Preparation and Properties of Alkali Activated Coarse Aggregates Using Fly Ash and Slag

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doi: https://doi.org/10.21467/proceedings.112.45

ABSTRACT

Coarse aggregate is an essential component of concrete which influences the properties of concrete. Generally, natural crushed stones are being used for the concrete production. The increased demand of aggregates for concrete production can be countered by using alternate aggregates. Production of artificial aggregates from industrial wastes appear as a promising and sustainable alternative to natural aggregates as it helps in utilizing large amount of industrial byproducts in concrete, reduces environmental pollution and also relieves the issues involved in their waste disposal. Hence, this study aims at the utilization of industrial wastes (fly ash and slag) for the manufacture of synthetic aggregates which could be a potential sustainable alternative for the coarse aggregates. Cold bonded pelletized aggregates were prepared by using alkali-activated Class F fly ash and ground granulated blast furnace slag. Alkali mixture of sodium silicate (Na2SiO3) and 10M sodium hydroxide (NaOH) solution were used for the chemical activation of fly ash and slag. Two types of synthetic aggregates were prepared using the fabricated disc pelletizer; mix containing only slag and another mix with equal proportion of fly ash and slag, and the aggregates were heat cured for 24 hours. Tests were done to determine properties such as aggregate surface texture and shape, particle size distribution, bulk density and specific gravity, and the results were compared with the properties of normal aggregates (natural crushed stones). The results indicate that synthetic aggregates made by alkali activation of fly ash and slag could be a potential alternative to the crushed stones.

Keywords: Artificial aggregate, alkali activation, coarse aggregate, fly ash, industrial waste, pelletization, slag; sodium silicate; sodium hydroxide, sustainable.

1 Introduction

Coarse aggregate is an important component of concrete which contributes to the properties of concrete. Generally, natural crushed stones are being used for the concrete production. About 60% of the concrete volume is occupied by the coarse aggregates alone. The bulk usage of natural coarse aggregates will cause the depletion of natural resources and environmental degradation. The environmental impacts are the limiting factors for aggregates extraction in many countries. The consequences of aggregate extraction comprise forest clearing, noise, dust, vibrations and quivering resulting from blasting of mountains and environmental pollution. Abnormal ill-treatment of massive rocks may lead to landslips and failure of mountain slopes. The anxiety about the extensive consumption of natural resources and its environmental impacts has led to the quest on the consideration on the possibility of use of synthetic aggregates as an alternative to the natural resources.

Production of artificial aggregate appears as a promising and sustainable option to recycle some of the industrial by-products as it helps in utilizing large amount of industrial waste materials in concrete (ASTM C330M, 2009). Large scale utilization of waste materials reduces environmental pollution and relieves the issues involved in

Proceedings DOI: 10.21467/proceedings.112; Series: AIJR Proceedings; ISSN: 2582-3922; ISBN: 978-81-947843-3-3

the waste disposal. Consequently, the production of artificial aggregates can provide simultaneous solution towards the solid waste management and conservation of natural resources up to a large extent. Fly ash is a by-product of coal based thermal power plants, which generates multiple problems of disposal as well as environmental degradation, due to its nature of causing air and water pollution on a large scale. If it is not properly disposed of, it can cause water and soil contamination consequently interrupts the ecological cycles. Slag is also a by-product that is produced in large quantities from the steel industry. Baykal et al. (2000) investigated the performance of moist cured fly ash pellets for geotechnical and concreting applications. Many studies are reported on the properties of cold bonded fly ash and light weight aggregates (Gesoglu et al. 2007; Gomathi and Sivakumar, 2014). Different types of fly ash were studied for the production of light weight and synthetic aggregates (Wang et al. 2002; Ramamurthy and Harikrishnan, 2006; Manikandan and Ramamurthy, 2007; Kockal and Ozturan, 2011; Vasugi and Ramamurthy, 2014). Jo et al. (2007) studied concrete properties using alkali activated fly ash lightweight aggregate. Less focus was given to the preparation and properties of aggregates using fly ash and slag using the concept of geopolymer technology. Thus, this study aims at the utilization of industrial wastes (fly ash and slag) for the manufacture of synthetic aggregates (using geopolymer technology) which could be a potential sustainable alternative for the coarse aggregates.

2 Materials

The experimental programme involved the preparation of synthetic coarse aggregates and the tests on aggregates. Two types of synthetic aggregates were prepared using the fabricated disc pelletizer; mix containing only slag and another mix with equal proportion of fly ash and slag. Alkali mixture of Na_2SiO_3 solution and 10 M NaOH solution is used for the chemical activation of fly ash. Aggregates were prepared by cold – bonding pelletization in a disc pelletizer of 600 mm diameter and 100 mm height. The efficiency of pelletization depends on the binder content, water content, speed of rotation of disc pelletizer and the angle of inclination of disc pelletizer to the normal. These parameters are fixed after several trials.

3 Methodology

For the preparation of synthetic aggregates, 15 kg of slag and 5 kg of Class F fly ash were taken. About 10 kg of slag was taken for preparation of aggregates designated as Mix 1 which includes 100% slag. The second mix (Mix 2) was prepared using 5 kg of slag and 5 kg of flyash as binder. Since class F fly ash and slag are used for producing aggregates, due to its low self-cementing capacity, alkali activation was carried out for the pelletization process. Sodium hydroxide solution of 10 M and sodium silicate solution is used for the alkali activation. The NaOH solution was prepared at the required molarity by dissolving 314 g NaOH in 686 g distilled water. The alkali solution for pelletization was made by mixing NaOH and Na_2SiO_3 solutions, the ratio of sodium silicate to sodium hydroxide solutions being 2.50. Since reaction between NaOH and Na_2SiO_3 is exothermic, investigators have suggested some time to cool. Hence, alkaline solution was kept for cooling for 24 hours before the preparation of aggregates. Alkali to binder ratio adopted was 0.30 for both the mixes.

Aggregates were prepared by using pelletization method. Pelletization is the process of converting finer moisturized particles into larger solid spherical pellets. When it is rotated in a tilted revolving pan and moisture is sprayed to the particles, pelletization occurs due to cohesive force between the particles, gravitational and centrifugal force due to rotation of pan. As the rotation increases, grains and seeds which are formed initially tend to grow in size and strength is attained due to the compaction forces inside the pan and without the

Proceedings DOI: 10.21467/proceedings.112 Series: AIJR Proceedings

ISBN: 978-81-947843-3-3 ISSN: 2582-3922

application of any external forces (process is shown in Figure 1). This principle is made use in the study in preparing alkali activated synthetic aggregates.

Figure 1. Fly ash pelletization in progress

Figure 2. Pelletizer

A miniature pelletizer disc of 600 mm diameter and 100 mm depth is fabricated for the study. The pelletizer is attached to a concrete mixer and the arrangement is shown in Figure 2. The angle of the disc is adjustable. Based on the trial-and-error study, the operating angle of the disc is fixed as 45^{o} and a speed of 26 rpm is provided. Trial operation was done by adjusting the angle of disc and speed of rotation and then angle and speed is fixed based on the pelletization efficiency. There were no vanes inside the disc pelletizer for agitation, and hence agitation is provided manually. The first set of aggregates was prepared by taking 100% slag (Figure 3) and the second mix was prepared by taking 50% slag and 50% fly ash as binders. After the pelletization process, aggregates were cured for the hardening process (Figure 4). Heat curing was done by oven drying them at 60 degree Celsius for 24 hours for mix 1, and heat curing by oven drying at 100 degree Celsius for 24 hrs for mix 2. Higher temperature of curing was adopted for mix 2 as it contained fly ash in addition to slag.

Figure 3. Freshly prepared pellets

Figure 4. After 24 hrs curing (mix 1)

4 Results and Discussion

In addition to the composition, character and structure of aggregate, its external characteristics also are of importance which has marked influence on the properties of concrete. Physical properties of aggregates are very important as it has major influence on packing of particles, mix proportion and bonding with paste. Physical properties of aggregate mainly considered for the manufacture of concrete are specific gravity, size, shape and texture of aggregates, bulk density, porosity and voids ratio and these properties were tested as per IS 2386.

4.1 Aggregate surface texture and shape

Surface texture is the pattern and the relative roughness or smoothness of the aggregate particle. Surface texture plays a big role in developing the bond between an aggregate particle and a cementing material. A rough surface texture gives the cementing material something to grip, producing a stronger bond, and thus creating a stronger concrete. Figure 5 shows the aggregate shape, surface texture and colour variations of different aggregates (mix 1, mix 2 and ordinary aggregates from left) whether polished or dull, smooth or rough etc. Surface texture depends on the hardness, grain-size, and pore characteristics. Though there is no recognised method of measuring the surface roughness, but surface textures of aggregates by visual observation are considered to give good indications. From visual observations, it can be noted that the surface texture of mix 2 was smoother than mix 1, which could be due to the presence of fly ash. Both the geopolymer aggregates were smoother and spherical than the ordinary quartzite aggregates used for the normal construction.

Figure 5. Comparison of shape of mix 1, mix 2 and normal aggregates

4.2 Sieve analysis

Table 1. Percentage finer of various aggregates

IS Sieve Size (mm)	Percentage finer		
	Mix 1 aggregate	Mix 2 aggregate	Normal aggregate
40	100	100	100
20	92.37	95	86.07
10	33.31	40.89	0.70
4.75	0.68	3.45	0
2.36	0	0	0
1.18	0	0	0
0.60	0	0	0
0.30	0	0	0
0.15	0	0	0
Fineness Modulus	6.74	6.61	7.13

Proceedings DOI: 10.21467/proceedings.112
ISBN: 978-81-947843-3-3

Series: AIJR Proceedings
ISSN: 2582-3922

The results of sieve analysis of aggregates are shown in Table 1. Figure 6 compares the particle size distribution curves of various aggregates. The fineness moduli of geopolymer aggregates were marginally lesser than the normal aggregates (of nominal size 20 mm). From Figure 6, it can also be ascertained that the aggregate particles obtained by alkali activation and pelletization are finer in size compared to selected normal aggregates.

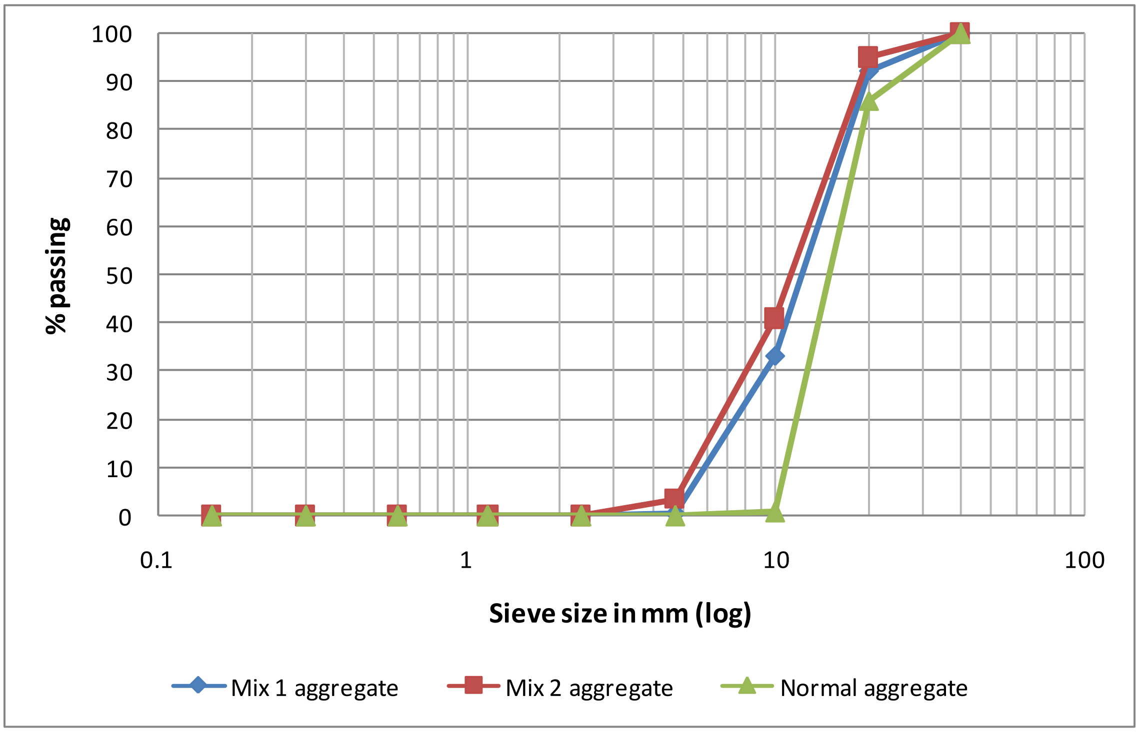

Figure 6. Particle size distribution of aggregates

4.3 Bulk density and Specific Gravity

Bulk density is an important physical property of aggregate related to the packing of the particles. Bulk density of aggregates is obtained by finding out the mass of aggregates required to fill a cylindrical container. From Table 2, it can be seen that the bulk density of geopolymer aggregates (mix 1 and mix 2) were 23.85% and 16.89% lower compared to normal aggregates. Apparently, specific gravity of geopolymer aggregates was also found to be lower compared to normal aggregates. As the bulk density and specific gravity of geopolymer aggregates are lower, these aggregates could be considered for light weight concreting applications.

Table 2. Bulk density and specific gravity of various aggregates

Property	Mix 1 aggregate	Mix 2 aggregate	Normal aggregate
Bulk density (g/cm^3)	1.226	1.338	1.610
Specific gravity	2.07	2.25	2.56

5 Conclusions

This study is aimed at the utilization of industrial wastes (fly ash and slag) for the manufacture of synthetic aggregates which could be a potential sustainable alternative for the naturally available coarse aggregates. Cold bonded pelletized aggregates were prepared by using alkali-activated Class F fly ash and ground granulated blast furnace slag. The following conclusions were drawn from the study.

- Pelletizer disc of 600 mm diameter and 100 mm depth, attached to the concrete mixer was used to produce alkali activated and pelletized geopolymer aggregates
- The geopolymer aggregates prepared using fly ash and slag (i.e. mix 1 containing only slag and another mix 2 with equal proportion of fly ash and slag) were smoother and spherical than the ordinary quartzite aggregates used for the normal construction.
- The fineness moduli of geopolymer aggregates were marginally lesser than the normal aggregates and well graded.
- The bulk density of geopolymer aggregates (mix 1 and mix 2) were 23.85% and 16.89% lower compared to normal aggregates. The specific gravity of geopolymer aggregates (mix 1 and mix 2) were 19.14% and 12.11% lower compared to normal aggregates.
- The results indicate that synthetic aggregates made by alkali activation of fly ash and slag could be a potential alternative to the crushed stones, and could be considered for prospective light weight concreting applications.

How to Cite this Article:

Sunil, R., Panicker, P., Megha, R., Athira, K., & Vijayan, A. K. (2021). Preparation and Properties of Alkali Activated Coarse Aggregates Using Fly Ash and Slag. *AIJR Proceedings*, 375-380.

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