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Review

A review of studies on bricks using alternative materials and approaches

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HIGHLIGHTS

- Two types of alternative bricks, namely material-oriented and process-oriented.
- Geopolymerisation is a preferable way to produce bricks.
- Clay-based geopolymer bricks can be one of the focuses of brick-related research.
- The key challenge is to improve the reactivity of clay at a low cost.

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ABSTRACT

Bricks have been playing a significant role in building and construction for thousands of years. Despite the reliable workability and accessibility, it is widely known that the production of fired clay brick has always been a rather energy- and resource-intensive process. Many researchers have been conducting a wide range of studies regarding sustainable and innovative bricks, to mitigate the large carbon footprint of brick industry. To better understand the development and current context of sustainable and innovative bricks during the past several decades, this paper provides an up-to-date review on the recent studies of bricks, categorising these publications according to the materials used and methods employed for the production of innovative bricks. This review found that firing is still the most common method to produce bricks, while this process involves enormous energy consumption and carbon footprint. Considering that cement and lime-based calcium-silicate-hydrate bricks are also not sustainable, Geopolymerisation is a preferable way to produce bricks, but corresponding cost and benefit analyses need to be conducted for relevant research. In addition, this paper suggests that clay-based geopolymer bricks could be one of the focuses of future brick-related research, and the key challenge is to improve the reactivity of clay at a low cost.

Contents

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1. Introduction

Bricks have been playing a significant role in building and construction for thousands of years because of its outstanding properties such as great durability, high strength, low costs and so forth. The first brick produced by human beings traced back to 10,000 BCE, found in Egypt [1]. Clay block bricks were hand-moulded and sun-dried at that time. The ancient city of Ur (modern Iraq) around 4000 BCE was the earliest construction adopting clay bricks as the main materials. Dating back to 5000 BCE, there has been some records about using fire to produce clay bricks to yield better performance. Since then, the brick industry has been enormously developing and evolving especially benefited from modern machinery, such as powerful excavation equipment, motors, tunnel kilns and so forth. These significantly stimulated the capacity of brick production. In 2015, the global annual fired brick production was estimated at 1500 billion units [2].

Generally, there are 6 phases within the modern brick firing cycle: evaporation (20–150 °C), dehydration (149–650 °C), oxidation (300–982 °C), vitrification (900–1316 °C), flashing (1150–1316 °C), and cooling (1316–20 °C) [3,4]. The evaporation phase entails removal of the moisture content within raw materials and water added for brick shaping. Gradual temperature increasing rates in this phase is applied to avoid cracking caused by the difference of contraction rates between surface and core of the bricks. In the dehydration phase, the carbonaceous substances and some other hydrates within bricks will be decomposed and removed. Gradual temperature rising rates are still employed in this phase since rapid increasing rate can result in bloated bricks. The oxidation phase involves further combusting the carbonaceous remnants and oxidising the metal residues. This is essential for the manufacture of good quality bricks. To achieve this, excess oxygen will be provided to the combustion chamber in this phase. The next phase is the vitrification, which is the most important phase since it is directly related to the strength development of bricks. When the firing temperature is above 900 °C, the sintering process will start. This process transforms partial solid particles into liquid, which covers the rest of the solid particles. The liquid will solidify as the temperature falling, forming as glass binding the solid particles together. This is where the strength of fired bricks developed. The last two phases are flashing and cooling. The flashing phase is related to the colour of the final product, affected by the peak temperature and corresponding holding time. Bricks are finally produced after a gradual cooling period from the peak temperature to ambient temperature.

Despite the reliable workability and accessibility, it is undeniable that the production of fired clay brick has always been a rather energy- and resource-intensive process. It is reported that the mean energy consumed per tonne of bricks is estimated at 706 kWh and the emission of carbon dioxide per tonne was measured at 0.15 tonne [5]. Such high energy consumption and large carbon footprint obviously contradict with the requirement of sustainable development. Due to the both environmental and economic issues raised by the high demand for energy, many researchers have been conducting a wide range of studies regarding sustainable bricks, trying to mitigate the large carbon footprint of the brick industry.

This paper provides an up-to-date review on the recent studies of bricks to better understand the development and current context of sustainable bricks during the past several decades. The experimental designs and results of these publications are reported. A discussion about some missing elements in the existing literature is also conducted.

2. Previous reviews

A number of review papers [6–13] have been delivered, identifying many key issues regarding the characteristics, manufacture and potential of these bricks utilising alternative materials and/or approaches. Table 1 summarises the number and period of references, classification criteria, and key finding of these review papers.

According to Table 1, it can be found that the existing review papers has been slightly out-of-date. Most of the brick-related reviews covered the publication up to 2013. Although Boltakova et al. [13] reviewed the studies up to 2015, whereas it merely focused on the studies done by Russian researchers, neglecting the other relevant research projects. In addition, most of the previous review articles classified brick-related studies as per single criterion only, such as types of waste [7,12], functions of waste [6,11] and methods of manufacturing [8,10]. Some of these papers only covered a single kind of waste materials or manufacturing approach, such as agro-waste [9], industrial inorganic waste [12] and fired bricks [13]. The range of these review papers were not sufficiently extensive. Moreover, some of these publications simply listed the benefits of bricks using alternative materials and/or manufacturing methods but did not mentioned and analysed the drawbacks and future opportunities in the field of brick.

Therefore, to provide a wider coverage, this paper will contain bricks studies involving utilisation of alternative materials and manufacturing approaches, namely material-oriented and method-oriented sustainable bricks. The reviewing period will be set from 1970 to 2017. The factors related to the properties of bricks are to be reviewed, including material characteristics, shaping methods, firing/curing conditions, additives and so on. Lastly, a discussion in terms of the benefits and drawbacks as well as insights into future brick-related research will be provided.

3. Material-orientation

Material-oriented innovative bricks refer to those bricks incorporating different kinds of waste materials. Fig. 1 shows the recycling and recovery status of many types of waste materials in Australia. Although a certain amount of these waste materials has been recycled and recovered, there is still considerable waste simply landfilled and/or stockpiled. Incorporating these waste materials into bricks is one possibility to address the issue. This review divides material-oriented studies as per the type of waste they utilised. Two main groups are classified: municipal-waste-added and industrial-waste-added bricks.