Sand Replacement by High Density Polyethylene in Concrete

Aditya Dhanuka [1] Aman Srivastava [2] Leena Khadke [3] Vijay Motamwar [4] Dr. S. S. Pusadkar[5]

[1,2,3,4]B. Tech. Student, Civil Engineering Department, Government College of Engineering, Jalgaon, Maharashtra, India

[5]Associate Professor, Head, Department of Civil Engineering, Government College of Engineering, Jalgaon, Maharashtra, India

Abstract— **In the research, the plastic was considered a non-biodegradable product engendered everyday throughout the world for diverse tenacities in different application. Production of plastic waste around the world was a leading risk which society was facing. Therefore, to diminish the quantity of plastic, there was a prerequisite to upsurge the supply of the material that entered various product streams or to find the economical usage of the plastic wastes. Concrete used significouldt quantities of aggregate comprising of natural sand and gravels. Some percentage of alternation in any of the component of the concrete may gave a pathway for improved performance of the concrete. Hence, this research was based on this attitude for the determination of an unexpected result of this trial.**

The objective was to determine the results for the partial replacement of natural sand with plastic (High-Density polyethylene). The experimental investigation was carried out for the replacement of the different percentage of the sand with High Density Polyethylene (HDPE). The concrete with 15 % plastic sand concrete showed 18.77% more compressive strength than normal concrete at 7 days. The concrete with 20 % plastic sand showed 1.54% less compressive strength than normal concrete at 7 days. The concrete with 15 % plastic sand showed 20.64 % more than concrete with 20 % plastic sand at 7 days. The 15 % use of plastic sand showed encouraging improvement in compressive strength of concrete. However, detail investigation along with durability test would make this concrete as environmental friendly product

Keywords— **Concrete, Plastic Sand, Compressive Strength, Concrete Mix Design, Water Cement Ratio**

I. INTRODUCTION

the rapid growth of industrialization and the upsurge of a throw away culture had let to plastic waste handling and disposal problem. The creation of plastic in the worldwide in 1950 is 1.7 million metric ton spinoff to 322 million Metric ton in 2015. The manufacturing of the plastic represented an alarm to the environmental safety, as only 7% of it was recycled. The remaining plastic was either disposed of in an unmanageable manner or land filled and burned. The principle approaches adopted include drop in the production of plastic waste commodity and recycling as far as possible of what was in unavoidably produced. Polyethylene-based commodity formed the largest percentage of waste i.e. about 29% of total waste plastic generated. These included polypropylene, linear low-density polyethylene (LLDPE), Polyethylene terephthalate (PET) high-density polyethylene (HDPE) and low-density polyethylene (LDPE), amount to 18 and 20%, respectively, of global plastic waste, and other polymer types represented about 33%. In 2013, survey was conducted by Central Pollution Control Board (CPCB) stating that the daily plastic waste produced in India was 15342 tones, of which about 60% was recycled (most were available in the informal sector) that let them to the conclusion that the recycling rate in India of plastic was 14% more than averagely global recycling. But, there were still over 6100 tons of plastic wastes which were either end up polluting stream, groundwater resources or landfill [8]. The instances like the plastic waste eaten by animal in search of food or burning polymers resulted in toxic gas emissions, including hydrogen cyanide gas, nitrogen monoxide, nitrogen dioxide carbon monoxide and carbon dioxide which polluted the environment was the alarm to get aware about the plastic waste and its negative impact. One of the options in this regard was to use this plastic waste in the form of plastic sand in the production of concrete.[1, 2, 3]

In the various works, the concrete was prepared by coarse aggregate bonded together with fluid cement which hardened over time. Most concrete used were lime-based concretes such as Portland cement . Asphalt concrete, which was frequently used for road surfaces, was also a type of concrete, where the cement material was bitumen, and polymer concretes were sometimes used where the cementing material was a polymer. There were several types of the concrete available like Pervious concrete, Microbial concrete, Polymer concrete, Standard Ready-Mix Concrete, Architectural and Decorative Concrete, Rapid-setting Concrete, Fibre-reinforced Concrete, Fluid-fill Concrete, Roller-compacted, Self-consolidating Concrete (SCC), Antibacterial Concrete and Light weight concrete [2]. Concrete used sand from river which resulted into the degradation and quantity of the river sand. Hence, it was required to determine the best replacement of the sand content with the plastic in any of these said concrete.

Plastic consisted of wide range of semi-synthetic or synthetic organic compounds that were malleable and so could be melded into solid objects. Plasticity was the archetypal property of all materials which could deform irretrievably without breaking but, in the class of mouldable polymers, this occurred to such a degree that their authentic name originated from this ability. Plastics were characteristically organic polymers of high molecular mass, but they often encompassed other constituents.

They were typically synthetic, generally resulting from petrochemicals, but many were manufactured from renewable materials such as polylactic acid from corn or cellulosic from cotton linters. Due to their comparatively low cost, affluence of manufacture, flexibility, and unyieldingness to water, plastics were used in a huge and intensifying range of products, from a pen to spaceships. They had already displaced many traditional materials, such as wood, stone, horn and bone, leather, paper, metal, glass, and ceramic, in most of their former uses. There were different types of plastic available as Polystyrene (Styrofoam), Polyvinyl Chloride (PVC), Polytetrafluoroethylene (Teflon), Polyvinylidene Chloride (Saran), Polyethylene, Thermoset or Thermosetting plastics, Thermoplastics, Polyethylene terephthalate (PET or PETE), LDPE and HDPE, Polypropylene (PP) etc. [1, 2, 3].

The literature showed the use of plastic as replacement to sand with varying percentage of 0 – 100 % sand effect on compressive strength, flexural strength and workability. The use of PET 0 – 20 % showed reduction in workability and 28 days' compressive strength 9 – 42 %. [4, 5, 6] The reduction in 28-day compressive strength varied from 11 to 72% as the percentage replacement of mixed waste plastic with sand or aggregate increases from 0 to 50%. [7] The reduction in 28-day compressive strength varied from 77 to 94% corresponding to increasing expanded polystyrene (EPS) as an aggregate replacement from 0 to 95%. [8] The replacement level of 75% of recycled waste polyethylene terephthalate bottles (WPB) showed the slump of WPB concrete increased by 51%, while the density, compressive strength, splitting tensile strength, modulus of elasticity, and structural efficiency were reduced by 31, 33, 43, 28, and 23% respectively compared to normal concrete. [9, 10]

The present study aimed the use of HDPE granules as replacement of sand. The concrete mix design was carried out as per IS 10262: 2009. The various tests were conducted on concrete to ascertain the strength. The concrete was casted in cube and tested by using the compressive testing machine.

II. Experimental Investigation

The experiment for present research was carried out in research laboratory of Government College of Engineering, Jalgaon, India. The HDPE granules were purchased from pipe manufacturer Manoj Industry, Jalgaon, India. It was basically by product during manufacturing of pipe which were reused for other purposes. Following were the characteristics taken into account for experiment.

A. Nomenclature for Concrete

The nomenclature of the concrete was identified by the name NSCx and HDPEyCx, where NS identified the natural sand, C identified the concrete, x identified water cement ratio, HDPEy identified percentage sand replacement by High Density Polyethylene (e.g., $HDPE_{20}C_{0.5}$ – $HDPE_{20}$ denotes 20% HDPE plastic, C stranded for concrete, and 0.5 represented water cement ratio).

B. Experimental Programmed Materials.

The Orient Birla A1 manufactured ordinary Portland cement of grade 43 was used. The cement had a density of 3150 kg/m^3, specific gravity of 3.15, and a fineness of 3500 cm^2/gm. Conventional coarse aggregate from the North Maharashtra region (Khandesh) of India was used in the experimental work for control mixes. The fine aggregate/sand used in this research was obtained from local market. High Density Poly-Ethylene (HDPE) shown in Fig. 1 was used to replace local sand in concrete. The HDPE was used for 15% and 20% replacement of sand. M20 grade concrete was designed by the principle of concrete mix design for experimental investigation.

The objective of the experimental investigation was designed to compare strength of the High-Density Poly-Ethylene (HDPE) concrete with normal concrete. The compressive strength was obtained by casting and testing 15 cm^3, as shown in Fig. 2.

Fig. 1: High Density Poly-Ethylene Granules Brought for the Experimentation

Fig. 2: Casted Concrete Block of Size 15cm^3 Using HDPE Granules

C. Mixture Proportion

The mix design of the concrete was designed with respect to the specifications mentioned in IS 10262: 2009. For the mixes containing High Density Poly-Ethylene (HDPE), the quantity of coarse aggregate and fine aggregate was calculated by using the specific gravity of individual material. The mixed proportions of all the mixes was determined in concrete mix design. For the experiment, we were needed different concrete samples with varying water-cement ratio. The concrete samples were prepared using water-cement (w/c) ratios of 0.483, 0.49 and 0.493. Each of the prepared samples was cured for 7 days.

D. Concrete Mix Design

The coarse aggregate was sieved by the 20mm sieve for the content of the concrete while sand was sieved by 4.75 mm sieve. For determining the workability of concrete, slump cone test was adopted and performed. The test resulted in 0 (zero) slump i.e.

true slump was obtained. The specific gravity of sand and coarse aggregate was determined using pycnometer test. Moisture content of sand was determined by the oven dry test. The size of HDPE granules used in the concrete in the replacement of sand was 3 mm on the average. Table I shows the characteristics of material used in experiment.

TABLE I
CHARACTERISTICS OF MATERIAL

Characteristics	Values
Target strength	20 MPa (N/mm^2)
Maximum size of Aggregate	20 mm
Workability	0 Slump i.e. True slump
Water/Cement (w/c) Ratio	0.5
Specific gravity of coarse aggregate	2.64
Specific gravity sand	2.54
Water Absorption for 20mm Aggregate	1.2%
Water Absorption for 10mm Aggregate	1.2%
Water Absorption for sand	0%
Moisture content for sand	3%

1) *Target Strength (f_{ck})*

Target strength was calculated taking into account the standard deviation on characteristic strength f_c as:

$f_{ck} = (f_c + 1.65) \times S$, where S= Standard Deviation for M20 grade = 4.

$f_{ck} = (f_c + 1.65) \times 4$

f_{ck} = 26.6 MPa, where MPa= Mega Pascal

2) *Water Content*

The calculation of water content was carried as per IS-10262, where, for M20, the w/c was equal to 0.5. Therefore, the water content was tabulated in Table II as:

TABLE II
DETERMINATION OF THE WATER CONTENT

Minimum water content	186 liter, for up to 50 mm slump,
Minimum Cement Content	250 kg/m^3, defined in IS 456 (2000)
Required Cement content	(Water Content/ w-c ratio) = 186/0.5 = 372 kg/m^3
	372>250, hence, required cement content is satisfactory.

3) *Aggregate & Sand*

For 20 mm aggregate & Zone 2 material as specified in IS 10262, volume of aggregates and sand were calculated as

Volume of aggregate = 0.62 × volume total aggregate (Aggregate + Sand)

Volume of Sand = 0.38 × volume total aggregate (Aggregate + Sand)

4) *Calculation for volume of materials*

Volume of concrete was assumed as 1m^3 and following equations were employed for calculation of volume of material.

Volume of Cement = Mass/ (Specific Gravity × 1000)
= 372 / (3.15 x 1000)
= 0.118 m^3

Volume of Water = Mass/ (Specific Gravity × 1000)
= 186 / (1 × 1000)
= 0.186 m^3

Volume of Material except total aggregate = Volume of cement + Volume of Water
= 0.118 + 0.186
= 0.304 m^3

Volume of Total Aggregate = 0.98 – Volume of Material except total aggregate, 2% of air Entrainment,
= 0.98 – 0.304 = 0.676 m^3

5) *Calculation for weight of materials*

Weight of materials were calculated by fundamental equations as:

Weight of Coarse Aggregate = Volume of total Aggregate × Volume of coarse aggregate × Specific Gravity × 1000
= 0.676 x 0.62 × 2.65 × 1000
= 1110.668 kg/m^3

Weight of Sand = Volume of total Aggregate × Volume of sand × Specific Gravity × 1000
= 0.676 × 0.38 x 2.65 x 1000
= 652.4752 kg/m^3

Therefore, following proportion were derived from above quantities as:

TABLE III

PROPORTION FOR CEMENT, SAND, AGGREGATE AND WATER WITHOUT SITE CORRECTION

Cement	Sand	Aggregate	Water
372	652.47	1110.67	186
1	1.754	2.986	0.5

6) *Applying site correction*

The site correction included various factors at site which affects the concrete mix design. By including this, we could achieve more accuracy for design.

6.1) For NSC0.483 i.e. without sand replacement

Water Absorption for sand = 0%

Water Absorption for Aggregate = 1.2% of weight of Aggregate
= 1.2 × weight of Aggregate
= (1.2 × 1110.668) / 100
=13.32 litre

Moisture content for sand = 3% of weight of Sand
= (3 × 652.4752) / 100
= 19.57 litre

Actual Water Required = Calculated water requirement + Total Water Absorption -Total Moisture Content
= 186 + 13.32 – 19.57
= 179.75 litre

Actual wt. of Aggregate = Calculated wt. of Aggregate - Water Absorption for Aggregate
= 1110.668 – 13.32
= 1097.348 Kg/m^3

Actual wt. of Sand = Calculated wt. of sand + Moisture content for sand
= 652.4752 + 19.57
= 672.0752 Kg/m^3

Therefore, actual proportion were derived as

TABLE IV
PROPORTION FOR CEMENT, SAND, AGGREGATE AND WATER FOR NSC0.483

Cement	Sand	Aggregate	Water
372	672.05	1097.35	179.75
1	1.8	2.95	0.483

Quantities for 10 Kg Concrete
Cement = 1.74 kg
Sand = 3.132 kg
Aggregate = 5.133 kg
Water = 0.84 litre

6.2) For HDPE$_{15}$C0.49 i.e. 15% replacement of sand by HDPE granules

Water Absorption for sand = 0%

Water Absorption for Aggregate = 1.2% of weight of Aggregate
= 1.2 × Weight of Aggregate
= (1.2 × 1110.668) / 100
= 13.32 litre

Moisture content for sand = 3% of actual wt. of Sand
= (3 × 0.85 × 652.4752) / 100
= 16.64 litre

Actual Water Required = Calculated water requirement + Total Water Absorption -Total Moisture Content
= 186 + 13.32 – 16.64
= 182.68 litre

Actual weight of Aggregate = Calculated weight of Aggregate - Water Absorption for Aggregate
= 1110.668 – 13 = 1097.348 Kg/m^3

Actual weight of Sand = Calculated weight of sand + Moisture content for sand
= 652.4752 + 16.64
= 669.1152 Kg/m^3

Therefore, Actual proportion were derived as

TABLE V
PROPORTION FOR CEMENT, SAND, AGGREGATE AND WATER FOR HDPE$_{15}$C0.49

Cement	Sand	Aggregate	Water
372	669.12	1097.35	182.68
1	1.8	2.95	.49

Quantities for 10 Kg Concrete
Cement = 1.74 kg

Natural Sand = 2.6622 kg
HDPE granules = 0.4698 kg
Aggregate = 5.133 kg
Water = 0.852 litre

6.3) For $HDPE_{20}C0.493$ i.e. 20% replacement of sand by HDPE granules
Water Absorption for sand = 0%
Water Absorption for Aggregate = 1.2% of Weight of Aggregate
= 1.2 × Weight of Aggregate
= (1.2 × 1110.668) / 100
= 13.32 litre
Moisture content for sand = 3% of actual weight of Sand
= (3 × 0.80 × 652.4752) / 100
= 15.66 litre
Actual Water Required = Calculated water requirement + Total Water Absorption -Total Moisture Content
= 186 + 13.32 – 15.66
= 183.66 litre
Actual wt. of Aggregate = Calculated Weight of Aggregate - Water Absorption for Aggregate
= 1110.668 – 13.32
= 1097.348 Kg/m^3
Actual wt. of Sand = Calculated Weight of sand + Moisture content for sand
= 652.4752 + 15.66
= 668.1352 Kg/m^3
Therefore, Actual proportion were derived as

TABLE VI
PROPORTION FOR CEMENT, SAND, AGGREGATE AND WATER FOR $HDPE_{20}C0.493$

Cement	Sand	Aggregate	Water
372	668.14	1097.35	183.66
1	1.8	2.95	0.493

Quantities for 10 Kg Concrete
Cement = 1.74 kg
Natural Sand = 2.51 kg
HDPE granules = .626 kg
Aggregate = 5.133 kg
Water = 0.858 litre

III. Result

A. *Compressive Strength*

The compressive strength of concrete with HDPE and normal sand at 7 days were shown in table VII. At 7 days, the compressive strength of $HDPE_{15}C0.49$ was 18.77% more than that of NSC0.483. The compressive strength of $HDPE_{20}C0.493$ was 1.54% less than that of NSC0.483. The compressive strength of $HDPE_{15}C0.49$ was 20.64% more than that of $HDPE_{20}C0.493$.

TABLE VII
SAMPLE DESCRIPTION WITH THEIR COMPRESSIVE STRENGTH.

Sample No.	Description	Nomenclature Name	Compressive Strength (MPa)
1	Normal concrete without sand replacement	NSC0.483	14.22
2	Concrete with 15% replacement of sand by HDPE granules	HDPE15C0.49	16.89
3	Concrete with 20% replacement of sand by HDPE granules	HDPE20C0.493	14

B. Surface Texture of Concrete Block after Testing.

The crack propagation in three different samples were inconsistent as shown in Fig. 3. The paramount propagation of crack was found in NSC0.483, while lowest was in the $HDPE_{20}C0.493$. As the proportion of plastic (HDPE granules) increases the crack propagation decreases. It may be due to stress transfer in normal concrete happened by cracking the concrete while stress transfer in plastic sand concrete by deformation of the plastic, resulting in non-brittle failure.

(a) . NSC0.483 (b). HDPE15C0.49 (c). HDPE20C0.493

Fig. 3 Surface Texture of Concrete Block after Testing

IV. Conclusions

The experiment was carried out by 15% and 20% plastic granules as replacement to sand. The concrete mix design was modified by accommodating a material of different specific gravity. The concrete cubes were casted and cured for 7 days and the compressive strength was determined. From the present limited work, it could be concluded that

1) The concrete with 15% of HDPE sand showed maximum compressive strength.
2) The concrete made of plastic sand was observed to be durable as compared to natural sand.
3) The cube failure plane was intact in plastic sand concrete.
4) The improved compressive strength of plastic sand concrete would consume non-decomposable plastic which may help in clean environment.
5) Even lower compressive strength concrete of higher plastic sand may be used as mass filling concrete material.

References

[1] https://en.m.wikipedia.org > wiki > plastic, visited on Nov 30, 2017.
[2] https://en.m.wikipedia.org > wiki > types of concrete, visited on Nov 30, 2017.
[3] https://m.economic times.com, Recycling Plastic Wastes in India visited on Nov 30, 2017.
[4] Albano, C., Camacho, N., Hernandez, M., Matheus, A., and Gutierrez, A. (2009). "Influence of content and particle size of waste pet bottles on concrete behaviour at different w/c ratios." Waste Manage., 29(10), 2707–2716.
[5] Rahmani, M. M., Islam, M. A., and Ahmed, M. (2012). "Recycling of waste polymeric materials as a partial replacement for aggregate in concrete." Int. Conf. on Chemical, Environmental and Biological Sciences (ICCEBS'12), Penang, Malaysia, 99–102.
[6] Marzouk, O. Y., Dheilly, R. M., and Queneudec, M. (2007). "Valorization of post-consumer waste plastic in cementitious concrete composites." Waste Manage., 27(2), 310–318
[7] Al-Manaseer, A. A., and Dalal, T. R. (1997). "Concrete containing plastic aggregates." Concr. Int., 19(8), 47–52.
[8] Babu, D. S., Babu, K. G., and Wee, T. H. (2005). "Properties of lightweight expanded polystyrene aggregate concretes containing fly ash." Cem. Concr. Res., 35(6), 1218–1223
[9] Choi, Y. W., Moon, D. J., Chung, J. S., and Cho, S. K. (2005). "Effects of waste PET bottles aggregate on the properties of concrete." Cem. Concr. Res., 35(4), 776–781.
[10] Choi, Y. W., Moon, D. J., Kim, Y. J., and Lachemi, M. (2009). "Characteristics of mortar and concrete containing fine aggregate manufactured from recycled waste polyethylene terephthalate bottles." Constr. Build. Mater., 23(8), 2829–2835.
[11] IS 10262: 2009 "Concrete Mix Proportioning – Guidelines", BIS 2009
[12] IS 456 (2000): Plain and Reinforced Concrete – Code of Practice [CED 2: Cement and Concrete]