Construction and Building Materials 56 (2014) 113–127

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Review

Geopolymer foam concrete: An emerging material for sustainable construction

Zuhua Zhang [a], John L. Provis [b], Andrew Reid [c], Hao Wang [a,*]

[a] Centre of Excellence in Engineered Fibre Composites (CEEFC), Faculty of Engineering and Surveying, Faculty of Health, Engineering and Science, University of Southern Queensland, Toowoomba, Australia
[b] Department of Materials Science and Engineering, The University of Sheffield, Sir Robert Hadfield Building, Mappin St, Sheffield S1 3JD, United Kingdom
[c] Halok Engineering Co. Ltd., Brisbane, Australia

HIGHLIGHTS

- A comprehensive review of current foam concrete technology and geopolymer technology.
- A concept of developing geopolymer foam concrete with great environmental benefits.
- A concrete with low cost, high strength/weight ratio and potential fire resistance.

ARTICLE INFO

Article history:
Received 20 August 2013
Received in revised form 25 January 2014
Accepted 27 January 2014
Available online 21 February 2014

Keywords:
Sustainability
Geopolymer
Foam concrete
Fire resistance
Efflorescence

ABSTRACT

The development of sustainable construction and building materials with reduced environmental footprint in both manufacturing and operational phases of the material lifecycle is attracting increased interest in the housing and construction industry worldwide. Recent innovations have led to the development of geopolymer foam concrete, which combines the performance benefits and operational energy savings achievable through the use of lightweight foam concrete, with the cradle-to-gate emissions reductions obtained through the use of a geopolymer binder derived from fly ash. To bring a better understanding of the properties and potential large-scale benefits associated with the use of geopolymer foam concretes, this paper addresses some of the sustainability questions currently facing the cement and concrete industry, in the context of the utilisation of foam concretes based either on ordinary Portland cement (OPC) or on geopolymer binders. The potential of geopolymer binders to provide enhanced fire resistance is also significant, and the aluminosilicate basis of the geopolymer binding phases is important in bringing high temperature stability. The standardisation (quality control) of feedstocks and the control of efflorescence are two challenges facing the development of commercially mature geopolymer foam concrete technology, requiring more detailed exploration of the chemistry of raw materials and the microstructural development of geopolymers.

Contents

* Corresponding author. Tel.: +61 402340468.
E-mail addresses: Zuhua.Zhang2@usq.edu.au (Z. Zhang), j.provis@sheffield.ac.uk (J.L. Provis), andrew.reid@haald.com.au (A. Reid), Hao.Wang@usq.edu.au (H. Wang).

http://dx.doi.org/10.1016/j.conbuildmat.2014.01.081

1. Introduction

Over the past century, Portland cement-based concrete has become the highest-volume manufactured product on Earth, due to the versatility and generally highly reliable performance of this material, and also the widespread availability and comparatively low cost of the necessary raw materials and processing technology. However, since the widespread adoption of 'sustainability' as a key criterion for the assessment of materials by both the engineering community and the general public, the construction materials industry is facing increased pressure as Portland cement production is becoming perceived as unsustainable. Although the embodied energy intensity per functional unit remains lower than most other available building materials [1], the very large production volumes required to meet global demand lead to high sector-wide consumption of raw materials and energy, emission of greenhouse gases (GHGs), and dust pollution [2]. Thus, the development of sustainable construction and building materials with reduced environmental footprint through both manufacturing and operational phases is currently a key focus in the global housing and construction industry.

This paper discusses the concept of geopolymer foam concrete as one potential aspect of the global solution to this issue. As a basis for this, the current status of foam concrete technology and some fundamental physico-chemical aspects of geopolymer formation are reviewed. A geopolymer is an aluminosilicate binder formed by alkaline activation of solid alumina- and silica-containing precursor materials at or slightly above room temperature. This class of materials has emerged as one of the key alternatives to ordinary Portland cement (OPC) as a binder for concrete production in the last decades [3]. Although considerable research has been conducted on many aspects of geopolymer technology, application of this technology is not yet widespread, for both technical and non-technical reasons [4,5]. This review highlights some of these issues in the specific context of foamed lightweight geopolymer concrete production, and outlines the importance of developing deeper and more comprehensive understanding of factors including feedstock materials chemistry, microstructure, and control of engineering properties, as part of the process of broadening the uptake of this technology.

2. Sustainability in the cement and concrete industry

2.1. Current status of sustainable development efforts

As published by the World Commission on Environment and Development (WCED) [6], the concept of sustainable development is defined as: '*the ability to meet our current needs without compromising the ability of future generation to meet theirs*'. This definition requires consideration across all aspects of a specific industry, through raw materials supply, energy consumption and environmental impact of a material, component or structure in manufacture and in service, as well as end-of-life processing and potential reuse or recycling.

A potential future shortage of low-cost raw materials is the first aspect which should be considered in the context of the cement and concrete industry, because of its huge consumption of conventional limestone-based materials. Fig. 1 summarises the global volumes of cement production and distribution in the first decade of the 21st century.

In the year 2011, the world cement production was around 3.6 billion tonnes [8]. This required more than 3 billion tonnes of limestone for clinker manufacturing, if considering a global average clinker factor of 0.77 [11]. Limestone is not inexhaustible because the transportation distance is limited for this low profit product. An example of this is the statistic given in the report *Cement Production in Vertical Shaft Kilns in China – Status and Opportunities for Improvement* [12], which reads: "*1326 limestone quarries are currently known in China containing approximately 56,120 million tonnes of limestone. Taking into account future growth of cement production these deposits can only maintain the need for manufacturing of cement for 59 years (other industry exploitation not taken into account)*".