Artificial Aggregate Production from Fly Ash

Synopsis: The paper makes out a case for use of Fly Ash based lightweight aggregate, as a substitute for normal crushed stone aggregate, in making of concrete for structural and other applications. The plea is primarily based on the logic of arresting degradation of nature, improvement of environment by making productive use of mounting stocks of fly ash—a nuisance by-product of thermal power plants. It describes the best known international technologies for production of such artificial fly ash aggregate. It also describes and compares an innovative recently patented process of the author, which is claimed to be far simpler and economical than any other known technology.

Aggregate – Definition & Importance

Aggregate is a stone like granular material. It is classified in two distinct types, viz.–Finer variety of less than 4.75 mm in size generally known as SAND and the coarser version called GRAVEL, which is larger than 4.75 mm and up to 50mm. (Though size up-to 150mm is also used in Mass Concrete works)

Used in many Civil Engineering and Construction applications including Cement Concrete, Asphalt Concrete, as base material for Roads, Ballast for Rail tracks, Foundations, Filler Material etc.

Billions of tonnes of material is consumed every year. Its extraction and its use provides employment to Millions of workmen,

Sources of Aggregate availability:

Naturally occurring, normally rounded with smooth surfaces, water born pieces of rock, in buried or current water stream beds, which may be screened to be graded in different sizes and marketed. Alternatively, larger gravel pieces may be reduced in size by a crushing, washing to remove undesirable material and screened to divide into desired size groupings.

Blasting, quarrying and processing natural rock formations of stones like Granite, Lime stone, Sandstone etc. through crushing and screening plant and reducing to desired size groupings.

Natural lightweight aggregate materials—prepared by crushing and sizing natural rock materials such as pumice, scoria, tuff, breccia, and volcanic cinders.

Recycled Aggregate; Aggregate made from municipal wastes, recycled concrete from demolished buildings and pavements and broken bricks. (However, this has high cost implications due to crushing, grading, dust control, and separation of undesirable constituents).

Classification of Aggregates

Normal Weight Aggregate: Natural Mineral aggregates like Crushed stone have a Bulk Specific Gravity of 2.4 to 2.9, and Bulk Density (of Bulk Unit Weight) of 1520 to 1680 kg/m³ (95 to 105pcf). This is the most commonly used class of material, accounting for nearly 99% of consumption, even in developing countries.

The aggregate used in making normal concrete is primarily crushed stone [though sometimes river shingle is also used] in different sizes obtained by quarrying naturally occurring river shingles or blasting hard rock and then crushing and sizing it into different sizes. This is leading to destruction of any rock outcrops, if any, available in the surroundings of major human settlements. It is not only destroying the nature, but also causing a great deal of noise, pollution. The process also consumes a lot of Energy. The situation has become quite alarming around many urban centers, with the result, that the local authorities and even courts of law, have banned stone quarrying in many states or in and around major urban centers.

Since our cities continue to expand with growing population and influx of people from rural areas, there is increasing construction activity to provide for work facilities and shelter. It is but evident that the cost of construction is steadily going up, due to ever rising delivery price of stone aggregate, which has now to be obtained from distant sources.

Heavy Weight Aggregate: Heavyweight aggregates may be natural or synthetic, which typically weigh more than 2,080 kg/m³ and can range up to 4,485 kg/m³. Some of the known varieties are Limonite, Barite, Illmenite, Magnesite, Hamatite etc. Heavy weight aggregate is most commonly used for radiation shielding, Bomb Shelters. counterweights
and other applications, where a high mass-to-volume ratio is desired.

Light Weight Aggregate: It could be from natural sources or of manufactured variety having Bulk Density of less than 1120 kg/m³.

The normal stone aggregate is a dense material, which makes heavy density concrete. The structural engineers would like to get alternative lighter density aggregate, so as to produce lightweight concrete. Use of lightweight concrete, as a substitute for normal dense concrete, reduces weight of structural elements like beams, columns, slabs, foundations, thereby saving on cost of foundations and reinforcing steel needed for the structure.

Other coincidental benefits include fewer delivery trucks and reduced labour input. Long term benefits in some instances, as in the case of exterior walls and roofs, can be even greater than the initial savings, because of reduced annual heating and cooling costs.

Lightweight Aggregates are sought after product not only for production of Lightweight concrete, but more recently as application in horticulture. As a horticultural application, it is not only 30% lighter as a growing medium, but the vehicles within the aggregate, become reservoirs of irrigation water and fertilizer (because of higher water absorption capacity) thereby reducing operation and maintenance costs. They are also very clean and used as common growing medium for planters deployed in household and offices.

In the quest to reduce the “heat island” generated by cities, the most sensible approach is to replace impermeable non-reflective surfaces, such as tar and gravel roofs with vegetation. This presents an increased structural load which can easily be reduced by employing lightweight aggregates, as part or whole of the growing medium and as a drainage layer. Not only does this reduce the load, but it also acts to provide a controlled release of irrigation water and fertilizer. In this instance aggregate with high water absorption is desirable. Germany is the leader in terms of numbers of green roofs, where they make extensive use of Leca® and Liapor® expanded clay aggregates as ingredients for the growing medium and also for the drainage layer. In the past several years a large number of roof top gardens have made good use of the expanded lightweight aggregates even in the USA.

Manufactured Lightweight Aggregates

Produced from natural materials. Most of these thermally processed lightweight aggregates are produced from materials such as clay, shale or slate. To produce such aggregate, the raw material (excluding pumice) is expanded to about twice the original volume of the raw material. The expanded material has properties similar to natural aggregate, but is less dense and therefore yields a lighter concrete product.

The production of lightweight aggregate begins with mining or quarrying the raw material. The material is crushed with cone crushers, jaw crushers, hammer mills or pug mills and is screened for size. Oversized material is returned to the crushers, and the material that passes through the screens, is transferred to hoppers. From the hoppers, the material is fed to a rotary kiln, which is fired with coal, coke, natural gas, or fuel oil, to temperatures of about 1200°C (2200°F). As the material is heated, it liquefies and carbonaceous compounds in the material form gas bubbles, which expand the material. In the process, volatile organic compounds (VOC) are released. From the kiln, the expanded product (clinker) is transferred by conveyor into the kilner cooler, where it is cooled by air, forming a porous material. After cooling, the lightweight aggregate is screened for size, crushed if necessary, stockpiled, and shipped. Figure below illustrates the Flow-process of this lightweight aggregate manufacturing process.

Although the majority (approximately 90 percent) of plants use rotary kilns, traveling grates are also used to heat the raw material. In addition, a few plants process naturally occurring lightweight aggregate such as pumice.

Emissions from the production of such lightweight aggregate consist primarily of particulate matter (PM), which is emitted by the rotary kilns, clinker coolers, and crushing, screening, and material transfer operations. Pollutants emitted as a result of combustion in the rotary kilns include Sulfur Oxides (SOx), Nitrogen Oxides (NOx), Carbon Monoxide (CO), Carbon Dioxide (CO2), and VOCs. Chromium, lead, and chlorides also are emitted from the kilns. In addition, other metals including aluminum, copper, manganese, vanadium, and zinc are emitted in trace amounts by the kilns. However, emission rates for these pollutants have not been quantified. In addition to PM, clinker coolers emit CO2 and VOCs.

By-product of Industrial Process

The pyro-processing of obtaining Lightweight aggregate from natural materials is damaging nature due to extraction of normal raw materials. The process also pollutes the environment emitting green-house gases into the atmosphere. It would be ideal, if we could obtain or make such lightweight aggregate without destroying any part of the environment. Manufactured Lightweight Aggregates for structural applications, are currently also being made available as by-products of Industrial Processes performed at elevated temperatures. These include Foamed and Granulated Slag, Organic Cinder, Coal Cinder etc., which after cooling are crushed and screened in different size grades for sale as alternative aggregate.

Aggregate Production from Fly Ash

The Thermal Power Plants currently supply 69% of India’s power requirements. All these are coal based power plants, which are currently also producing nearly 165 million tonnes / year of a waste and nuisance by-product called Fly Ash. This fly ash production, as per Planning commission
The estimate is likely to increase to 300 million tonnes/year in 2017 and 900 million tonnes/year by 2031-32. All efforts are being made to gainfully utilize this waste product in cement making, mine filling, road embankment making and some in brick making. Despite all this nearly 100,000 Acres of land is currently buried under Ash Ponds.

This fly ash is a very fine material, which not only pollutes the environment while coming out of power plant chimneys and by blowing off with wind from storage sites. Leaching from these coal ash dumps carries toxins with it, which poisons the water bodies, like lakes, rivers, ponds, wells, tube wells, water pumps in the vicinity. Environment Pollution Control agencies have established, that those consuming water from any of the sources, in the surroundings of these fly ash impoundments, are prone to cancer, respiratory, lung, stomach, respiratory and other diseases due to poisoning from arsenic and other toxic metals present in fly ash.

We can ill afford to risk the health of our people, waste precious land resource for stocking of this detrimental waste product, especially because we are an over populated country with growing population, where land cultivation is the major occupation.

The government of the day, is quite alive to the problem and has initiated steps to give increased stress to alternative environment friendly power generation sources, like Solar, Atomic, Hydraulic. Consumption of fly ash into filling of abandoned mines, low lying areas, road making, cement production, brick making, agriculture etc. is being promoted.

Under the circumstances, it would be most desirable, if we could somehow also convert this fly ash, into artificial aggregate. Many other countries, around the world, who are also facing similar problem with fly ash output, have made and continue to make, efforts in this direction.

A few companies in UK, USA, Japan etc. have introduced manufacture of such lightweight fly ash aggregate using a process of sintering the fly ash pellets at elevated temperature of around 1,200°C. The process has a lot of similarities with the pyro-processing of normal materials for manufacturing Lightweight aggregate, as described under 4.1 above. Therefore, it also has some detrimental effects on the air quality.

A Dutch companyk has developed another technology processing pellets of fly ash with quick lime and water at around 85°C in a special plant. They are marketing their product by the name of “Aardelite” in Holland. They mention to also have set-up plants in California and India and claim their process to be simpler and cheaper than sintering.

![Schematic of the Aardelite plant, a chemically bonded manufactured aggregate](image)

The typical properties of aggregate produced by these two industrial processes mentioned above, of producing Fly Ash aggregate have been compared hereunder, with normal aggregate.

<table>
<thead>
<tr>
<th>Item</th>
<th>Sintered Pellets</th>
<th>Aardelite Aggregate</th>
<th>Crushed Stone Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>1.30 – 1.60</td>
<td>1.70</td>
<td>2.75 – 2.95</td>
</tr>
<tr>
<td>Shape</td>
<td>Round</td>
<td>Round</td>
<td>Angular</td>
</tr>
<tr>
<td>Bulk Density</td>
<td>750-900 kg/m³</td>
<td>1050 kg/m³</td>
<td>1450 – 1750 kg/m³</td>
</tr>
<tr>
<td>Particle Size</td>
<td>&gt;5mm but &lt;15 mm</td>
<td>5mm to 40mm &amp; greater</td>
<td></td>
</tr>
<tr>
<td>Water Absorption</td>
<td>14 % – 18 %</td>
<td>18 %</td>
<td>0.15 % – 0.50 %</td>
</tr>
</tbody>
</table>

Typical Properties of Different Types of Fly Ash Aggregates

A company in eastern India is learnt to be in the process of commissioning a plant, utilizing sintering technology stated above. They are in the process of launching their fly ash lightweight aggregate in the market very soon.

![Sintered Fly Ash Aggregate (Lytag)](image)

A new Innovative Technology. The writer has, some time back, obtained a patent of a different and very simple process of producing a similar kind of Light-weight Fly ash aggregate. The uniqueness of this innovative process, is that it is performed under ambient conditions. It makes use of...
Test Results of different density samples produced using Innovative technology

simple basic equipment, warrants no critical control at any stage and can be performed by unskilled manpower. The power requirement for this plant is less than 10% of power load needed for the sintering technology. Moreover, it does not create any kind of pollution and the capital investment is also very low. The process enables production of wide variety of particle sizes, as also a varied range of different controlled densities, to suit diverse applications. Reproduced above right is a picture of the different sized aggregates produced using this simple process.

Three typical test reports of different density samples, produced using this technology, are being reproduced here, for a comparison with the properties of other varieties of fly ash aggregates, produced using any other alternative technology, including the two technologies mentioned above.

It would be seen that the Artificial Aggregate, produced as per this innovative process has similar primary physical characteristics, as obtained from the established processes, mentioned above. The merits of this alternative process are:

(i) The process is performed under ambient conditions and the green aggregate produced is cured with water spray.
(ii) Energy requirement for this system is minimal as compared to others.
(iii) The investment in this technology is far lower than the above alternatives. A sintering plant, would need an investment in the range of Rs. 100 Crores, while a plant using this innovative process could even be set-up as a Small Scale Unit, with investment of less than 10 Crores and avail additional concessions available to this sector.
(iv) This process also offers flexibility of producing different sized aggregate and in varied densities.
(v) Fly ash content of the input material can be over 80%, with the flexibility of also using other low cost waste fine materials like quarry dust etc.
(vi) It can, therefore, be easily inferred, that the production cost of such end product would not only be cheaper than products of other processes, but also cheaper than natural crushed stone aggregate.

The writer had the privilege of introducing “Site produced Fly Ash based Cellular Lightweight Concrete technology”, way back in 1995, which currently is being extensively exploited all over the country. It is expected that even this technology, shall prove to be very popular and beneficial to the construction industry, while also contributing to reduction of pollution from fly ash.

References

a) CM 425: Concrete Technology; University of Washington
b) T.W. Bremer, J.P. Ries and W.H. Wolfe; Environmentally Friendly uses of Lightweight aggregate.
c) Derren Cresswel; Manufactured Aggregate; Mineral Industry Research Organization, Industry Sector Study Oct 2007
d) Alfred L Bush, Dennis P. Bryan and Daniel R. Hack; Lightweight Aggregates
e) PCA’s Mineral Products Industry; High Strength Aggregate Manufacture.
f) R K. Joshi, Department of Science and Technology; Fly Ash Scenario in India. pp3
g) Physicians for Social Responsibility, US affiliates of International Physicians for Prevention of Nuclear War; Coal Ash Hazards to Human Health
h) Kobe Steel Ltd. Japan, Research and Development Department, Osaka, Japan; Waste Treatment Technology in Japan, Artificial Lightweight Aggregate
i) PMI Ash Technologies LLC, 6300-170, Greenmoor Road # 372, Raleigh, NC - 27612 (USA)
j) India Metals and Ferro Alloys, Bhubaneswar; IMFA Sintered Fly Ash Aggregate