Achieving Sustainability with Lightweight Aggregates

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ABSTRACT: The use of lightweight aggregate concrete for building and bridge construction has intrinsic and easily documented benefits that contribute to the sustainability of our built environment. The traditional benefits associated with a 20 to 30% reduction in density and up to a 50% reduction in heat conductivity as compared to normalweight concrete are well known and will be noted. What is less well known is the multitude of other uses that have become important. One of the uses discussed is using lightweight aggregates as the growing media for green roofs which reduces the heat island effect in urban areas. In the purification of water, the use of lightweight aggregates provides enhanced area for the development of bacterial growth which is particularly effective in lowering phosphate content in rain water runoff in urban centres. The new uses mostly emanate from the vesicular nature of lightweight aggregates, and the mechanism of how water flows into and out of the aggregate will be discussed and related to the uses of this sustainable and user friendly material. Now that the traditional lightweight concrete building industry has matured, a service record has been established. This clearly shows repair and replacement of the infrastructure is minimized when lightweight aggregate concrete is used which accounts for its enhanced sustainability as compared to normalweight concrete.

1 INTRODUCTION

Lightweight aggregates can fill many roles that will make human activity more environmentally responsible. The green house gas emission associated with both the processing of the raw material and from the fuel burned to produce the expansion of the raw material pales in comparison to the environmental rewards derived from its use. The raw material being mostly composed of silica releases low amounts of green house gases upon heating unlike the ingredients used to make cement. The emissions from manufacturing cement are about one tonne of CO_2 per tonne of cement and for expanding shale, clay and slate is never above about 0.3 tonnes of CO_2 per tonne of aggregates produced. With the rotary kiln used to make both cement and lightweight aggregates, the fuel consumption is significant being about 5.5 gigajoules per tonne for cement and 3.0 gigajoules per tonne for expanding shale, clay or slate (Malhotra 2004, Haseltine,1972).

It was shown some three decades ago that the extra expenditure of energy to make lightweight aggregates as compared to normalweight aggregate was more than compensated by~~affect by~~ savings ~~associated with~~in the reduction in the amount of materials needed. ~~Studies have shown that t~~The savings that accrue at the time of construction result from reduced footing, column and beam sizes, as well as from reduced amounts of steel reinforcing (Tobin 1972). Other coincidental benefits include fewer delivery trucks and increased mason productivity because of lightweight masonry units. 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. The reduced heating and cooling loads arise from the ~~insulating~~special thermal qualities of the lightweight aggregate concrete (Bremner 1976).

In efforts to improve economics and reduce greenhouse gasses some manufactures found sources of combustible waste liquids such as motor oils which normally would be consumed in an incinerator. Alternative methods of producing lightweight aggregate exist. Sintering preformed fly ash particles to produce a lightweight aggregate has had very limited success in the market place and is only an alternate and less environmentally desirable use than using fly ash as a pozzolan in concrete mixtures where it replaces some of the energy intensive portland cement. The same applies for lightweight aggregates made from blast furnace slag. Also lightweight aggregates can be manufactured from fly ash without resorting to high temperature; however this process requires binding agents, which present additional environmental problems in the manufacture of these agents. ~~However~~ After extensive research and financial investment this cold bonded ~~finished~~ product has not gained commercial acceptance.

The structural and insulating properties of lightweight concrete made from expanded shale, clay or slate are well known and are well appreciated in commercial applications (Bremner 1998). Less is known about the potentially greater impact on the environment of the many other ways in which expanded aggregates can be used. These uses emanate from the intrinsic nature of the lightweight aggregates themselves.

2 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 vesicules 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 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.

3 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 normalweight 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 microcracking 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 normalweight 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).

~~For~~In the production of lightweight concrete it has been common practise to prewet the lightweight aggregates prior to batching. Normally the water content is about equal to the 24 hour absorption but less than the saturated surface dry moisture content. This absorbed water does not contribute to the water-to-cement ratio of the concrete nor does it seriously influence the slump loss of the concrete as the change in moisture content with time by the aggregates imbibing mixture water is not significant between mixing and placing the concrete. This is because lightweight aggregates initially absorb water rapidly but when they approach the 24 hour moisture content, the water loss to the cement ~~past~~ through further absorption by the aggregate is insignificant and consequently slump loss from this cause is not important. This water within the lightweight aggregate when it is incorporated in a concrete mixture serves as an important source of water for extended moist curing of the concrete and is one of the reasons for the observed good performance of lightweight concrete.

Recently ~~with~~ high performance, low W/C normalweight concrete is increasing by being used in the hope that it will produce more durable facilities than regular concrete with its propensity to need repair or replacement at ages less than the anticipated service life. Unfortunately, c~~c~~oncerned has been expressed because of the ~~about the~~ occurrence of desiccation in this type of~~of the~~ ~~c~~concrete in that it is being robbed of its anticipated benefits. Self-desiccation is the removal of free water by chemical reaction and particularly with low W/C concrete, this can cause such a reduction in internal relative humidity in the concrete so as to cause cessation of strength gain and also cracking of the concrete due to volume change that is normally associated with the loss o~~f~~f free moisture within the concrete.

The addition of small amounts of finer fractions of lightweight aggregate that have been pre-soaked prior to be incorporated into the normalweight mixtures can provide extra curing water that will allow hydration to continue to proceed there by enhancing the concrete strength and alleviating potential cracking to occur due to self-desiccation.

By minimizing cracking and enhancing the strength of the ~~both lightweight and normalweight~~ concrete the need for repair and replacement of constructed facilities can be decreased there by minimizing the rate of consumption of energy and the use of non-renewable resources.

The disruption of the countryside in~~–~~ providing these additional inputs to compensate for ~~the~~ construction ~~industry~~ as well as the ~~–~~extra urban traffic ~~problem~~ associated with lack of durability of ~~the~~ building ~~industry~~ materials is substantial. The benefits should be substantial from th~~e~~is use of lightweight aggregate by mitigating the adverse aspects of the most used construction material-concrete by relieving the need for greater input of raw materials and lowering of the net output of wastes.

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Examination of the interface between lightweight aggregate and the cement paste matrix reveals excellent bonding with no signs of a weak interfacial layer as is evident in normalweight concrete. Apparently the high temperature in the rotary kiln activates the aggregate surface so as to make it act as a pozzolan. This is believed to be the reason not only for the good adhesion between the paste matrix and the aggregate but also for lightweight fine aggregate tending to ameliorate the effect of alkali reactive aggregate (Boyd 2000).

4 REDUCED HEAT ISLAND EFFECT IN URBAN AREAS

The magnitude of the heat island effect is the temperature difference between a city's hot built-up core and its surrounding cool rural areas which can amount to 6ºC or more (EPA). According to NASA's Goddard Space Flight Centre, as a result of this heat island effect, monthly rainfall is about 28% greater between 12 and 24 km downwind of cities, compared with upwind (Guardian). This effect is the result of replacing the verdant countryside with material hostile to vegetation both in the form of impermeable building materials and sterile soil supporting a veneer of sod struggling to survive. It is only by increasing the amount of healthy green vegetation in the city core that we can expect to counteract this effect.

By incorporating expanded lightweight aggregates into the soil, the tiny pores act as reservoirs that hold and release as needed water and soluble nutrients for the vegetation to absorb. The porous cellular lightweight aggregates help manage water by acting as a moisture flywheel absorbing moisture during wet periods and slowly releasing it along with soluble nutrients during dry spells. Incorporating plating and vegetated areas in an urban environment increases the perviousness of the surface and thereby reduces the amount of runoff. In addition this minimizes the need for irrigation.

5 HORTICULTURE USES SUCH AS GREEN ROOFS

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 expanded aggregates as part 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 irrigating 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 in the USA. (ESCSI). In horticultural mixtures it is common to use much lighter and ever more absorptive materials such as vermiculite; however to withstand occasional foot traffic and the need to provide some mass to counteract wind uplift forces heavier particles are required. The combination of high water absorption (up to 35%) and a relative particle density of from 1.2 to 1.5 found in lightweight aggregates make them ideally suited for this use.

6 MEDIUM FOR RECYCLING WASTE MATERIALS

In the production of lightweight aggregates the material is heated in excess of 1000ºC with a long retention time in a kiln. This temperature regime renders many waste benign and at the same time these combustible liquids contribute to the fuel requirements to heat the kiln. These secondary combustible materials can easily contribute to a large part of the fuel requirements of a rotary kiln and at the same time provide an environmentally acceptable method of disposing of hazardous waste products that could contaminate our streams and rivers.

By-products such as fly ash and bottom ash from power generating plants can be processed into lightweight aggregates. Also slag from the blast furnace can be pelletized to make lightweight aggregates. However, it is environmentally more effective to grind these by-products to a fine powder and use them as supplementary cementing materials.

The same is true of post consumer glass which has been used to make a very lightweight aggregate with a particle relative density as low as 0.3. To make this aggregate it must first be ground to the fineness of cement and at that fineness it acts as an effective pozzolan. When used as a pozzolan it has a much greater value than if it is used for lightweight aggregates.

7 WASTE WATER FILTER BEDS

In the treatment of municipal waste, filter beds are used where a bacterial film anchors and develops on aggregate surfaces. The surface of lightweight aggregates provides an ideal medium for the development of this bacterial growth and is particularly effective in lowering the phosphates content. The texture of vesicular aggregate provides and effective attraction for the beneficial organisms to form or as compared to normalweight aggregates. The same beneficial result occurs when drainage from urban areas flow through lightweight aggregates, or through soils containing lightweight aggregates.

8 CONCLUDING REMARKS

New applications for lightweight aggregates have been discussed that relate to environmentally friendly uses. Lightweight aggregates for horticultural uses, particularly for green roofs, is one such example. No doubt there are many other applications for lightweight aggregates that the designer might wish to explore.

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