COMPRESSIVE STRENGTH OF CONCRETE WITH ARTIFICIALLY PRODUCED FLY ASH AGGREGATES

K N Shivaprasad [1], B B Das[1]

1. National Institute of Technology Karnataka, Surathkal, Mangalore, India

ABSTRACT. This experimental investigation reports methodology for production of fly ash aggregates using low calcium fly ash and utilization of produced aggregates in ordinary Portland cement concrete. Fly ash aggregates were produced with alkaline solution through pelletisation process and subjected under heat curing has satisfied all mechanical properties. However, the water absorption of produced aggregates found to be slightly higher. The compressive strength of concrete produced with artificially produced fly ash aggregate found to be satisfying the design requirements. The artificially produced fly ash aggregate investigated in this research shows good potential to be used as a lightweight coarse aggregate in Portland cement concrete, with the significant benefit in reducing the environmental impact by utilizing the fly ash produced from coal fired power plants.

Keywords: Fly ash aggregate, Alkaline solution, Pelletization, Cement, Concrete

K N Shivaprasad is a Research Scholar in Department of Civil Engineering at National Institute of Technology Karnataka, Surathkal, Mangalore, India. He has strong research interests in alkaline activation of cementitious materials, production of artificial aggregates, life cycle energy analysis and micro-structure characterization of materials.

Dr B B Das is working as Associate Professor in Department of Civil Engineering at National Institute of Technology Karnataka, Surathkal, Mangalore, India. His area of research includes sustainability in built environment including sustainable utilization of industrial by- products, production of artificial construction materials, green construction management, microstructure characterization of materials, non-destructive testing of concrete structures, corrosion of reinforcement and durability studies.

INTRODUCTION

The global concrete production annually is about 25 gigatons [1]. Typically, ordinary concrete contains about 65% of aggregate by volume of concrete, which is essential component in the concrete properties [2-3]. On the other hand, the use of aggregates in the construction of aggregates is enormous. In the year 2015, global demand for construction aggregates was more than 48.3 billion tonnes is estimated to grow 5.2% annually. In 2012, about 2.2 billion tonnes of aggregate was consumed in India alone and it was reported that demand will be more than 5 billion metric tonnes by 2020 [4]. This will create many challenging issues for the next decades concerning environmental impacts due to aggregate production. Thus, a major challenge for the aggregate and construction industries is finding alternative aggregate sources.

Literature has widely reported that recycled aggregates from demolition and building waste can also be used for concrete production [5-6] and researchers has reported that artificial materials such as sintered fly ash or sintered silty clays dredged from the sea can replace natural aggregates in concrete [3, 7]. However, the main concern raised on use of these materials is their purity, which in turn affects the properties of concrete. This research has been focused on manufacturing fly ash aggregates using low calcium fly ash, which is a waste product from coal power stations. In India, more than 150 coal based thermal power plant meets the 62% of India's electricity. The production of fly ash and bottom ash found to be over 170 million tons and 50 million tons, respectively which requires huge land for its disposal and also creates potential environmental and health hazards [8-9]. Most of the collected fly ash and bottom ash are disposed into the nearby ash ponds and small amount of the fly ash only has been consumed by the construction industry. This will significantly affect the environment. Thus, use of fly ash in aggregates production will be an added benefit while conserving landfills and storage lagoons.

This paper initially discusses the production process of fly ash aggregates through pelletization and then presents the production of ordinary Portland cement concrete with fly ash aggregates. The experimental test results are reported up to 28 days age and then compared with concrete produced with the conventional crushed aggregates.

MATERIALS

Fly ash

Fly ash was collected from Udupi thermal power plant, Karnataka, India. The physical properties along with chemical compositions of the fly ash were analysed and it is presented in Table 1. It is classified as class F type as per IS 3812 (part 1) – 2013 classification [10]. The fineness of the fly ash was assessed using Blaine's air permeability apparatus as per the guidelines prescribed in IS 1727 – 1967 [11].

Alkaline solution

Laboratory grade sodium silicate solution (Na_2SiO_3) with silica modulus (SiO_2/Na_2O) of 3.3 (8.0% Na_2O, 26.5% SiO_2, 65.5% H_2O by mass) and sodium hydroxide (NaOH) flakes of 98%

purity were used to prepare the alkaline solution. Sodium hydroxide in flakes form was dissolved in deionised water to produce a sodium hydroxide solution. The alkaline solution prepared by mixing both sodium silicate and sodium hydroxide solutions to maintained constant of Na_2O content of 5% by mass of fly ash, SiO_2/Na_2O ratio of 0.4 and water content of 20 % by mass of fly ash is used throughout the production of artificial aggregates [12-13]. The prepared alkaline solution is transferred to an air tight container and allowed to cool for 24 h, before using it in the production process.

Cement

Locally available ordinary Portland cement of 53 grade was used in the present study. Physical tests were carried out as per IS 4031-1999 and it conforming to IS 12269-1987 was used in this study [14-15]. The physical properties along with chemical compositions of the cement were analysed and it is presented in Table 1.

Table 1 Physical properties and chemical composition of the materials used

PARAMETERS	FLY ASH	CEMENT
Specific gravity	2.2	3.15
Blaine's fineness (m^2/kg)	260.3	300
CHEMICAL COMPOSITION (%)		
SiO_2	60.6	20.5
Al_2O_3	28.6	4.0
Fe_2O_3	3.9	4.2
CaO	1.5	64.0
MgO	1.8	1.2
SO_3	1.2	1.8
Na_2O	0.4	-
K_2O	0.1	-
LOI	1.6	1.2

Fine aggregates

In the present study natural available river sand was used as fine aggregate. The specific gravity of the fine aggregates found to be 2.6 and particle size distribution is confirming to the Zone II of IS 383:2016 [16].

Natural coarse aggregates

Locally available natural coarse aggregates were used in the present study and these aggregates are characterised with accordance with IS 383:2016 [16].

METHODOLOGY

Artificial aggregate production

In the present study artificial coarse aggregates are produced with laboratory disc pelletizer. A fabricated disc pelletizer as shown in Figure 1 was used in this study which has a disc diameter of 500 mm and depth 125 mm. The angle of pelletizing disc is maintained at 45° [7, 13, 17] and 15 minutes duration of pelletization is used in the production of artificial aggregates [13, 17]. For this present investigation rotational speed of pelletizing disc is maintained at 40 rotations per minute [13, 17]. Pelletization was carried out in the following steps.

i) Fly ash which is free from lumps was transferred to the pelletizing disc.

ii) Alkali solution was sprayed within three minutes to the fly ash during the process of pelletization.

Figure 1 Laboratory scale disc pelletizer.

The artificial aggregates produced through pelletization process are subjected to temperature of 80°C for 24 hours and removed pellets after heat curing are kept in ambient temperature conditions until it is tested for aggregates properties.

Tests on aggregates

The efficiency of pelletization is expressed in percentage weight of aggregates of size greater than 4.75mm (amount of pellets retained on IS sieve no 480) produced against the total weight pellets produced and it is calculated using the following equation. The distribution of particle sizes present was determined using standard set of sieves in accordance with the Bureau of Indian Standards – IS 383: 2016 [16]. Specific gravity, water absorption, aggregates impact value, aggregate crushing value tests were carried out in accordance with the Bureau of Indian Standards - IS 2386:1963 [18]. The crushing strength of individual aggregate was determined using a crushing testing machine [13, 17].

Concrete mix proportioning and production

The concrete mix was designed according to IS: 10262-2009 to have desired compressive strength of 30 MPa with w/c ratio 0.45. The mix is designed for a slump of 25 mm and the mix proportion are presented in the Table 2. The necessary corrections of water content reduction for the pelletised fly ash (rounded) aggregates and natural aggregates mixes also considered in the mix design as per clause 4.2 of IS 10262:2009 [19]. The addition of any plasticizers is avoided in the concrete mix design, to investigate only the effect of pelletized fly ash aggregates on the strength development of concrete.

Table 2 Mix proportion for concrete production

Mix	QUANTITIES (kg/m^3)			
	Cement	Fine Aggregate	Coarse Aggregate	water
C - NA	360	692	1171	186
C - AA	360	692	913	161

The concrete is mixed with above mix proportion in the production of concrete after necessary corrections for aggregate water absorption.

Tests on concrete

Density of harden concrete was estimated from the cubes prepared for the compressive strength and it is tested of compressive strength in accordance to IS 516:1959 [20]. The visual inspection was carried with aggregate distribution in the concrete mix and failure pattern was also observed on the compressive strength test specimens.

RESULTS AND DISCUSSION

Test results on Aggregate

Artificial produced aggregate and natural aggregates were characterised with accordance with IS code as explained in the earlier section. The particle distribution of the aggregates is presented in Figure 2 and the engineering properties of the artificial produced aggregates along with natural aggregates are presented in the Table 3.

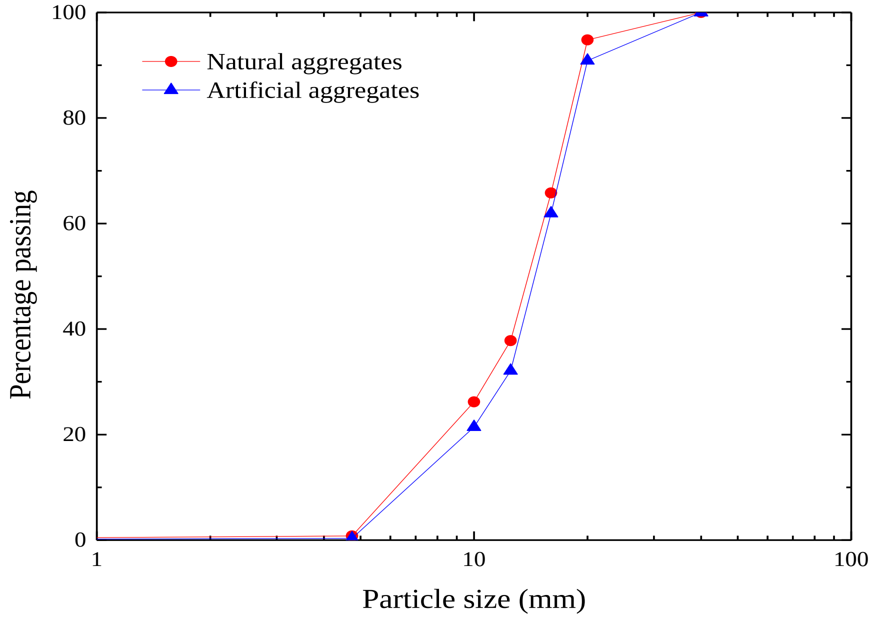

Figure 2 Particle size distribution of aggregates

Table 3 Properties of aggregates used in the present study

AGGREGATE PROPERTIES	NATURAL AGGREGATES	ARTIFICIAL AGGREGATES
Specific gravity	2.7	1.95
Aggregate impact value	19	22.8
Aggregate crushing value	24.7	27.5
Water absorption (%)	0.5	10.1
Crushing strength of individual aggregate (MPa)	-	4.14
Bulk density (kg/m^3)	1410-1620	1050-1170

Test results on concrete

Density of concrete is found be 2470 kg/m^3 and 2110 kg/m^3 for concrete produced with natural aggregates and artificial aggregates respectively. The compressive strength tests conducted at 7, 14 and 28 days on the different mixes are graphically represented in Figure 3. It is observed from the results that, control concrete mix attained a strength of 41.33 MPa at 28 days, whereas the concrete produced with artificial fly ash aggregates achieved 33.33 MPa.

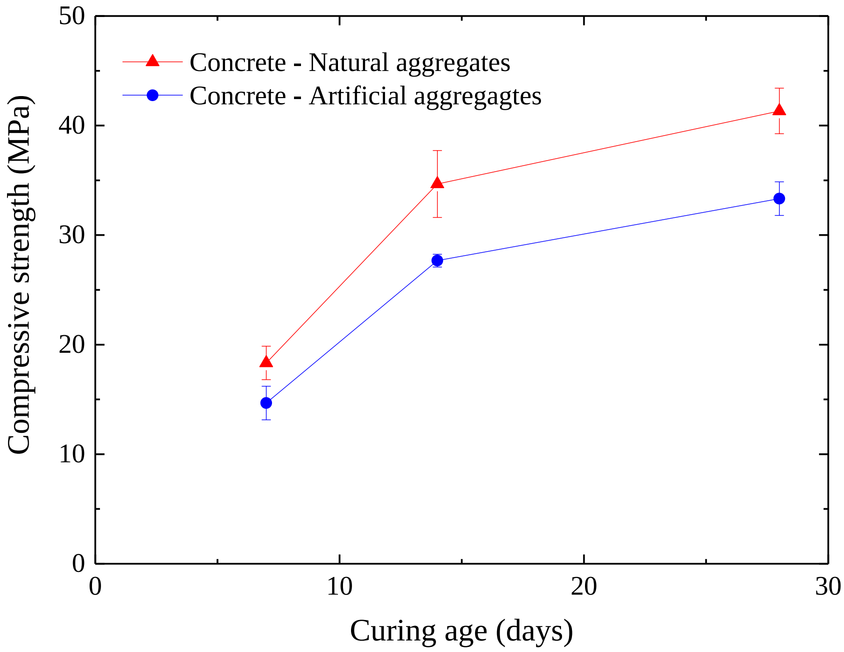

Figure 3   Compressive strength test results of control concrete and concrete produced with artificial fly ash aggregates

i) concrete with natural aggregates

ii) concrete with artificial aggregates

Figure 4   Failure pattern of the concrete produced with i) natural aggregates and ii) artificial fly ash aggregates

After compression testing of specimens, their failure patterns and surfaces were visually inspected. The specimens generally failed in a standard pyramidal fracture shape. It was observed that, the concrete produced with natural aggregates failed in a pyramidal shape as shown in Figure 4 (i). The concrete produced with artificial aggregates found to be in similar failure pattern which can be seen in Figure 4 (ii). Also, the distribution of aggregates across the fractured surfaces can be visually observed Figure 4 that the aggregates distribution is uniform through the failed surface. However, in the special concrete produced with artificial aggregates which is clearly visible in the Figure 4 has some aggregates failed through the aggregates and most of the aggregates are in full intact.

CONCLUDING REMARKS

Artificially production fly ash aggregates through pelletization process using alkaline solution has shown ample potential as light weight aggregates when compared to natural crushed aggregates.

Medium strength concrete (30 MPa) can be easily produced with complete replacement of artificial produced fly ash aggregates.

From experimental results, the concrete produced with complete replacement of pelletized fly ash aggregates has similar failure pattern to that of control concrete and failure surface was observed that most of the aggregates are full intact.

REFERENCES

1. GURSEL A P, MASANET E, HORVATH A AND STADEL A, Life-cycle inventory analysis of concrete production: a critical review, Cement and Concrete Composites. 2014 Aug 1, Vol 51, pp 38-48.
2. MEHTA P K, Greening of the concrete industry for sustainable development. Concrete international, 2002, Vol 24, No 7, pp 23-28.
3. MARK A AND SIDNEY M, Aggregates in concrete, Modern concrete technology series, Taylor and Francis, 2005, 432p.
4. FREEDONIA, World Construction Aggregates – Industry study with forecasts for 2015 and 2020, The Freedonia Group, USA, Study report 2838, January 2012, 334p.
5. NIXON P J, Recycled concrete as an aggregate for concrete—a review, Materials in Construction, 1978 Sep 1, Vol 11, No 5, 371.
6. VAZQUEZ E AND GONCALVES A, Recycled aggregate in concrete, RILEM report, 2005 Sep, Report 30, pp 41-44.
7. RAMAMURTHY K AND HARIKRISHNAN K I, Influence of binders on properties of sintered fly ash aggregate, Cement and Concrete Composites, 2006, Vol 28, No 1, pp 33-38.
8. CENTRAL ELECTRICITY AUTHORITY report, Executive Summary Power Sector, Central electricity authority, New Delhi, Ministry of Power, April 2016, Government of India, 52p.

9. CENTRAL ELECTRICITY AUTHORITY report, Fly ash generation at coal/lignite based thermal power stations and its utilization in the country for the year 2011-12 and 2012-13, Central electricity authority, New Delhi, Ministry of Power, January 2014, Government of India, 45p.
10. BUREAU OF INDIAN STANDARDS, IS 3812 – part 1, Specification for pulverized fuel ash: For use as pozzolana in cement, cement mortar and concrete, BIS, New Delhi, India, 2013.
11. BUREAU OF INDIAN STANDARDS, IS 1727: Methods of test for pozzolanic materials, BIS, New Delhi, India, 1967.
12. SHIVAPRASAD K N AND DAS B B, Determination of optimized geopolymerization factors on the properties of pelletized fly ash aggregates, Construction and Building Materials, 2018 Feb 28, vol 163, pp 428-437.
13. SHIVAPRASAD K N AND DAS B B, Influence of alkali binder dosage on the efficiency of pelletization of aggregates from iron ore tailing and fly ash, International Journal of Engineering Research in Mechanical and Civil Engineering, March 2017, Vol 2, No 3, pp 388-392.
14. BUREAU OF INDIAN STANDARDS, IS 4031: Methods of physical tests for hydraulic cement, BIS, New Delhi, India, 1999.
15. BUREAU OF INDIAN STANDARDS, IS 12269: 53 grade ordinary Portland cement, BIS, New Delhi, India, 2013.
16. BUREAU OF INDIAN STANDARDS, IS 383, Coarse and fine aggregates for concrete – Specification, BIS, New Delhi, India, 2016.
17. GOMATHI P AND SIVAKUMAR A, Characterization on the strength properties of pelletized fly ash aggregate, ARPN Journal of Engineering and Applied Sciences, 2012, Vol 7, No 11, pp 1523-1532.
18. BUREAU OF INDIAN STANDARDS, IS 2386: Methods of test for aggregates for concrete, BIS, New Delhi, India, 1963.
19. BUREAU OF INDIAN STANDARDS, IS 10262: Guidelines for concrete mix design proportioning, Bureau of Indian Standards, New Delhi, 2009.
20. BUREAU OF INDIAN STANDARDS, IS 516: Method of Tests for Strength of Concrete, BIS, New Delhi, India, 1959.