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Determination of optimized geopolymerization factors on the properties of pelletized fly ash aggregates

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HIGHLIGHTS

- This paper focuses on the development of pelletized fly ash aggregates.
- Parameters influencing the geopolymerization in pelletized aggregates were studied.
- Study ensured the potential manufacture of pelletized aggregate using alkaline solution.
- Pelletized fly ash aggregates depended mainly on the water content and curing methods.
- Solution curing method enhanced the properties of the pelletized fly ash aggregates.

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ABSTRACT

This research investigates the effect of geopolymerization factors on the pelletization in the production of artificial fly ash aggregates. The proportion of pelletized fly ash aggregate mixes was designed through Taguchi's L9 orthogonal array. The properties of the aggregates produced from the optimal mixes were characterized according to the standard specifications. The effect of geopolymerization factors such as Na_2O content, water content, and curing regime on the properties of the pelletized fly ash geopolymer aggregates was determined through response indices at the age of 14, 28 and 56 days. In addition, Grey relation based analysis was performed to identify the most critical parameter for optimization among three geopolymerization factors selected in this investigation, for the production of pelletized fly ash geopolymer aggregates. It is observed from the response indices and Grey relation results that the impact value of the aggregates and crushing strength of individual pellets is governed by heat curing and high water content at the age of 14 and 28 days. However, at the age of 56 days these response indices are significantly governed by the solution curing and high water content. It was also noted that the minimum Na_2O content of 3.5–4.5% is adequate for the production of pelletized fly ash aggregates.

1. Introduction

The global demand for construction aggregates exceeded 48.3 billion tons in the year 2015 and is expected to grow 5.2% annually. In India, the consumption of aggregate was about 2.2 billion metric tons in 2010 and further the demand is going to be more than 5 billion metric tons by 2020 [1]. On the other hand more than 150 thermal power plants are there for generation of electricity and consume 790 million tons of coal annually. A recent report from the central electricity authority in October 2015 presented that fly ash production in India is about 184.14 MT [2]. Non-utilization of fly ash produced from coal-based thermal power plants may bring several problems from environmental point of view. It is being used as an artificial pozzolanic material for manufacturing of Portland pozzalona cements or blended cements in the production of building materials such as fly ash bricks, in concrete, in agriculture, construction of roads, land filling of mines and low lying areas. Further, it is reported that by the year 2025 fly ash production is expected to increase by around 300–400 MT per year [2,3].

Hence, utilization of fly ash can be used in the production of artificial coarse aggregates. The production of pelletized fly ash aggregate is effectively carried out by using granulation or pelletization. The pelletization theory or agglomeration of fines was developed in 1940 [4]. Some effort has been made on utilizing the fly ash in the production of artificial aggregates using different additives such as cement, clay and glass powder [5–8]. Many

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researchers reported that the factors affecting the pelletization process in producing the pellet varies from finer particles such as raw materials, moisture content, binder type, dosage and duration of pelletization [5–11]. It is also reported that the hardening methods adopted for producing pellets are sintering, normal water curing, autoclaving and steam curing [7,8,11,12]. The engineering performance of produced pellets is predominantly depends on the binder used in the process [5–11,13]. The produced artificial aggregates should satisfy minimum acceptance criteria as per the Bureau of Indian Standards. This review indicated that the available literature on aggregate production dealt mostly with different binders and hardening methods and no study has been reported on use of geopolymer as binder for the production of the aggregates.

Binder such as geopolymers have many applications including replacement of cement in building materials [14], concretes [15] and pavement materials [16,17]. In geopolymerization, alkali activator or chemical activator solution plays a vital role in the initiation of surface hydrolysis of the particles present in the aluminosilicate materials as the raw material [15]. The effect of the process is greatly affected by the number of factors such as type of alkali activator [15,18–20], concentration of the alkali solution [20–27], binder to alkali ratio [28–30] and curing regime [15,28–32].

The motivation of the present investigation is on the production of pelletized fly ash aggregates with alkaline solution as a binder. The effect of geopolymerization factors are investigated along with different curing regimes are considered to enhance the properties of the aggregates. The relative assessment of pelletized fly ash aggregates properties was made through series of tests. Further, Scanning Electron Microscopic (SEM) analysis was carried out to understand the surface morphology of the produced fly ash aggregates.

To study the complexity of relative influences of geopolymerization factors on the properties of aggregates and to identify the optimum value of factors the experimental design play an important role. There are several experimental designs that can be used to prepare or reformulate an optimal process. Some of these designs are: full factorial design, fractional factorial design, central composites, Taguchi method, and response surface methodology [10,33]. It is understood that Taguchi method reduces the number of experiments to a practically possible level and allows the basis for determining the functional relationship between selected geopolymerization factors and properties of the pelletized fly ash aggregates and is related to finding the best values of the controllable factors to make the problem less sensitive to the variations in uncontrollable factors [33]. It defines the best understanding between the individual properties evaluated with factors considered through the response indices. However, for getting clear understanding of all the response indices together in the experimental program, are aided with Grey relation analysis [34].

1.1. Significance of the study

The amount of utilization of aggregates is increasing because of the fast change in the infrastructure development of the country. However, the availability of natural aggregates is very scarce and mining leads to serious environmental impacts. Hence, it is necessary to find alternate material which can replace the natural mined aggregate for construction works. Along with alternate material, technology plays a vital role in the manufacturing of artificial aggregates with the local available resources. In this scenario, considering the industrial by products as one of the important raw material in producing artificial aggregates poses a great challenge to the researchers. A substantial utilization of this industrial waste in concrete can be one of the good solutions to waste management, disposal problems and also to alleviate potential health hazards.

2. Materials and methodology

2.1. Materials

Fly ash was collected from Udupi thermal power plant, Karnataka, India. It is classified as class F type as per IS 3812 (part 1) – 2013 classification [35]. The physical properties and chemical compositions of the fly ash were analysed and it is presented in Table 1. The fineness of the fly ash was assessed using Blaine's air permeability apparatus as per the guidelines described in IS 1727 – 1967 [36]. The particle size distribution of the fly ash is presented in the Fig. 1. Laboratory grade sodium silicate solution (8.0% Na_2O, 26.5% SiO_2, 65.5% H_2O by mass) with silica modulus of 3.3 (SiO_2/Na_2O ratio) and sodium hydroxide flakes of 98% purity were used as alkaline activators in the present study. Sodium hydroxide in flakes form was dissolved in distilled water to produce a sodium hydroxide solution. The alkaline solution prepared by mixing both sodium silicate and sodium hydroxide in the required proportions for different mixes and transferred to an air tight container with cap and allowed to cool for 24 h, before using in the mix.

2.2. Production and curing of aggregates

The pelletization of fly ash has been carried out in a laboratory disc pelletizer. A fabricated disc pelletizer was used in this study which has a disc diameter of 450 mm and depth 100 mm. The angle of disc maintained at 45° and 15 min duration of pelletization is used in the process of pelletization. For this present investigation rotational speed of disc is maintained at 10 rotations per minute for all mixes. The pelletization process included: i) transferring of uniform fly ash which is free from lumps to the pelletizing disc, ii) alkali solution is sprayed within 3 min to the fly ash mix during pelletization. The dosage of water is represented as a percentage by weights of total solids in the mix. The produced fly ash geopolymer aggregates were cured under three different curing regimes.

Ambient curing: The pellets produced in pelletization process are kept ambient temperature conditions of 28 ± 2 °C and relative humidity of 80% until it is tested for aggregates properties.

Heat curing: The pellets produced in pelletization process are allowed in ambient temperature as rest period for 24 h. After that the pellets are subjected to 80 °C for 24 h and removed pellets after heat curing are kept in ambient temperature conditions until it is tested for aggregates properties.

Solution curing: The pellets produced in pelletization process are allowed in ambient temperature as rest period for 24 h. After that pellets are subjected to solution curing in laboratory grade sodium silicate solution for 30 min and removed pellets are kept in an ambient temperature conditions until it is tested for aggregates properties.

Table 1
Physical and chemical properties of the fly ash.

Parameters	Fly ash
Specific gravity	2.2
Blaine's fineness (m^2/kg)	204.3
Chemical properties	
SiO_2	60.65
Al_2O_3	28.62
Fe_2O_3	3.95
CaO	1.70
MgO	1.84
SO_3	1.26
Na_2O	1.11
K_2O	0.11