade concrete for construction applications, addressing concerns related to material handling, mix design, and quality control.

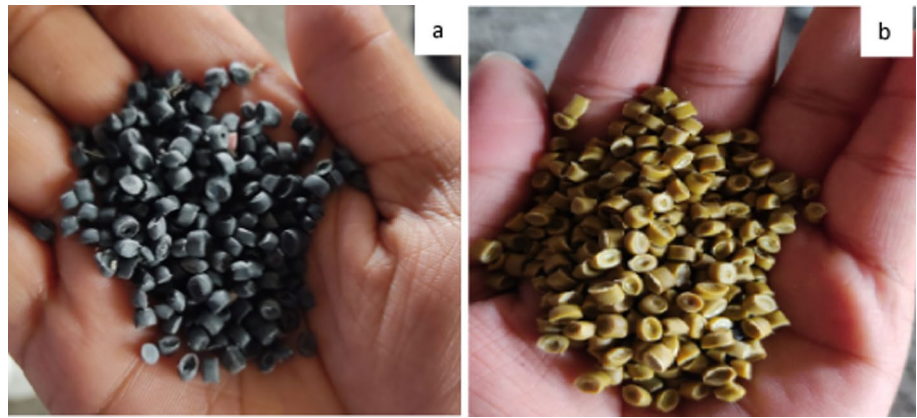
## 2 Materials

Ordinary Portland cement 43 (OPC-43) grade conforming to IS: 8112–1989 was used. The physical properties of cement was tested according to IS 4031–1988, where the consistency, initial setting time, final setting time, fineness modulus & specific gravity were 34%, 27 min, 184 min, 3% & 3.15 respectively. Fine aggregate (FA) as river sand passing through 4.75 mm sieve was used. All the physical properties of FA were evaluated using IS 2386 (part-1)-1963. The specific gravity, sieve analysis, water absorption, Fineness modulus and other properties is given in Table 1. The sieve analysis for FA and CA was performed to find the fineness modulus and zone of the material which is shown in Fig. 1. Locally available High Density Polyethylene (HD-PE) and polypropylene (PP) with its tensile strength as 31.37–42 Mpa for HDPE and 27.5–39.9 Mpa for PP, as it is observed that both HD-PE and PP have nearly same tensile strength. The flexural strength of HDPE is 10 to 50 MPa and for PP it is 10–20 MPa, because of this property we can incorporate it in concrete to improve its mechanical properties. The flash point of HDPE and PP is 388 °C and 260 °C respectively. The size of HDPE and PP was less than 4.75mm sieve which was partially replaced with fine aggregate (FA) as shown in Figs. 1 and 2. Recycled aggregates were broken from the failed concrete cubes and the cement paste was removed by placing these aggregates in water for 24 h and then drying it in hot sun/oven, its physical properties are given in Table 1. To improve the workability of concrete locally available admixture as Superplasticizer (AC Plast BV) is used (Fig. 3).

**Table 1** Physical Properties

Properties	Cement	Fine Aggregate (FA)	Coarse Aggregate (CA)	Recycled Aggregate (RA)	HDPE	PP
Specific gravity	3.15	2.61	2.75	2.45	0.864	1.225
Water absorption (%)	12%	2.64	0.85	0.92	0.38	0.27
Fineness modulus	-	2.45	8.35	6.25	3.12	5.36
Maximum particle size (mm)	50 $\mu$ m	4.75	20	20	3.75	27.50
Density	1.44 g/cm <sup>3</sup>	2400–2900 kg/m <sup>3</sup>	1200–1450 kg/m <sup>3</sup>	1750 kg/m <sup>3</sup>	0.90–0.94 g/cm <sup>3</sup>	0.90–0.91 g/cm <sup>3</sup>
Chemical resistance	chemical resistant	-	-	-	Solvents, alkalis and acids	Organic solvents, strong bases, acids and alkalis
Electrical resistivity	1 $\Omega$ -m	-	-	-	1016–1018 $\Omega$ -cm	1014–1016 $\Omega$ -cm

**Fig. 2** a waste plastic 1 HDPE  
2 PP



### 3 Methodology

To understand the behaviour of HDPE and PP in concrete, different tests were conducted. Initially all its physical properties were evaluated which are listed in Table 1. Many trial mixes were conducted with different water/cement (W/C) ratio for M30 & M40 grade concrete and a W/C ratio of 0.45 and 0.40 respectively was fixed. The mix proportion of M30 and M40 was designed according to IS 10262–2019 and IS 456–2000. The complete mix proportion and its quantity per m<sup>3</sup> is given in Tables 2 and 3 for M30 and M40 grade respectively.

The mix design of M30 and M40 grade concrete were found using IS 10262–2019 and IS 456–2000 and its proportion is given in Tables 2 and 3. Different test performed on concrete were, workability (Slump cone) (IS 456:2000), compressive strength (3, 7, 28 and 60 days) (150 × 150 × 150 mm) (IS 516 (1959)), flexural strength (3, 7, 28 and 60 days) (100 × 100 × 500 mm) (IS 516:1959), acid attack (28, 56 and 90 days) (100 × 100 × 100 mm) (ASTM C1898-20), sulphate attack (28, 56 and 90 days) (100 × 100 × 100 mm) (ASTM C101), thermal conductivity (180 mm dia x 20 mm thick) (IS 9490 (1980)).

## 4 Results and discussion

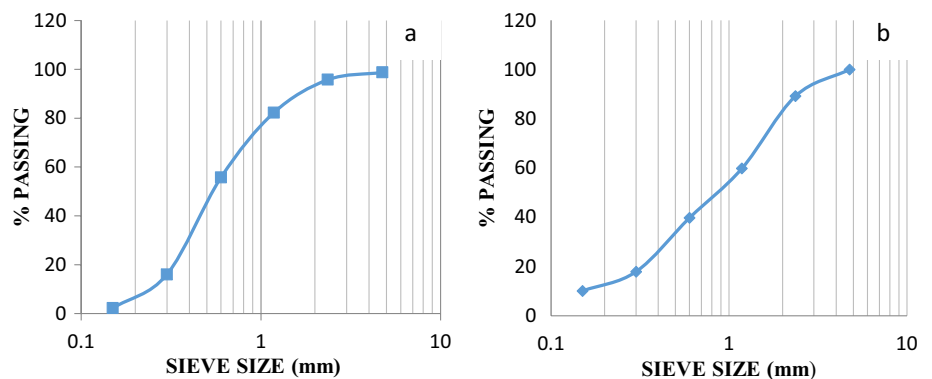
### 4.1 Compressive strength for M30 grade concrete

The mix design of M30 grade concrete was proportioned using IS: 10262-2019 and IS 456–2000. The fine aggregate (FA) was partially replaced with HDPE and PP material as shown in Figs. 4 and 5. The compressive strength was calculated using IS: 516-1959 as given in Eq. (1).

$$\text{Compressive strength} = \frac{P}{A} \quad (1)$$

where P = Load in N.

**Fig. 3** Particle size distribution of 1 Fine Aggregate (FA) and 2 Coarse Aggregate (CA)



**Table 2** Mix proportion of M30 grade concrete

Nomenclature	W/C = 0.45						
	Cement (Kg/)	Admixture (Kg)	FA (Kg)	CA (Kg)	RA (kg)	HDPE (Kg)	PP (Kg)
CC	323	6.46	855	1200		-	-
HDPE-2.5			833.63			21.37	-
HDPE-5			812.25			42.75	-
HDPE-7.5			790.88			64.12	-
HDPE-10			769.50			85.5	-
RA-100 PE-7.5			790.88	-	1750	64.12	-
PP-2.5			833.63	1200		-	21.37
PP-5			812.25			-	42.75
PP-7.5			790.88			-	64.12
PP-10			769.50			-	85.5
RA-100 PP-5			812.25	-	1750	-	42.75

Admixture is Superplasticizer

**Table 3** Mix proportion of M40 grade concrete

Nomenclature	W/C = 0.40							
	Cement (kg/m <sup>3</sup> ) (OPC53)	Admixture (kg/m <sup>3</sup> )	FA (kg/m <sup>3</sup> )	CA (Kg)		RA (Kg)	HDPE	PP
				20mm	12.5mm			
CC	335	1.82	765	890	221	-	-	
HDPE-2.5			745.88			19.12	-	
HDPE-5			726.75			38.25	-	
HDPE-7.5			707.63			57.37	-	
HDPE-10			688.50			76.50	-	
RA-100 PE-7.5			707.63	1750	-	1750	57.37	
PP-2.5			745.88	890	221		19.12	
PP-5			726.75				38.25	
PP-7.5			707.63				57.37	
PP-10			688.50				76.50	
RA-100 PP-5			726.75	1750	-	1750	38.25	

**Fig. 4** Compressive strength test





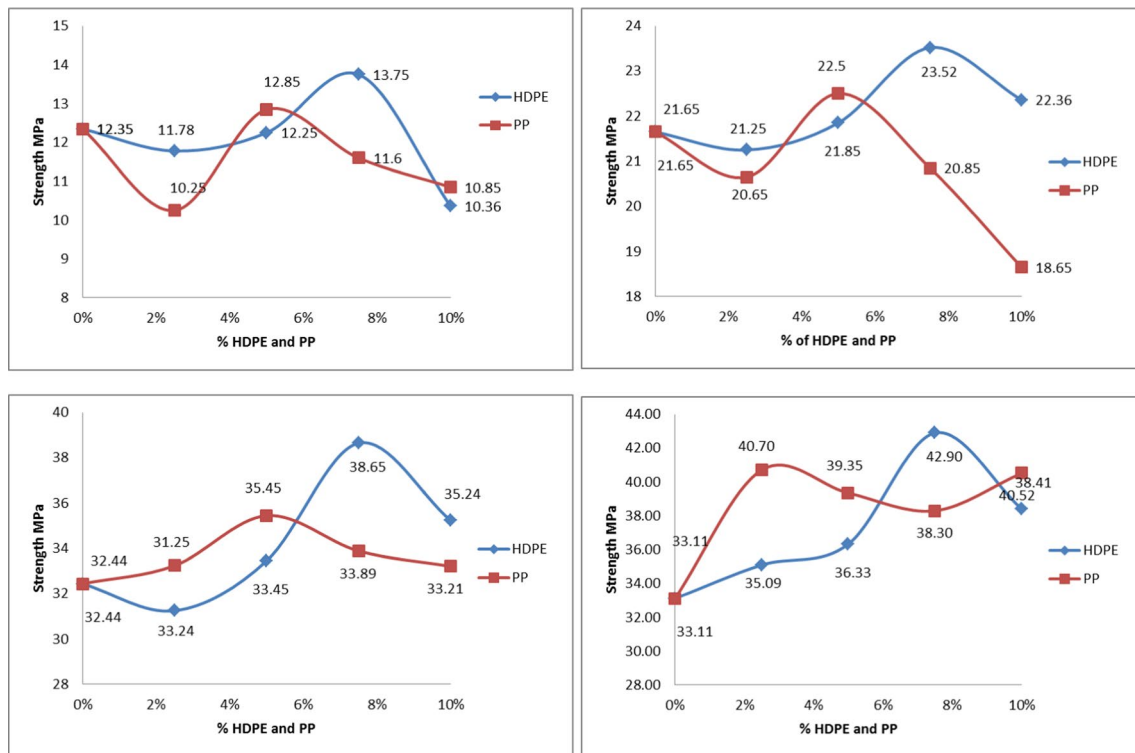


Fig. 5 Compressive strength for M30 grade concrete **a** 3 days **b** 7 days **c** 28 days **d** 60 days

$A = \text{Area in mm.}^2$

The trend of HDPE in concrete for all the ages showed an increment in compressive strength till 7.5% replacement with FA, but for 10% replacement there was a decrease in its compressive strength. For PP material, the trend with respect to age showed similar pattern in 3 and 7 days similarly it was a different pattern for 28 days and 60 days. It is observed from Fig. 5 that the initial strength gain in early age was for 5% replacement but as the curing times increases the material and the concrete undergo chemical reactions and after 60 days for 2.5% it gave maximum strength gain. This is because the solid plastic particles occupy the voids present in the concrete, which helps in improving the mechanical property of concrete [25–27]. A similar study carried by Yang et al. [28] showed that the replacement of PP plastic with FA in concrete from 10 to 30% gave optimum value at 15% for compressive strength. When detail literature review is carried it was observed that HDPE and PP material has very little research, this is because of the short fiber characteristics in concrete [29, 30]

The compressive strength was gradually increased with partial replacement of HDPE and PP material in concrete. The patten of compressive strength for HDPE material was same form 3 days to 60 days as shown in Fig. 5. The patten of compressive strength of PP was slightly different, for 3 and 7 days the compressive strength was reduced for 2.5% but as the curing time increased to 28 days and 60 days it was gradually increased and the maximum 40.70 MPa. The trend for HDPE and PP was very different and it was observed that initially for 2.5% the PP material showed less compressive strength for first 7 days but the trend has changed after 7 days the compressive strength was gradually increasing from 2.5% till 10% with and increment of 2.5%. It is clear that an optimum percentage of 2.5% for PP and 7.5% for HDPE. The compressive strength of HDPE was 42.90 MPa for 7.5% replacement after 60 days.

It is recommended to use the waste plastic in construction to improve the mechanical property –compressive strength. As the replacement of plastic can reduce the plastic waste from dumping yards and save the environment.

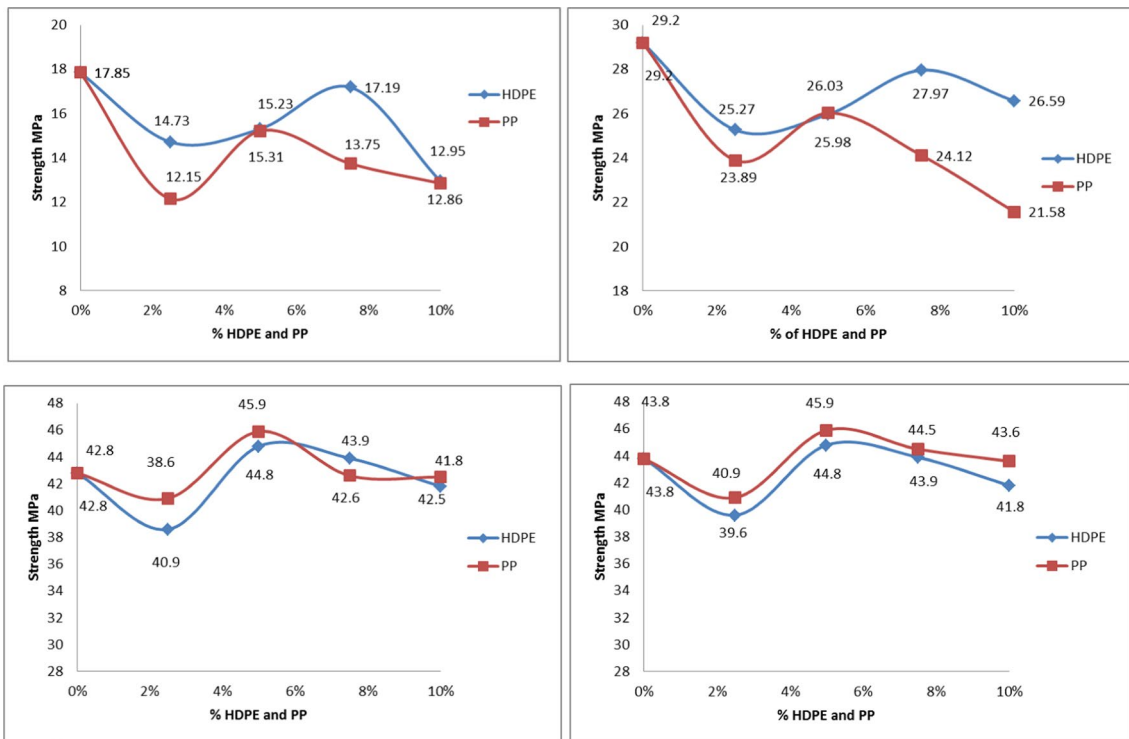


Fig. 6 Compressive strength for M40 grade concrete a 3 days b 7 days c 28 days d 60 days

### 4.2 Compressive strength for M40 grade concrete

The same pattern to that of M30 grade concrete was observed for M40 grade in 3 and 7 days, but for 28 days and 60 days the strength for PP material was improved to that of HDPE as shown in Fig. 6. The maximum compressive strength of 17.19 MPa for HDPE with 7.5% replacement of FA and similarly 15.31 for PP material at 5% partial replacement of FA at 3 days. The HDPE material achieved nearly same strength to that of conventional concrete (CC) for 7.5% replacement but for PP material it is observed that the compressive strength is 20% less than conventional concrete. As the curing time is increased to 7 days the maximum compressive strength of 27.97 MPa and 25.98 MPa for HDPE and PP respectively was observed. The compressive strength was reduced by 8% and 17% for 7.5% and 5% of HDPE and PP material respectively when compares with CC.

The pattern of PP was different for M40 grade concrete when compared to M30 grade concrete for 28 and 60 days. The compressive strength was improved for PP material when compared with HDPE material and even it was more than CC as shown in Fig. 6. The maximum compressive strength of 44.8 MPa for HDPE material with is 6% more than CC and 45.9 MPa for PP material which is 8% more than CC and 3% more than HDPE material at 5% replacement for both the materials at 28 days. The same pattern of HDPE material was observed in PP material but PP material achieved more strength then HDPE material at 5% replacement in concrete at 60 days. The maximum compressive strength of 45.9 MPa and 44.8 MPa for PP and HDPE material was observed as shown in Fig. 6. The increase in compressive strength by 6% and 3.5% for PP and HDPE material respectively at 5% for 60 days curing was observed.

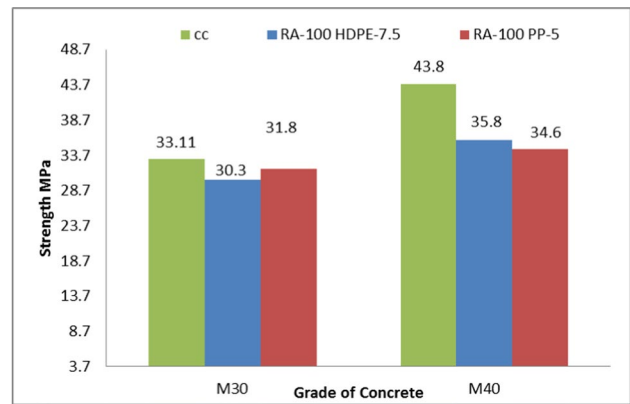
It is recommended that both the materials HDPE and PP showed an increment in compressive strength till 5% replacement in concrete, beyond which the strength was reduced but which was more than CC at 28 and 60 days.

### 4.3 Compressive strength for M30 and M40 grade concrete with 100% recycled aggregate

The coarse aggregate (CA) was completely replaced with recycled aggregate (RA) to find the compressive strength after 28days. It is clearly observed from the Fig. 7 that RA can be used to make 30–35 MPa strength with 7.5% HDPE and 5% PP respectively. For M30 grade concrete the PP material showed 4% less than CC but 4.9% more than HDPE.



**Fig. 7** Compressive strength of M30 and M40 concrete with 100% RA



The maximum compressive strength of 31.3 MPa for M30 grade concrete with 5% replacement of PP and 35.8 MPa for M40 grade concrete with 7.5% replacement of HDPE in concrete. For M30 grade concrete with 100% RA, PP gave more strength than HDPE but for M40 grade concrete the strength for PP was reduced when compared with HDPE. This is because the solid plastic particles occupy the voids present in the concrete, which helps in improving the mechanical property of concrete [25–27].

It is sustainable to use RA in concrete with HDPE and PP materials, as all the materials cause hazardous impact on environment. It is recommended to implement the use of RA, HDPE and PP in IS code to control and use of Construction and Demolish (C&D) waste and Plastic Waste (PW) on land-fills.

#### 4.4 Flexural strength for M30 grade of concrete

The flexural strength of concrete was calculated using IS 516–1959. The flexural specimen is shown in Fig. 8.

$$\text{Flexural strength} = \frac{PL}{bd^2} \quad (2)$$

where.

P= Load in N; L= Length (mm); b= width (mm); d= depth (mm).

The flexural strength of concrete with HDPE and PP as partial replacement in concrete is showed in Fig. 9. It is observed that there is a decrease in flexural strength by 0.22 MPa for 2.5% of PP and increase by 0.10 MPa of HDPE material in concrete at 3 days of curing. The same value of flexural strength i.e., 1.58 MPa for CC, HDPE and PP material at 3 days for 5% replacement was observed as shown in Fig. 9. As the percentage of HDPE and PP was increased to 7.5% the flexural strength for PP material was reduced by 0.14 MPa but it was reverse for HDPE material as the strength was increased by

**Fig. 8** Flexural specimens



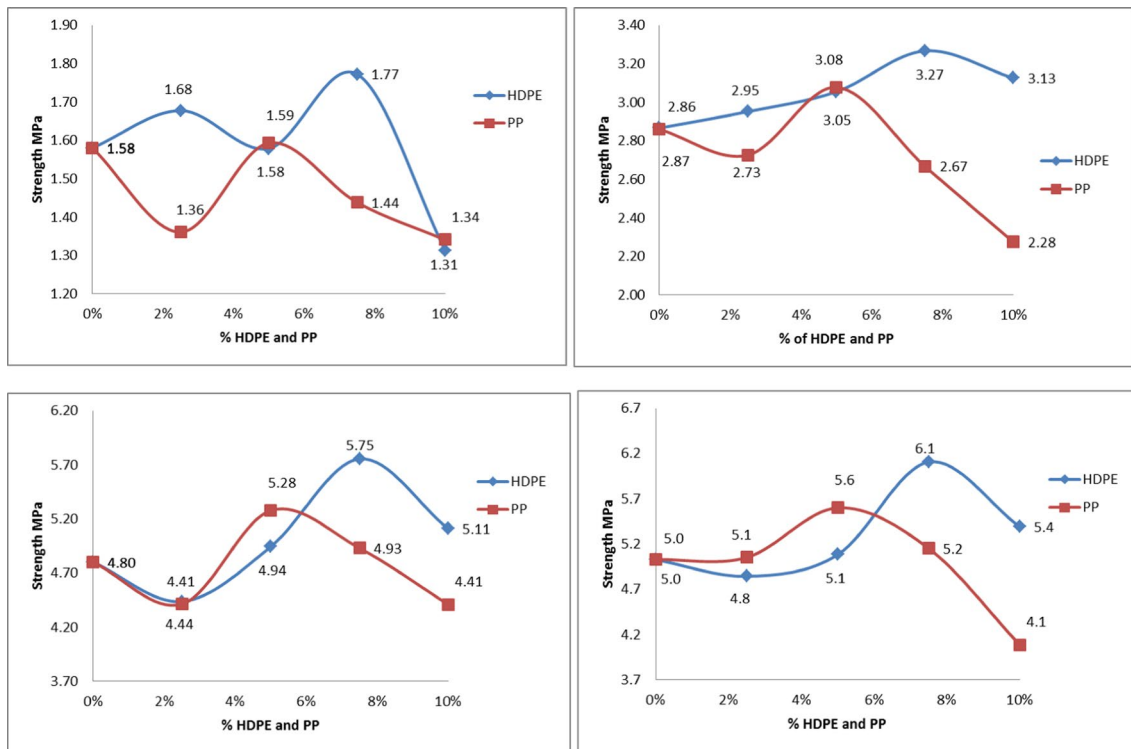


Fig. 9 Flexural strength of M30 grade concrete with HDPE and PP material at a 3days b 7days c 28 days d 60days

0.19 MPa at 3 days. For 10% replacement of both HDPE and PP material showed reduction in compressive strength by 0.27 MPa and 0.25 MPa respectively at 3 days. The similar study carried by R. I. Umasabor et.al. [31], showed that waste plastics (polyethylene terephthalate) can be used as an additive to improve the flexural strength of concrete [31].

As the curing time increased to 7 days the flexural strength for HDPE material showed an increase in strength for all the percentage replacement from 2.5% till 10% when compared with CC. But, for replacement of PP material there was reduction in strength by 0.05 MPa at 2.5% then there was increase in strength by 0.19 MPa for 5% and then there was drastic reduction for 7.5% and 10% replacement of PP material in concrete. The maximum flexural strength of 3.05 MPa was observed which 1.2% increase when compared with CC. The HDPE material when replaced in concrete showed a maximum flexural strength of 3.08 MPa which is 1.5% increase when compared with CC. The increase in strength was nominal (< 5%) at all the percentages when compared with CC.

The relationship between the mechanical properties of concrete was even discussed by Juki et al. [32]. The trend for 28 days and 60 days was similar for both the material for all percentage replacement in concrete. The maximum flexural strength of 5.28 MPa and 4.94 MPa for 5% of PP and HDPE material respectively at 28 days as shown in Fig. 9. At 5% replacement PP material showed more strength than HDPE and CC at 28 days, which shows that the optimum percentage of 5% can be incorporated in concrete. The HDPE material showed maximum flexural strength of 5.75 MPa for 7.5% replacement in concrete at 28 days. At 60days the maximum flexural strength of 5.6 MPa for PP material at 5% and 6.1 MPa for HDPE material at 7.5% replacement was observed as shown in Fig. 9. HDPE and PP material act as a promising material to improve the flexural strength of concrete. The optimum percentage of 5% and 7.5 for PP and HDPE material respectively can be replaced in concrete.

#### 4.4.1 Flexural strength for M40 grade of concrete

The flexural strength pattern was nearly similar to that of M30 grade concrete. The trend of 3 days and 7 days is same and 28 days and 60 days are same as shown in Fig. 10. The maximum flexural strength of 1.99 MPa was observed at 5% replacement of PP in concrete which is 0.06 MPa strength less than CC at 3 days. The remaining replacement of PP i.e., 2.5%, 7.5% and 10% showed less flexural strength than CC. The HDPE material showed 2.11 MPa and 2.33 MPa at 2.5% and 7.5% replacement in concrete which is 0.06 MPa and 0.18 MPa more than CC at 3 days. For 7 days, the maximum

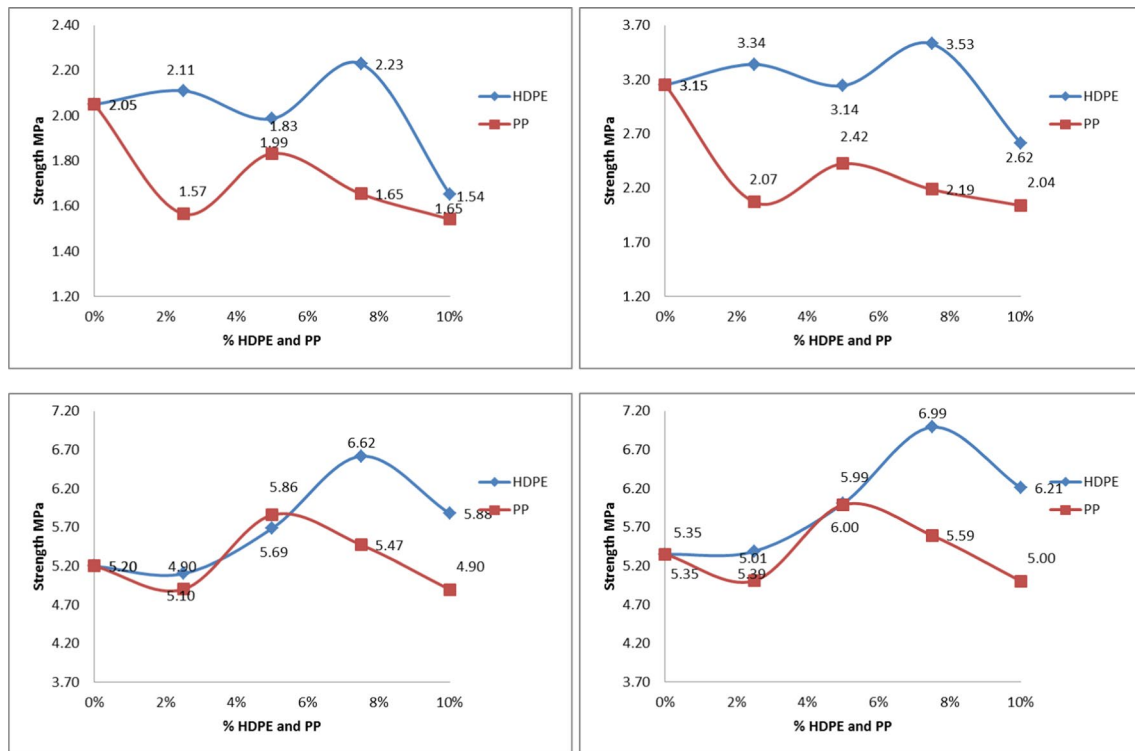


Fig. 10 Flexural strength of M40 grade concrete with HDPE and PP material at a 3days b 7days c 28 days d 60days

flexural strength of 2.42 MPa was observed in PP material which is 0.73 MPa less than CC. Similarly, for HDPE material 3.53 MPa was observed which 0.38 MPa is more than Conventional Concrete.

The trend for 28days and 60days were nearly same as shown in Fig. 10. It is observed that as the curing time increased for PP material the flexural strength increased by 0.66 MPa and 0.64 MPa for 28 days and 60 days respectively. When 2.5% of PP material was incorporated in concrete its flexural strength was reduced by 0.10 MPa but the strength was increased when 5% of PP material was replaced in concrete to 0.66MPa. But, when the percentage of PP was still increased to 7.5% and 10% the strength was reduced when compared with CC at 28 days.

In preparation of concrete mix, the flexural strength of concrete decrease because the HDPE and PP or any waste plastic material will be of plain, rounded with shiny surface which will not have good bond with the aggregates or cement paste in concrete. Because of less friction it loses its tendency to improve the flexural strength of concrete [33]. So, it is recommended to use less amount of plastic waste to achieve the targeted flexural strength [33].

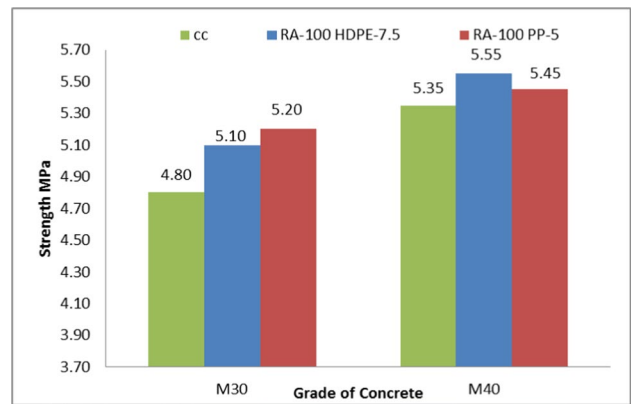
In concrete mix, the strength value is decreased by less bonding between add HDPE aggregates and cement paste. Concrete gives good compressive strength at the good bonding between ingredients in concrete. In this mix also concrete gives good strength at less HDPE and less strength at more HDPE material. Because of HDPE is flat, plain and shiny surface it will not easy to bonding with ingredients in concrete. That's why to use less quantity of HDPE gives targeted strength of concrete and more [6].

The flexural strength for 60 days in PP material was 5.20 MPa, 6.00 MPa, 5.59 MPa and 5 MPa at 2.5%, 5%, 7.5% and 10% respectively. Similarly, for HDPE material only 2.5% gave less value i.e., 5.01 which is 0.25 MPa less than CC but remaining percentages i.e., 5%, 7.5% and 10% gave more value than CC. The optimum percentage of PP and HDPE material in concrete to improve the flexural strength of concrete is 5% and 7.5% respectively.

#### 4.4.2 Flexural strength for M30 and M40 grade of concrete with 100% RA

The flexural strength for 100 × 100 × 500 mm specimen were casted with 100% RA and 7.5%/5% HDPE/PP material for 28 days and then tested in universal testing machine (UTM) of 1000 KN capacity. The flexural strength for PP material with 100% RA was 5.20 MPa which is 7.6% more than CC and 0.19% than HDPE for M30 grade concrete as shown in Fig. 11. When M40 grade concrete was prepared with 100% RA, it gave maximum flexural strength for HDPE material

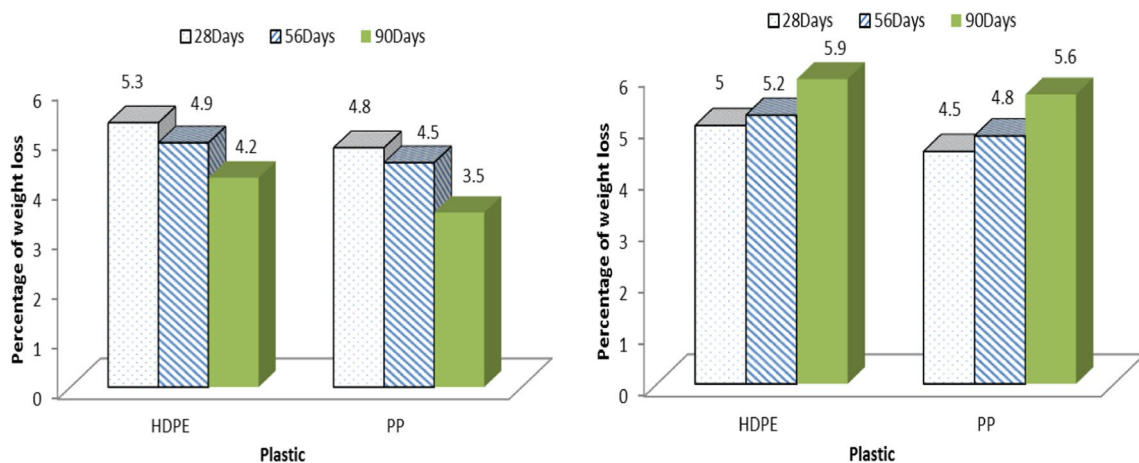
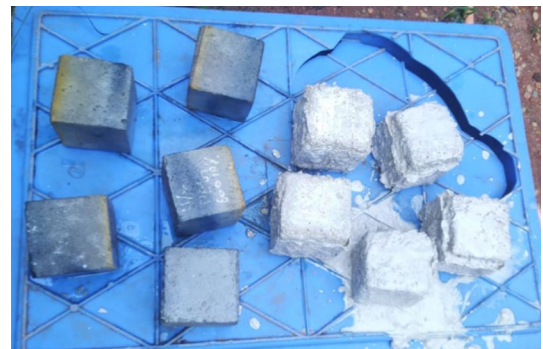
**Fig. 11** Flexural strength of M30 and M40 concrete with 100% RA



i.e., 5.55 MPa which is 3.6% more than CC and 1.8% more than PP. Both the materials HDPE and PP showed more value for flexural strength when compared with CC.

It is observed from the Fig. 11 that 100% usage of RA to prepare M30 or M40 grade concrete with 7.5% HDPE and 5% PP material for flexural strength achieved more strength than CC. Even PP material with RA gave 7.6% more strength for M30 grade concrete and 1.8% for M40 grade concrete when compared with CC.

**Fig. 12** Acid and Sulphate attack



**Fig. 13** Acid attack **a** M30 grade **b** M40 grade

## 4.5 Durability for M30 and M40 grade concrete

### 4.5.1 Acid attack

The acid attack for 5% of HCL was conducted (ASTM C, 262–2001) for both HDPE and PP material for M30 and M40 grade concrete is shown in Fig. 12. The sulphate attack for M30 grade concrete gave reduction in percentage of weight loss than CC at all the ages. The trend of acid attack for HDPE and PP was similar for M30 grade concrete but this trend was quite opposite for M40 grade concrete as shown in Fig. 13. The maximum reduction was 4.2% and 3.5% for HDPE and PP material at 90 days for M30 grade concrete.

A similar case study was carried by some of the authors [35]. For M40 grade concrete the percentage of weight loss was increased for all the ages as shown in Fig. 13. The maximum increase in weight loss was 5.9% for HDPE material and 5.6% for PP material at 90 days. The least percentage loss was observed at 28 days for both HDPE and PP material but for 56 days and 90 days the percentage loss of weight was significantly less (< 5%).

### 4.6 Sulphate attack

The sulphate attack was conducted (ASTM C 1012–2012) on both HDPE and PP material for M30 and M40 grade concrete. The pattern of HDPE and PP material for M30 grade concrete was same at all the ages but for M40 grade concrete the HDPE material showed less percentage weight loss at 56days but the percentage weight loss was gradually decreasing for PP material as shown in Fig. 14. The maximum percentage weight loss was observed at 28days for both M30 and M40 grade concrete i.e., 8.9% and 8.5% for HDPE and 8.5% and 8.2% for PP material respectively.

Generally, the sulphate ions which are present in water penetrate into the concrete and these ions interact with the cement paste which forms mineral components that leads to expansion of concrete. The sulphate attack test is the important parameter to judge the durability of concrete which expands internally and starts deterioration [34].

A similar case study was carried by some of the authors [35]. The percentage weight loss for both M30 and M40 grade concrete was less than 10% at all the ages. The weight loss for M30 and M40 grade concrete was nearly same i.e., 8.9% and 8.5% respectively. The above sulphate attack can be reduced using by using admixtures such as flyash, GGBS, allcofine etc. The sulphate attack for both M30 and M40 grade concrete showed less than 10% percentage loss in weight till 90 days.

#### 4.6.1 Thermal conductivity for M30 grade concrete

Thermal Conductivity (TC) (k) test was performed on all the specimens according to IS 3346 (1980). The specimen of dimension 180 mm dia and 20 mm thick was prepared to find the one dimension heat transfer in the specimens as shown in Fig. 15.

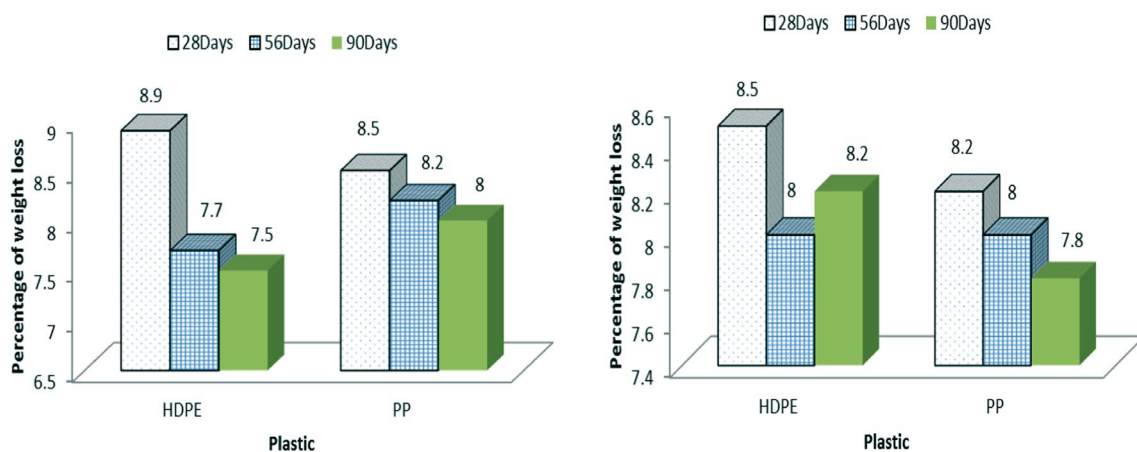


Fig. 14 Sulphate attack **a** M30 grade **b** M40 grade



**Fig. 15** Thermal conductivity apparatus with the specimen

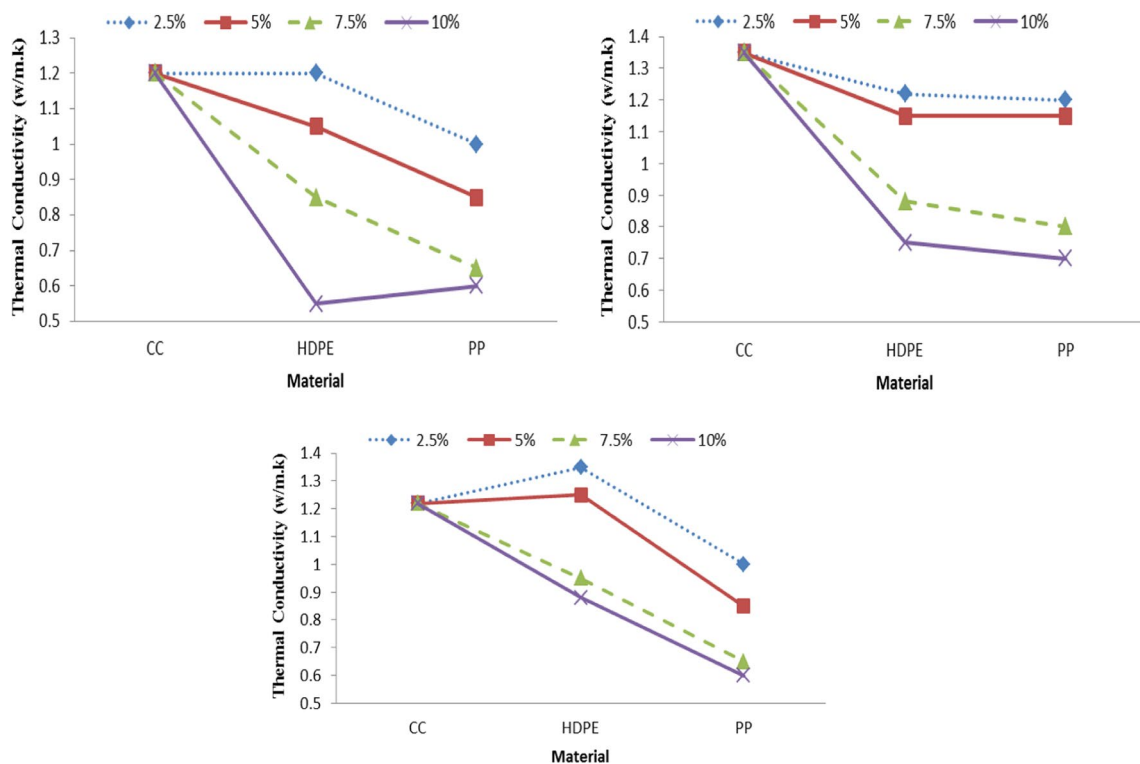


The thermal resistance is inversely proportional to TC. It gives the characteristics properties such as surface area, temperature gradient, material property and thickness in a steady state heat flow condition [36]. According to Fourier's law Eq. (3) [39], the TC is a material characteristic property which can transfer the heat from higher temperature to lower temperature. According to the case study of Klein [37] the TC of LDPE, HDPE and PP material was 0.35, 0.43 and 0.23 W/(m·K), while the TC of normal conventional concrete was in the range of 1.34–2.92 W/(m·K), which is nearly 3–13 times higher [38]. A similar study carried by Tae Sup Yun et al. [30] showed that the TC of concrete and mortar was 2.0 W/(m·K). The concrete with plastic fibers helps in reducing the TC due to its property.

To average strength of two specimens for each mix is prepared to ensure the heat flows only through the specimens only. The value of k can be calculated using Eq. (3).

$$K = \frac{Q}{2A} \left( \frac{L}{T_h - T_c} \right) \tag{3}$$

where; K=Thermal Conductivity of sample, W/m<sup>2</sup>.k (In S.I. units).



**Fig. 16** Thermal conductivity for **a** 3days **b** 7days **c** 28days



Q= Heat flow rate in the specimen, Watts (In S.I. units).  
 A= Metering area of the specimen, m<sup>2</sup>.  
 T<sub>h</sub>= Temperature of Hot plate, °C.  
 T<sub>c</sub>= Temperature of Cold plate, °C.  
 L= Specimen thickness, m

The thermal conductivity (K) was reduced for both HDPE and PP material when compared with conventional concrete (CC) as shown in Fig. 16. The maximum reduction was observed in HDPE material by 55% when compared with CC for 10% replacement. The value of K for CC was 1.2 w/m.k, 1.35 w/m.k and 1.22 w/m.k for 3 days, 7 days and 28 days respectively. As the curing days increased to 28days the K value was less for PP material rather than HDPE material i.e., 0.6 w/m.k.

#### 4.6.2 Thermal conductivity for M40 grade concrete

The thermal conductivity (k) for M40 grade concrete was 1.11 w/m.k, 0.12 w/m.k and 1.11 w/m.k for 3 days, 7 days and 28 days respectively for CC. As plastic cannot transfer the heat, the thermal conductivity was reduced for both HDPE and PP. The maximum reduction in K value was same for both HDPE and PP material i.e., 0.82 w/m.k for 3 days for 10% replacement. similarly, the K value for both the materials for 7 days and 28 days was 0.75 w/m.k respectively for 10% replacement as shown in Fig. 17.

The above material act as a promising material to reduce K value till 10% for HDPE and PP material in both M30 and M40 grade concrete. By utilizing the waste plastic from dumping yards in construction of rigid pavements, paver blocks, commercial/residential buildings can save the environment.

### 5 Conclusions

The above material HDPE and PP for different mechanical, durability and thermal properties were evaluated.

- The compressive strength of HDPE was 42.90 MPa for 7.5% replacement after 60 days.

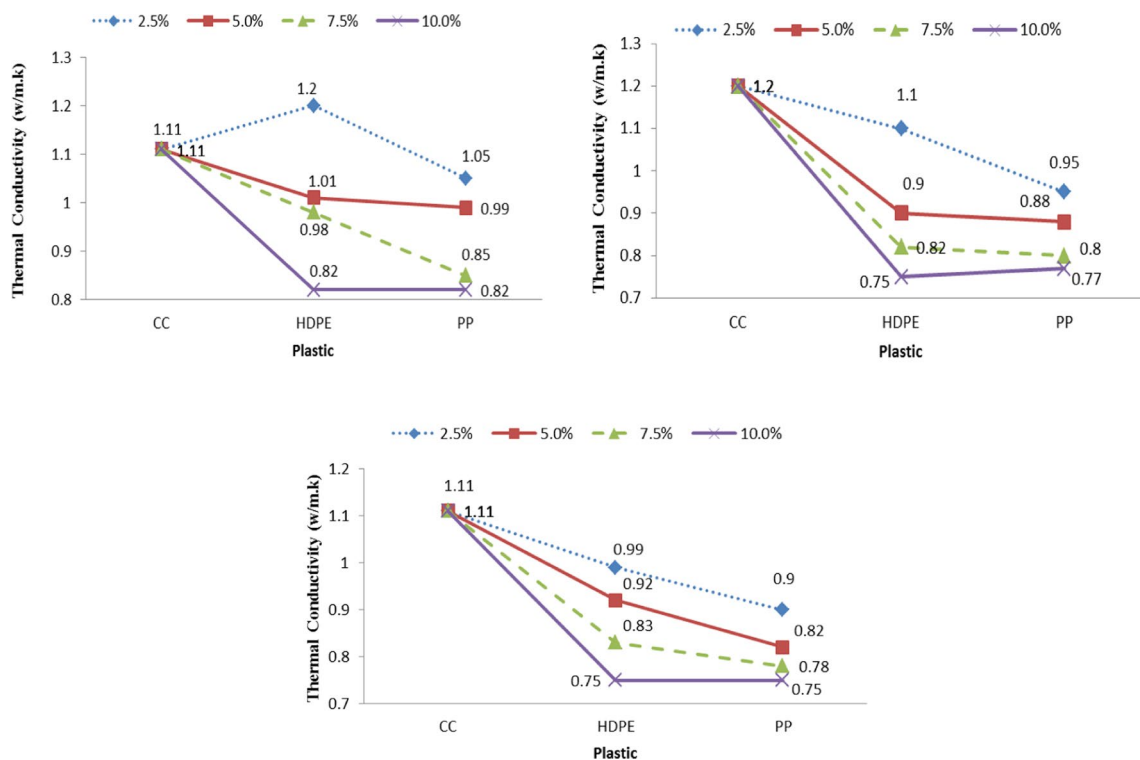


Fig. 17 Thermal conductivity for a 3days b 7days c 28days

- It is recommended that both the materials HDPE and PP showed an increment in compressive strength till 5% replacement in concrete, beyond which the strength was reduced but which was more than CC at 28 and 60 days.
- The replacement of coarse aggregate with recycled aggregate gave nearly same strength to that of conventional concrete for both M30 and M40 grade concrete.
- The flexural strength with 100% RA gave more strength for both M30 and M40 grade concrete for 7.5% HDPA and 5% PP.
- The optimum percentage of 5% and 7.5 for PP and HDPE material respectively can be replaced in concrete.
- The least percentage loss was observed at 28 days for both HDPE and PP material but for 56 days and 90 days the percentage loss of weight was significantly less (< 5%).
- The sulphate attack can be reduced using by using admixtures such as flyash, GGBS, alccofine etc. The sulphate attack for both M30 and M40 grade concrete showed less than 10% percentage loss in weight till 90 days.
- As the curing days increased to 28 days the K value was less for PP material rather than HDPE material i.e., 0.6 w/m.k.
- The maximum reduction in K value was same for both HDPE and PP material i.e., 0.82 w/m.k for 3 days for 10% replacement. Similarly, the K value for both the materials for 7 days and 28 days was 0.75 w/m.k respectively for 10% replacement.

## 6 Further studies

It is recommended to conduct microstructural properties, different thermal properties, use of different waste plastics in different types of concrete.

**Author contributions** Suvidha Y1: She is the research scholar and she has performed all the experiments. Umesh Jain2: He is the research supervisor, who helps in guiding the proper research, publication help. C. Arvind Kumar3: He is co-supervisor, he helps conducting and performing the specific experiments and in doing good research, writing paper and publication help.

**Data availability** All data underlying the results are available as part of the article and no additional source data are required.

## Declarations

**Competing interests** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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