Innovating Concrete with Recycled Plastic (HDPE) Aggregates

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ABSTRACT

This research investigates the performance of HDPE plasto sand coarse aggregate concrete using a water-cement (w/c) ratio of 0.60. Four different handmade aggregate types with ratios of 1:1, 1:2, 1:3 and 1:4 was utilized to assess the mechanical and durability properties of the concrete. Comprehensive tests, including compressive strength, tensile strength, and durability assessments, were conducted to evaluate the effectiveness of HDPE aggregates in concrete. The integration of recycled high-density polyethylene (HDPE) aggregates offers a sustainable alternative in concrete production. This study assesses the feasibility and effectiveness of utilizing recycled plastic aggregates to enhance concrete performance through material characterization studies to understand the physical and mechanical properties of HDPE aggregates and their compatibility with cementitious matrices. The influence of varying proportions of recycled plastic aggregates on the fresh and hardened properties of concrete is also investigated. Principal findings reveal that recycled HDPE aggregates can positively impact concrete properties, contributing to improved workability without compromising mechanical strength. Additionally, the use of recycled plastic reduces the environmental footprint of concrete production by diverting plastic waste from landfills. In conclusion, this research underscores the viability of innovating concrete with recycled plastic aggregates, presenting a sustainable solution for addressing environmental concerns while enhancing material performance. The findings hold significant implications for the construction industry, advocating for eco-friendly practices in concrete production.

Keywords: Concrete, Recycled plastic aggregates, High-density polyethylene (HDPE), Sustainability, Material characterization.

Introduction

In recent years, the construction industry has increasingly focused on the use of recycled materials to enhance sustainability and reduce environmental impact. High-Density Polyethylene (HDPE) plastic aggregates have emerged as a promising candidate for replacing conventional aggregates in concrete due to their lightweight nature and environmental benefits. Studies have demonstrated that HDPE aggregates can reduce the weight of concrete while maintaining satisfactory mechanical properties (Marzouk et al., 2007). Additionally, using

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plastic aggregates in concrete enhances durability by reducing water absorption and increasing resistance to chemical attacks (Ismail and Al-Hashmi, 2008). Research has shown that HDPE aggregates significantly improve the toughness and impact resistance of concrete, making it suitable for various structural applications (Choi et al., 2005). Furthermore, the substitution of natural aggregates with recycled plastic helps in waste management and reduces the carbon footprint of concrete production (Siddique et al., 2008). The compatibility of HDPE aggregates with cementitious matrices has also been explored, revealing good bonding characteristics and ensuring structural integrity (Rahman et al., 2012). HDPE aggregates have been found to enhance the thermal resistance of concrete, making it more energy-efficient for building applications (Soroushian et al., 2003). Comprehensive reviews of mechanical and durability properties of concrete with recycled plastic aggregates reinforce the potential of plastic aggregates to improve concrete performance while addressing environmental concerns related to plastic waste (Alqahtani et al., 2019). Other studies have further confirmed these findings, with Gupta et al. (2017) noting the improvement in freeze-thaw resistance, and Babu and Babu (2003) highlighting the reduction in permeability. Plastic aggregates have also been found to improve the flexural strength of concrete, as observed by Saikia and Brito (2012). The environmental benefits extend to reduced greenhouse gas emissions during production, as reported by Silva et al. (2014). Kim et al. (2010) discussed the positive effects on concrete's fire resistance properties. A meta-analysis by Huang et al. (2020) underscored the overall efficiency of plastic aggregates in enhancing multiple concrete properties simultaneously. More recent research by Zhang et al. (2021) and Wang et al. (2022) has shown the long-term durability and sustainability benefits of using HDPE aggregates. These extensive studies collectively highlight the promise of HDPE plastic aggregates in developing sustainable, high-performance concrete.

Materials and Methods

The only material utilized in the concrete mixes in this investigation was HDPE plasto-sand aggregates, which were handmade from HDPE plastic waste. To ensure that the cement (Ramco brand 53 grade) and fine aggregates could be utilized to create concrete, the experimental activity included conducting basic tests on them. The next step was to combine the HDPE-plasto-sand aggregates cement with varying concentrations of plastic at constant amount of sand. To determine the consistency and ease of working with new concrete, experiments were conducted on its slump. The mechanical properties of cured concrete were investigated by testing its compressive, tensile, and flexural strengths. The durability and performance of the HDPE-enhanced concrete were further investigated through other experiments, including the measurement of its density and surface resistance. The various aggregates produced from recycled HDPE plastic and sand in different ratios are depicted in Figure 1: one part sand to one-part recycled HDPE plastic (1:1), one part sand to two parts recycled HDPE plastic (1:2), one part sand to three parts recycled HDPE plastic (1:3), and one part sand to four parts recycled HDPE plastic (1:4). ASTM C330/C330M and IS 383-2019 criteria are met by the cumulative percentage passing of the coarse aggregate employed.

Fig.1 mix photo of 1:1, 1:2, 1:3 and 1:4 type of aggregates with fine aggregates and cement.

Physical Properties of Recycled HDPE Plastosand coarse Aggregates (RHPSCA)

The physical properties of recycled HDPE plastosand coarse aggregates (RHPSCA) for different mix ratios (1:1, 1:2, 1:3, and 1:4) are summarized in Table 1. These properties were measured according to Indian and American standards. Aggregate impact values, abrasion values, flakiness index, and elongation index were determined as per IS 2386-1963. Bulk density values, measured according to ASTM C330-99 (Table-2), vary (for 1:1, 1:2, 1:3, and 1:4) with HDPE content. Absorption percentages, measured according to ASTM C128, indicate minimal water absorption. The particle shape is sub-angular, classified as crushed type with a nominal maximum size of 20 mm (ASTM C33). Surface texture is partially rough or porous, enhancing cement bond. Specific gravity, tested as per IS 2386-1963, is consistent across all mixes, with all aggregates being brown in colour.

Table 1. Physical properties of RHPSCA

Physical Property.	1:1-RHPSCA	1:2-RHPSCA	1:3-RHPSCA	1:4-RHPSCA
Aggregate impact value.	4.74	8.7	8.31	8.91
Abrasion value.	7.9	8.2	8.7	9.3
Flakiness index.	12.7	13.1	13.9	14.5
Elongation index.	13.7	12.6	14.3	15.0
Bulk Density(kg/m3).	703	713	757	765
Absorption (%).	0.40	0.85	0.50	0.605
Specific Gravity (IS:2386-1963).	1.65	1.66	1.74	1.77

Mixture proportions

The mix design method used for this concrete mix follows ACI 211.2-98 (reapproved 2004). The exact mix proportions were derived from the method detailed in "Recycled Plastic (HDPE) Coarse Aggregate Manufacturing Method and Performance in Concrete" by Vinod Kumar

Ratod and Dr. Rupesh Kumar Dhondy. This method serves as the basis for the concrete mix used in this study.

Table 2: Particulars of the mixed concrete.

W/C ratio	Type of sample	Cement Kg/m^3	Water Kg/m^3	Fine aggregate Kg/m^3	Coarse aggregate Kg/m^3	Superplasticizer Kg/m^3	Density Kg/m^3
0.65 (with 2% air content (ACI211.2-98))	1:1 RHPSCAC	238	187	1190	506	2.38	2000
	1:2 RHPSCAC	238	187	1309	476	2.38	1991
	1:3 RHPSCAC	238	187	1200	546	2.38	2117
	1:4 RHPSCAC	238	187	1203	553	2.38	2140

Table -3: Experimental Investigation.

Property Tested	Water-Cement Ratio	Standards/Guidelines	Measurement Details
Fresh Properties	0.60 with 1;1, 1:2, 1:3 and 1:4 types of aggregates.	ASTM C143, ASTM C138, IS 1199	Slump and compaction factor
Dry Density of Cured Concrete		BS EN 12390-7:2009, IS 456	Measured after 28 days of water curing
Compressive Strength		ASTM C579−01, IS 516	Tested after 28 days of water curing
Flexural Strength		ASTM C580−02, IS 5816	Tested after 28 days of water curing
Tensile strength		ASTM C579−01, IS 516	Tested after 28 days of water curing
Durability properties and Variation in Results		ASTM1202, IS 13311-1 (1992), IS 1124	Water absorption, RCPT (rapid chloride ion permeability test, UPV(ultrasonic pulse velocity test) Average values of three specimens per test, Results within ±5% of the mean value

Results and discussions

Fresh Properties: Slump and Compaction Factor

The fresh properties of RHPSCA concrete, specifically slump and compaction factor, were evaluated for different aggregate ratios (1:1, 1:2, 1:3, and 1:4). The slump values obtained were 47 cm for 1:1, 52 cm for 1:2, 43 cm for 1:3, and 61 cm for 1:4 aggregate concrete, compared to the desired slump range of 25-50 cm. Notably, the 1:2 and 1:4 mixes exceeded the upper limit, indicating a higher workability than anticipated. The compaction factors for these mixes were 0.89, 0.93, 0.95, and 0.97, respectively. These results show a progressive increase in

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compaction factor with a higher proportion of recycled HDPE plastic, suggesting improved ease of compaction and workability.

Mechanical properties

Compressive Strength

The compressive strength (observe fig.1 and fig.1a) of RHPSCA concrete with a water-cement ratio of 0.60 was evaluated for different aggregate ratios (1:1, 1:2, 1:3, and 1:4). The results indicated that the compressive strength values were 16.81 MPa for the 1:1 mix, 15.56 MPa for the 1:2 mix, 15.03 MPa for the 1:3 mix, and 14.76 MPa for the 1:4 mix. These results show a decreasing trend in compressive strength with an increasing proportion of recycled HDPE plastic in the aggregate mix. The highest strength was observed in the 1:1 mix, while the 1:4 mix exhibited the lowest compressive strength. This trend suggests that higher HDPE content may reduce the overall strength of the concrete, which is an important consideration for structural applications.

Fig.1 compression test setup

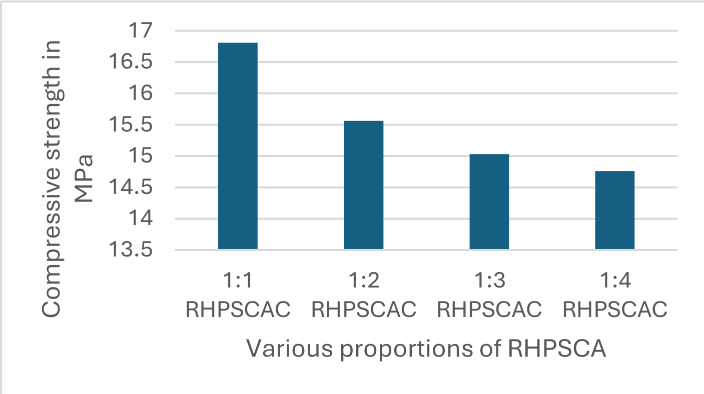

Fig.1a Compressive strength results with respect to Various proportions of RHPSCA

Flexural Strength

The flexural strength (observe fig.2 and fig.2a) of RHPSCA concrete with a water-cement ratio of 0.60 was assessed for various aggregate ratios (1:1, 1:2, 1:3, and 1:4). The measured flexural strength values were 3.51 MPa for the 1:1 mix, 3.68 MPa for the 1:2 mix, 3.61 MPa for the 1:3 mix, and 3.53 MPa for the 1:4 mix. The results demonstrate that the 1:2 mix achieved the highest flexural strength, indicating enhanced tensile performance compared to the other mixes. While the flexural strength varied slightly across the different ratios, all mixes-maintained values within a close range, suggesting that the inclusion of recycled HDPE plastic aggregates does not significantly impact the flexural strength of the concrete. This consistency in flexural strength is promising for the potential structural application of these sustainable concrete mixes.

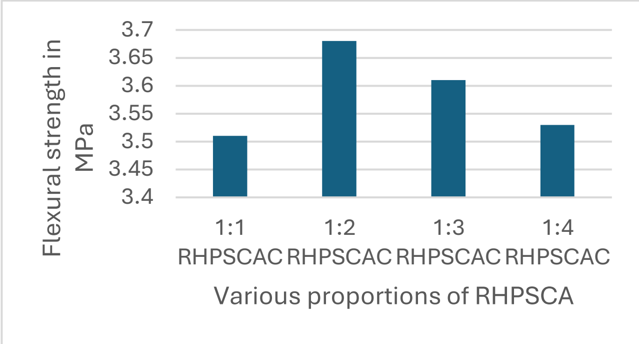

Fig.2 flexural test setup

Fig.2a Flexural strength results with respect to Various proportions of RHPSCA

Tensile strength

The tensile strength (observe fig.3 and fig.3a) of RHPSCA concrete with a water-cement ratio of 0.60 was evaluated for different aggregate ratios (1:1, 1:2, 1:3, and 1:4). The tensile strength results were 1.48 MPa for the 1:1 mix, 1.185 MPa for the 1:2 mix, 1.20 MPa for the 1:3 mix, and 1.16 MPa for the 1:4 mix. These findings reveal a general decrease in tensile strength as the proportion of recycled HDPE plastic in the aggregate increases. The highest tensile strength was observed in the 1:1 mix, while the lowest was in the 1:4 mix. This trend suggests that higher HDPE content may positively impact the tensile strength of the concrete, which is a critical factor to consider for applications requiring high tensile performance.

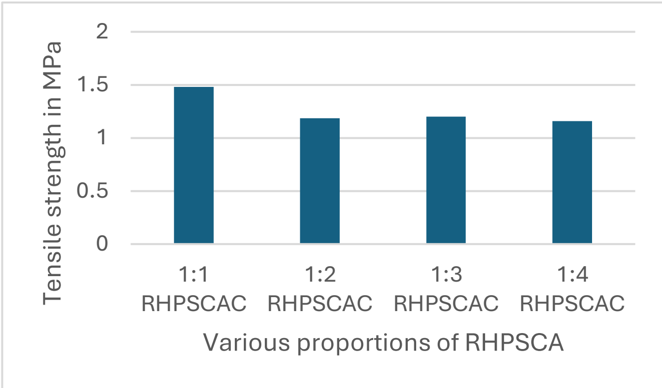

Fig.3 Tensile test setup

Fig.3a Tensile strength results with respect to Various proportions of RHPSCA

Durability properties of concrete

Water Absorption

The water absorption of RHPSCA concrete with a water-cement ratio of 0.60 was analysed for different aggregate ratios (1:1, 1:2, 1:3, and 1:4). The water absorption values obtained were 2.51% for the 1:1 mix, 3.09% for the 1:2 mix, 3.17% for the 1:3 mix, and 3.25% for the 1:4 mix. These results indicate an increasing trend in water absorption with a higher proportion of recycled HDPE plastic aggregate in concrete. The lowest absorption was recorded in the 1:1

mix, while the highest was in the 1:4 mix. This trend suggests that decreasing the HDPE content in the aggregate may lead to higher porosity and water absorption in the concrete, which could affect its durability and performance in certain applications.

Rapid Chloride Ion Permeability Test (RCPT)

The rapid chloride ion permeability test (RCPT) was conducted on RHPSCA concrete with a water-cement ratio of 0.60, following the ASTM 1202 standard. The results for different aggregate ratios (1:1, 1:2, 1:3, and 1:4) were 731.28 coulombs (very low permeability), 1028 coulombs (low permeability), 1170 coulombs (low permeability), and 831 coulombs (very low permeability), respectively. These findings indicate that the 1:1 and 1:4 mixes exhibited very low chloride ion permeability, suggesting better resistance to chloride ingress. In contrast, the 1:2 and 1:3 mixes showed low permeability, indicating a moderate increase in chloride ion penetration with higher HDPE content. This variation highlights the potential of using recycled HDPE plastic aggregates to enhance the durability of concrete by reducing its susceptibility to chloride ion penetration.

Ultrasonic Pulse Velocity Test (UPV)

The ultrasonic pulse velocity (UPV) test was conducted on RHPSCA concrete with a water-cement ratio of 0.60, in accordance with the IS 13311-1 (1992) standard. For the direct method, the velocities (V) recorded were 4144.33 m/s for the 1:1 mix, 3922.33 m/s for the 1:2 mix, 4121 m/s for the 1:3 mix, and 4225 m/s for the 1:4 mix, with corresponding times (T) of 36.13 µs, 43.83 µs, 35.7 µs, and 36 µs. Additionally, the velocities for the indirect method were 3472 m/s for the 1:1 mix, 3069 m/s for the 1:2 mix, 3683 m/s for the 1:3 mix, and 3704 m/s for the 1:4 mix. The corresponding times (T1 and T2) for the indirect method were 49.86 µs & 105.93 µs for the 1:1 mix, 60 µs & 114.7 µs for the 1:2 mix, 54 µs & 108 µs for the 1:3 mix, and 57.8 µs & 112.1 µs for the 1:4 mix. These results indicate that the concrete mixes exhibited good quality, with the velocities indicating a relatively homogenous and dense material. The variations in velocity and time reflect the influence of different aggregate ratios on the concrete's internal structure and uniformity.

Conclusion

Comprehensive testing of RHPSCA concrete with a 0.60 water-cement ratio and aggregate ratios of 1:1, 1:2, 1:3, and 1:4 reveals key insights into its fresh and hardened properties. Fresh property analysis shows that slump values exceeded the desired range of 25-50 cm for the 1:2 and 1:4 mixes, indicating higher workability, while the compaction factor improved with increasing HDPE content, enhancing ease of compaction. In terms of compressive strength, a decreasing trend was observed with higher HDPE content, with the 1:1 mix achieving the highest strength (16.81 MPa) and the 1:4 mix the lowest (14.76 MPa). Flexural strength remained relatively consistent, peaking at 3.68 MPa in the 1:2 mix, suggesting minimal impact from HDPE aggregates. Similarly, tensile strength decreased with higher HDPE content, with the 1:1 mix registering the highest value (1.48 MPa) and the 1:4 mix the lowest (1.16 MPa). Water absorption increased from 2.51% in the 1:1 mix to 3.25% in the 1:4 mix, indicating higher porosity and potential durability concerns. The RCPT results showed very low chloride ion permeability in the 1:1 and 1:4 mixes, with low permeability in the 1:2 and 1:3 mixes, indicating good chloride resistance for some configurations. Ultrasonic Pulse Velocity (UPV) tests confirmed good quality concrete across all mixes, with higher velocities observed in the 1:4 mix, indicating a dense and homogeneous structure. In conclusion, while higher HDPE content enhances workability and compaction, it tends to reduce compressive, tensile, and flexural strengths and increase water absorption, raising durability concerns. However, chloride ion permeability and UPV results suggest that certain mixes, particularly 1:1 and 1:4, maintain good resistance to chloride ingress and overall material quality.

Conflict of Interest Statement

The authors declare that there is no conflict of interest regarding the publication of this manuscript. The research was conducted independently, without any financial or personal relationships that could inappropriately influence or bias the findings presented.

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