Performance of Recycled Plastic Waste and Used Foundry Sand as a Replacement of Fine Aggregate in Concrete

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1 Introduction

In the construction sector concrete is a universally used material. In addition to cement, the production of concrete includes both sand and aggregate. The quarrying operations needed for sand and aggregate production are an energy-intensive process that results in a considerable amount of waste. In addition, the shortfall of sand (fine aggregate) and coarse aggregate has led to long-distance transportation and high costs in many countries like India, United States, etc. [1]. In recent years due to the global warming issues, environmental protection policies have led the construction sector to look for various alternatives for cement such as ground granulated blast furnace slag, fly ash, bottom ash, ferrochrome ash, etc. [2–9]. and sand such as used foundry sand (UFS), ferronickel slag aggregate crusher dust (CD), recycled plastic waste (RPA), etc., [10–12] and coarse aggregates such as construction demolition waste, industrial slag aggregates and tailings, etc. [13–15]. Today, there is a need and requirement to do research in the utilization of recycled HDPE (High Density Polyethylene) plastic waste (RPA) and used foundry sand (UFS) in various fields such as the construction sector, recycled plastic manufacturing units, etc. In addition to having useful and realistic application of plastics, contributes to improvement of energy efficiency of buildings, the cost of realization, enhancing the quality of life and conserve the environment. However, this method is not a leading method for disposing of the wastes. The present work is aimed to study the mechanical properties of concrete modified by RPA and UFS as FA replacements ranging from 5 to 30% by volume, to produce sustainable concrete [16].

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2 Materials

In the present study, the materials used are cement, sand, coarse aggregate, water, used foundry sand and recycled HDPE plastic waste aggregate.

2.1 Cement

43 grade Ordinary Portland Cement (OPC) is used with fineness of 225 m^2/kg. The composition of chemical and mineralogical classification shown in Tables 1 and 2 are determined using X-ray Fluorescence (XRF) and EDX respectively. The mechanical properties of the cement are done confirming to IS 455:1989 [17] and the results are given in Table 3.

2.2 Recycled Plastic Waste Aggregates (RPA)/HDPE

RPA from waste/refused pipes as shown in Fig. 1 is brought from the Murthy industries in Visakhapatnam (India) are ground in a knife mill to produce aggregates smaller than 4.36 mm in size, RPA/HDPE properties is shown in Tables 4 and 5. RPA is used as a partial substitution of fine aggregate and is tested according to IS 2720 (Part 3), IS 2386 (Part 1 and 3) [18–20].

Table 1 Chemical composition of (OPC) cement

Component (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	Na_2O	PAF	MgO	SO_3	Cl^-	H_2O
Cement	17.05	4.15	2.6	61.44	0.55	0.45	9.9	1.45	2.34	0.016	0.41

Table 2 Mineralogical composition of clinker (%)

Minerals	C_3S	C_2S	C_3A	C_4AF
Cement	62	16	7	13

Table 3 Mechanical properties of cement

Fineness (%)	Normal consistency (%)	Setting time (min)	Soundness (mm)	Specific gravity	Compressive strength (N/mm^2)
2	32	Initial = 48; Final = 252	2	2.93	44.6

Fig. 1 **a** Corrugated tubes-HDPE, **b** HDPE waste

Table 4 Physical properties of fine aggregates

Sand (FA)	Natural	HDPE/RPA
Shape	Angular	–
Apparent volumetric mass (g/cm^3)	1.53	0.363
Actual density (g/cm^3)	2.64	0.923

Table 5 Mechanical properties of FA

FA	Fineness modulus	Specific gravity	Bulking (%)
Natural sand	2.27	2.54	6
UFS	2.45	2.7	8
HDPE/RPA	3.11	–	–

2.3 Used Foundry Sand (UFS)

UFS used in this study is obtained locally from ferrous foundry located in the Visakhapatnam, India, which produces metal/alloy components for the automotive industry. UFS is used as a partial replacement of fine aggregate and mechanical properties of same are given in Table 5 and is tested according to IS 2720 (Part 3), IS 2386 (Part 1 and 3) [18–20].

2.4 Natural Sand

Sand used in this study is obtained locally in Rajam, India. Sand size is less than 4.36 mm and the main properties of same are given in Tables 4 and 5 and is tested according to IS 2720 (Part 3), IS 2386 (Part 1 and 3) [18–20].

Table 6 Mechanical properties of CA

Fineness modulus	Specific gravity	Water absorption	Flakiness	Elongation
7.81	2.66	0.3%	4.81%	24.87%

2.5 *Coarse Aggregate*

CA used in this study is obtained locally in Rajam, India. The CA size is 20 mm down and the mechanical properties of the same are given in Table 6. The individual aggregates were blended to get the desired combined grading is tested according to IS 2720 (Part 3), IS 2386 (Part 1 and 3) [18–20].

3 Methodology

3.1 *Mix Design*

M20 grade concrete mix proportion of 1:1.63:3.19 design is done confirming to IS 10262:2009 [21]. A constant water to cement ratio (W/C) of 0.5 is used for all types of mixes, out of seven mixes, six mixes which are referred as non-conventional mix (NCM) are prepared by substituting natural sand with 5, 10, 15, 20, 25 and 30% of UFS and RPA and the rest of the mix is control mix (CM) without UFS and RPA. To simplify, all the seven mixes are labelled as CM, NCM5, NCM10, NCM15, NCM20, NCM25 and NCM30 and the detailed mix proportions are given in Table 7. For example, NCM5 indicates that the concrete mix containing cement, 95% natural sand, 5% of UFS and RPA a replacement of natural sand, coarse aggregate and water whereas CM indicates a mix with cement (OPC), natural/river sand, coarse aggregate and water.

Table 7 Concrete mix proportions

Ingredients	CM	NCM5	NCM10	NCM15	NCM20	NCM25	NCM30
Water (Kg/m^3)	186	186	186	186	186	186	186
Cement (Kg/m^3)	372	372	372	372	372	372	372
Fine aggregate (Kg/m^3)	609	609	609	609	609	609	609
Coarse aggregate (Kg/m^3)	1189	1189	1189	1189	1189	1189	1189
Used foundry sand (Kg/m^3)	–	30.45	60.9	91.35	121.8	152.25	182.7
Recycled plastic aggregate (Kg/m^3)	–	30.45	60.9	91.35	121.8	152.25	182.7

3.2 Preparation of Specimen

The concrete mixes are filled in cube moulds of size 150 mm × 150 mm × 150 mm in three layers and subsequently compacted in a table vibrator. Total of 21 specimens is prepared subjected to 3 for each type of mix. Later all specimens are covered with polythene sheets to avoid moisture loss and kept in room temperature for 24 h and thereafter demoulded, kept in curing tanks filled with water until the day of the test. The cube specimens of all types mixes are tested for compression capacity in compression testing machine (CTM—2000 kN capacity) according to IS 516:1959, IS 456:2000 [22, 23].

4 Result and Discussion

4.1 Workability

Slump cone test was used to determine the degree of workability of control and the non-conventional concrete mixes. The influence of UFS and RPA on the slump of mixes were shown in Fig. 2. From the figure, it was evident that workability reduced up to NCM30. The substitution effect of UFS and RPA in NCM5 and NCM10 on workability were insignificant and were comparatively equal to the CM, but there

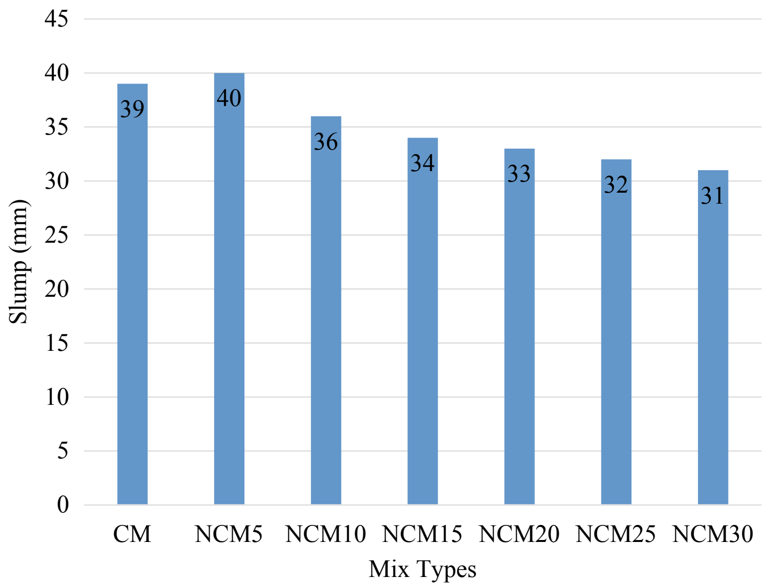

Fig. 2 Workability of all mixes—Comparison

was a higher loss in the workability for substitution rates of 15, 20, 25 and 30% was observed. The workability and fineness of the material were directly related, 8% of particles of UFS has a lesser size than 75 µm compared to natural sand and also UFS consists of particles of clay and ash, due to which water absorption of UFS was high and resulted in low slump values. Slump loss usually happens due to the hydration of water from the concrete. Based on the fineness of the substitution, the decision was made to adjust the water content to the mixes. However, the addition of RPA along with UFS does not lead to major water loss.

4.2 Compressive Strength

The compression capacity of all types of mixes for various curing days such as 7, 14, 28, 56 and 90 days was measured. The results were shown in Table 8 and the same were represented graphically in Fig. 3. It is evident from the results that 28 days compressive strength of the mix NCM5 (i.e., natural sand replaced by UFS and RPA at 5%) was 2.61% higher than CM. However, the 28 days compressive strength of all other mixes NCM10, NCM15, NCM20, NCM25 and NCM30 were 10.16, 38.87, 40.67, 43.17 and 45.26% respectively lower than CM. A decrease in concrete strength was observed in all the curing periods with the increment in the replacement rates of UFS and RPA. Presence of high silica in the UFS would help to enhance the process of hydration and increase the C3S formation considerably. However, the UFS fineness, decreases the concrete workability and the compressive strength and also simultaneous replacement of natural sand with RPA in concrete does not involve in the hydration process, after drying, the free water makes small channels, it results in tiny pores in the concrete [24] and thereby reduced the strength with increment in its substitution rate as shown in Fig. 4. (ASTM Type 1) ACI 209

Table 8 Compressive strength of all mixtures

Mixture Id	Percentage replacement (%)	Experimental compressive strength (N/mm^2)					Calculated compressive strength (N/mm^2) as per ACI 209 (Type 1)	
		7 days	14 days	28 days	56 days	90 days	56 days	90 days
CM	0	17.18	22.46	28.35	30.54	31.05	30.77	31.70
NCM5	5	17.53	23.53	29.09	31.62	32.12	31.57	32.52
NCM10	10	16.7	18.48	25.47	26.97	27.62	27.64	28.48
NCM15	15	15.2	17.24	17.33	18.24	19.21	18.81	19.38
NCM20	20	13.4	16.73	16.82	18.05	18.52	18.25	18.80
NCM25	25	12.35	16.27	16.11	17.01	17.95	17.48	18.01
NCM30	30	12.12	14.32	15.52	15.74	17.12	16.84	17.35

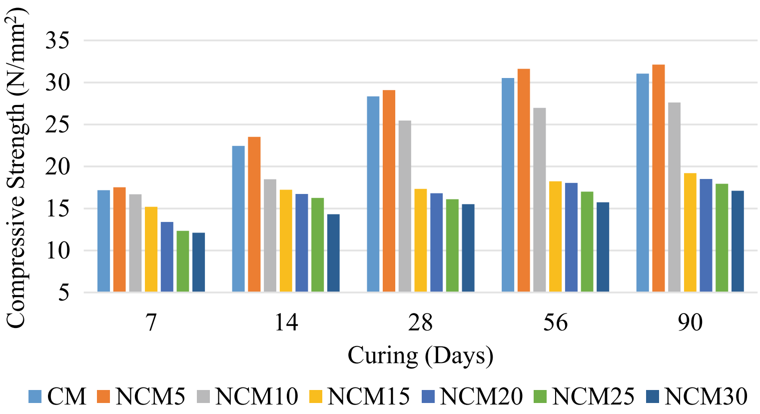

Fig. 3 Compressive strength of all mixes at various curing days—comparison

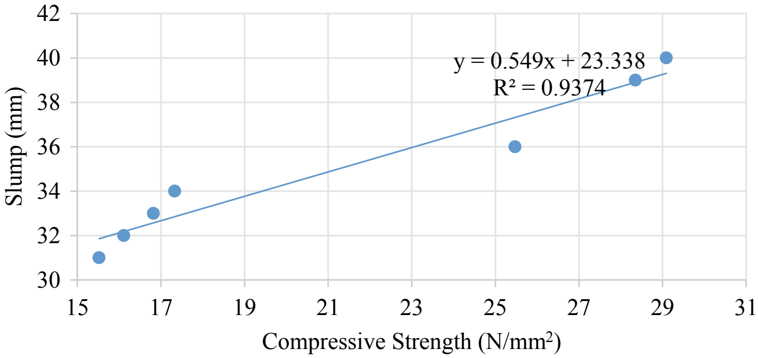

Fig. 4 Compressive strength (28 days) and slump

recommended the Eq. (1) to determine the strength of concrete in compression with time [25].

$$f_{cm}(t) = f_{c28}\left(\frac{t}{4 + 0.85t}\right) \tag{1}$$

where $f_{cm}(t)$ indicates average compressive at t days, f_{c28} indicates 28 days average compressive strength and t indicates age of concrete in days. The calculated compressive capacity of concrete for 56 and 90 days is computed using Eq. (1) and the values are presented in Table 8. The relation between experimental and calculated compressive strength of concrete for 56 and 90 days are shown in Fig. 5, it showed that the experimental and calculated values are in well agreement with $R^2 = 0.999$.

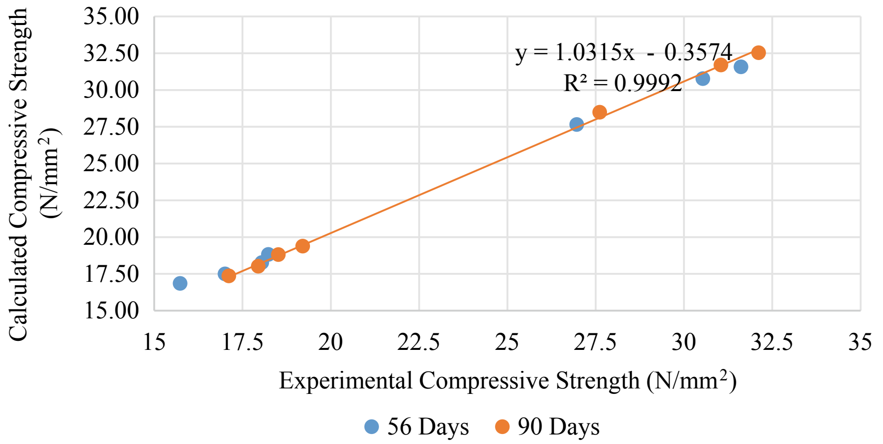

Fig. 5 Experimental and calculated compressive strength

According to IS 13311(Part 1):1992 [26], the durability property of all types concrete mixes at 28, 56 and 90 days were determined with Ultra Sonic Pulse Velocity (UPV). From the results, it was concluded that the measured NCM5 UPV values were slightly greater than CM UPV values, the values measured for mixes (NCM5 and NCM10) were higher than 3500 m/s, that was categorized as good, whereas for other mixes (NCM15, NCM20, NCM25 and NCM30) the measured UPV values were in between 3300 and 3500 m/s as RPA is not involved in a chemical reaction with cement resulted in voids and due that UPV values, these mixes were categorized as medium. Figure 6 demonstrates the relationship between the UPV and concrete compressive strength, wherein results were good agreement with $R^2 = 0.9189$. From the experimental results, it was evident that for producing good concrete, UFS and

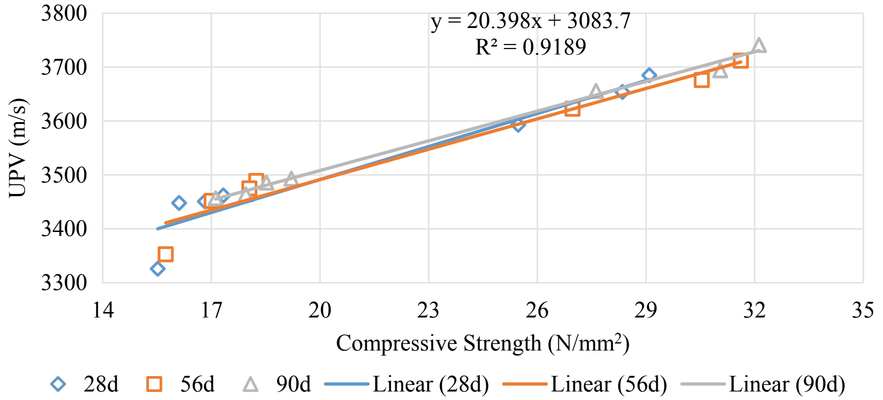

Fig. 6 Compressive strength and UPV values of concrete at all ages

RPA up to 5% can be used as a fine aggregate without compromising the strength parameter.

4.3 Density of Concrete

The 28 days density of all mixes against the slump indicated that due to the increase in the porosity resulted in the poor workability of the mix and thereby causes a reduction in the compaction of the mix. From Fig. 7, it was evident that with an increase in porosity, concrete density reduced. It was also understood that due to the addition of RPA and UFS in concrete, which are lightweight compared with natural sand resulted in less dry density with the decrease in the slump value. In general, the concrete density was influenced by the material physical properties. Still in India, clay, sawdust and ash were used as binding agent in the foundry industries. The specific density of the material was reduced due to the presence of those particles. Due to the presence of RPA and it's less bonding in the concrete, its density decreased. The variation of dry density with compressive strength of concrete of all mixes at 28 days indicated with the increase in substitution rates of UFS and RPA reduced the compressive strength, which is directly related to the dry density as shown in Fig. 8 [27].

4.4 Elastic Modulus

The elastic modulus was predominantly effected by the elastic properties of aggregate and to a lesser extent on the age of concrete, type of curing, mix proportions and cement type. The modulus of elasticity was calculated from the compressive strength

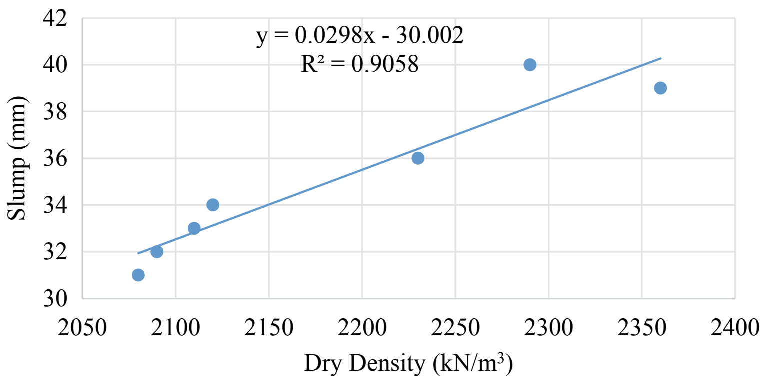

Fig. 7 Slump and dry density of concrete at 28 days

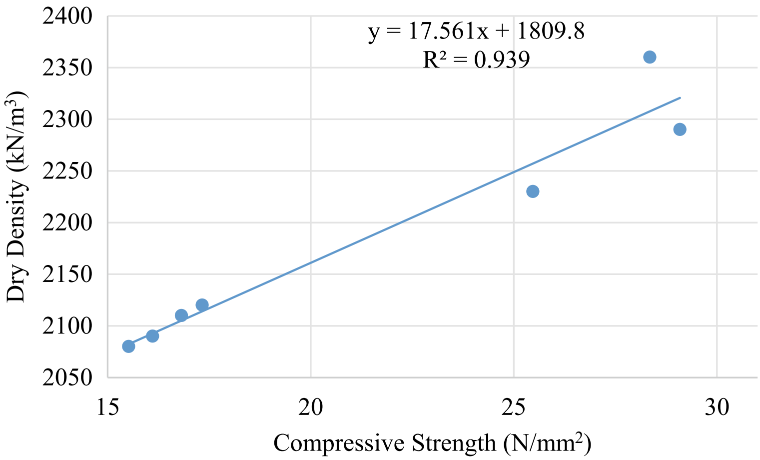

Fig. 8 Dry density and compressive strength of concrete at 28 days

obtained and UPV values using the Eqs. (2) and (3) recommended by IS 456:2000 and IS 13311(1):1992, respectively and is shown in Fig. 9.

$$E_c = 5000\sqrt{f_{ck}} \tag{2}$$

$$\mathrm{E} = \rho V^2 \frac{(1+\mu)(1-2\mu)}{(1-\mu)} \tag{3}$$

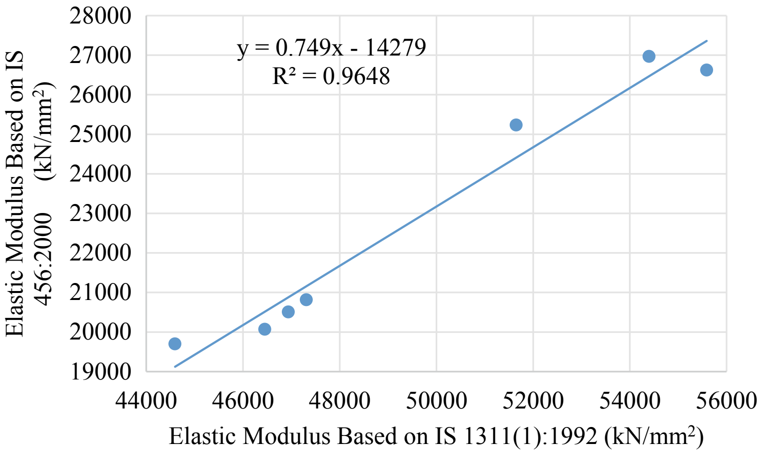

Fig. 9 Elastic modulus based on IS 1311(1):1992 and IS 456:2000 at 28 days

where E indicates dynamic elastic modulus (MPa), fck indicates compressive strength of concrete, ρ indicates density of concrete in kg/m^3, V indicates pulse velocity in m/s and μ indicates dynamic Poisson's ratio of the concrete. There was no substantial difference between the modulus of elasticity calculated using IS 456:2000 and IS 13311(1):1992, and the values were relatively similar ($R^2 = 0.9648$) [28, 29].

5 Conclusion

Based on the test results of the present work on the combined influence of UFS and RPA as a partial replacement of fine aggregate in the production of concrete, the following conclusions were drawn.

1. Compressive strength, slump and modulus of elasticity for 5% replacement of natural sand with combined UFS and RPA (i.e., NCM5) shown slightly higher values (i.e., 2.61, 2.56 and 1.29% respectively) when compared with control mix.
2. Dry density for 5% replacement of natural sand with combined UFS and RPA (i.e., NCM5) shown slightly lesser value (i.e., 2.97%) when compared with control mix.
3. Concrete mix (NCM5) of all ages (i.e., 28, 56 and 90 days) showed slightly higher values in durability like ultrasonic pulse velocity when compared with the control mix.
4. When compared to the CM, all the NCM mixes showed inferior values except NCM5, because of presence of fineness, clay, sawdust and ash in UFS and no reaction of RPA with cement matrix.
5. The mechanical and durability properties of NCM5 concrete mix showed slightly higher values compared with the control mix.
6. The experimental results showed that UFS and RPA can be effectively utilized up to 5% replacing natural sand in the concrete mix without affecting the concrete properties.

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