International Journal of Research
Available at https://edupediapublications.org/journals
e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 05 Issue 7
March 2018

Properties of Green Lightweight Aggregate Concrete for Smart city Applications

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Abstract

With increasing concern over the excessive exploitation of natural aggregates, synthetic lightweight aggregate produced from environmental waste is a viable new source of structural aggregate material. The uses of structural grade lightweight concrete reduce considerably the self-load of a structure and permit larger precast units to be handled. In this paper, the mechanical properties of a structural grade lightweight aggregate made with fly ash and clay will be presented. The findings indicated that water absorption of the green aggregate is large but the crushing strength of the resulting concrete can be high. The 28-day cube compressive strength of the resulting lightweight aggregate concrete with density of 1590 kg/m^3 and respective strength of 34 MPa. Experience of utilizing the green lightweight aggregate concrete in prefabrication of concrete elements is also discussed.

I. Introduction

Most of normal weight aggregate of normal weight concrete is natural stone such as limestone and granite. With the amount of concrete used keeps increasing, natural environment and resources are excessively exploited. Synthetic lightweight aggregate produced from environmental waste, like fly ash, is a viable new source of structural aggregate material. The use of lightweight concrete permits greater design flexibility and substantial cost savings, reducing dead load, improved cyclic loading structural response, longer spans, better fire ratings, thinner sections, smaller size structural members, less reinforcing steel, and lower foundation costs [1-3]. Weight of lightweight concrete is typically 25% to 35% lighter but its strengths is comparable to normal weight concrete. This paper discusses the mechanical properties of a newly developed structural lightweight aggregate which is made from expanded clay. The aggregate is reinforced with a PFA rich surface coating applied at a later stage of firing. The experience of utilizing this green lightweight aggregate concrete in the prefabrication of structural element is also presented [4].

II. Nature of lightweight aggregates

When shale, clay or slate are heated in a rotary kiln to a temperature in excess of 1000ºC gases are released which coalesce to form a myriad of spherical voids or vesicle's that cause the particle to almost double in size. Upon cooling, the particles retain their distended form resulting in a particle density that during the manufacturing process has gone from about 2.65 to about 1.5. During the cooling process and as a result of some crushing to make the various sized particles needed by industry, some of the surface vesicules are intersected by conduits or cracks that communicate with the surface. This results in some of the vesicules being easy to saturate when submerged in a liquid and some being essentially impossible to saturate when submerged. The degree to which a particular aggregate particle communicates with the surface has been fully visualized by submerging a particle in coloured drafting ink and then after a period of time drying the aggregate the particle is broken open and examined in a microscope and the extent to which liquids are absorbed into the aggregate becomes evident. It is this combination

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of easily accessible pores and difficult to access pores, as well as the vesicular nature of the aggregate particles, that makes them such an environmentally useful material.

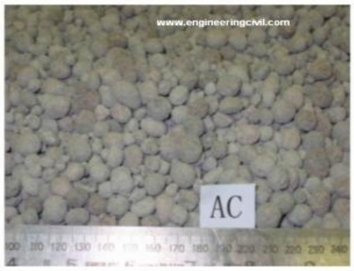
III. Enhanced durability that minimizes the need for repair and replacement

One of the most effective methods of minimizing the problems of the building industry is to produce durable facilities. Fortunately with expanded shale, clay or slate made in a rotary kiln there is a well documented track record of good performance. One of the reasons for this is because the patentee of the process, Stephen Hayde, some nine decades ago came up with a method of manufacture, which is essentially unchanged to this day. In fact, the microstructure of the aggregates made in 1919 for the building of one of the first concrete ships is indistinguishable from aggregates made today. This concrete made in 1919 was subjected to detailed testing and the result of this testing indicates excellent long-term durability. Surprisingly little distress as a result of corrosion has occurred except in areas where hard berthing had occurred and in the deck where improper placing procedures were used as well as where salvage of scrap metal during the Korean War damaged the structure. Cores taken from a lightweight World War II ship at Port Charles near Annapolis had a carbonation depth after 49 years exposure of less than 7 mm (Holm 1988). Bridges built over the years with lightweight aggregates have been surveyed and results show that they perform at least as well as normal weight concrete bridges, and in some instances provide superior performance. (FHWA 1985) The reason for the good long-term performance can be attributed to the lack of micro cracking as a result of the close matching of stiffness between the aggregate and the cement paste matrix. This minimizes the stress concentrations at the aggregate matrix interface (Bremner 1986). Measurement of permeability under increasing stress confirms this in that permeability starts to increase at about 0.6 of the ultimate compression stress in normal weight concrete, whereas with lightweight concrete, the stress must be increased to 0.8 of the ultimate compressive strength before permeability starts to increase (Sugiyama 1995).

IV. Experiments and Results

A. Characteristics of the aggregate

The quality of the green aggregate [in terms of crushing strength] was specified by a crushing strength test based on GB2842-81 (China Standard). The strength as measured by compressing the aggregate in a steel cylinder through a prescribed distance of 20 mm is 3.8 MPa. Results of the sieve analysis and water absorption of the aggregate at different time are given in figure 1.



Bulk Density	840 kg/m^3
Apparent Density (pre-wet 1 hour)	1525 kg/m^3
Crushing Strength	3.7 MPa
Sieve Ratio (mass %)	
>14mm	0
14mm~10mm	23.2
10mm~5mm	60.2
5mm~2.36mm	15.1
2.36mm~1.18mm	1.3
<1.18mm	0.2

Time (min.)	5	10	30	60
Water absorption rate (%)	9	11.2	12	13

Figure 1: Properties of the aggregate

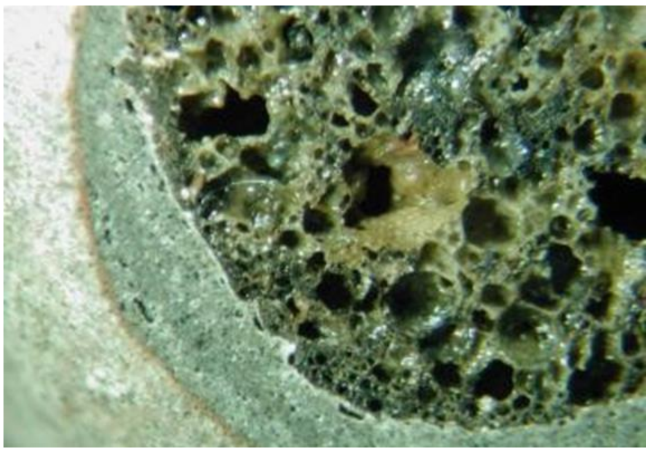


Figure 2: section of the lightweight aggregate

Fig. 2 examines the topography of the aggregate specimen using an optical microscope with 200X magnification. We can see that there is a thick shell rich in PFA at the outside surface of the aggregate.

The compact external shell of the aggregate contributes to the higher strength resistance than the traditional lightweight aggregate without coating. Moreover, it is critical in controlling the water absorption of aggregate during concrete mixing, reducing the slump loss of concrete with time [4].

B. Prefabrication using

Lightweight Aggregate Concrete: The structural lightweight aggregate was used to develop precast concrete elements for green construction. The mix proportion used is given in Table 2.

Table 2: Mix proportion of the green lightweight concrete (kg/m^3)

Cement	Sand	Water	AC agg. (prew-etted)	Admixture
420	175	715	630	1000 ml

Figure 3: Highly workable fresh concrete

Fig. 3 displays that a good workable fresh concrete for concrete casting. The slump of lightweight concrete measured 30 minutes after batching was 50 mm.

Figure 4: Protocol of finished lightweight concrete precast facade

Fig. 4 shows the protocol of finished lightweight concrete precast façade. Comparison of the design requirements with the concrete quality of the prefabricated façade are given in Table 3 below. It is seen that the gross weight of the lightweight concrete façade achieved only 70% of the density of normal weight concrete with the same compressive strength. Fig. 4 also indicated the bonding between reinforcing steel and lightweight concrete is good.

Table 3: Comparison of design requirement with actual concrete produce

	Specification	Façade quality
Unit weight	kg (normal concrete)	kg
1-day strength	MPa	14.5 MP a
days	MPa	MPa

e-ISSN: 2348-6848
p-ISSN: 2348-795X
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Slump	mm	mm
Density	kg/m^3	kg/m3

Figure 4: Bonding between the steel bars and the lightweight concrete

The following advantages are concluded for using lightweight concrete in prefabrication in building:

- Reduce the dead weight of a façade from 5 tons to about 3.5 tons
- Reduce craneage load, allow handling, lifting flexibility with lighter weight
- Good thermal and fire resistance, sound insulation than the traditional granite rock
- Allow design and construction flexibility for larger prefabrication modules
- Allow maintenance flexibility with replaceable modules
- Factory production of module enhances quality of product
- Enhance speed of construction, shorten overall construction period
- Enhance green building construction, minimize wet trade on site
- Improve damping resistance of building
- Utilization of PFA in aggregate production resolves the waste disposal problems of ash and reduce the production cost of concrete

4. Conclusions

The successful application of structural lightweight aggregate demonstrated that lightweight used for precast structural elements can be used in building construction to increase the speed of construction, enhance green construction environment such as reducing the wet trade on site and keep dust level at construction site to the minimum.

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