Production and Utilisation of Artificial Coarse Aggregate in Concrete - a Review

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Abstract. This present work provides a study of several successful approaches in producing artificial aggregates using a pelletiser machine and the parameters affecting efficiency. These aggregates were contrived from substances of nature such as fly-ash, GGBS, Rice husk ash, volcanic ash, etc. Different sets of artificial aggregates are to be made with different molarity. The common methods of developing them include cold bonding, autoclaving, and sintering. The aggregate pellets (with lightweight and possessing less specific gravity and high impact value than gravel) were batch manufactured by a cold bonded technique using disc pelletiser (used to perform agglomeration). The prepared aggregates are characterised based on their crushing and impact strength rate and also moisture absorption. This paper explicitly reviews various effective and eco-friendly artificial aggregate and their potential usage in the construction industry.

1. Introduction
In day-to-day life, enormously booming construction field demands mass production of Portland cement and aggregates. The tremendous growth in the infrastructural sector around the world and the demand for a huge quantity of cement and aggregates in construction have occurred. Aggregates are obtained from natural resources such as granite and other rocks, especially the ones which are fine grained find their source enormously from natural river sand. Due to the enormous demand for these aggregates, natural resources are depleting faster leading to demand for alternate mode of aggregates. The scarcity of river sand has increased the burden on coarse aggregates. So crushed granite is replaced by river sand in almost all construction activities. Hence there is no scarcity of fine aggregate due to the availability of M sand. It is produced from hard granite stone by crushing. The enormous production of M-sand leads to the depletion of natural resources. This leads to serious issues of the unavailability of coarse aggregates also. So in-order to avoid the depletion of natural aggregates, coarse aggregates are replaced by recycled aggregates or artificial aggregates. Recycled aggregates are nothing but released aggregates from different concrete waste products in construction. The major limitation with respect to the utilisation of recycled aggregates is the quality of recycled aggregates, such as high water absorption and lower strength. So there is a major necessity of utilisation of artificial coarse aggregates for construction purposes. They were obtained from the engineered co-products such as ashes of fly, husk or volcanic type and GGBS. In India, in most of the industries (like the thermal power plant, iron industry) coal is burnt in large numbers. Thus in the above process, a significant amount of fly types of ashes were produced in our country, but they turned as a menace to our society owing to their health hazard. This burning issue was overcome by stacking them on low-lands, producing bricks, and
proportioning concrete mix [1]. The fly-ash replaced coarse aggregate in construction with a mix of cement as a binder gave good cementation quality and also provided an efficient solution by depressing the environment concern. For purpose of sustainable city with green purpose, fly-ash aggregates are also critical as it is manufactured by recycling of fly-ash from industries. Like fly-ash, several raw materials can be used for the manufacture of artificial aggregates. Identical to waste materials like fly-ash, several others can also be used effectively for the production of aggregates. Their utilisation as by-products of artificial aggregates production also found to address the disposal issue in these industrial waste along with concern for healthy environment [2]. This paper reviews the techniques, materials, and methodologies for producing and utilising artificial aggregates in the construction industry.

2. Artificial aggregates

2.1. Materials
The fractional binding alternative by FA for the creation of artificial aggregate improves their cementitious properties. These artificially fabricated ones decoded the major environmental issue of pollution and natural resource depletion. The parent materials of concrete production plays the main governing factor in the behaviour of their properties [3]. By the process of geopolymerisation, full replacement of cement by other materials is possible. Geopolymers, with an amorphous microstructure and chemical composition of zeolites, is a co-polymerisation product of high pH and single alunino and silicate species (composing silicon and aluminium in dissolved form) with soluble alkali metal silicates. The unused alunino-silicate materials in surroundings were utilised as building and mining materials, as they possessed satisfactory chemical and physical properties [4]. By pelletisation technique, artificial geopolymer aggregates can be made from volcano ash, which reacts with the geopolymer binder and alkaline activator (sodium silicate (Na$_2$SiO$_3$) and sodium hydroxide (NaOH) solutions). These aggregates sized with 14-20 mm are sintered at temperature 500 °C, 600 °C and 800 °C for 1 hour [5]. Various waste materials like FA, Volcanic ash, etc. can be used for the production of artificial aggregates. Upon close examination of these materials and their properties, minimal change in their nature and strength was noticed. The physical properties of different materials for the production of aggregates are shown in table 1.

| Table 1. Physical properties of raw materials [6]. |
|-----------------------------------------------|
| Raw materials | Physical properties |
|                | Specific gravity | Mean particle size (m$^2$/kg) |
| Cement         | 3.15            | 346                          |
| FA             | 2.20            | 311                          |
| GGBS           | 2.86            | 435                          |
| RHA            | 2.06            | 311                          |

By and large, their creation is observed primarily to occur when the ground discarded materials as new pellets are blended in their predetermined dimension. The diverse varieties of raw materials, binders and additives used in the manufacture of artificial aggregates with reference to the literatures are particularised below in table 2.

| Table 2. The different types of raw materials, binders and additives used for the manufacture of artificial aggregates. |
|--------------------------------------------------------------------------------|
| Sl No | Raw material | Binder | Molality | Silica Modulus/Alkali ratio | Inferences | Further Research                                                                 |
|-------|--------------|--------|----------|----------------------------|------------|----------------------------------------------------------------------------------|
| 1     | Class F fly ash, GGBFS, RHA | Na$_2$SiO$_3$, NaOH | 10 M      | 1.5                        | Various factors affecting the production efficiency of the cold bonding method are binder | Properties of cold-bonded aggregates can be improved by treating their surface and reduce water absorption. | [7] |
2.2. Methods of manufacturing

Production of different artificial aggregates from various sources involves various methods. The primary focus is integration of the reduced residue to any definite predetermined size for their targeted production. After the process of agglomeration through pelletisation, the new post-processed pellets achieved forte as aggregate replacement in concrete. Sintering, autoclaving, and cold bonding are the commonly available techniques used for the post-processing of fly-ash aggregates.

2.2.1. Sintering. This technique involves the fusion of green pellets (GP) at a temperature of more than 1200°C [10]. For that, a large quantity of coal requirement helped this course in producing the aggregates. But the huge energy requirement for making aggregates makes the process undesirable. Better durability properties like corrosion resistance and permeability exhibited by them, showed this process advantageous. In this process, the fused FA particles at the contact points form good strength pellets. For this process, spot welding with very high temperature is preferred additionally with maintained minimal temperature for overcoming enormous fusion. Through the sintering surface, the 200-300 mm thick GP is conveyed on the endless belt. The high volume of coal content, causing higher sintering temperature, leads to enormous energy usage and money for the preparation of aggregates [11].

2.2.2. Autoclaving. This method mainly consists of chemical accumulation like cement, lime, or gypsum in the agglomeration phase. The formed material binding property produced good aggregate strength. At 1400°C temperature, the new pellets are healed in coerced drenched vapour. This method gave fast aggregate production with a minimal binding material and curing time[12].

2.2.3. Cold bonding. In this method, normal curing water at room temperature was used. At ordinary room temperatures, this process leads to FA reaction with calcium hydroxide resulting in a moisture-proof binder. By using compaction agglomeration techniques, drying shrinkage and the creep of the bonding material can be overwhelmed. Agglomeration stands for the conversion of the complete consolidation of solid particles into larger shapes. This can be achieved by agitation granulation by drum granulation, disc granulation, etc. [11]. This method helps to prevent energy utilisation compared to other methods of manufacturing. The increment of curing time provided the comparable aggregate properties as on autoclaving and steam curing and gave the maximum strength to the aggregates. [13].

2.3. Properties of artificial aggregates

The improved moisture absorption and lesser density are the fundamental assets of the artificial fly ash aggregates. Their mechanical properties rest on the binder kind and measure, curing temperature, and its duration. In contrast, the moisture content influences the size, shape, and texture of the aggregates and angle of pelletisation used. Mechanical properties like crushing strength and specific gravity are the
significant properties of artificial aggregates. The average value of crushing strength is generally expressed in terms of their ‘aggregate crushing value’. Mainly artificial aggregates were synthesised using the pelletisation technique of various fraction of waste material and cement. Numerous mix proportions with replacement of 20, 40, 60, 80, and 100 % of natural replacing artificial aggregate in concrete were found out with their characteristics [1]. Mechanical Properties of artificial geopolymer aggregates are mainly specific gravity, water absorption, etc. The Specific Gravity of artificial geopolymer aggregate produced by the sintering process is less compared to natural aggregates. For the production of lightweight concrete, these types of aggregates are beneficial. The water absorption for artificial geopolymer aggregate with volcano ash is more compared to natural aggregates. The water absorption can be controlled by adjusting the expansion sintering temperature [5]. Pelletisation based on aggregate size obtained from the various works of literature is listed in Table 3. The aggregate strength based on various experimental methods is tabulated below in table 4.

Table 3. Pelletisation based on aggregate size.

| Sl. No. | Size of Aggregate (mm) | Pelletiser dimensions | Mechanical parameters of pelletiser | Pelletisation duration (min) | Reference |
|--------|------------------------|-----------------------|------------------------------------|-------------------------------|-----------|
|        |                        | Diameter (mm)         | Depth (mm)                         | Angle (˚)                     | Speed (rpm) |                     |                        |                         |
| 1      | 16-20                  | 800                   | 300                                | 53                           | 35         | -                    | [6]                     |
| 2      | 4-8                    | 400                   | 100                                | 35 & 40                      | 20,30,40   | 15                   | [7]                     |
| 3      | 10                     | 400                   | 150                                | 43                           | 45         | 20                   | [14]                    |
| 4      | 2-8                    | 1000                  | 150                                | 45                           | 15         | 15                   | [15]                    |
| 5      | 10-12                  | 500                   | 270                                | 36                           | 55         | 15                   | [16]                    |
| 6      | 10-20                  | 560                   | 250                                | 55                           | 50         | 7- 14                | [17]                    |
| 7      | 4-14                   | 800                   | 350                                | 30-92                        | 54         | 20                   | [18]                    |

Table 4. The strength of the aggregate based on experimental approaches.

| Sl. No. | Raw materials          | Crushing Strength of LWA (MPa) | Water Absorption (%) | Specific gravity (g/cm³) | Reference |
|---------|------------------------|-------------------------------|----------------------|--------------------------|-----------|
| 1       | FA + GGBS + RHA        | 8.1–8.8                       | 9.8–10.1%            | -                        | [6]       |
| 2       | Fly Ash                | 22.7                          | 13.23                | 2.12                     | [19]      |
| 3       | FA                     | 5.7                           | 10.6%                | -                        | [6]       |
| 4       | Volcanic Ash           | 5.1—8.6                       | 12-16%               | 1.1 to 1.8               | [8]       |
| 5       | FA + GGBS              | 15.5–15.7                     | 7.8–8.3%             | -                        | [6]       |
| 6       | FA + RHA               | 6.0–8.1                       | 10.8–20.5%           | -                        | [6]       |

2.4. Properties of concrete produced from artificial aggregates

Artificial aggregates comprise of the waste products like fly-ash, GGBS whose properties depend mainly on the native material, cementing material, the structure to develop them, and other factors, which primarily affect the strength and durability of concrete.

2.4.1. Properties of fresh concrete. The fresh concrete is controlled by the texture and shape of aggregate, notably the smooth-edged ones stimulate the workability, and the pointed nature helped with better workability. The cost reduction in concrete by well-graded aggregate consumed lesser and denser cement paste, by reducing the void ratio which further lead to the decreased amount of paste for void filling. This reduction in void reduced the workability of the concrete as the latter depends on the volume fraction of cold bonded aggregate, which can be overcome by proper gradation of aggregate[12].

2.4.2. Hardened properties of concrete. In the case of hardened properties, such as compressive strength, flexural strength, tensile strength, etc.; they change based on the aggregate properties. The strength also varies with the volume fraction of cold bonded aggregates. The novel geopolymer artificial aggregate concrete showed an average compressive strength of 37 MPa, which is the vital element of the final mix
strength[20]. The high strength artificial aggregates (fly ash) concrete produced high strength than the conventional aggregate concrete [2].

2.4.3. *Durability of concrete produced from artificial aggregates*. Concrete durability depends upon the degree of exposure, the concrete grade (or strength), and the cement content. Since concrete is a porous material, reinforcement bars within the concrete will be subject to possible corrosion. So permeability is an important parameter in the durability of concrete. The permeability of artificial aggregate concrete was lower than the conventional concrete, whereas when cold-bonded fly ash was used for lightweight concrete, the permeability value increases [21]. Their properties such as the resistance to acid attack, corrosion, etc., are primary factors affecting the durability of the concrete. Also, the durability of concrete is determined by the pore structure. The value of durability is measured by the water penetration depth. Its value was found to be less for concrete. The water depth should be measured after the water penetration test on the hardened concrete cubes [15]. Water and chloride ion permeability of fly ash aggregate lightweight concrete were slightly lower than normal-weight concrete. This transportation by the water within the unsaturated concrete specimens can be determined from the sorptivity. The Nano-silica particles usage in concrete reduces the water sorptivity and improve the durability of concrete [22].

3. Conclusions

The main observations which can be drawn from the study are as follows:

- The outbreak of construction activities and the fast depletion of natural resources demands the use of artificial aggregate.
- The specific gravity of artificial aggregate is 30 to 50 % less than natural aggregates favouring the lightweight concrete structures.
- Water absorption of artificial aggregates is 2 to 5 times higher when compared with normal aggregate.
- The compressive strength of the mix with artificial aggregates was found to be almost 5- 15 % less than conventional concrete.
- The durability varies according to different methods in manufacturing of artificial aggregates and mix design of concrete and it is less than conventional concrete.

4. References

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