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Production of Pelletized Fly Ash Aggregates by Geopolymerisation

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Abstract
Aggregates constitute the major part of any concrete construction. The requirement of aggregates is increasing day by day. The replacement of conventional aggregates with a proper substitute is a very relevant requirement. Fly ash which is a dangerous by product of the coal industry is proven to have geopolymer properties when treated with certain chemicals like sodium silicates and sodium hydroxide. The production of the artificial fly ash aggregate is done on a laboratory scale disc pelletizer whose angle of rotation and speed can be adjusted. The aggregates are produced as different trial mixes based on sodium hydroxide to sodium silicate ratio, rpm and angle of disc. These aggregates are then allowed to rest in ambient temperature for 24 hours and are then heated up to 80℃again for 24 hours. The properties of the aggregates produced from optimal mixes were characterized according to standard specifications. Tests like sieve analysis, efficiency of pelletizer, water absorption, crushing strength are conducted on the prepared aggregate. The factors affecting the geopolymerization process like Na_2O content, water content and curing regime was analyzed. The evaluation is conducted on the basis of sieve analysis, water absorption, efficiency of pelletizer and crushing strength of aggregates.

Keywords: *Artificial aggregates, fly ash, geopolymerisation*

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I. Introduction

One of the most important industrial byproduct is the fly ash. Fly ash is a by-product of burning of coal for power generation. Its collection and disposal are necessary process in power generation [1]. The quantity of fly ash produced in India is approximately 80 million tons each year, and its percentage utilization is less than 10%. Majority of fly ash produced is of class F fly ash [2]. If not properly disposed fly ash can cause various health issues in the living beings and also contaminate water and soil and disturb the whole ecological cycle.

Aggregate constitutes the major part of any concrete construction. They include fine aggregates which passes through IS 4.75mm sieve, coarse aggregates which retains on IS 4.75mm sieve and ‘ all in aggregates’ which constitutes all of the major fractions. Conventional aggregates are obtained directly from the nature. The major problem associated with conventional aggregates is the depletion of resources. Once they are used in concrete it cannot be brought back into its original form. The harm caused to the environment is tremendous. So, the requirement of a proper substitute for conventional aggregate is a matter of immediate importance.

Utilization of fly ash as aggregate can reduce the problem of disposal of fly ash as well as the problem of depletion of aggregates. Artificial aggregates can be manufactured from fly ash from various processes such as sintering, hydrothermal treatment and cold bonding.Flyash is proven to exhibit geopolymer properties when treated with certain chemicals like sodium silicate and sodium hydroxide. By utilizing this advantage we can produce artificial aggregates from the waste fly ash with a comparatively minimal cost rather than the existing techniques like sintering and autoclaving. The production is done on a laboratory pelletizer whose angle and speed can be adjusted. Since alkaline solution is used as binder the cost of production is decreased and that too without compromising the efficiency of production. This paper is used to study the production of artificial aggregates using alkaline solution as a binder and the effect of the heat curing hardening process on the produced fly ash aggregates.

II. Objectives

- Optimization of the rpm of the disc and angle of disc of a laboratory scale pelletizer by analyzing the production efficiency.
- Production of fly ash artificial aggregates by geopolymerisation using optimum factors and analysis of physical and mechanical properties of the produced aggregates.

III. Materials and Methods

3.1 Materials

3.1.1 Fly Ash

Class F fly ash is collected from North Chennai Power Plant station, Athipattu, Tamil Nadu. Fly ash is a waste product obtained by the combustion of pulverized coal in thermal power plants. It is obtained as fine powder and is proven to be extremely toxic component. Fly ash particles are generally spherical in shape. The size varies from 0.5μm to 300μm.Class F fly ash is pozzolanic in nature and contains lesser that 7% of lime (CaO). They are obtained from burning bituminous coal. In addition to pozzolanic properties it has also got some self-cementing properties. The fly ash used for the present study is of class F. Class F fly ash is collected from North Chennai Power Plant station, Athipattu, Tamil Nadu.The chemical composition of the collected fly ash is as in table 3.1.

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Figure 3.1 Fly Ash

Table 3.1 Composition of fly ash

Component	Percentage (%)
SiO_2	56.9
Al_2O_3	26.8
Fe_2O_3	7.17
CaO	3.55
Na_2O	0.231
MgO	1.59
P_2O_5	0.407
SO_3	0.243
K_2O	1.61

3.1.2 Alkali Solution

Alkali solution was prepared using sodium hydroxide and sodium silicate. Sodium hydroxide in pellet form and sodium silicate in solution form was taken for the study. Initially sodium hydroxide solution of 10 M was prepared and after that experiments were also done using 12 and 14 molar. The sodium hydroxide to sodium silicate ratio was taken as 1:1.5 and this solution was added to fly ash in the ratio 0.4:1.

3.2 Machine Design

The design of a laboratory scale disc pelletizer is important because of their low market availability and high price. Most common models starts from a price range of near lakhs. So, it is economical to design a pelletizer which suits the mode of operation of low scale aggregate manufacture. The following design concept enables a fairly good production efficiency and simplicity in handling.

Pan: - it enables the placing and mixing fly ash powder with the binders by providing a circular motion. The pan is made of GI sheets and it has a diameter of 450mm and height of 100mm. The pan is connected to the rotating shaft of a gear box at its centre to enable the circular motion.

Motor: - A 3phase 0.5hp AC motor is used in the design. The motor has an rpm of 1440. A three-phase motor is selected because of the factor that it can provide more torque for very low speeds.

Gear box :- The pelletizer is designed to work in very low rpm. So, a gear box of ratio 1:20 is used to convert the rpm output of the motor from 1440 to merely 72 without compromising the torque.

VFD :- A Variable Frequency Drive is used to alter the frequency of their output by rectifying an incoming AC current into DC and then using voltage pulse-width modulation to recreate the waveform of AC current and voltage. The motor will receive the input through a VFD which is so programmed that the rpm of the disc can be varied from 0 to 72 in this case. VFD also helps in converting single phase input to three phase output so that the motor can work without damage.

Steel frame : Steel frame provides support to the setup and also a bolt and screw arrangement is provided to change the angle of the disc with the horizontal. The angle can be varied from 00 to 350 which can be further increased by increasing the length of the screw and the ground clearance.

Blades : blades are provided on a frame connected steel beam spanning through the diameter of the disc inclined to the direction of motion. The circulating particles collides with blades and gets deflected to the pan bottom resulting in the formation of round pellets.

Push on/off button : it is provided to turn on and off the machine. It provides a less fragile platform suitable for rough use and also facilitates to shut down the machine in emergencies.

MCB and Potentiometer : these are components which are externally connected to the VFD for increasing the safety. MCB automatically trips when there is sudden voltage variation. Potentiometer is provided to adjust the speed of the machine without using the knob of the VFD so that it can be given full covering against dust.

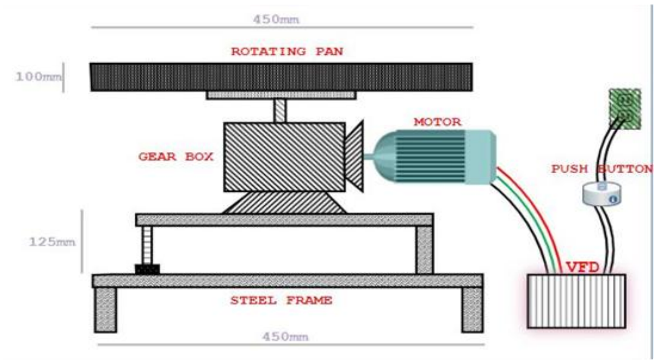

Figure 3.2a: Design model of disc pelletizer

Figure 3.2b: Manufactured disc pelletizer

Note: The motor can be replaced with a similar power DC motor but an extra rectifier has to be purchased and in that case the cost of manufacture may rise higher. The total cost of manufacture for the current mode of design is just around thirty thousand rupees including the cost of weld and work.

3.3 Aggregate Production and Testing

The pelletization process for the production of fly ash aggregates was basically carried out in a disc pelletizer. The fly ash is first spread on to the disc where the rpm at which the disc is rotated and the angle of rotation of the disc is adjusted. As the disc rotates with the fly ash, slowly a solution of sodium silicates and sodium hydroxide is added as drops which acts as moderators and initiates geopolymerisation.

Aggregate will be produced under different trial angles and rpm. 20, 40 and 60 were the rpms and 15, 25 and 35 were the degrees of the disc plate under the experiment. Sieve analysis were conducted for the produced aggregates and it was found that the disc plate with 25 degree and under 20 rpm worked more efficiently. This was because the maximum peak in sieve analysis was obtained under this set up.

In case of sodium hydroxide solution initially a 10 molar solution was prepared and after that experiments were also done with 12 and 14 molar solutions.. The sodium hydroxide to sodium silicates ratio followed was 1:1.5 and this solution was added to fly ash in the ratio 0.4:1.

The produced geopolymer aggregates was heat cured. First the pellets were allowed to rest in ambient temperature conditions for 24 hours, after that the pellets are heated up to 80 ℃ again for 24 hours. The aggregates are then removed and kept in ambient temperature conditions until it is ready to test for aggregate properties.

Sieve analysis, specific gravity, bulk density, percentage voids, water absorption and crushing strength of individual pellets are the main tests conducted on the produced aggregates.

Figure 3.3a : Production of fly ash aggregate

Figure 3.3b: Produced Fly Ash aggregate

IV. Results and Analysis

4.1 Efficiency of pelletization

Efficiency of pelletization is obtained by calculating weight of fly ash fine aggregate retained on the 4.75 mm IS sieve to the total weight of aggregate produced multiplied by 100.For calculating efficiency 1 kg of fly ash fine aggregate were taken. When the angle of the disc was set up for 35^0 the majority of aggregate produced was coarse aggregate but when angle of disc was at $25^0$and 15^0 the majority of aggregate produced was fine aggregate so major part of study deals with fly ash fine aggregates.

Max Efficiency =0.469/1*100=47%

From the curve maximum production efficiency obtained was 47% at 25^0 and 20 rpm. Based on these efficiencies following test were conducted.

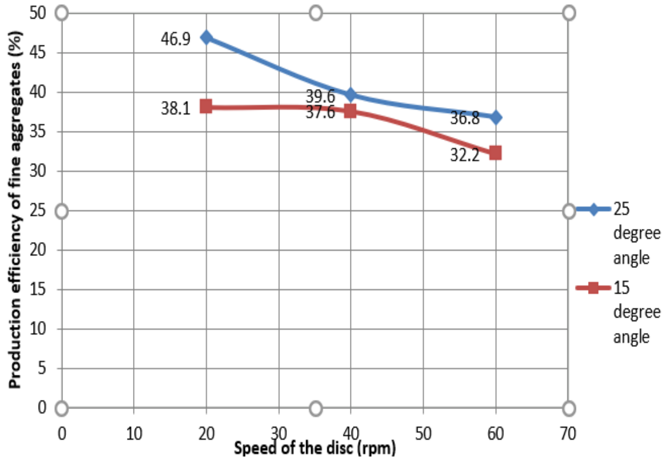

Figure 4.1: Production efficiency of aggregates with speed of disc.

4.2 Specific gravity of aggregate

Specific gravity of fine aggregate is the ratio of the weight of the given volume of aggregate to weight of equal volume of water. Specific gravity is calculated by pycnometer method. 500 g of fly ash aggregate were taken. Apparent specific gravity is the weight of dry sample to the weight of equal volume of water.

Specific gravity of fine aggregate $=W_2/W_2-(W-W_1)$.

Table 4.2: Specific gravity with molarity of NaOH solution

Molarity of NaOH solution	Specific gravity
10 molar	1.69
12 molar	1.7
14 molar	1.72

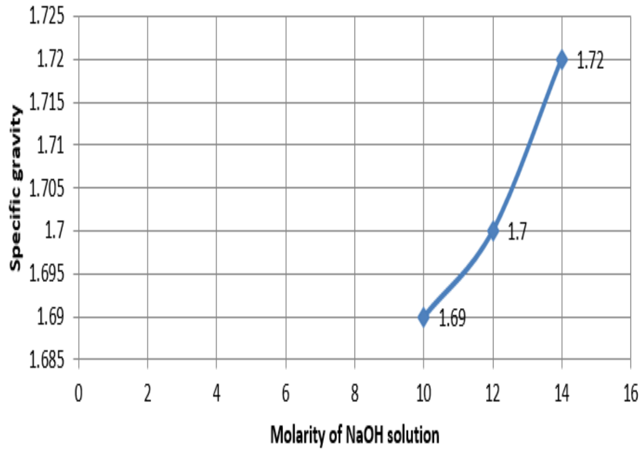

Figure 4.2: Specific gravity with molarity of NaOH solution

4.3 Water absorption of aggregates

Water absorption capacity represents the maximum amount water the aggregate can absorb. It is calculated from the difference in the weight between saturated dried sample and oven dried sample expressed as a percentage of the oven dried sample.
Weight of oven dried sample W_1, Weight of surface dried sample W_2
Water absorption= $(W_2-W_1)/W_1*100$

Table 4.3: Water absorption with molarity of NaOH solution

Molarity of NaOH solution	Water absorption
10 molar	4.2%
12 molar	4%
14 molar	3.6%

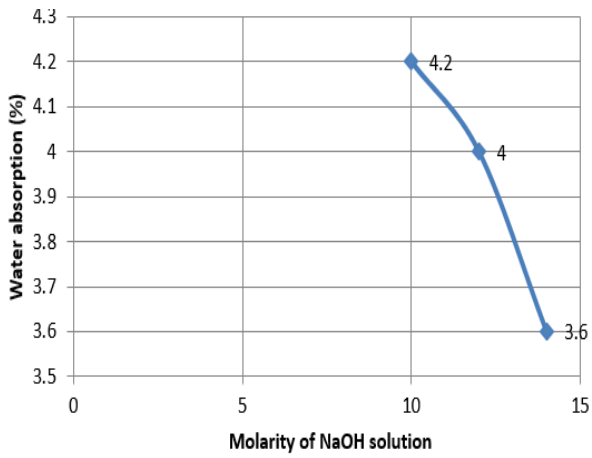

Figure 4.3: Water absorption with molarity of NaOH solution

4.4 Bulk density of aggregates

Bulk density of aggregates is the mass of aggregates required to fill the container of a unit volume after aggregates are batched based on loose packed aggregates or compacted packed aggregate.
Loose bulk density = (Weight of container + Loose aggregate)-(weight of empty container)/volume of container.
Compacted bulk density=(weight of container +compacted aggregate)-(weight of empty container)/volume of container.

Table 4.4: Density of aggregates with molarity of solution

Bulk density (kg/m^3)	10 molar	12 molar	14 molar
Loose bulk density	1272.66	1278.33	1293.33
Compacted bulk density	1383.22	1396	1402

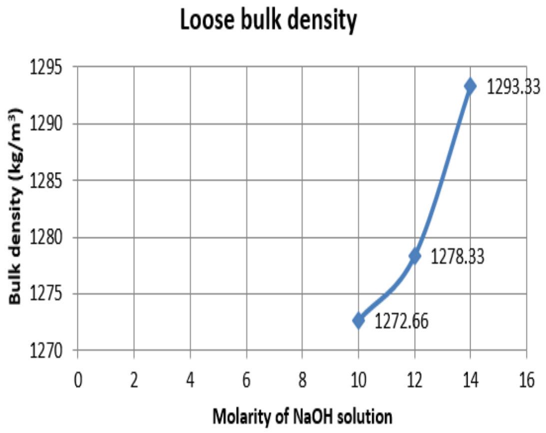

Figure 4.4: Loose bulk density

From the graph it is clear that the loose bulk density and compacted bulk density of fly ash fine aggregate is increasing with increase of molarity of NaOH solution.

4.5 Percentage of voids

Percentage of voids is the difference between specific gravity of the aggregate (Gs) and bulk density (γ) expressed as the percentage of specific gravity of aggregates.

Percentage of voids =(Gs-γ)/GS*100

Table 4.4 Percentage of voids

Molarity of NaOH solution	Percentage of voids
10 molar	24.69
12 molar	24.8
14 molar	24.806

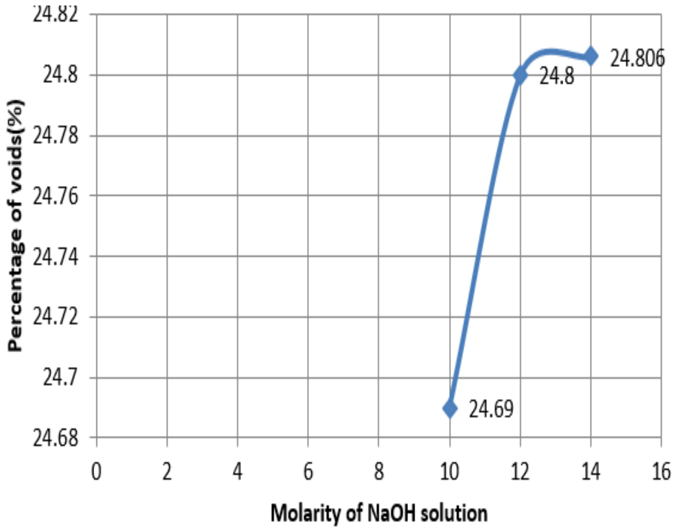

Figure 4.5: Percentage of voids with molarity of solution

The graph shows that the percentage of voids of fine aggregate increasing with increase of molarity of NaOH solution.

4.6 Crushing strength of individual pellets

The crushing strength of individual pelletized fly ash aggregate was determined using a crushing testing machine. P is the failure load and X is the size of the aggregate or distance between two plates. Crushing strength can be obtained by equation

Crushing strength=$(2.8*P)/(\pi*X^2)$

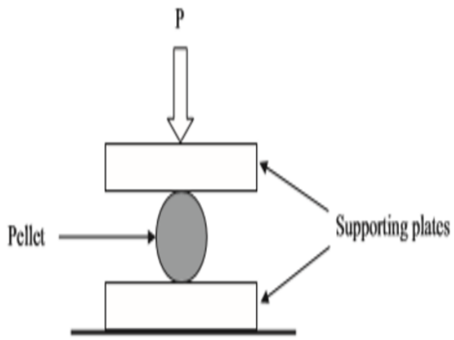

Figure 4.6: Crushing strength test

Table 4.6: Crushing strength of aggregates

Molarity of NaOH solution	Crushing strength (MPa)
10 molar	1.13
12 molar	1.17
14 molar	1.34

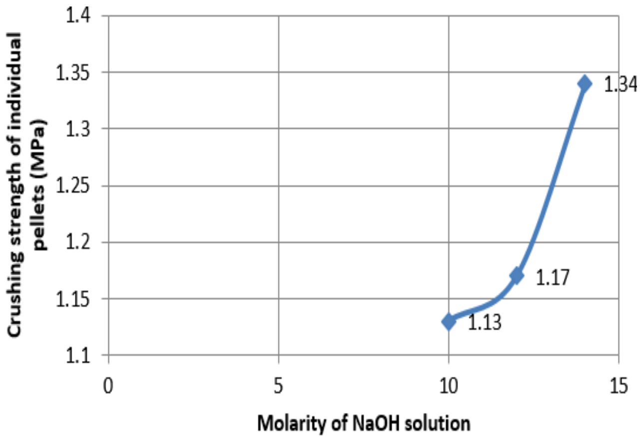

Figure 4.6: Crushing strength with molarity of NaOH solution

From the curve crushing strength value of fly ash fine aggregate is increasing with increase of molarity of NaOH solution

V. Conclusions

The maximum value obtained for specific gravity of fly ash fine aggregate was 1.72. Generally specific gravity value of river sand is 1.65, So the obtained value for fly ash fine aggregate is slightly greater value. The greatest water absorption value obtained for fly afine aggregate is 4.2%. According normal fine aggregate water absorption range is less than1% which is lesser than the fly ash fine aggregate produced. The highest value of bulk density obtained for fly ash aggregate is1293.33kg/m3. Generally bulk density for fine aggregates ranges from 1440 to 1680kg/m3, the produced fly ash fine aggregate value is within the limit. The maximum value for percentage of voids fly ash fine aggregate is 24.806. Normally fine aggregate percentage of voids ranges from 38 to 43%, the percentage of voids is lesser compared to normal fine aggregates. The highest value of crushing strength of individual pellet is 1. 34MPa.According to normal coarse aggregate crushing strength is greater than 80MPa so our produced aggregate has lesser crushing strength. From all these, it is clear that artificial fly ash aggregates produced by geopolymerisation cannot be a proper substitute for natural aggregates under all cases. But the value of specific gravity and bulk density proves to be comparatively higher than several other forms of artificial aggregates currently under production. This implies the suitability of the produced fly ash aggregates to be used as substitute for normal aggregates for small scale construction works.

Scope for Future Study

More tests can be conducted in order to ascertain properties of coarse aggregates like impact test, abrasion test etc. the curing regime also plays an important role in the strengthening of aggregates. Studies can be conducted by replacing the binder solutions with proper substitutes.

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