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Investigation into the use of unground rice husk ash to produce eco-friendly construction bricks

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HIGHLIGHTS

- A combination of fly ash and residual rice husk ash is used as binder material.
- Unground rice husk ash is added to the brick mixture as fine aggregate substitution.
- Densified mixture design algorithm is applied to design a ratio of brick ingredients.
- Compressive strength of the bricks ranged from 20.9 to 31.5 MPa.
- Using URHA reduces brick weight, environmental impact, and production cost of bricks.

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ABSTRACT

Using solid waste materials in the production of construction materials has received considerable attention across the world. The present study investigates the feasibility of using the densified mixture design algorithm (DMDA) method to incorporate unground rice husk ash (URHA) as a partial fine aggregate replacement (0–40%) in the production of eco-friendly construction bricks. Fly ash (FA) and residual rice husk ash (RHA) are the main binder materials considered in this study. Solid bricks of 220 × 105 × 60 mm in size were prepared in accordance with official Vietnamese product standards in steel molds under 35 MPa forming pressure. After casting, the brick samples were stored at 35 °C and a relative humidity of 50% until the ages required for testing. The brick samples were checked for dimensions and visible defects. The effects of URHA content on the engineering properties of the solid bricks, including compressive strength, flexural strength, water absorption, bulk density, and void volume, were also investigated. The test results showed that all brick samples exhibited good physical and mechanical properties. Compressive strength and flexural strength ranged, respectively, between 20.9–31.5 MPa and 5.7–6.7 MPa. All of these values were significantly better than the values required by the official Vietnamese standards. The results of this study demonstrate a significant potential for applying URHA in the production of eco-friendly construction bricks.

1. Introduction

Used extensively in the construction industry, bricks are an important and prevalent building material that is used in a wide range of construction projects. India and the United States, for example, consume some 20 billion and 9 billion bricks each year, respectively [1,2]. Various types of bricks are used in construction. The most common are conventional bricks that are either produced from natural clay and cured by high-temperature kiln firing or produced from ordinary Portland cement (OPC) using the cementing method. Other types of bricks are mostly "unburnt" building bricks (UBBs) that are made from industrial by-products or solid waste materials and not fired at high temperatures. The current worldwide production of construction bricks is about 1.391 trillion units per year, and demand for bricks is expected to continue rising [3]. In Vietnam, the general demand for bricks is increasing rapidly. According to official government estimates, the demand in Vietnam for UBBs in 2015 and 2020 is expected to be 32 and 42 billion units, respectively. However, the conventional fired clay bricks made in certain regions are of poor quality. Moreover, the quarrying operations that are necessary to obtain the clay and the high-temperature firing that is necessary to cure bricks are energy-intensive, environmentally harmful, and highly polluting.

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Additionally, the production and use of OPC release a significant amount of CO_2 into the environment, accounting for around 7% of total annual global CO_2 emissions. Producing one kilogram of OPC reportedly consumes around 1.5 kWh of energy and releases about 1.0 kg of CO_2 into the atmosphere [3], while each fired-clay-brick has approximately 2.0 kWh of embodied energy and causes the releases about 0.41 kg of CO_2 into the environment during its production [4]. Fired-clay and OPC bricks are thus major contributors to man-made CO_2 greenhouse gas emissions, which are a key contributing factor in global warming and climate change. Furthermore, the Government of Vietnam is currently promoting the gradual replacement of conventionally fired clay bricks supplies with UBBs as a measure to reduce the mining of clay, which is considered a non-renewable natural resource. The government now officially encourages the use of UBBs in all types of construction projects regardless of funding source, urban/rural setting, or number of stories.

In recent years, various new techniques for producing UBBs have been introduced to reduce the environmental pollution generated during the mining, manufacturing, and usage phases of brickmaking. These techniques may be divided into three categories: firing, cementing and geopolymerization [3]. Both high-temperature kiln firing and cementing require high inputs of energy and produce large quantities of greenhouse gas emissions [2]. Therefore, many researchers have studied the potential of using geopolymerization technology to produce bricks. Geopolymerization uses the natural chemical reaction between amorphous silica and alumina rich solids that occurs in highly concentrated hydroxide or silicate solutions at ambient or slightly elevated temperatures to form a very stable material called a geopolymer, which has amorphous polymeric structures with interconnected Si–O–Al–O–Si bonds. Various types of solid waste materials such as fly ash (FA), bottom ash, slag, and rice husk ash (RHA) have been considered for producing bricks through geopolymerization [5–10]. Using this technology to produce bricks consumes significantly less energy and releases significantly lower amounts of greenhouse gases in comparison with conventional brickmaking techniques.

The annual worldwide production of rice husks, an agricultural by-product, was estimated to be 130 million tons in 2007 [11], 136 million tons in 2009 [12], and 149 million tons in 2010 [13]. These volumes are sufficient to produce approximately 37 million tons of RHA each year through rice husk incineration. In Vietnam, RHA, which currently has no commercial use, is most often dumped into rivers where it is a source of serious environmental pollution [14,15]. Additionally, large amounts of FA, an industrial solid waste sourced mainly from electric power plants, are generated each year. According to the European Coal Combustion By-products Association (ECOBA), the global production of FA was approximately 480 million tons in 2000 [16]. Therefore, the effective disposal of these wastes is a primary environmental issue of concern in most countries that has encouraged the civil engineering sector both to reduce natural-resources use and to develop practical materials that safely incorporate solid wastes [17]. Several trials have been carried out on the use of a mixture of rice husks and RHA as a low-cost concrete admixture due to the existing role of these materials as filler and pozzolan in other industrial uses such as brickmaking. Under optimized rice husk incineration temperature conditions, the resulting RHA may contain up to 95% reactive silica in non-crystalline or amorphous form [18]. Its high percentage of silica makes RHA a valuable material for industrial applications [15]. Furthermore, the abundant supply and the pozzolanic properties of RHA make it important to assess the efficacy of using RHA in the production of construction bricks in terms of environmental benefits and cost advantages.

Many previous studies have considered the use of FA as a raw material in bricks manufacturing [6,7,10]. Recent research has suggested that FA may improve the mechanical properties of bricks and enhance frost resistance [19]. However, very few researchers have studied the production of geopolymer bricks using RHA or a combination of RHA, FA, and unground rice husk ash (URHA). Freidin [6] studied the production of geopolymer bricks from FA and bottom ash using a sodium silicate (Na_2SiO_3) solution as the alkali activator and investigated the effects of Na_2SiO_3 content, compaction pressure, and hydrophobic additive. Their results indicate that mixtures of FA and bottom ash that use Na_2SiO_3 as the alkali activator produce concrete-like building materials. The full-size blocks that Freidin subsequently made from this material met the official Israeli standards for conventional cement concrete blocks. Arioz et al. [7] investigated the production of geopolymer bricks from FA, Na_2SiO_3, and a sodium hydroxide (NaOH) solution. They found that the compressive strength of the FA-based geopolymer bricks ranged between 5 and 60 MPa and that the effect of heat-treatment temperature and duration on the density of the bricks was not significant. Kumar and Kumar [10] studied the production of geopolymer paving blocks from FA and red mud and examined the influence of 0–40% red mud content on the reaction, structure, and properties of the FA geopolymer. Test results showed that the intensity of reaction improved progressively through all red-mud replacement levels and that setting time and compressive strength improved progressively only in the samples that contained 5–20% red mud. Structural characterization revealed that the rate of reaction was dependent on the NaOH concentration but that development of mechanical properties was related to the compact microstructure that developed due to the combined effects of NaOH concentration, solubility of silicates, and the presence of iron oxides.

The use of UBBs has increased in the construction industry in many countries due to the advantages of this category of brick. However, production and usage remain far below ideal levels in spite of the many studies confirming that construction bricks made from solid waste materials meet various standards requirements and in spite of the patents already approved [3]. Further research is clearly necessary in order to achieve greater production and utilization of UBBs. Therefore, the primary aim of the present research is to evaluate the potential of producing geopolymer bricks using RHA, FA, and, especially, URHA, which is a very low-cost and readily available material, as binders and fine aggregates. The geopolymer bricks made and tested for this study are produced using geopolymerization technology and the densified mixture design algorithm (DMDA) method developed by Professor Chao-Lung Hwang of the National Taiwan University of Science and Technology [20]. DMDA method is developed from the hypothesis that the physical properties will be optimum when the physical density is high. The major difference from other mixture design algorithms is that DMDA uses mineral admixtures to fill the void between aggregates and increase the density of the aggregate system. The porosity can be minimized by filling the void between coarse particles with fine ones. As a result, both the pozzolanic effect and the physical or filler effect can be obtained that ensure the good physical and mechanical properties of the finished bricks. Additionally, engineering properties including strength development, water absorption, bulk density, and void volume are examined to evaluate the performances of eco-friendly construction bricks that contain RHA, URHA, and FA.

2. Materials and experimental methods

2.1. Materials

URHA and locally available natural sand were used as fine aggregates in the mixtures. The URHA (density 2.1, absorption capacity 27.6%, and modulus of fineness 2.6) was sourced from southern Vietnam. Fig. 1 shows the URHA particles and their scanning electron micrograph (SEM). The natural sand (density 2.6, absorption capacity 1.4%, and modulus of fineness 3.0) was sourced from local