Journal of Materials and Engineering Structures

Research Paper

Expanded Fly Ash Clay Aggregate a Sustainable Alternative Coarse Aggregate for Concrete

J.Bright Brabin Winsley[a,]*, M.Muthukannan[b]

[a]*Faculty, School of Civil Engineering, Mar Ephraem College of Engineering and Technology, India.*

[b]*Faculty, Department of Civil Engineering, Kalasalingam Academy of Research and Education, India.*

ARTICLE INFO

Article history:

Received : 28 June 2018

Revised : 15 October 2018

Accepted : 5 November 2018

Keywords:

Expanded Clay Aggregate

Sustainability, Durability

Compressive Strength

Workability

ABSTRACT

Demand for natural aggregates in making concrete is increasing everyday. Concrete is widely used in turnkey projects and small-scale projects. An alternative sustainable coarse aggregate for natural coarse aggregate can reduce the amount of pollution and preserve natural resource. An attempt is made in this research project to use locally available soil from the site and flyash waste to prepare an alternative sustainable coarse aggregate for concrete to be used in small constructions. Concrete mix is prepared with natural aggregate and expanded flyash clay aggregate EFCA and their fresh state, strength and durability properties were studied. The slump value of EFCA concrete under same water content is similar to that of natural aggregate concrete. Compressive strength of 21.45 MPa is achieved for EFCA concrete, which is acceptable for normal structural concrete. Flexural strength of 3.67 MPa is measured. Rapid chloride penetration test conducted on EFCA concrete showed moderate resistance to sulfate attack and higher water penetration.

1 Introduction

The growth of population in developing countries like India makes urbanization a mandatory process towards development. To meet this, a large number of construction activities are to be made, which intern requires a large amount of raw materials. Among all, concrete is the material used most widely all over the world. Coarse aggregate, fine aggregate and binder are the key ingredients of concrete, about 60 – 70 % of the concrete volume is contributed by the coarse aggregate. The natural source of coarse aggregate is by quarrying rocks, causing depletion of resource and potential environmental pollution. Construction of small buildings of less than two storey with conventional concrete is more common in small-scale residential construction, which needs comparatively lesser strength, more sustainable and durable concrete.

* *Corresponding author. Tel.: +919443376177.*
E-mail address: brightwinsley@gmail.com

e-ISSN: 2170-127X,

RESEARCH REVIEW of Sciences and Technologies

Red soil and fly ash when mixed at 70:30 ratio, spherically rolled to 10 mm nominal size, sun-dried at room temperature, burned at 950 degree Celsius and gradually cooled shows properties similar to that of natural aggregate at much lesser density [1].Concrete prepared with expanded clay aggregate, when compared with recycled polyethylene showed a density of 1900kg/m^3 with compressive strength up to 70.2 MPa, pre-wetted expanded clay aggregate creates optimal conditions for cement hydration [2]. Reinforced concrete beams produced by expanded clay aggregates, crushed bricks and no fines were studied for compressive and flexural strength and reported 29 MPA and 6.1 MPa respectively, which is higher than other mixes compared [3]. Review of structural concrete using sintered flyash aggregate showed compressive strength in the range of 27 - 74 MPa, with a density ranging 1651 - 2017 kg/m^3. The durability properties indicated satisfactory performance [4]. Incorporation of LECA in concrete increased its workability, decreased density, decreased mechanical strength, decreased freeze/thaw resistance, increased water absorption, decreased chloride penetration resistance, but increased thermal insulation and fire resistance [5]. Recycled lightweight expanded clay aggregates RLCA were characterized in terms of compressive, tensile strengths, Modulus of elasticity and abrasion. The properties improved with the addition of RLCA [6]. Mix design for structural lightweight self-compacting concrete with lightweight expanded clay aggregates were made effectively [7].

The objective of this research is to develop a sustainable alternative material to natural coarse aggregate in concrete for small-scale construction, which could be used by less skilled labors at the site very easily, having properties similar to that of natural aggregate. In this study the workability, strength and durability properties of concrete made with 10 mm natural aggregate and 10 mm expanded fly ash clay (EFCA) is compared and the results were discussed.

2 Experimental Study

2.1 Characterization of Materials

Portland pozallana cement of 53 MPa compressive strength, Ramco brand from a single lot is used throughout the experiment. The cement used is within one month of manufacture and there were no lumps. The physical and chemical properties are satisfying the requirements of confirming to BIS 1489 part I 1991 [8] is used as binder material. The character of the cement used is measured by Vicat apparatus and Le Chatelier flask is given in table 1. Natural river sand confirming to zone II of BIS 383 - 1997[9] table 4 of maximum size 4.75mm, free from dust, organic impurities and silt is used. The physical properties of fine aggregate are given in table 2. Conventional coarse aggregate obtained from quarrying with nominal size 10 mm is used. Expanded fly ash clay aggregate (EFCA) with a nominal size of 10 mm prepared by blending red soil passing through 300 micron sieve and class F fly ash in 70:30 proportion, air dried and burned at 950 degree Celsius is used as an alternative coarse aggregate[1]. The physical properties of coarse aggregates used are given in table 3.

Table 1 – Properties of Cement

Initial Setting Time	49 minutes
Final Setting Time	487 minutes
28 days Compressive Strength	53 MPa
Consistency	29%
Specific Gravity	3.11

Table 2 – Properties of Sand

Water Absorption % of weight	1.10
Silt Content %	0.6
Fineness Modulus	2.6
Specific Gravity	2.62
Grading	Zone II as per table 4 of BIS 383
Bulk Density kN/m^3	16.78

Table 3 – Properties of Coarse Aggregates

Property	Conventional Aggregate	Expanded Fly Ash ClayAggregate
Water Absorption %	0.66	17.8
Bulk Density kN/m^3	14.9	10.4
Specific Gravity	2.82	1.54
Impact Value %	30.1	27.8
Crushing Value %	2.68	1.53
Fineness Modulus	7.12	6.97

2.2 Concrete Mix Proportioning

Mix proportioning of concrete is done as per BIS 10262 2009 [10]. Two different mixes, one with conventional coarse aggregate (NAC) and other with expanded fly ash clay aggregate (CAC) as the full replacement for conventional coarse aggregate were made. The self-desiccation and autogenous shrinkage in concrete during hydration of cement cause a reduction in water content, which intern causes cracks in early stage and affects the hydration process. The expanded fly ash clay aggregate is immersed in water for about 24 hours before using in concrete. The water in the aggregate will aid the hydration of cement. All other aggregates were used dry. The mix design is made for M20 grade of concrete with a slump value of 75 – 100 mm. Trial mixes were made and the ingredients were proportioned. The ingredients are weight batched and hand mixed to get enough consistency. No admixtures were added in the mix. The water-cement ratio is maintained constant in both the mixes. The mix proportion of concrete is given in table 4.

Table 4 - Mix Proportion of Concrete

Mix	W/C	Water (L)	Cement (Kg)	Sand (Kg)	Coarse Aggregate(Kg)
NAC	0.47	182	386	793.6	882.6
CAC	0.47	203	432	793.6	508.8

2.3 Sample Preparation and Test Methods

Cubes of size 150 mm x 150 mm x 150 mm, prisms of size 100 mm x 100 mm x 500 mm and cylinders of 150 mm diameter, 300 mm height were cast to determine the compressive strength, flexural strength and split tension strengths. For every size of mould, eighteen specimens were cast on CAC and NAC. All the casted specimens were de-moulded after 24 ±1 hours and were cured at room temperature in the water tank for the required curing time.

2.3.1 Workability Tests

Slump test is conducted with a steel cone having a bottom diameter of 20 cm, top diameter of 10 cm and a height of 30 cm. Compaction factor apparatus with upper hopper top internal diameter of 25.4 cm, bottom internal diameter of 12.7 cm and internal height of 27.9 cm, lower hopper with top internal diameter of 22.9 cm, bottom internal diameter of 12.7 cm and internal height of 22.9 cm and the cylinder at the base with an internal diameter of 15.2 cm and internal height of 30.5 cm. Flow table apparatus with a cone at the base of 25 cm in diameter, an upper diameter of 17 cm and a height of 12 cm and capable of raising and dropping at a height of 12.5mm on a rate of 15 times per 15 seconds. The workability tests were conducted as per BIS 1199 - 2004 [11]. The experimental setup for conducting workability tests is given in figure 1, 2 & 3.

Figure 1 – Experimental Setup of Slump test

Figure 2 – Experimental Setup of Compaction Factor Test

Figure 3 – Experimental Setup of Flow Test

2.3.2 Strength Tests

For compressive strength, the specimens are tested on 150 x 150 x 150 mm cubes as per IS 516 -2004 [12]. During testing, the load is applied at the rate of approximately 140 kg/ sq.cm/min, as shown in figure 4. Flexural strength is tested on prism 100 x 100 x 500 mm by three-point loading method as per IS 516– 2004 [12]. The experimental setup is as shown in figure 5. The load is applied at the rate of 180 kg/ min. Split tension test is conducted on cylinder specimen 150 mm diameter and 300 mm length, the surface of the specimen is wiped out for any impurities. The load is applied continuously at the rate of 16 kg/cm^2/minute and the breaking load is noted.

Figure 4 – Experimental setup for compressive strength of concrete

Figure 5 – Experimental setup for flexural strength of concrete by three point loading

2.3.3 Durability Tests

2.3.3.1 Rapid chloride ion test:

The rapid chloride penetration test (RCPT) is conducted in accordance with ASTM C 1202 [13]. The specimen of size 100 mm diameter is prepared for the mixes NAC and CAC. The specimens were placed in a vacuum container and surface dried afterwards. Both end surface of the specimen were exposed, the inside pressure is reduced to 30 ± 5 millibars for a period of 3 hours. The container is filled with Ca(OH)2 solution and all the specimens were immersed. The specimens were kept in the solution for another 18 hours. They are then coated with epoxy and clamped to dry. The specimens were placed in the apparatus for testing. One side of the specimen is exposed to 3% NaCl solution connected to the negative terminal of the power supply. The other end of the cell is exposed to 0.3N NaOH solution connected to the positive of the power supply. The test voltage is applied to the sample for about 6 hours. The current through the specimen is measured at an interval of 30 minutes as shown in figure 6.

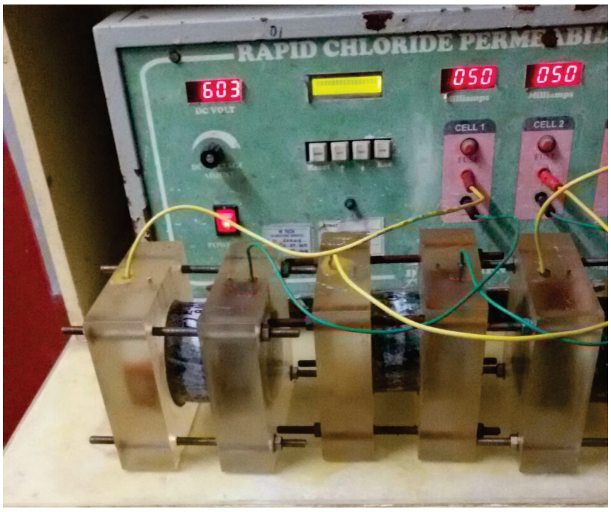

Figure 6 – Experimental setup for rapid chloride penetration test

2.3.3.2 Penetration Test

Three specimens of size 100 mm diameter are used for both NAC and CAC mixes. The test is conducted in accordance with BIS 3085 – 1965 [14]. The specimen is thoroughly sealed and water pressure is applied at the rate of 1 bar for 48 hours, 3 bars for the next 24 hours and 7 bar for the next 24 hours. The specimen is then split to measure the depth of water penetration.

3 Results and Discussions

3.1 Workability

The results of the slump test, the compaction factor test and flow test are given in table 5. The workability of fresh concrete is almost similar for all the tests. The designed workability is obtained in both the mixes. The slump value of CAC is 10% lesser than that of NAC. The compaction factor of CAC is 2% lesser than NAC. Flow value of CAC is also lesser than NAC. The reduction in workability is due to the absorption of water by the EFCA. The EFCA aggregates were saturated in water before mixing to avoid excess water absorption but as the surface are more porous, due to the surface contact between the aggregate and atmosphere loss in water occurred. The porous surface of EFCA allowed more binder content to adhered to its surface, which showed a relative lesser slump and flow value.

Table 5 – Results of Workability tests

Test	NAC	CAC
Slump Value in mm	85	95
Compaction factor	0.92	0.94
Flow Value %	102	130

3.2 Strength

The compressive strength on 7, 14 and 28 days, flexural strength and split tensile strength for both the mixes are given in table 6. Under the same designed strength, a deviation of 14% is observed. The failure pattern of the NAC is along the binding material but in CAC the failure happened on the EFCA. The compressive strength of CAC on 7 days is less compared to NAC and gaining strength with respect to time, this may be due to the availability of absorbed water inside the pores of aggregate, that aids hydration process. The flexural strength of CAC shows a reduction of 32%, split tensile strength of CAC also reduced by 45%. The tensile load carrying capacity of CAC is lesser compared with NAC. The decreased strength of the CAC is due to the lesser density of the EFCA material.

Table 6 – Results of Strength tests in MPa

Mix	7 days	14 days	28 days	FlexuralStrength	SplitTension
NAC	17.71	24.7	26.84	5.43	3.38
CAC	12.23	18.2	21.45	3.67	1.85

3.3 Durability

The conductivity of charges in Coulomb from rapid chloride ion penetration test and water penetration in mm from water penetration test is given in table 7. The chloride ion conductivity for NAC is low with 1155 Coulombs, while for CAC moderate with 2580 Coulombs. On water penetration test the NAC showed high penetration resistance but the porous nature of aggregate in CAC made water to penetrate to almost 96%.

Table 7 – Results of Durability tests

Test	RCPTCoulombs	Water Penetration mm
NAC	1155	12
CAC	2580	145

4 Conclusion

This study analyzed the comparison of concrete made with natural aggregate and expanded fly ash clay aggregate for workability, compressive, tensile strengths and durability. The following conclusions have been made.

The test results were compared for concrete specimens with natural aggregate and expanded fly ash clay aggregate were analyzed with workability, compressive, tensile strength and durability in which the EFCA showed positive results and can be recommended as an alternative for conventional natural aggregate.

The workability of fresh concrete with EFCA is at an acceptable range, the addition of admixtures can improve the workability. An average of 14 % reduction in compressive strength is observed in EFCA, also the gain in strength is increasing with respect to time. However the tensile strength of concrete is comparatively less than normal aggregate concrete, so it is recommended for structural members with shorter span.

The chloride penetration is moderate and in EFCA, providing more cover to reinforcement with good waterproofing practice can improve the life of concrete.

The failure pattern of EFCA in compression is along the aggregate, mix designs of strengths higher than 20MPa could be made with further improvements in the strength of the EFCA aggregate.

The decrease in strength of CAC made with EFCA aggregates and increase in permeability are due to the lesser density of EFCA aggregates.

EFCA can be used as a sustainable alternative to normal coarse aggregate for structures of shorter span and lesser service load, thereby reducing the amount of pollution made by quarrying and preserve the natural resource.

REFERENCES

[1]- J.B.B. Winsley, M. Muthukannan, A preliminary study on the physical properties of an alternative coarse aggregate made with red soil and fly ash. Open Constr. Build. Technol. J. 12(218) 1-8. doi:10.2174/1874836801812010001

[2]- D. Rumšys, D. Bačinskas, E. Spudulis, A. Meškėnas, Comparison of material properties of lightweight concrete with recycled polyethylene and expanded clay aggregates. Procedia Eng. 172 (2017) 937–944. doi:10.1016/j.proeng.2017.02.105.

[3]- J. Alduaij, K. Alshaleh, M.NaseerHaque, K. Ellaithy, Structural behaviour of selected light weight concrete beams. Kuwait J. Sci. Eng. 30(2) (2003) 139-152.

[4]- M.S. Nadesan, P. Dinakar, Structural concrete using sintered flyash lightweight aggregate: A review. Constr. Build. Mater. 154(2017) 928–944. doi:10.1016/j.conbuildmat.2017.08.005.

[5]- A.M. Rashad, Lightweight expanded clay aggregate as a building material – An overview. Constr. Build. Mater. 170 (2018) 757–775.doi:10.1016/j.conbuildmat.2018.03.009.

[6]- J.A. Bogas, J. de Brito, J.M. Figueiredo, Mechanical characterization of concrete produced with recycled lightweight expanded clay aggregate concrete. Journal of Cleaner Production 89(2015) 187-195. doi:10.1016/j.jclepro.2014.11.015.

[7]- M.C.S. Nepomuceno, L.A. Pereira-de-Oliveira, S.F. Pereira, Mix design of structural lightweight self-compacting concrete incorporating coarse lightweight expanded clay aggregates. Constr. Build. Mater. 166 (2018) 373–385. doi:10.1016/j.conbuildmat.2018.01.161.

[8]- M. Hubertova, R.Hela, Durability of lightweight expanded clay aggregate concrete. Procedia Eng. 65 (2013) 2-6. doi:10.1016/j.proeng.2013.09.002.

[9]- BIS 1489 – 1 Specification for Portland pozzolana cement, Part 1: Fly ash based. 1991 reaffirmed in 2005.

[10]- BIS 383 – Specification for coarse and fine aggregates from natural sources for concrete. 1970 reaffirmed in 1997.

[11]- BIS 10262 – Concrete mix proportioning – guidelines. 2009.

[12]- BIS 1199 – Methods of sampling and analysis of concrete. 1959 reaffirmed in 2004.

[13]- BIS 516 – Methods of tests for strength of concrete. 1959 reaffirmed in 2004.

[14]- ASTM C1202-18, Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration, ASTM International, West Conshohocken, PA, 2018. doi:10.1520/C1202-18

[15]- BIS 3085 – Method of test for permeability of cement mortar and concrete. 1965 reaffirmed in 2002.