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Recycled Low Density Poly Ethylene Plastic Powder Substitute for Sand in Mortar and Concrete

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Abstract

The mortar and concrete are essential construction materials. The cement, sand, aggregates, and water are used to manufacture mortar and concrete. The sand is mined from riverbeds, which results in environmental impacts. The environmental effects can be reduced by substituting a low-cost replacement material for sand. The low-cost material used in this study is Recycled Low Density Poly Ethylene (R-LDPE) plastic powder. The R-LDPE is replaced in mortar and concrete mixes from 5% to 30%. This study conjectures that the R-LDPE's excellent water-repellent properties will make the mortar and concrete less pervious to water. In this study, the selected mortar mix for testing is 1:3, and the concrete mix for testing is M-45. The mortar and concrete samples are tested for compression, flexure, conventional seepage, and the Rapid Chloride Permeability Test (RCPT). The suitable R-LDPE replacement percentage concerning the volume of the sand is identified as 15% for compression, flexure, conventional seepage, and RCPT tests. The conjecture of this study fails as R-LDPE particles make the mortar and concrete samples porous. The testing mortar and concrete samples containing 15% R-LDPE replacement are suitable for making porous concrete.

1. Introduction

Mortar and concrete are inevitable composite materials for construction. The sand is a vital ingredient for the preparation of mortar and concrete. The sand mining in riverbeds is causing environmental impacts. The low-cost substitute material for sand will reduce environmental impacts caused by sand mining [1]. The low-cost substitute material used in this study is Recycled Low Density Poly Ethylene plastic powder (R-LDPE). The acronym for Low Density Poly Ethylene is LDPE which is classified under the polyethylene group of plastics [2]. People use LDPE for industrial, commercial, and domestic purposes. Things like polythene bags, wraps, squeezable bottles, milk cartons, bowls, buckets, cable insulations, flexible pipes, and many articles of daily use are manufactured with LDPE plastic. A huge quantity of LDPE is available for recycling because of daily usage. The cost of R-LDPE is low when compared to LDPE. The R-LDPE substitute for sand in mortar and concrete will minimize the environmental impact. Therefore, the R-LDPE is a low-cost substitute for sand replacement. The R-LDPE replaces sand in the 1:3 ratio mortar and M-45 grade concrete [3] [4].

2. Materials and Methods

A 1:3 mix ratio (one part cement to three parts fine aggregate) is used to test the mortar mix. The mortar test is a preliminary step to the concrete mix design for M-45. The M-45 concrete mix design begins with the selection and testing of basic materials. Ordinary Portland Cement (OPC) 43 grade is used for this study. Fine aggregate is sourced from the Sone River in Bihar, India, while coarse aggregate is sourced from Pakur, Jharkhand, India. Potable water is used for concrete blending, and the sand replacement material R-LDPE is sourced from the plastic industry. All material tests for the mix design are conducted in the concrete laboratory of the National Institute of Technology Patna. The properties of OPC 43-grade cement are tested according to Indian Standard (IS) specification IS 8112:2013 [5], and the results are shown in Table 1. Compressive strength tests of the cement are performed at intervals of 3, 7, and 28 days, with results tabulated in Table 2. Aggregates are tested following IS specification IS 383:1970 [6], and the findings are presented in Table 3. According to IS 383:1970, the sieve analysis is conducted on five kilograms of coarse aggregates, and the results are detailed in Table 5.

Table 1 *Physical properties of cement*

Characteristics	Values obtained	Standard values
Normal consistency	29%	-
Initial setting time	36 min.	Not less than 30 min
Final setting time	570 min.	Not greater than 600 min
Fineness	2%	<10%
Specific gravity	3.10	3.15

Table 2 *OPC grade 43 cement compressive strength*

No. of Days	Values obtained (N/mm^2)	Standard values (N/mm^2)
3	26.72	23
7	36.89	33
28	51.43	43 to 58

Table 3 *Coarse aggregate physical properties*

Characteristics	Values
Type	Crushed
Maximum size	20 mm
Specific gravity	2.71
Water absorption	0.5%

Table 4 *Fine aggregate physical properties*

Characteristics	Values
Type	River sand
Maximum size	Passing 4.75 mm
Specific gravity	2.68
Water	1.0%

Table 5 *Coarse aggregate sieve analysis results*

IS sieve size (mm)	Weight retained (gm)	Cumulative weight retained (gm)	Cumulative weight (%)	Finer (%)
40	0	0	0	100
20	1400	1400	28	72
12.5	3010	4410	88.2	11.8
10	450	4860	97.2	2.8
4.75	140	5000	100	0
PAN	0	5000	100	0

IS 383:1970 tests for fine aggregate are carried out, and the test results are shown in Table 4. One kilogram of the fine aggregate sample is subjected to sieve analysis, and the results are tabulated in Table 6 according to the values of the size of the fine aggregate and weight retained in the sieve. According to Table 6 of IS 383:1970, the sand is identified as being from Zone III. The Zone III sand is suitable for reinforced cement concrete.

Table 6 *Fine aggregates sieve analysis results*

IS sieve size (mm)	Retained weight (gm)	Cumulative weight (gm)	Cumulative weight (%)	Finer (%)
4.75	21	21	2.1	97.9
2.36	57	78	7.8	92.2
1.18	251	335	33.5	66.5
600	87	422	42.2	57.8
300	503	925	92.5	7.5
150	59	984	98.4	1.6
75	9	993	99.3	0.7
Pan	7	1000	100	0.0

Sieve analysis is performed on the sand substitute material R-LDPE. Sieve analysis of 100 grams of R-LDPE is performed to determine its fine-grained nature. The results are presented in Table 8. The inference from Table 8 shows the conformity of materials to sub-millimeter size. The physical property test results of R-LDPE are shown in Table 7.

Table 7 *R-LDPE physical properties*

Characteristics	Values
Type	Powdered
Maximum Size	≤300µ
Specific Gravity	0.55
Water Absorption	0%
Melting Point	120°C - 160°C

The significant physical properties of the R-LDPE used in this study are its melting point and specific gravity, which are mentioned in Table 7. The R-LDPE has lower tensile strength and density. The R-LDPE is highly resilient, resistant to corrosion, and insulates from heat, cold, and noise. The preferable chemical property of the R-LDPE is resistance to alcohol, bases, dilute and concentrated acids. R-LDPE material can be used in place of sand in mortar and concrete, as the aforementioned properties are suitable. The chemical admixture FOSROC CONPLAST SP430

G8 is used in the concrete mix design of M-45 to reduce water content, permeability, shrinkage, and creep to improve concrete strength. As per Indian Standard specification IS 9103:1999 [7] the specific gravity is 1.25, and chloride content is nil.

Table 8 *R-LDPE Sieve analysis results*

IS sieve size (mm)	Retained weight (gm)	Cumulative weight (gm)	Cumulative weight (%)	Finer (%)
4.75	0	0	0	100
2.36	0	0	0	100
1.18	0	0	0	100
600	0	0	0	100
300	52	52	52	48
150	44	96	96	4
75	3	99	99	1
PAN	1	100	100	0

2.1 Mix Proportion M-45

The concrete mix proportion of M-45 is carried out using Indian Standard specifications IS 10262:2009 [8], IS 456:2000 [9], IS 383:1970, and IS 2386 (Part 3):1963 [10]. The Indian standard for mortar testing recommends a mix of 1:3. The study is adapted for the mixed proportion given in Table 9.

Table 9 *Proportion of concrete blend M-45*

Water	Cement	Fine aggregate	Coarse aggregate	R-LDPE	Admixture
0.36	1	1.7	2.7	5% to 30% (by volume)	8×10^{-3}

2.2 Methodology

The focal point of this study is to ascertain the suitable R-LDPE substitute level in the mortar and concrete by replacing sand. This study conjectures that the R-LDPE used in the sand replacement may block pores in the mortar and concrete to make it less permeable to water. The permeability is tested using cubes of sample sizes 15 cm x 15 cm x 15 cm for mortar and concrete through a conventional seepage test. The permeability is also tested using the Rapid Chloride Permeability Test (RCPT) method with a cylinder sample size of 10 cm diameter x 5 cm height for mortar and concrete. The study is carried out by commencing compression, flexure and seepage tests. The compression tests are performed with sample sizes of cube 7.06 cm x 7.06 cm x 7.06 cm for mortar and 15 cm x 15 cm x 15 cm for concrete. The flexure test is performed with prism sample sizes 4 cm x 4 cm x 16 cm for mortar and 10 cm x 10 cm x 50 cm for concrete. The methodology is explained as work flow diagram in Fig. 1. The mortar and concrete batch are prepared with 5% R-LDPE substitution to the volume of sand. The successive batch of mortar and cement cubes are substituted with a 5% increment of R-LDPE up to 30% to the volume of sand. The mortar and concrete batch of R-LDPE substitutions to the volume of sand are 5%, 10%, 15%, 20%, 25% and 30%. A mortar R-LDPE substitution batch consists of 10 cubes, one prism, and one RCPT sample. Three mortar cubes are tested per interval at 3, 7, and 28 days from the date of casting. A mortar cube sample is tested for permeability after 28 days from the date of casting. One mortar prism is tested after 28 days for flexure. One mortar cylinder sample is subjected to RCPT after 28 days. The mix design M-45 concrete samples are prepared and tested at 7, 14, 21, and 28 days for compression. The flexure and permeability test of concrete follows similar methods used for mortar. All the casted samples are demoulded after 24 hours and preserved in curing at 27°C in water until recommended testing intervals.

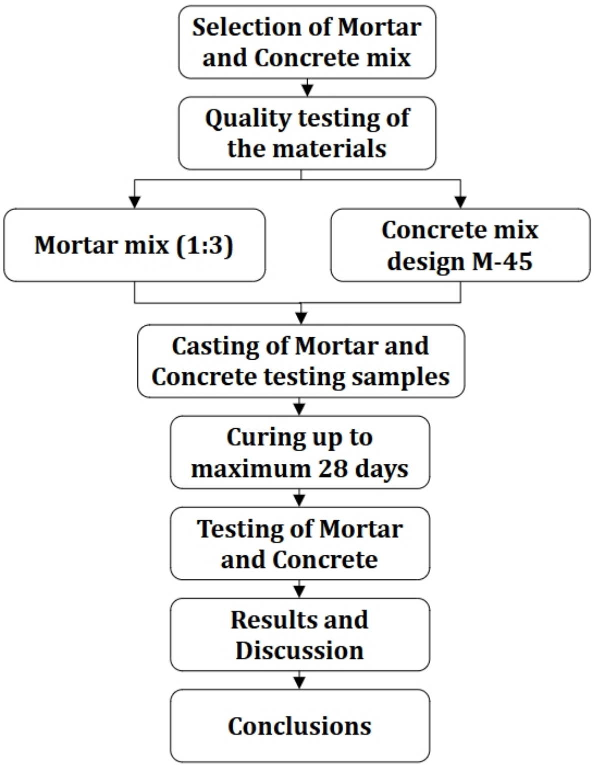

Fig. 1 *Work flow diagram*

2.3 Seepage Tests

The conventional seepage test follows Indian Standard specification IS 3085:1965 [11]. The equipment contains a concrete cube-shaped chamber linked to a pressurized water cylinder. The concrete cube is left to dry at room temperature for 24 hours. After drying for 24 hours, the sidewalls of the equipment are coated with water sealant polyethylene terephthalate with a concrete cube in its place inside the equipment. This assembly is left undisturbed for 24 hours, and polyethylene terephthalate will allow water only to seep through the top and bottom of the concrete cube inside the equipment. Fig. 2 (a) shows the process diagram of the conventional seepage test.

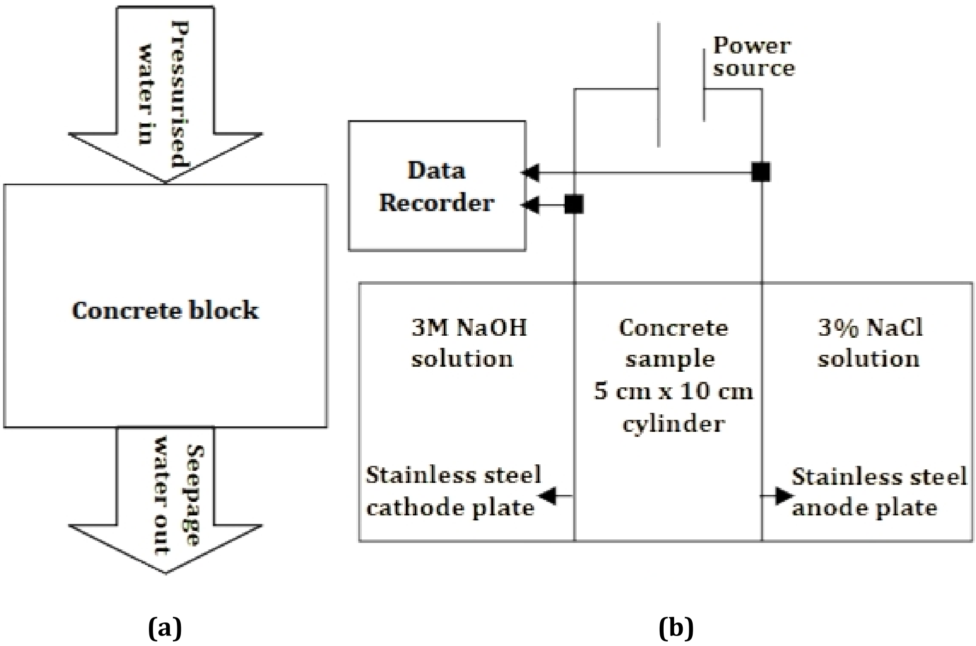

Fig. 2 *Seepage Tests (a) Conventional procedure; (b) Rapid Chloride Permeability Testing procedure*

According to the American Society for Testing and Materials specifications ASTM C 1202-19, the RCPT measures how many chloride ions can get through the sample in 6 hours. Place the sample between the two steel terminals, which are connected to a 60V direct current. The opposite side of a sample of steel terminal is immersed in 3% sodium chloride (NaCl) solution, and the other side is immersed in 0.3 M sodium hydroxide (NaOH) solution. The quantity of charge passing across the sample provides a direct correlation to seepage. Figure 2(b) shows the process diagram of RCPT.

3. Results and Discussion

The test results for mortar and concrete are as follows.

3.1 Compressive Strength

Figure 3 shows the compressive strength of OPC-43 grade mortar mix (1:3) with 5% to 30% R-LDPE replacing the volume of sand. The results show that the favourable percentage of R-LDPE replacement is 15%. Beyond 15%, the strength of the mortar mix reduces considerably, which is obvious from Table 10. Table 10 shows the strength of mortar mix 1:3 with 5% to 30% of R-LDPE replacement to the volume of sand. Table 10 and Fig. 3 also show the relationship between the curing periods of samples and the strength achieved at the respective intervals of testing

Table 10 *Compressive strength of mortar mix 1:3*

Compressive strength of / Days of curing	0% R-LDPE (N/mm^2)	5% R-LDPE (N/mm^2)	10% R-LDPE (N/mm^2)	15% R-LDPE (N/mm^2)	20% R-LDPE (N/mm^2)	25% R-LDPE (N/mm^2)	30% R-LDPE (N/mm^2)
3 days	23.5	23.71	24.12	24.32	23.69	22.71	22.15
7 days	34	34.54	35.19	35.84	34.84	32.58	31.46
28 days	43.8	44.08	45.12	46.73	44.03	42.1	40.89

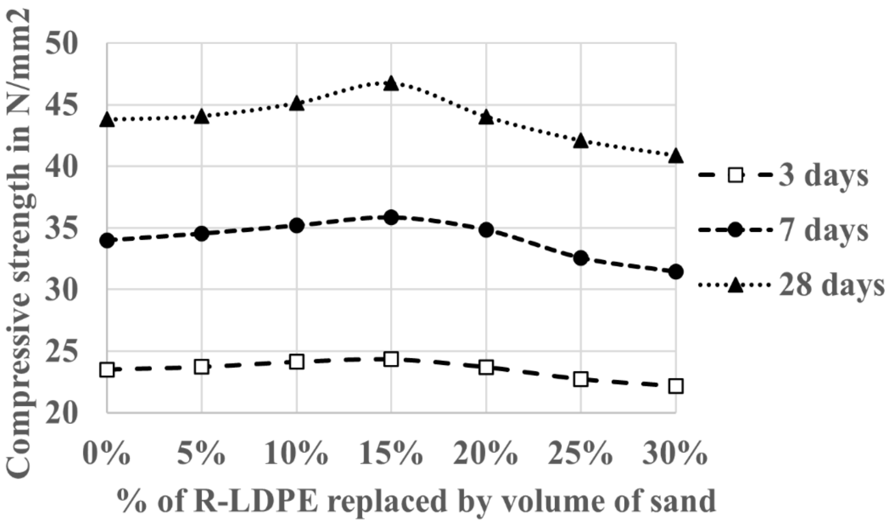

Fig. 3 *Compressive strength of mortar mix 1:3*

Table 11 *Compressive strength of concrete M-45*

Compressive strength of / Days of curing	0% R-LDPE (N/mm^2)	5% R-LDPE (N/mm^2)	10% R-LDPE (N/mm^2)	15% R-LDPE (N/mm^2)	20% R-LDPE (N/mm^2)	25% R-LDPE (N/mm^2)	30% R-LDPE (N/mm^2)
7 days	35.81	37.54	38.21	39.2	38.03	35.83	33.71
14 days	44.14	44.85	46.1	47.95	46.23	43.41	40.93
21 days	49.87	50.85	52.4	55.02	52.89	48.78	46.41
28 days	54.1	55.2	56.95	59.41	55.67	52.12	50.21

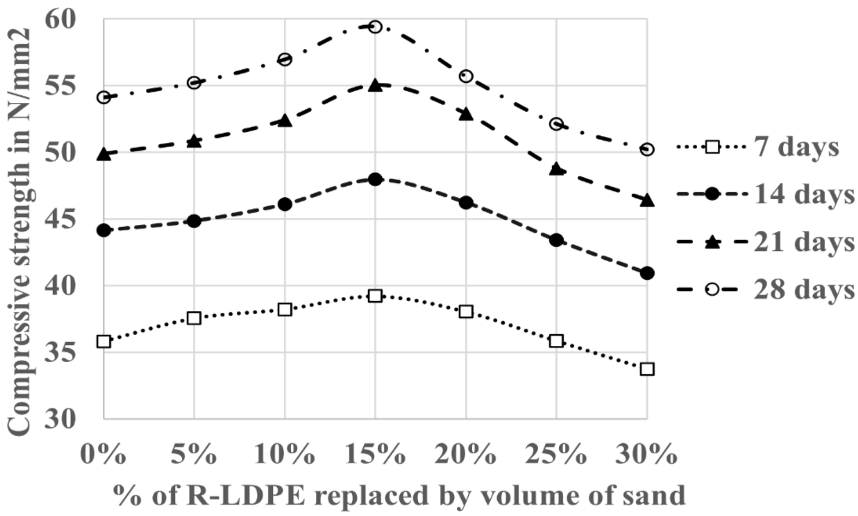

Fig. 4 *Compressive strength of concrete M-45*

Figure 4 shows the compressive strength of OPC-43 grade concrete mix M-45 with 5% to 30% R-LDPE replacing the volume of sand. The results show that the favourable percentage of R-LDPE replacement is 15%. Beyond 15%, the strength of the mortar mix reduces considerably, which is obvious from Table 11. Table 11 shows the strength of concrete mix M-45 with 5% to 30% of R-LDPE replacement to the volume of sand. Table 11 and Fig. 4 also show the relationship between the curing periods of samples and the strength achieved at the respective intervals of testing.

3.2 Flexural Strength

Figure 5 shows the flexural strength of OPC-43 grade mortar mix (1:3) with 5% to 30% R-LDPE replacing the volume of sand. The results show that the favourable percentage of R-LDPE replacement is 15%. Beyond 15%, the strength of the mortar mix reduces considerably, which is obvious from Table 12. Table 12 shows the strength of mortar mix 1:3 with 5% to 30% of R-LDPE replacement to the volume of sand. Table 12 and Fig. 5 also show the relationship between the curing period of samples and the strength achieved.

Figure 6 shows the flexural strength of OPC-43 grade concrete mix M-45 with 5% to 30% R-LDPE replacing the volume of sand. The results show that the favourable percentage of R-LDPE replacement is 15%. Beyond 15%, the strength of the mortar mix reduces considerably, which is obvious from Table 13. Table 13 shows the strength of concrete mix M-45 with 5% to 30% of R-LDPE replacement to the volume of sand. Table 13 and Fig. 6 also show the relationship between the curing periods of samples and the strength achieved.

Table 12 *Flexural strength of mortar mix 1:3*

Flexural strength of / Days of curing	0% R-LDPE (N/mm^2)	5% R-LDPE (N/mm^2)	10% R-LDPE (N/mm^2)	15% R-LDPE (N/mm^2)	20% R-LDPE (N/mm^2)	25% R-LDPE (N/mm^2)	30% R-LDPE (N/mm^2)
28 days	3.41	3.89	4.16	4.45	3.81	3.7	3.56

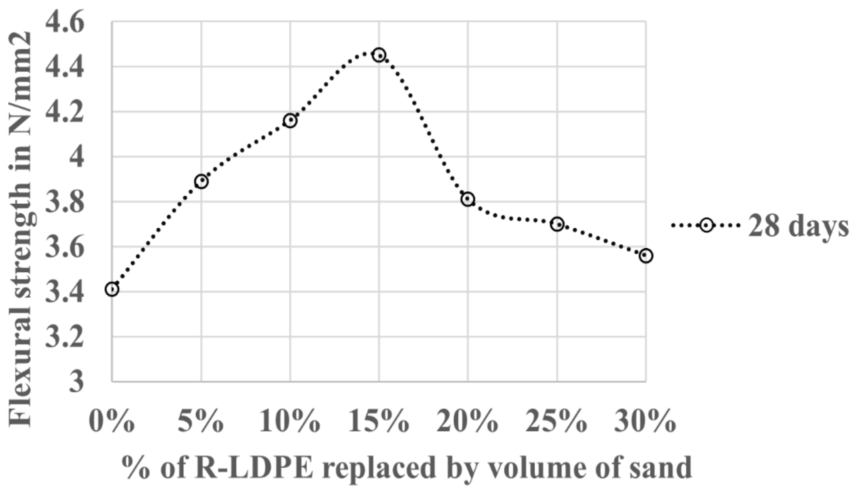

Fig. 5 *Flexural strength of mortar mix 1:3*

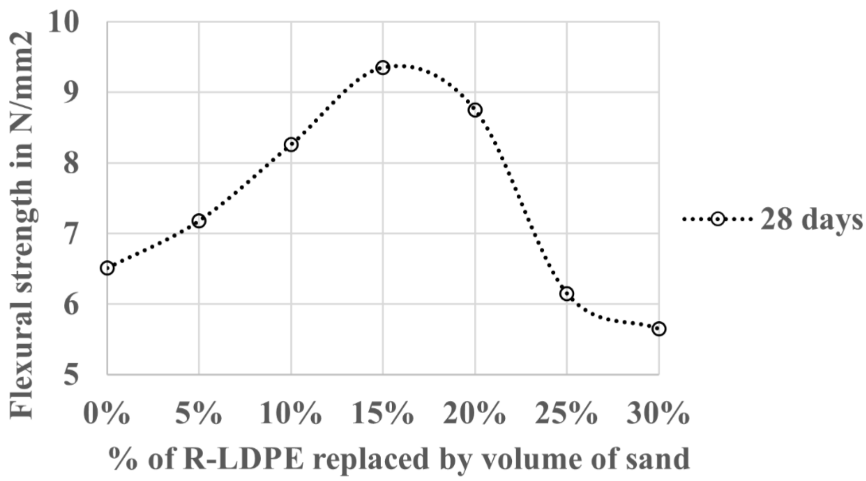

Fig. 6 *Flexural strength of concrete M-45*

Table 13 *Flexural strength of concrete M-45*

Flexural strength of / Days of curing	0% R-LDPE (N/mm^2)	5% R-LDPE (N/mm^2)	10% R-LDPE (N/mm^2)	15% R-LDPE (N/mm^2)	20% R-LDPE (N/mm^2)	25% R-LDPE (N/mm^2)	30% R-LDPE (N/mm^2)
28 days	6.51	7.18	8.26	9.35	8.23	7.18	6.5

3.3 Seepage Test

The results of the conventional seepage test of OPC 43-grade mortar mix 1:3 after 28 days from casting are shown in Fig. 7 and tabulated in Table 14. The results show that the R-LDPE in mortar increases water permeability in the mortar mix 1:3. As the contentment of R-LDPE increases, the porosity of the sample parallelly increases. The inference from the seepage tests shows that replacing R-LDPE with sand makes the sample porous. The conjecture of this study fails because the R-LDPE replacement to the volume of sand makes the concrete porous and increases permeability. R-LDPE's excellent waterproofing properties make it suitable for finished plastic products. But fine R-LDPE particles are not blocking the voids in the composite mortar mix. The increase in R-LDPE percentage increases the porosity of the sample, which is shown in Fig. 7 and Table 14, ensuring the validity of the results.

Table 14 *Permeability of mortar mix 1:3*

Days of curing	0% R-LDPE	5% R-LDPE	10% R-LDPE	15% R-LDPE	20% R-LDPE	25% R-LDPE	30% R-LDPE
28 days	3.41E-05	3.66E-05	3.90E-05	4.32E-05	5.85E-05	7.82E-05	1.00E-04

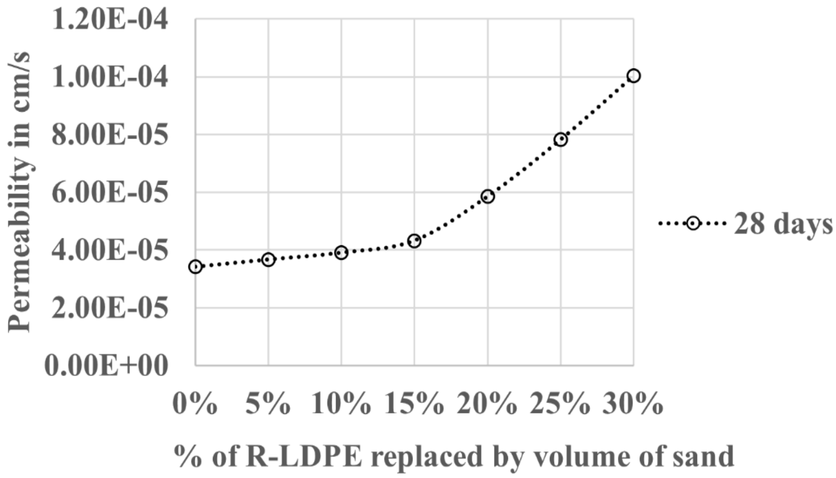

Fig. 7 *Permeability of mortar mix 1:3*

The results of the conventional seepage test of the OPC-43 grade concrete mix M-45 after 28 days from casting are shown in Fig. 8 and tabulated in Table 15. The results show that the R-LDPE in concrete increases water permeability in the concrete mix M-45. As the contentment of R-LDPE increases, the porosity of the sample parallelly increases. The inference from the seepage tests shows that replacing R-LDPE with sand makes the sample porous. Aforesaid, the conjecture of this study fails as R-LDPE makes the concrete mixture porous. The inference from the seepage tests shows that replacing R-LDPE with sand makes the sample porous. The increase in R-LDPE percentage increases the porosity of the sample, which is explained in Fig. 8, and Table 15 ensures the validity of the results.

Table 15 *Permeability of concrete M-45*

Days of curing	0% R-LDPE	5% R-LDPE	10% R-LDPE	15% R-LDPE	20% R-LDPE	25% R-LDPE	30% R-LDPE
28 days	2.40E-07	6.25E-07	6.71E-07	7.21E-07	7.96E-07	8.49E-07	9.50E-07

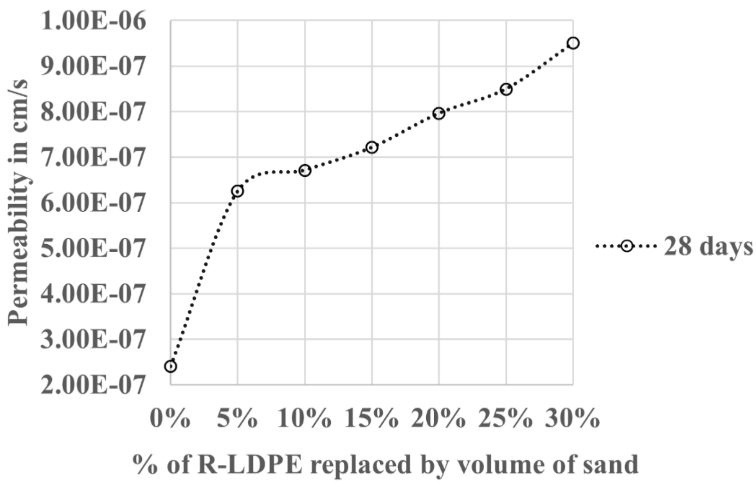

Fig. 8 *Permeability of concrete M-45*

3.4 Rapid Chloride Permeability Test

Figure 9 shows and Table 16 tabulates the RCPT test results for the OPC-43-grade concrete mix M-45. Table 16 shows that the concrete becomes porous by replacement of R-LDPE to the volume of sand. The normal concrete with 0% R-LDPE shows 2400 coulombs of charge discharged between the two terminals. After the addition of R-LDPE, the discharge of charge between the terminals increases more than double-fold. The ratio between conventional permeability tests and the RCPT (Kscm/Ko) shows slight variations in the graph. Nevertheless, the ratio value increases proportionally to the percentage of R-LDPE increase. Figure 10 shows the ratio between conventional permeability tests and the RCPT. The R-LDPE increase proportionally increases porosity in the sample, leading to an increase in the exchange of charges between the terminals. The sample analysis showcases that when the quantity of R-LDPE increases, that results in increased porosity, causing the increase in seepage.

Table 16 *RCPT of concrete M-45*

Days of curing	0% R-LDPE	5% R-LDPE	10% R-LDPE	15% R-LDPE	20% R-LDPE	25% R-LDPE	30% R-LDPE
28 days	2400	5200	5470	5586	5768	5925	6017
Kscm/Ko	0.1	0.12	0.123	0.129	0.138	0.143	0.158

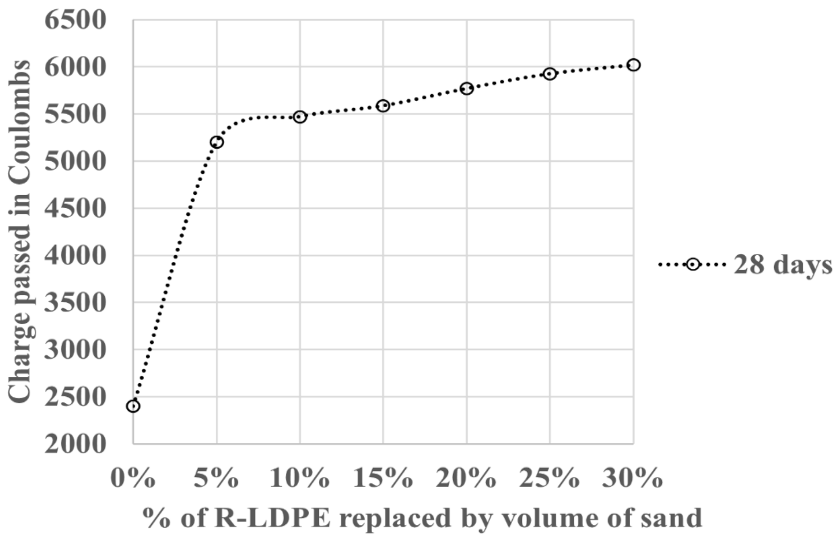

Fig. 9 *RCPT of concrete M-45*

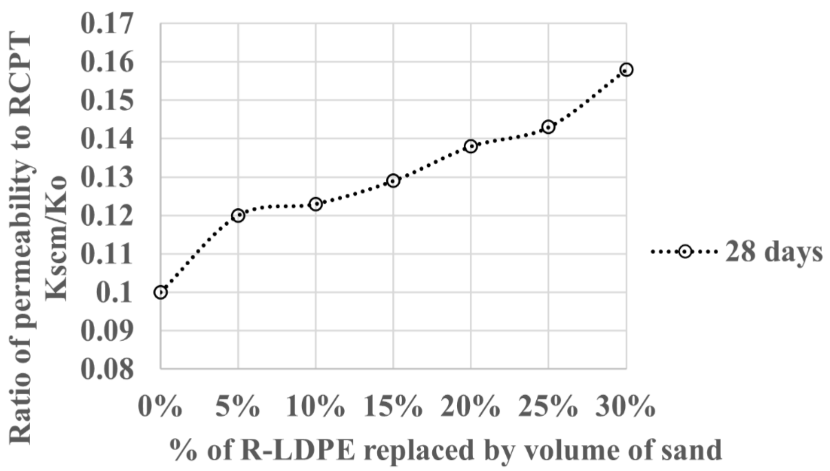

Fig. 10 *Permeability to RCPT ratio Kscm/Ko*

3.5 Significance of the Study

The study of the R-LDPE replacement to the volume of sand with a 5% increment up to 30% aids us in identifying a suitable replacement percentage of R-LDPE plastic powder in mortar and concrete. The flexure tests show the flexural strength achieved by using R-LDPE [13]. The seepage test and RCPT evaluate the permeability nature of the mortar and concrete [14, 15]. This study proves that using R-LDPE plastic powder [16, 17] can create porous concrete in an eco-friendly way. The porous concrete is suitable for pavement, paver blocks, garden tiles, and plant pot making [18, 19, 20]. The mortar and concrete mix using LDPE wastes will reduce environmental impact and pave the way for the reuse of waste as raw material [21, 22, 23]. Substituting up to 15% of sand with R-LDPE will reduce the environmental impact of low-density plastics [5, 24]. Replacing 15% of sand with R-LDPE does not compromise the compressive and flexural strengths of mortar and concrete.

4. Conclusions

Using R-LDPE as a replacement for sand in mortar and concrete provides amicable results. The inferred results show the favourable replacement limit lies between 15% and 20%. The further replacement percentages of R-LDPE show a reduction in compressive and flexural strength. The seepage test and RCPT show that both the mortar and concrete became porous, resulting in water seepage. The seepage test to RCPT ratio shows similar results. The flexural strength anomalies are because of the distribution of R-LDPE particles in the concrete. The conjecture of this study fails, as the R-LDPE plastic particles fail to block pores in the concrete. This property of R-LDPE particles results in porous mortar and concrete. 15% R-LDPE replacement by sand volume is the suitable substitution percentage for mortar and concrete. The mortar and concrete prepared using 15% of R-LDPE replacement can be used for laying porous roads, which will aid in effective water seepage to the water table. Using a 15% R-LDPE replacement for sand allows manufacturers to make paver blocks, garden tiles, and plant pots with effective draining and seepage of excess water. The 15% R-LDPE usage will reduce the pollution impact of waste LDPE on the environment.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Gopikrishnan T****; testing materials and concrete casting:*** *Mahendra Kumar, Rajdhar Dwivedi, Jitendra Sharma;* ***analysis and interpretation of results:*** *Gautam Kumar;* ***draft manuscript preparation:*** *Gopikrishnan T. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Z. Z. Ismail and E. A. AL-Hashmi, “Use of waste plastic in concrete mixture as aggregate replacement,” Waste Management, vol. 28, no. 11, pp. 2041–2047, Nov. 2008, doi: 10.1016/j.wasman.2007.08.023.

[2] R. Siddique, J. Khatib, and I. Kaur, “Use of recycled plastic in concrete: A review,” Waste Management, vol. 28, no. 10, pp. 1835–1852, Jan. 2008, doi: 10.1016/j.wasman.2007.09.011.

[3] N. Saikia and J. D. Brito, “Waste polyethylene terephthalate as an aggregate in concrete,” Mat. Res., vol. 16, no. 2, pp. 341–350, Feb. 2013, doi: 10.1590/S1516-14392013005000017.

[4] T. S. Vadivel, M. Doddurani, and K. S. Shobana, “An Experimental Study on Waste Plastic Aggregate Based Concrete - An Initiative Towards Cleaner Environment,” vol. 24, no. 3, pp. 552–556, 2016, doi: 10.5829/idosi.mejsr.2016.24.03.23101.

[5] “IS 8112 (1989): Specification for 43 grade ordinary Portland cement,” Bureau of Indian Standards, New Delhi, ICS 91.100.10, Mar. 2013. Accessed: Dec. 24, 2024. [Online]. Available: https://law.resource.org/pub/in/bis/S03/is.8112.1989.pdf

[6] "IS 383 (1970): Specification for Coarse and Fine Aggregates from Natural Sources for Concrete," Bureau of Indian Standards, New Delhi, UDC 691.322, Apr. 1971. Accessed: Dec. 24, 2024. [Online]. Available: https://law.resource.org/pub/in/bis/S03/is.383.1970.pdf

[7] "IS 9103 (1999): Specification for Concrete Admixtures," Bureau of Indian Standards, New Delhi, ICS 91.100.30, Apr. 1999. Accessed: Dec. 24, 2024. [Online]. Available: https://law.resource.org/pub/in/bis/S03/is.9103.1999.pdf

[8] "IS 456 (2000): Plain and Reinforced Concrete - Code of Practice," Bureau of Indian Standards, New Delhi, ICS 91.100.30, Apr. 2007. Accessed: Dec. 24, 2024. [Online]. Available: https://law.resource.org/pub/in/bis/S03/is.456.2000.pdf

[9] "IS 2386-3 (1963): Methods of test for aggregates for concrete, Part 3: Specific gravity, density, voids, absorption and bulking," Bureau of Indian Standards, New Delhi, UDC 691.322: 531.75, Mar. 1997. Accessed: Dec. 24, 2024. [Online]. Available: https://law.resource.org/pub/in/bis/S03/is.2386.3.1963.pdf

[10] "IS 3085 (1965): Method of Test for Permeability of Cement Mortar and Concrete," Bureau of Indian Standards, New Delhi, UDC 666.97: 620.193.19, Jan. 1996. Accessed: Dec. 24, 2024. [Online]. Available: https://archive.org/details/gov.in.is.3085.1965

[11] "C1202 Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration." Accessed: Jun. 25, 2024. [Online]. Available: https://www.astm.org/c1202-19.html

[12] M. A. R. Bhutta, K. Tsuruta, and J. Mirza, "Evaluation of high-performance porous concrete properties," Construction and Building Materials, vol. 31, pp. 67–73, Jun. 2012, doi: 10.1016/j.conbuildmat.2011.12.024.

[13] N. Saikia and J. D. Brito, "Waste polyethylene terephthalate as an aggregate in concrete," Mat. Res., vol. 16, no. 2, pp. 341–350, Feb. 2013, doi: 10.1590/S1516-14392013005000017.

[14] G. O. Bamigboye, K. Tarverdi, A. Umoren, D. E. Bassey, U. Okorie, and J. Adediran, "Evaluation of eco-friendly concrete having waste PET as fine aggregates," Cleaner Materials, vol. 2, p. 100026, Dec. 2021, doi: 10.1016/j.clema.2021.100026.

[15] A. Yao, H. Ding, X. Zhang, Z. Hu, R. Hao, and T. Yang, "Optimum Design and Performance of Porous Concrete for Heavy-Load Traffic Pavement in Cold and Heavy Rainfall Region of NE China," Advances in Materials Science and Engineering, vol. 2018, no. 1, p. 7082897, 2018, doi: 10.1155/2018/7082897.

[16] D. Chan and P. C. Sun, "Effects of Fine Recycled Aggregate as Sand Replacement in Concrete," HKIE Transactions, vol. 13, no. 4, pp. 2–7, Jan. 2006, doi: 10.1080/1023697X.2006.10668055.

[17] G. A. Habeeb and H. B. Mahmud, "Study on properties of rice husk ash and its use as cement replacement material," Mat. Res., vol. 13, pp. 185–190, Jun. 2010, doi: 10.1590/S1516-14392010000200011.

[18] R. Siddique, J. Khatib, and I. Kaur, "Use of recycled plastic in concrete: A review," Waste Management, vol. 28, no. 10, pp. 1835–1852, Jan. 2008, doi: 10.1016/j.wasman.2007.09.011.

[19] K. Shyam Prakash and Ch. H. Rao, "Study on Compressive Strength of Quarry Dust as Fine Aggregate in Concrete," Advances in Civil Engineering, vol. 2016, no. 1, p. 1742769, 2016, doi: 10.1155/2016/1742769.

[20] S. V. Deo and A. D. Pofale, "Parametric Study for Replacement of Sand by Fly Ash for Better Packing and Internal Curing," OJCE, vol. 05, no. 01, pp. 118–130, 2015, doi: 10.4236/ojce.2015.51012.

[21] T. F. and P. Partheeban, "Granite powder concrete," INDJST, vol. 3, no. 3, pp. 311–317, Mar. 2010, doi: 10.17485/ijst/2010/v3i3.6.

[22] B. Rai, S. T. Rushad, B. Kr, and S. K. Duggal, "Study of Waste Plastic Mix Concrete with Plasticizer," ISRN Civil Engineering, vol. 2012, pp. 1–5, 2012, doi: 10.5402/2012/469272.

[23] M. Guendouz, F. Debieb, O. Boukendakdji, E. Kadri, M. Bentchikou, and H. Soualhi, "Use of plastic waste in sand concrete," JMESCN, vol. 7, no. 2, pp. 382-389, 2016.