Rapid Evaluation of Compressive Strength of HDPE-Plasto Sand Aggregate Concrete

Ratod Vinod Kumar[1*], *D Rupesh* Kumar[2], *V* Bhikshma[3]

[1]Assistant Professor, Department of Civil Engineering, Mallareddy (MR) Deemed to be University, Hyderabad, India.
[2,3] Professor, Department of Civil Engineering. University College of Engineering, Osmania University, Hyderabad, India.

Abstract. In this study, the compressive strength of HDPE-Plasto Sand Aggregate (HDPE-PSA) concrete has been investigated, where the rough surface aggregates have been prepared by melting the High-Density Polyethylene (HDPE) plastic in the 1:1, 1:2, 1:3 and 1:4 ratios with sand. In this way, the aggregates made of HDPE-PSA had lower density and specific gravity than natural aggregates and were classified as lightweight aggregates. For the concrete mix design, 0.40 and 0.65 w/c ratio used. we adhered to the ACI 211.2-98 (re-approved 2004) code. An accelerated curing tank was used in order to determine the compressive strength. Overall, the study reveals that HDPE-PSA aggregates hold promise for creating concrete with appropriate compressive strength, offering a novel solution to recycling plastic waste and promoting sustainable construction practices. The incorporation of HDPE-PSA aggregates in concrete is a step toward sustainability and a potential substitute for traditional aggregates, which is in line with the global trend towards greener construction practices and circular economy.

Keywords: HDPE-Plasto Sand Aggregate, Compressive Strength, HDPE Recycling, Accelerated Curing, Concrete Mix Design

1 Introduction

The construction sector is growing increasingly under the pressure to become sustainable and to lower impact on the environment. The control of waste, especially plastic waste, with its high ecological impact is one of the main challenges. One such plastic that is widely used is High-Density Polyethylene (HDPE), whose disposal is a significant challenge for the environment. In recent years, studies have concentrated on recycling HDPE for application in building materials, such as aggregates for concrete, to reduce waste and achieve sustainable development. HDPE is a thermoplastic polymer with high strength-to-density ratio which is found to be attractive for different applications. However, itis a big pollutant

* Corresponding author: vinodrathod918@osmania.ac.in

in the environment because of its durability and biodegradation resistant nature. The traditional disposal methods like landfill and incineration are unsustainable. So, itis important to find innovative approaches to reutilize HDPE. Use of recycled HDPE in concrete as a substitute for natural aggregates is a potential solution. This research aims to study the compressive strength of HDPE–Plasto Sand Aggregate (HDPE-PSA) concrete. Sand was mixed with molten HDPE plastic at 300 °C in ratios of 1:1, 1:2, 1:3, and 1:4 to produce rough-surfaced aggregates. Concrete mixes were then prepared using these aggregates, following ACI 211.2-98 (reapproved 2004) for the mix design. An accelerated curing tank was used to determine the compressive strength of the concrete.

1.1 Literature Review

Previous studies have shown that recycled plastics can be used in concrete [1] and have the potential to enhance some properties and decrease environmental impact when used as a partial replacement for fine aggregate in concrete. Likewise, Akinyele [2] studied the application of plastic waste as aggregate in concrete, finding that it has the potential to improve the sustainability of construction materials. A number of researchers, including Concrete, studied the mechanical properties of concrete with plastic aggregates and found a decrease in weight and compressive strength of the plastic aggregates concrete compared to traditional concrete, which classifies it as low-density concrete [3]. But it can be advantageous for certain uses where lighter materials are desired. The ACI 211.2-98 (re-approved 2004) code offers guidelines for the mix design of light weight concrete, with the goal of ensuring that mixes do not deviate excessively from the required performance. To assure consistency and proper proportioning of the HDPE-PSA concrete mixes, the following code was employed in our study. Study of accelerated curing technique was used in several studies to determine the early age compressive strength of concrete, which it was determined to be a good technique to get early strength results [4]. The technique was used in our study to evaluate the compressive strength of HDPE-PSA concrete in a short time. There are many who have dedicated themselves to the same area as the one mentioned [5]. The HDPE-PSA aggregates in our study had lower density and specific gravity values than the natural aggregates, which is similar to results from previous studies. These aggregates may have a desirable low weight which can be beneficial in situations where weight reduction of the structure is required. Moreover, the rough surface of the HDPE-PSA aggregates is obtained by adjusting the sand ratio, which is expected to increase the bond between the aggregates and the cement matrix, and hence, the mechanical properties of the concrete.

1.2 Research Significance

The utilization of HDPE-PSA aggregates in concrete not only helps mitigate the problem of plastic waste but also promotes the creation of sustainable building materials. This research promotes the principles of the circular economy in which wastes are converted into valuable resources, particularly through the use of waste HDPE in concrete aggregates. Furthermore, because of its light weight, HDPE-PSA concrete can result in substantial material savings and less environmental impact for construction projects. The aim of this study is to give a detailed assessment of the compressive strength of the HDPE-PSA concrete comparing to the traditional concrete and to shed light on the possibility of using it as a sustainable material to replace concrete. The results will be part of a growing amount of information on the application of recycled plastics in construction and encourage the use of more environmentally friendly building techniques.

1.3 Need of the Study

Environmental Impact: The environmental problem with plastic waste is that it is not biodegradable and especially with HDPE. Finding sustainable disposal methods is crucial to mitigating its ecological impact. Recycling HDPE for construction material is a novel approach in addressing plastic waste challenges and turning it into a useful resource worldwide.

1. Sustainable Construction: Green approaches in the construction industry. The use of recycled materials in concrete is a measure towards sustainability and conservation of natural resources.
2. Lightweight Concrete: Lightweight concrete is in demand in the construction field because of its advantages, such as lightweight of structures and better seismic performance. This can be met by using the HDPE-PSA aggregates.
3. Solutions that are cost-effective: The use of waste material in construction can also help to reduce the cost of waste disposal and the overall economic burden of the project. The promotion of the use of recycled materials in building contributes to the principles of circular economy where waste is reused, recycled and reused as products.
4. Innovative Materials: The research of alternative aggregates, e.g. HDPE-PSA, may result in new, innovative building materials with new properties.

1.4 Objectives

- Assess Material Properties: To analyse the density, specific gravity and other properties of HDPE-PSA aggregates compared to natural aggregates.
- To formulate an appropriate mix design of the HDPE-PSA concrete based on ACI 211.2-98 code for ratio of 0.40 w/c and 0.65 w/c and to determine the effect of the accelerated curing method on the development of the compressive strength of HDPE-PSA concrete.
- Assess Compressive Strength: To find out the compressive strength of HDPE-PSA concrete with varying ratios of sand to HDPE. 4.Study Bond Strength: To do study on the bonding characteristics of the aggregate of HDPE and the cement matrix (crack propagation).

1.4.1 Scope of the Work

Material Properties Assessment: Density and Specific Gravity: Determine and compare the density and specific gravity of HDPE-Plasto Sand Aggregate (HDPE-PSA) and natural aggregates. Run additional tests to assess other potential properties of HDPE-PSA aggregates, including water absorption, abrasion resistance and impact resistance. Mix Design Development and Accelerated Curing Assessment: Mix Proportions: A range of mix designs for HDPE-PSA concrete is developed in accordance with the guidelines given in the ACI 211.2-98 code (Prestera et al. 1998) with different proportions of sand to HDPE. An accelerated curing method was used to speed up the curing process and to assess its effect on the early-age compressive strength of the concrete. The results were then compared with those from standard curing to determine the efficiency of the accelerated curing method.

1. Compressive Strength Evaluation: Testing Regimes: Make up HDPE-PSA concrete samples for different sand to HDPE ratios (1:1, 1:2, 1:3, 1:4) and test the compressive strength of the concrete at specific ages. Bond Strength Investigation:

Bond Strength Tests: Perform tests to assess the bond properties of the HDPE-PSA aggregates with the cement matrix, with emphasis on crack propagation.

2. Sustainability Analysis: Environmental Impact Assessment: Conduct a life cycle assessment (LCA) to assess environmental benefits of utilization of recycled HDPE in concrete production such as waste reduction, reduction of resources usage and reduction in CO_2 footprint.

2 Materials

In this study, we developed a concrete mix using a combination of cement, sand, and HDPE-plasto sand coarse aggregate (HDPE-PSCA) Maximum Size is 20mm and Particle Shape is sub-angular which are formed like 1:1 plastic-sand Aggregates (one part of plastic of plastic and 1part of sand), 1:2 plastic-sand Aggregates (one part of plastic and 2parts of sand, 1:3 plastic-sand Aggregates (one part of plastic and 3 parts of sand, 1:4 plastic-sand Aggregates (one part of plastic and 4parts of sand. To investigate the potential of recycled plastic aggregates in enhancing concrete properties and promoting sustainable construction practices. Figure 1 and 2 shows the Mix proportions producer and values.

Table 1. Properties of materials

Physical Property of Cement	**1:1- HPSCA**	**1:2- HPSCA**	**1:3- HPSCA**	**1:4- HPSCA**
Specific gravity (Used) IS 4031 (Part 11)	3.14	3.14	3.14	3.14
Fine Aggregate				
Specific gravity (Used) IS 2386 (Part 3)	2.63	2.63	2.63	2.63
Fineness modulus (**IS 2386 Part 1)**	2.61	2.61	2.61	2.61
Physical Property of HPSCA	1:1- HPSCA	1:2- HPSCA	1:3- HPSCA	1:4- HPSCA
Aggregate impact value.	2.7	4.8	5.7	8.3
Abrasion value.	7.08	8.34	9.7	11.01
Flakiness index.	13.9	14.44	12.6	13.7
Elongation index.	14.8	14.13	13.7	14.3
Bulk Density(kg/m3) (ASTM C330-99: table-2).	693	700	757	765
Absorption (%).	0.450	0.602	0.50	0.605
Surface Texture.	Partially rough/ porous	Partially rough/ porous	Partially rough/ porous	Partially rough/ porous
Specific Gravity (IS:2386-1963 part-3).	1.498	1.557	1.756	1.775
Colour.	brown	brown	brown	brown

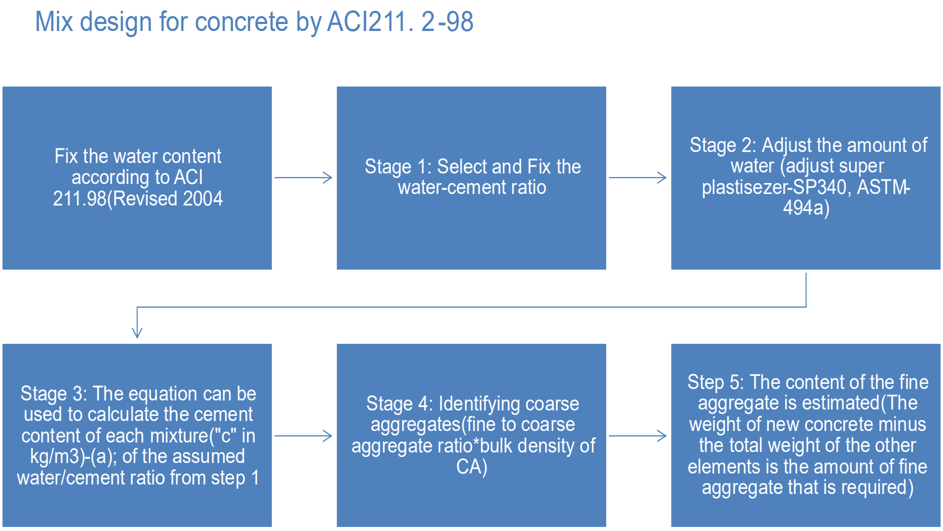

Fig. 1. Step-by-step procedure for mix design of concrete

Table 2. Concrete mix proportions obtained from mix design (ACI 211.2-98)

w/c ratio	Sample type	Cement kg/m^3	Water kg/m^3	Fine aggregate kg/m^3	HPSCA aggregate kg/m^3	Superplasticizer kg/m^3
0.40						
	1:1	353	142	1028	499	3.53
	1:2	353	142	1114	504	3.53
	1:3	353	142	1085	545	3.53
	1:4	353	142	1089	551	3.53
0.65						
	1:1	217	142	1148	499	2.17
	1:2	217	142	1165	504	2.17
	1:3	217	142	1199	545	2.17
	1:4	217	142	1202	551	2.17

2.1 Procedure for rapid curing of concrete cubes using an accelerated curing tank Boiling Water Method (100° C)

The compressive strength of concrete is normally determined at 7 and 28 days. For certain construction activities, however, waiting this long may be impractical when the strength needs to be known before construction proceeds. In such cases, the accelerated curing test (IS 9013-1978) is used. In this method, cubes cast in cast-iron moulds are cured in a curing tank filled with water maintained at a uniform temperature (55 °C or 100 °C) until they are removed immediately before testing. Figure 2 shows the accelerated curing tank.

1. Prepare the samples: The specimens were cast in cube moulds and left for 23 hours and 15 minutes after casting.
2. Prepare the curing chamber: Place cube with Molds on supporting stands within the chamber and fill with water, making sure that cube Molds are completely covered in water. Switch the system on with the main MCB switch (step 4): Start the curing

process. Use the temperature indicator cum controller to set the temperature to 100°C and close the chamber lid.

3. Curing Period: The RTD Sensor will hold the chamber temperature of the specimens will be cured for 3½ hours at 100°C.
4. Post-curing: After 3½ hours in the accelerated curing tank, the moulds were removed, and the cubes were demoulded and placed in cold water for 1 hour before compressive strength testing. This accelerated procedure allows strength to be assessed much earlier than the standard 28-day period.

Fig. 2. Accelerated curing tank

3 Results and discussion

Here's the specific formula for concrete compressive strength using the accelerated curing method (IS 9013-1978).

$$\mathbf{R_{28} = 8.09 + 1.64\, R_0}$$

Where:
R_0 = Accelerated curing Compressive strength
R_{28} = The corresponding strength at 28 days
R_{28} = The corresponding strength at 28 days

The figure 3 shows the compressive strength of concrete mixtures prepared with different proportions of handmade aggregates and two different water-cement (w/c) ratios. The data shows interesting trends in concrete performance in various mix designs. At 0.40 w/c ratio, the compressive strength demonstrates a non-linear trend with the varying proportions of aggregates. Among the different proportions, the 1:2 mix has the highest strength of 30.886 MPa, which is nearly equal to the 1:4 mix at 30.72 MPa. A fluctuating pattern is evident as the 1:1 and 1:3 mixes have lower strengths of 27.114 MPa and 27.61 MPa respectively. The 0.65 ratio w/c, on the other hand, shows a more regular increase in strength with increasing proportion of aggregate. The compressive strengthincreasescontinuouslyfrom1:1 mix as 18.422 MPa, 1:2 mix as 19.898 MPa and 1:3 mix as 19.4 MPa till 1:4 mix (20.24 MPa).

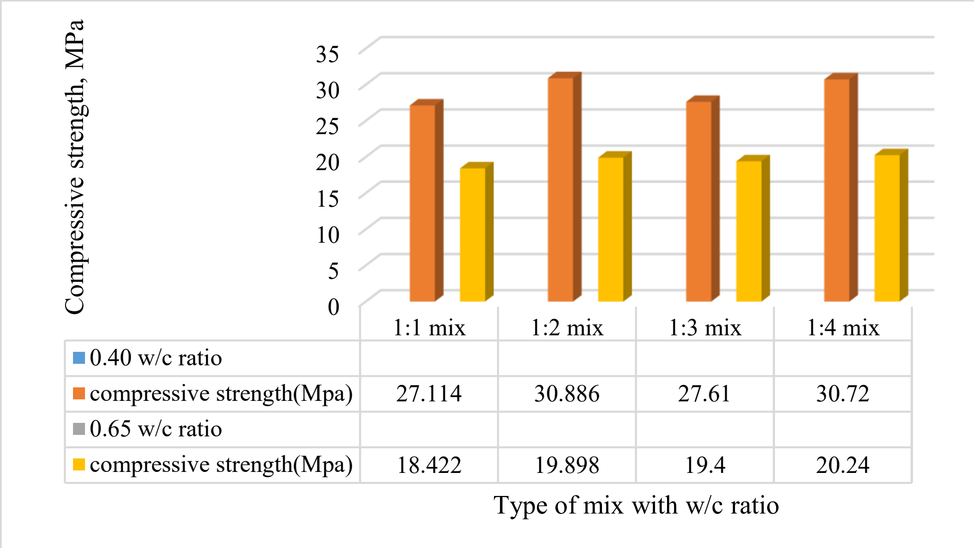

Fig. 3. Strength of concrete cured in boiling water at 100°C (water/ cement ratio=0.40 and 0.65, rapid curing applied after 24hours of casting)

The strengths of 0.40 w/c ratio are consistently higher than the 0.65 w/c ratio at all mix proportions with difference in strength ranging from 8.692 MPa to 10.988 MPa. This is an indication of the importance of the water content on the strength of the concrete. It also indicates that an optimum aggregate proportion maybe possible to partially offset higher w/c ratios, since the 0.65 w/c median mix (1:4) strength is higher than the strength of the 0.40 w/c medians (1:1 and 1:3). The results of this research reveal that the effect of the w/c ratio and aggregate ratios on concrete strength is complex, and itis crucial to carefully design concrete mixes to meet the desired performance characteristics.

3.1 Concrete cube failure patterns

In the Compression Testing Machine (CTM, displayed in figure 4a), a number of possible modes of failure of concrete cubes are discussed in this paper. Matrix, Aggregate, or Bond Failure: Concrete cubes can fail due to three main reasons: matrix failure, aggregate failure, or bond failure. Failure in the cement paste matrix is due to the failure of the matrix itself of the cement paste. Failure of the aggregates is called aggregate failure, failure between the aggregates and the cement paste (as illustrated in figure 4b) is known as Bond failure. Failure of bond between aggregates and cement paste due to presence of dust or particles in between the aggregates and the cement paste (compression failure, show in figure 4c). Cube failure due to eccentric loading: If the loading is not uniform across the cube, then the loading can fracture the cube prematurely at a certain location (shown in figure 4d), this is called eccentric loading. The study of different types of failures in concrete cubes can be used to understand these failure modes and to help improve the concrete mix design and construction practices. Concrete Cubes Testing Analysis: Identification of Failures: It is important to identify the failures during concrete cube testing analysis to understand the quality and strength of concrete mix. Understanding the mode of failure will help engineers and researchers develop strategies to improve the lifespan and performance of concrete structures. Fig.4 shows the crack patterns of cubes.

a b c d

Fig.4. Failure pattern of cubes

4 Conclusion

The aim of this study was to assess the viability and performance of HDPE-Plasto Sand Aggregate (HDPE-PSA) concrete by conducting a detailed study of the material properties, mix design, compressive strength, bond strength and sustainability of the concrete. Based on the research objectives the following conclusions can be drawn: The results from material properties assessment of the HDPE-PSA aggregates showed that their density and specific gravity were lower than natural aggregates, indicating that the HDPE-PSA aggregates are lightweight. Further testing showed that the physical properties of the HDPE-PSA aggregates are sufficient for their use in concrete but may require certain handling and mixing procedures to maximize properties of the concrete. The mix designs developed after the ACI 211.2-98 code (Prestera et al. 1998) showed that it is possible to produce the HDPE-PSA concrete using different sand to HDPE ratios. The accelerated curing methods proved effective for acquiring higher early age compressive strengths, which can contribute to faster construction processes for HDPE-PSA concrete. Accelerated curing was found to be favourable as compared to standard curing.

1. Compressive Strength Evaluation: The compressive strength of the HDPE-PSA concrete was found to be different for different ratios of Sand to HDPE. The study concluded that the optimum mix proportions were obtained which gave a satisfactory compressive strength, in some cases comparable with the conventional concrete. The performance of the HDPE-PSA concrete was satisfactory for use in light weight applications, but has a lower compressive strength. Bond Strength Investigation: The bonding properties of the HDPE-PSA aggregates and the bond properties of the cement matrix were examined using different tests (4). It was found that the rough surface of the aggregates of HDPE-PSA led to improved bond with the cement matrix.
2. The application of the recycled HDPE in concrete manufacturing is a major benefit to the environment, since it can help to reduce waste and conserve natural resources. A life cycle assessment (LCA) identified the improvement in carbon footprint and energy savings that can be achieved by using HDPE-PSA aggregates, thereby reducing the environmental impact of building construction. The economics also indicated that the cost of manufacturing HDPE-PSA concrete may be competitive, considering savings on waste disposal and the possible savings in regulations for using recycled material. In conclusion, HDPE-PSA concrete presents a promising alternative to traditional concrete, combining the benefits of lightweight properties, adequate compressive strength, and enhanced sustainability. The results obtained from this research are extremely useful in the process of developing and introducing HDPE-PSA aggregates to the construction sector and in the global movement aiming at building more sustainable and environmentally friendly.

Further studies are recommended to optimize mix designs of HDPE-PSA concrete, enhance bond strength and investigate other uses of HDPE-PSA concrete.

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