Manufacturing and Performance Evaluation of Recycled Plastic (HDPE) Coarse Aggregates in Concrete

RATOD VINOD KUMARa, Dr. D. RUPESH KUMARb

*a Research scholar, Department of Civil Engineering University College of Engineering, Osmania University, Hyderabad, India.*

*b Professor, Department of Civil Engineering. University College of Engineering, Osmania University, Hyderabad, India*.

**Abstract:** The process for preparing plastic aggregate to be used in concrete mixtures, The plastic can be reprocessed plastic that has been broken into strips after being washed through the templates. Sand and plastic rock dust aggregates are strong contenders for concrete mixes. This article uses recycled plastic collected from a local plastic shredder, measuring between 1mm and 6mm, melted at a temperature between 294 and 339°C, and mixed with sand and rock dust. After 100% melting of the plastic bond with sand particles and rock dust particles, this mixture is poured into the water through a suitable size mesh we need, the hot particles mixed with the plastic sand and plastic rock dust when in the water will form a stronger bond. These aggregates are stronger in compression and very strong in tension than the ones we can use in concrete. Here in this paper, the secondary or backscattered electron signal is detected capturing the secondary or backscattered electron signal after projecting a concentrated electron beam through the medium, and a detailed high-resolution image of the sample particles can be obtained. scanning electron microscopy (SEM). And Elemental identification and quantitative composition information are also obtained using an “energy-dispersive X-ray analyzer” (EDX. or EDA). The size of the aggregates manufactured in the beginning varies. between 2.36 and 20 mm, which is covered with a granulometry under the ASCE-C330, C33-99a, and IS 383-2019 standards. were adopted to further test the concrete and make a precast concrete part. In concrete, by use of light-weight plastic aggregates, as well as the use of high-density plastic materials to prepare plastic aggregates (single and well-graded), the method of manufacturing plastic aggregates for civil infrastructure, and the composition that incorporates this type of aggregate, are the concepts of this research.

**Author keywords**: high-density polyethylene (HDPE), Filler; Recycled plastic rock dust and plastic sand aggregate, “Scanning electron microscopy” (SEM), “Energy Dispersive X-Ray Analyzer” (EDX or EDA), Compressive strength of concrete.

**Introduction:**

“One of the most pressing issues in the field of environmental protection is the increased making use of various forms of an object made of plastic”[1]. “The use of the materials containing plastic trash business is a green method of reducing the amount of waste disposed of in landfills”. Only about 20% of plastic garbage is appropriately managed. In current history, the building industry has emerged as one of the most promising avenues for using recycled materials in concrete, Plastic trash is used in concrete as an aggregate alternative[2]. which account for 60 to 70% of the overall volume of concrete, is one solution to this problem. Additionally, by enhancing the percentage of plastic waste utilized as an aggregate substitute, the consumption of natural aggregates will be reduced[2]. National standards, which encourage the use of waste and secondary materials, are increasing political pressure on producers, assisting in the building of a culture in which the sustainable use of materials is connected with development [3]. Aggregates are fundamental to the characteristics of cured concrete. Concerns regarding natural resource depletion and the impact on the environment have mostly centered on the possibility of Synthetically generated aggregates (made from garbage) being used to replace natural resources. This study can give a dual solution for trash management and high-level natural resource protection[3] This study describes the manufacture of a new recycled plastic aggregate based on HDPE and two different types of fillers, sand, and rock dust. Furthermore, this study investigates the viability of employing recycled plastic aggregates as a complete substitute for normal coarse aggregates in concrete. The influence of recycled plastic aggregates on the properties of fresh and cured concrete was tested at various w/c ratios [4].

***The material used for manufacturing*** was high-density plastic (Polyethylene (C2H4) n), Natural sand, and rock dust obtained from a local crusher. AADI plastic manufacturing plant in KUKATPALLY-Hyderabad was used to collect waste High-Density Polyethylene (HDPE).

**Table:1** Natural sand and rock dust chemical compositions[5]

|  |  |  |  |
| --- | --- | --- | --- |
| Constituent | Quarry rock dust (%) | Natural sand (%) | Test method |
| * SiO2
* Al2O3
* Fe2O3
* Cao
* MgO
* Na2O
* K2O
* TiO2
* Loss
 | 61.4918.6006.44 04.9402.4500.0003.0401.3500.37 | 81.8211.0801.6403.3200.7701.3101.2900.0000.31 | IS: 4032-1968[5] |

***Manufacturing Methodology***: Natural fine aggregate river sand which was passed through a 4.75 mm IS screen conforming to IS 383:1970[6]grading zone II and had a specific gravity of 2.63[7]relative bulk density 1460, and rock dust which was used with a specific gravity of 2 .54[7]1745 relative bulk density [7]The plastic aggregate generated was light, ranging between 650 and 870 kg/m3 and absorbing between 0.114 and 0.369 percent of water. Various formulations of RPSCA and RPRDCA (recycled plastic sand coarse aggregate and recycled plastic rock dust coarse aggregate) are suitable and used in concrete. Following are the main manufacturing composition of the plastic aggregates. Plastic-Sand Aggregates and plastic-rock dust Aggregates are manufactured by fallowing proportions.

**Table:2** systematic variation of samples

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Experiment | Plastic-type | Plastic to sand proportion (in grams) | Plastic to rock dust proportion (in grams) | Temperature(°C)  | Time (in min) | Final aggregate weight(dry) in grams |
| Mesh Shaking Technique(MST) | HDPE | 1:1(500:500)1:2(500:1000) | 1:1(500:500)1:2(500:1000) | 290-340294-340 | 2535 | 930-9901250-1450 |

**Detailed procedure**: - Plastic collected from waste and shredded, as shown in Fig. 2a: Below is a step-by-step guide on collecting recyclable plastic. Plastics come in a variety of shapes and sizes, including containers, jars, bottles, plastic bags, and packaging. To be processed further and to make packing, transportation, and distribution of recovered products easier, plastics must usually be broken down into smaller bits. Communities can offer four different types of plastic recycling services for bottles and containers made of plastic. a). curbside, b). drop-off, c). buy-back d). deposit/refund programs[8].



 **figure 2a figure 2b figure 2c figure 2d**

Figure 2a. No-2) Take the weight of the plastic on the scale: set the pointer of the scale to the zero level of the top loader. Remove dust particles from the weighing platform. Take the plastic out of the bag, place the tray on the scale, pour the plastic into the tray, read the scale at eye level to 0.1kg, and take the weight of the plastic. **figure 2a. No-3 and 4**) pour the plastic into a pan: remove the top loader cover and pour the plastic into a hot pan. **figure 2a. No-5)** Weighing sand and rock powder (Fig: 2b): Do not handle the sand and rock dust to be weighed with bare hands. Use paper towels or gloves. The same procedure as that used to weigh the plastic is repeated. Record the number on the report sheet. Remove the pan from the top-loading weigh and pour the sand and rock dust into a hot pan. **figure 2a. No-6 and 7**) mixed with plastic particles: **figure 2a. No-8 and 9**) fire under the pan and the plastic begins to melt at a temperature of 294°C.

**Table**:3 physical properties of RPSCA and RPRDCA aggregate

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Physical Property** | 1:1-RPSCA | 1:2-RPSCA | 1:1-RPRDCA | 1:2-RPRDCA |
| Bulk Density (kg/m3) (ASTM C330-99: table-2) | 653 | 845 | 660 | 867 |
| Absorption (%) | 0.352 | 0.369 | 0.106 | 0.114 |
| Particle Shape | Sub angular | Sub angular | Sub angular | Sub angular |
| Type | Crushed | Crushed | Crushed | Crushed |
| Nominal Maximum Size(mm) | 20 | 20 | 20 | 20 |
| Surface Texture | Partially rough/ porous | Partially rough/ porous | Partially rough/ porous | Partially rough/ porous |
| Specific Gravity(IS:2386-1963) | 1.42 | 1.57 | 1.42 | 1.56 |
| Color | Brown | Brown | brown | brown |

***Making procedure***: - The aggregates were prepared by using MESH SHAKING TECHNIQUE 500grams of plastic HDPE was heated in a locally available metallic iron TAWA, starting from room temperature at 27°C. The HDPE was then further heated until melted at temperatures between 294 to 339°C as shown in Fig 2d. The sand was taken initially 500grams for the first mix one and 1000grams for mix two, then mixed into the molten HDPE until a homogenous dark paste was formed. This was then poured into steel mesh, by rubbing action with hand the melted mix was directed to fall in water directly, then aggregates are formed in necessary shapes concerning the size of the mesh, the formed size of the aggregate range from 2.36mm to 20mm, all temperature measurements were recorded using a thermometer. At the time of production following materials have to wear that is a face mask to control unhealthy gas when it is released at the time of burning the HDPE, safety shoes, gloves, and eyeglasses to reduce the effect of gasses on the eyes. The smoke may contain various health risk compounds, that may affect the respiratory system, nervous system, and various organ damage. the produced fire smoke was shown in Fig. 2c. all aggregates are weighed and kept under the sun to dry the sample and the formed aggregate is separated by sieves size ranging from 150micron to 20mm (sieve analysis is done).

**Grading of aggregate:**Bulk density is obtained from procedure IS 2386 (PART III)-1963, which is under ASTM C330-99: Table 2, Particle Size Distribution Curves for RPSCA 1:1, RPSCA 1:2, RPRDCA 1: 1, and 1:2 RPRDCA is made for two types of aggregates, The first is a single-size aggregate and the second is a well-graded aggregate, the coarse aggregate sieve analysis shown in the figure.

The cumulative percentage pass of the coarse aggregate used according to ASTM C330/c330M[9]and IS 383-2019 as pictured, in 1.18-20mm specification. For the two types of coarse aggregates (single and well-graded), the specific gravity and water absorbency were 1.42, 1.57, 1.42, 1.56, and 0.352 percent, 0.369 percent, 0.106 percent, and 0.114 percent, respectively.

***Microstructure investigation on aggregates*:** "The electronic console and electron column [10]are both parts of the SEM instrument, and Instrument adjustments, such as filament current, are controlled via the electronic console's control knobs and switches, gear voltage, focus, magnification, brightness, and contrast. "The scanning electron microscope (SEM) magnifies images of a sample's Other physical and chemical characteristics include size, shape, composition, crystallography, and others."[11]A computer is used to access all of the main controls. Because SEMs can detect secondary and backscattered electrons, the specimens must be fixed on the stage with a goniometer. During the microanalysis of plastic aggregate, the movable X-ray detector is normally mounted close to the sample on one side of the chamber[11]. EDX makes use of X-rays spectrum generated by bombarding a solid sample with a focused electron beam to provide a chemical analysis that is focused on a specific area [11]



 1:1 RPSCA (a) 1:2 RPSCA (b)

 1:1 RPRDCA (c) 1:2 RPRDCA (d)

 Figure:6(a)(b)(c)(d) (SEM images of 1:1,1:2,1:1,1;2 plastic sand and rock dust aggregate

“Information in a nutshell and Figure 6(a)(b)(c)(d) shows a microstructural study of aggregate mixture samples made with 1:1,1:2,1:1,1;2 plastic sand and rock dust aggregate using SEM imaging”. In the case of rock dust, the recycled plastic is strongly bonded due to the small size of the particles, indicating that rock dust In comparison to other materials, particles are embedded in the plastic matrix in a high concentration.[2] to the HDPE plastic as a binder agent. This proved that the efficiency of the aggregate preparation process is correct. Aggregate made with plastic sand also has a strong bond between sand particle and HDPE plastic which have few void spaces. EDX results show C, O, Al, Mg, Si, P, S, K, Ca, Mn, Fe, K, Co, Cu, Zn, and Mo.



Figure:7 EDX or EDA images of 1:1,1:2,1:1,1;2 plastic sand and rock dust aggregate

***Materials and proposed mix design methodology for concrete made with plastic aggregates:***

The binding substance was ordinary Portland cement, which met the IS: 12269[12] criteria.

To construct a tightly packed aggregate matrix, compacted fractions of 1:1-RPSCA, 1:2-RPSCA, 1:1-RPRDCA, 1:2-RPRDCA, and natural river sand with a maximum particle size of 4.75mm were utilized as fine aggregate, coarse aggregate available in a multitude of sizes (single and well-graded) was used. The specific gravities of the coarse aggregates (single and well-graded) with fractions ranging from 1.18 to 20 mm were 1.42, 1.57, 1.42, and 1.56, respectively, The specific gravity of the fine aggregates[4] was 2.63. Table 3 lists the aggregate properties that were employed in the current experiment. A commercially available sulfonated naphthalene polymer-based concrete superplasticizer[13] was used in the present research.

The current study's goal is to develop a simple and reliable solution. mix design process based on proper aggregate compaction. The purpose of this research is to come up with a simple and reliable solution. mix design process based on proper aggregate compaction. The majority of the theoretical work has been done on three areas of mix design: water/cement ratio, water absorption[3] of the additives, and particle size of the additives. Abrams discovered a link between the water-cement ratio and concrete compressive strength in 1919. According to this equation, The w/c ratio has an inverse relationship with concrete strength. Even in modern times, most composite design techniques are still based on this notion. However, in concrete with conventional particles, where the weakest connection is the pasty matrix [3] This relationship is more appropriate. A novel link between strength and the w/c ratio has been created as a result of a recent study[3].

When dosing different size groups of aggregates, the primary objective is to reduce the aggregate matrix's void ratio. Additional related techniques include Goltermann et aleuro .'s pack model, De Larrard's compressible packing model[14], and Dewar's particle mixing theory[15].

It should be noted, however, that if the aggregates' specific gravity varies, the absolute volume methodology should be employed. The combined grading of aggregates proposed by ASTM C330/C330M, IS 383-2019[6]standards are used to create this dense matrix of aggregate s. For lightweight concrete, ACI 211-98 suggests a mixed proportioning approach according to the materials' weight or volume. The proposed technique for the design of elaboration mixtures can be divided into the following stages[3].

*Stage 1: Select and Fix the water-cement ratio*: 0.4, 0.6, and 0.65[10] were used in this research, Because of several kinds aggregates and cement Produce various strengths at the same time with the same w/c, having or developing the link between w/c & strength for the materials used is highly desirable[3], lack of such information, conservative and approximate values are used [16] for Portland cement concrete concerning IS 10262-2019[17]can be taken (Free w/c ratio vs. 28-day compressive strength ratio curve).For the development of plastic aggregate concrete, this study suggests a revolutionary w/c relationship.[16]

*Stage 2:* *Adjust the amount of water*: Concrete requires a certain amount of water ("w" in kg/m3) [16]can be determined using the guidance in ACI 211-98 and the workability criterion for a particular situation[3] The free water content of concrete without entrained air(non-air-entrained) can be determined between 187 kg/m3 and 237 kg/m3 [16]Typically, 1.5% superplasticizer (sulfonated naphthalene polymer concrete mix) can be reduced by 25% water content [13].

Stage 3: The equation can be used to calculate the cement content of each mixture("c" in kg/m3)-(a); of the assumed water/cement ratio from step 1[3]

Cement content(kg/m3) = w/(w/c) …………………(a)

*Stage 4:* Identifying coarse and fine aggregates The coarse aggregates in this technology are produced by plastic sand and plastic rock dust aggregates, whereas the fine aggregates are natural river sand. To compute the total aggregate quantity, utilize the absolute volume approach[7]. Four different coarse aggregate types were employed in this study. These were the aggregates mixed[18] as though they virtually met the ASTM C330/C330M(4)and ASTM C33[18] combined grading specification for w/c ratios of 0.40, 0.60, and 0.65. Non-air-entrained concrete has about 2% entrapped air [16] For every unit volume of concrete, a specific amount of coarse aggregate is used on a dry, loose basis[11], concrete with almost the same nominal maximum size and grading will attain appropriate workability. ACI 211-98 gives suitable values for this total volume of aggregate (Table 3.5). Changes in dry loose unit weight compensate for variances, because of changes in particle form and grading when it comes to the amount of mortar needed for workability with various aggregates [16].

*Step 5:* The content of the fine aggregate is estimated. After estimating all concrete materials except fine aggregate in step 4, Difference [10] is used to determine the amount. The weight of new concrete minus the total weight of the other elements is the amount of fine aggregate that is required [10] assuming the concrete's weight per unit volume is determined from history.

**Results and discussion**

**Table:4 Mix details for the developed concrete**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| w/c ratio | Sample type | CementKg/m3 | WaterKg/m3 | Fine aggregateKg/m3  | Coarse aggregate Kg/m3 | SuperplasticizerKg/m3 |
| 0.400.600.65 | 1:1 RPSCA1:2 RPSCA1:1 RPRDCA1:2 RPRDCA1:1 RPSCA1:2 RPSCA1:1 RPRDCA1:2 RPRDCA1:1 RPSCA1:2 RPSCA1:1 RPRDCA1:2 RPRDCA | 405405405405290290290290268268268268 | 162162162162174174174174174174174174 | 91877191073699484798681310128651005727 | 471608475624471608475624471608475624 | 4.854.854.854.852.312.312.312.312.122.122.122.12 |

The concrete was found to be free of segregation and bleeding during the visual assessment[3]. The superplasticizer dosage was calculated using the table above.The lesser necessity for superplasticizers[13] could be attributed to the aggregates' subangular shape, which may have rendered the concrete more workable.

Fresh, air-dry, and oven-dry densities exist in all types of concrete, as shown in table 5. The plastic densities of lightweight concrete with synthetic aggregates are estimated to be between 1940 and 2113 kg/m3, while standard concrete's plastic densities are 2200-2600 kg/m3[19] This statement demonstrates that when the coarse aggregates of regular concrete are totally replaced by recycled plastic sand and coarse rock dust. Most guides divide structural lightweight concrete into two categories: air-dry density (less than 2000 kg/m3) and wet density (more than 2000 kg/m3)[19] The air-dry density, as a result, ranges from 1941 to 2091 kg/m3 for the present research.

**Table:5** Densities of the developed concretes.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| w/c ratio | Sample type | Fresh Density(kg/m3) (WGCA) | Fresh Density(kg/m3) (SSCA) | Air-dry Density(kg/m3) (WGCA) | Air-dry Density(kg/m3) (SSCA) |
| 0.400.600.65 | 1:1 RPSCA1:2 RPSCA1:1 RPRDCA1:2 RPRDCA1:1 RPSCA1:2 RPSCA1:1 RPRDCA1:2 RPRDCA1:1 RPSCA1:2 RPSCA1:1 RPRDCA1:2 RPRDCA | 210921342090211320482058198620252009201719962001 | 194219451933194719481968194819611927193319231935 | 206920912051206920102011194119741977198219691971 | 193119391927194119411958193819481919192319181927 |

**Compressive strength**

The minimum compressive strength necessary in structural lightweight concrete is 17Mpa, ASTM C 330 is a standard that specifies how a product should be manufactured.[9], When comparing single-graded aggregate to well-graded aggregate, all 0.40 prepared concretes meet this criterion, but 0.60 and 0.65 do not. Figure 8(a)(b)(c) shows the compressive strengths obtained for several types of concrete.

The results for the compressive strength of concrete with a ratio of 0.40 w/c from Figure 8(a), 1:1 RPSCA, and 1:2 RPSCA show lesser results than 1:1 RPRDCA and 1:2 RPRDCA for single-size coarse aggregate (SSCA), but the compressive strength of well-graded coarse aggregate (WGCA) 1:2 RPSCA and 1:2 RPRDCA showed almost the same result for 28 days. Similarly, for a w/c ratio of 0.60, SSCA has less compressive comparability than WGCA for 1:1 RPSCA and 1:2 RPSCA compared to 1:1 RPRDCA and 1:2 RPRDCA at age of 28 days. Meanwhile, the difference in strength between the maximum (1:1 RPRDCA and 1:2 RPRDCA) and minimum (1:1 RPSCA and 1:2 RPSCA) compressive strengths at 28 days of age for the 0.65 w/c ratio, same single graded aggregate for 28 days of the period. among SSCA and WGCA of 0.65 w/c ratios 1:1 RPSCA, 1:2 RPSCA 1:1 RPRDCA, and 1:2 RPRDCA, There was the lowest decrease in compressive strength.

 **0.40 w/c ratio graph 0.60 w/c ratio graph 0.65 w/c ratio graph**

 Figure:8(a) Figure:8(b) Figure:8(c)

Furthermore, when compared to WGCA concrete, the variance in compressive strength percentages[3] for SSCA concrete with various filler amounts was reduced. The results also suggest that 1:1RPSCA, 1:2RPSCA, and 1:1RPRDCA, 1:2RPRDCA for a ratio of w/c of 0.40 (SSCA and WGCA), 1:1RPRDCA (SSCA) and 1:2RPSCA, 1:1RPRDCA(WGCA) for a w/c ratio of 0.60, 1:1RPRDCA,1:2 RPRDCA(SSCA) and 1:1RPRDCA, 1:2RPRDCA(WGCA) for a w/c ratio of 0.65 meets the strength requirements of ASTM C330 -04[9], These varieties of concrete may be suitable for structural application because their compressive strength was greater than 17 MPa[16].

**Conclusion**

In general, "Because this revolutionary aggregate is lighter than typical aggregate, it has potential applications as a replacement for natural aggregate." The following are some of the conclusions that can be derived from this study:

* New plastic aggregates have been successfully manufactured from recycled plastics using HDPE and various types of filler (HDPE/sand, rock dust)
* The new recycled plastic aggregate meets the limits of ASTM C330-04, In concrete, recycled plastic aggregate can be utilized as a complete replacement for traditional material.
* SEM images showed the perfect type of material structure Optical microscope images indicated a sharp bond between the filler and HDPE plastic.
* The strength of SSCA (single-size coarse aggregate) concrete is lower than that of WGCA (well-graded coarse aggregate) concrete. the difference in coarse aggregate size causes a drop in compressive strength.
* Crack propagation through the aggregate distinguishes the failure mechanisms in SSCA and WGCA concrete.
* All types of 0.4. w/c ratio concrete met ASTMC 330-04's compressive strength requirements. As a result, it can be utilized in applications like sidewalks, driveways, and backfilling where low strength is acceptable.
* For 0.60 w/c ratio concrete Only 1:1 RPRDCA for SSCA and 1:2 RPSCA, 1:1 RPRDCA, 1:2 RPRDCA for WGCA, and 0.65 w/c ratio concrete 1:1 RPRDCA, 1:2 RPRDCA for SSCA and 1:1 RPRDCA, 1:2 RPRDCA for WGCA met ASTMC 330-04's compressive strength requirements.
* However, it is suggested that more detailed and durable mechanical sustainability tests, including environmental and economic evaluation, are needed to determine the potential uses of plastic aggregates for civil infrastructure.

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**References**

[1] H. A. Leslie, M. J. M. van Velzen, S. H. Brandsma, A. D. Vethaak, J. J. Garcia-Vallejo, and M. H. Lamoree, “Discovery and quantification of plastic particle pollution in human blood,” *Environ. Int.*, vol. 163, no. March, p. 107199, 2022, doi: 10.1016/j.envint.2022.107199.

[2] F. K. Alqahtani, G. Ghataora, S. Dirar, M. I. Khan, and I. Zafar, “Experimental study to investigate the engineering and durability performance of concrete using synthetic aggregates,” *Constr. Build. Mater.*, vol. 173, no. June, pp. 350–358, 2018, doi: 10.1016/j.conbuildmat.2018.04.018.

[3] M. S. Nadesan and P. Dinakar, “Mix design and properties of fly ash waste lightweight aggregates in structural lightweight concrete,” *Case Stud. Constr. Mater.*, vol. 7, no. September, pp. 336–347, 2017, doi: 10.1016/j.cscm.2017.09.005.

[4] F. K. Alqahtani, M. I. Khan, G. Ghataora, and S. Dirar, “Production of Recycled Plastic Aggregates and Its Utilization in Concrete,” *J. Mater. Civ. Eng.*, vol. 29, no. 4, p. 04016248, 2017, doi: 10.1061/(asce)mt.1943-5533.0001765.

[5] IS-4032 1985, “Method of chemical analysis of hydraulic cement,” *Indian Stand.*, pp. 1–47, 1985.

[6] IS:383, “Specification for Coarse and Fine Aggregates From Natural Sources for Concrete,” *Indian Stand.*, pp. 1–24, 1970.

[7] IS 2386- Part III, “Method of Test for aggregate for concrete. Part III- Specific gravity, density, voids, absorption and bulking,” *Bur. Indian Stand. New Delhi*, p. (Reaffirmed 2002), 1963.

[8] R. Vinod Kumar and D. D. Rupesh Kumar, “Recycled plastic (HDPE) coarse aggregate manufacturing method and performance in concrete,” *Mater. Today Proc.*, vol. 92, pp. 1304–1309, 2023, doi: 10.1016/j.matpr.2023.05.489.

[9] Anonim, “ASTM C330-28a, Standard Specification for Lightweight Aggregates for Structural Concrete, ASTM Standards: Concrete and Aggregates,” vol. 552, no. 18, 1996.

[10] IS 456, “Plain Concrete and Reinforced,” *Bur. Indian Stand. Dehli*, pp. 1–114, 2000.

[11] N. Ural, “The significance of scanning electron microscopy (SEM) analysis on the microstructure of improved clay: An overview,” *Open Geosci.*, vol. 13, no. 1, pp. 197–218, 2021, doi: 10.1515/geo-2020-0145.

[12] IS-12269:, “Specification for 53 grade ordinary Portland cement,” *Bur. Indian Stand.*, p. New Delhi,India, 1987, [Online]. Available: https://law.resource.org/pub/in/bis/S03/is.12269.b.1987.pdf

[13] ASTM C494-99, “C494 - 99 Standard Specification for Chemical Admixtures for Concrete,” *ASTM Int.*, vol. 04, pp. 1–9, 2013.

[14] J. I. Goldstein *et al.*, “Generation of X-Rays in the SEM Specimen,” *Scanning Electron Microsc. X-ray Microanal.*, pp. 271–296, 2003, doi: 10.1007/978-1-4615-0215-9\_6.

[15] J. Dewar, *Computer Modelling of Concrete Mixtures*. 1999. doi: 10.4324/9780203031148.

[16] S. G. Barton *et al.*, “Standard Practice for Selecting Proportions for Structural Lightweight Concrete (ACI 211 . 2-98) Reported by ACI Committee 211,” *Aci 211.2-98*, vol. 98, no. Reapproved, pp. 1–18, 1998.

[17] I. Standard, “IS 10262: 2019 ,Concrete Mix Proportioning,” *Indian Stand.*, no. January, 2019.

[18] American Society for Testing and Materials, “ASTM C 33-99a : Standard Spesification for Concrete Aggregates,” *Annu. B. ASTM Stand.*, vol. i, no. C, pp. 1–11, 2010.

[19] L. Horn, “Targeted/emerging therapies for metastatic non-small cell lung cancer,” *JNCCN Journal of the National Comprehensive Cancer Network*, vol. 13. pp. 676–678, 2015. doi: 10.6004/jnccn.2015.0201.