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Review

Use of clay in the manufacture of lightweight aggregate

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HIGHLIGHTS

- Clay from infrastructure development is a raw material for LWA production.
- LWA is an excellent reuse for clay as part of a circular economy.
- Controlling the pore structure is critical to the production of an ideal LWA.
- Using secondary materials to partially replace clay in LWA can be viable.
- Using clay to manufacture LWA is expected to reduce total carbon emissions.

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ABSTRACT

Clay is used as a raw material for the production of lightweight aggregates because it is readily processed into suitable granules and forms low-density but high strength aggregate particles when sintered at relatively low temperatures. The use of waste clay generated by major infrastructure development projects to make lightweight aggregate has a positive environmental impact and contributes towards a more circular economy. This paper reviews the manufacturing process used to produce lightweight aggregates from clay and the influence of processing conditions on properties. It also reviews secondary materials that have been incorporated into clays to produce lightweight aggregates. Additional research is required to improve understanding of the effects of composition and production parameters on the pore structure, density, water adsorption and strength of clay derived lightweight aggregates.

Contents

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1. Introduction

Managing clay containing mineral wastes has become a major challenge for many major civil infrastructure construction projects [1]. Problems are often associated with transporting high volumes of clay mineral wastes, which causes pollution, increased road congestion and risks to public safety. The disposal options for excavated materials are also an issue. For example, construction of the Crossrail 1 underground tunnel in London UK, resulted in more than 4 million tonnes of waste London clay which was primarily used in land reclamation [2]. Additional future and ongoing tunnelling projects in London include the Thames Tideway Tunnel and the High Speed Two (HS2) rail link, and these two infrastructure development projects will produce an estimated 18.8 million tonnes of excavated materials that predominantly contain clay minerals [3].

There are often significant economic and environmental drivers to use recycled materials in construction as this can contribute to a circular economy in which waste materials remain part of the economic cycle [4]. The use of clay in the manufacture of lightweight aggregates (LWA) is a potential recycling option for clay wastes. LWA has previously been produced from London clay generated by Crossrail at pilot plant scale, and it was estimated that 2.8 million tonnes of LWA could have been manufactured from Crossrail excavated clay. This would have produced more than 9.0 million cubic metres of low-carbon lightweight structural concrete [2].

The market for LWA is expected to increase as the demand for lightweight and thermally insulating concrete increases. Of the alternative secondary raw materials available to produce LWA, clay remains the most viable, due to consistent properties and availability close to urban areas from excavations and tunnelling. Table 1 contains journal publications on the use of clay in manufacturing LWA over the past two decades. In addition to excavation wastes, clay minerals are extracted from harbours, river beds and reservoirs where they cause serious sedimentation problems. Research on recycling these materials into LWA also provides a potential reuse option [5–13].

This paper reviews the properties of LWA produced from clays and discusses the role of chemical composition, processing conditions and microstructure in manufacturing optimum products. In addition, the review provides guidance on the types of secondary materials that have been incorporated into clay to produce LWA and identifies areas where further research is required.

Table 1
Lightweight aggregate research studies using clay that have been reviewed.

Raw Material	Secondary material incorporated	References
Clayey diatomite rock	Sawdust	[1]
Clay	CaF_2 sludge	[2]
Smectite-rich clay stone	Sand	[3]
White clay and shale	MSWI* fly ash	[4]
Clay	Sewage sludge	[5]
Reservoir Sediment	–	[6]
Clay	Granite polishing residue	[7]
Silt-clay waste	CC** fly ash	[8]
Silt-clay waste	Sewage sludge	[9]
Reservoir Sediment	MSWI fly ash	[10]
Reservoir sediment	–	[11]
Reservoir sediment	–	[12]
Harbour sediment	Waste glass	[13]
Reservoir Sediment	MSWI fly ash	[14]
Reservoir sediment	–	[15]
Clay	–	[16]
Silt-clay waste	CC fly ash	[17]
Clay	–	[18]
Clay	–	[19]
Clay	APC*** residues	[20]
Clay	APC residues	[21]
Clay	CC fly ash	[22]
Clay	FeCr slag	[23]
Clay	Granite	[24]
Silt-clay waste	Sewage sludge	[25]
Clay	Bauxite (red mud)	[26]
Clay	Sewage sludge	[27]
London clay	–	[28]

* Municipal solid waste incineration.
** Coal combustion.
*** Air pollution control residues.

2. LWA manufactured from clay

LWA was first manufactured commercially in the UK during the 1950s using clay and shale from the mining and slate industries. Additional types of LWA were developed to meet increasing national demand. Lytag is a LWA manufactured from pulverized fuel ash (PFA), a by-product from coal-fired power stations [14,15]. It was first manufactured in 1958 and remains a commercially leading LWA for structural lightweight concrete [16]. The availability of PFA in the UK and EU will decline in the future due to the move away from coal fired power stations [17]. In addition, PFA can be used as a supplementary cementitious material (SCM) and this is an alternative reuse application that may limit PFA availability for LWA production [18–20].

Fig. 1 shows a typical manufacturing process for producing LWA from clay. The two main stages are granule formation and sintering [21]. The raw materials are finely ground and mixed in specific proportions. Unfired 'green' granules are formed by extrusion or agglomeration using an appropriate water addition. The physical properties of 'green' granules are important during handling and stockpiling and these depend on the granulation process, the properties of the clay and the moisture content [22,23]. The influence of granulation parameters on the properties of 'green' granules is complex and a comprehensive model that predicts granulation behaviour and performance is not currently available. After granulation, the 'green' granules are normally dried and then sintered. The sintering temperatures for clay LWA are typically between 1050 °C and 1250 °C, using typical dwell times in the kiln of between 3 and 20 min.

The production of clay derived LWA requires processing in a temperature range where pyro-plastic deformation, gas generation and gas retention occur simultaneously. The main sources of gas generation in clay-containing minerals at high temperatures are dissociation or reduction of ferric oxides, combustion of organic matter, release of interlayer water molecules and thermal decomposition of carbonates [24,25]. The temperatures at which gases are generated vary and this influences/controls the bloating behaviour [26]. It is not normally possible to identify the critical components that cause bloating from bulk chemical composition data, but the ratio of silica and alumina content to the flux content is normally considered to be an important parameter [27]. However, the proportion of alumina-iron oxides-alkaline earths, regardless of silica content is also reported to control bloating [28]. As a result, it is difficult to predict whether or not a material will bloat based only on chemical composition data, and normally firing trials need to be completed [29].

2.1. Properties of LWA manufactured using clay

Standards for concrete, mortar and grout define LWA as a granular material with a loose bulk density below 1.2 g/cm^3 or a particle density not exceeding 2.0 g/cm^3 [30]. An ideal clay LWA for use in concrete would be roughly spherical, 4–14 mm in diameter, with a strong, porous, sintered core and an impermeable rough surface to enhance the hydrated cement-aggregate bond [31].