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Effect of waste rice husk ash (RHA) on structural, thermal and acoustic properties of fired clay bricks

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ABSTRACT

A potential use of rice husk ash (RHA), a residual of brick firing process on the manufacturing of fired clay bricks was identified. Although addition of waste RHA may influence the structural properties of building materials, it is not clear how this affects on thermal and acoustic performances. For these reasons, industrial scale productions of fired-clay bricks were used for experimental investigation on structural, thermal and acoustic properties of the fired clay bricks manufactured with the waste RHA.

Clay was mixed manually with six different RHA contents: 0%, 2%, 4%, 6%, 8% and 10%, by weight of the brick. Bricks having the dimensions of 195 mm × 95 mm × 50 mm were prepared and fired in an industrial scale kiln. Physical properties (Atterberg's limits, particle size distribution), chemical composition of materials, structural properties (compressive strength), thermal performance and acoustic performance of the bricks were evaluated.

Clay mixed with waste RHA improved the mixture for brick manufacturing. Lightweight bricks produced with waste RHA show the optimum compressive strength of 3.55 N/mm^2, (32.7% improvement compared to the conventional fired clay brick) and water absorption of 19% at 4% RHA, implying that the RHA has a potential to improve the structural properties. At 4% RHA, the brick shows 6 °C in-door temperature reduction and 10 dB noise reduction compared with that of the conventional fired clay brick. Waste RHA added clay brick showed better structural, thermal and acoustic properties compared with the conventional clay bricks, while managing waste RHA by decentralization, which will be a remarkable environmental and ecological achievement.

1. Introduction

Most of agricultural countries produce large amount of rice, as a result, large amount of rice husk is disposed to the environment as waste. World rice production is 637 million tons in 2006 [1], 704.4 million tons in 2010 [2] 749.8 million tons in 2015 [3] and expected to increase in future. By weight, 10% of the rice grain is husk [4], which are accumulated near-by rice-mills creating environmental issues.

In most of agricultural areas, rice husk is open dumped, while in a few of industrial areas, rice husk is used as a fuel. For example, in Sri Lanka, the handmade brick producers use rice husk to fire clay bricks. In Nigeria, rice husk is used to produce energy for rice drying oven and the resulting RHA is rich in silica [5]. In Malaysia, rice husk is used for steam boilers, where rice husk has undergone self-burning process at maximum of 1000 °C [6]. The use of rice husk on energy production is a one of the sustainable energy practices, however, the RHA a by-product from burning as a fuel has not been effectively utilised.

In previous studies, attempts have been given to investigate possible ways of making waste rice husk ash for bricks manufacturing. Sultana et al. [7] produced rice husk ash (burning 750 °C for 2 h in furnaces) and used for test specimens. The specimens were fired from 800 °C to 1100 °C temperature, in an electric furnace and tested for mechanical strength. Increasing percentage of RHA did not improve the compressive strength. No improvement of strength properties was observed, probably, because the rice husk ash used in the study was in black colour, mostly consisting with unburnt carbon; available SiO_2 was found to be 74.2%.

Mohan et al. [8] found no improvement of the strength of the bricks due to addition of waste RHA. Hossain et al. [9] collected RHA from a local rice mill, where rice husk was burnt in an uncontrolled environment, and then used for replacement of clay in brick production. With inclusion of RHA water absorption increases and crushing strength decreases in two different phases: higher rate upto 20% RHA addition, beyond that the strength decreases at lower rate. Agbede and Joel [10] investigated the effect of RHA on properties of fired clay bricks. RHA was collected from the heap of the rice husk being burnt at a rice mill

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and used for preparing test specimens of 40 mm × 40 mm × 40 mm. The test specimens were fired in an electric muffle furnace with a rise of 200 °C/h for 4 h. They found 6% improvement in compressive strength with 2% of RHA (having 49.8% SiO_2). Strength improvements have not consistently found in previous studies, possibly, because waste RHA collected from different residual have different chemical properties. A systematic study on structural properties of fired clay bricks, manufactured at an industrial scale plant, together with chemical properties of waste RHA is necessary to identify a potential use of RHA wasted from brick firing process onto the brick manufacturing process, enhancing effective management of waste RHA by decentralization.

Centralised waste management has known to fail at scale, largely because of the complexity while decentralised systems however run on smaller, but manageable scales [11]. The centralised waste disposal arrangements shift the waste management problem from the source of waste generation to waste disposal sites. Centralised mechanisms also involve long distance transportation of waste, with possible negative externalities and higher fuel consumption. Given Sri Lanka energy dependence, and continuing high oil prices, such an option would be enormously expensive. The decentralised community-based waste RHA management arrangements do not suffer from the above limitations. For example, waste RHA can be utilised near to the origin (i.e., at the brick kiln), eliminating the need for transport, landfill, or treatment at the waste disposal site. Decentralised community-based waste RHA management method will have a remarkable environmental and ecological gain.

The fired clay bricks, which are popular as a walling material due to its low cost, are expected to have better structural, thermal and acoustics performances. To improve strength properties of clay bricks, chemical properties and behaviour of clay materials plays a significant role. De Silva and Crenstil [12] have investigated the chemical behaviour of clay materials under different ratio of SiO_2/Al_2O_3 and found that the proper SiO_2/Al_2O_3 can improve the strength characteristics of clay. The best form of RHA, suitable for masonry is in amorphous form, which is produced under controlled burning temperature. However, if controlled combustion is used, bulk production of RHA is not economical. Adding waste RHA, which contains high amount of silica, will be a cost-effective method to increase the SiO_2/Al_2O_3 ratio in the clay mixture and improve strength characteristics of fired clay bricks. In a brick kiln, where the rice husk is used as a fuel, the temperature varies from 600 °C to 850 °C [13] and produced RHA is having about 90% of SiO_2 [14,15], which are amorphous and reactive in nature [15]. However, utilization of this waste RHA on fired clay bricks has not investigated previously.

Buildings scarcely control the internal environment to comfortable conditions without cross ventilation or mechanical air conditioning. Application of thermal insulator in the walls and roofs is the only technique to reduce the scale of air conditioning [16]. A few studies investigated thermal conductivity on bricks by estimating thermal resistance from density, but rarely conduct any specific tests. For example, Sutcua and Co [17] investigated thermal performance of walling material (i.e., hollow clay bricks) by FEM modelling. Santos et al. [18] performed numerical investigation on thermal performance of walls built with the new eco-efficient perforated clay bricks by using finite element model, which was calibrated and validated with experimental results. Better thermal performances in wall materials would be green and sustainable, although most of the investigation on wall materials, including masonry block and bricks, were limited for investigation on physical and mechanical properties.

Building's constructional elements should be able to protect residents from the negative effect of noise caused by surroundings [19]. The World Health Organization estimates that each year more than one million Healthy Life Years are lost in the European Union member states and other Western European countries, solely because of traffic noise [20] prevailing in cities. The world urban population is expected to increase from 3.6 billion in 2011 to 6.3 billion in 2050. By mid-century the world urban population will likely be the same size as the world's total population was in 2002 [21]. Although growing cities with urbanization offers numerous economic advantages, people who live in cities are vulnerable to disturbances due to noise exposures, especially in the frequency range of 1–8 kHz that are prevailing in cities. This environmental noise can interfere with communication, recreation, or concentration. Environmental noise, especially that caused by transportation means, is viewed as a significant cause of sleep disturbances [22]. Sleep disturbance is considered the most deleterious non-auditory effect because of its impact on quality of life and daytime performance [23]. Although no attentions has given to sound insulation properties of walling materials, noise insulated walling material will reduce deterioration of psychological and mental health of the population.

Thermal performance and acoustic response of bricks are rarely reported [24], although these properties have great influence on occupants comfort. Investigation of these performances is increasingly important in order to characterise clay bricks, especially produced with waste materials. Objective of the present study is to investigate the effect of the waste rice husk ash (RHA), produced as a residual of brick firing process, on structural properties, thermal and acoustic performances of fired clay bricks manufactured in an industrial scale plant.

2. Materials and methods

Methodology includes selection of materials, manufacturing of fired clay brick with RHA in an industrial scale plant and conducting laboratory experiments. The experiments were included: Specific gravity test, Atterberg limit test, Sieve analysis test, X-Ray Fluoresce (XRF) test, X-Ray Diffraction (XRD) test for characterization of raw materials and clay mixtures, Water Absorption, Compressive Strength for structural properties, thermal performance test and acoustic performance test of the bricks.

2.1. Materials

2.1.1. Clay

The clay for this study is collected from Dankotuwa (located in Puttlam District, North Western Province). It was collected from a pit about 1 m deep near the bank of the river, Maa Oya, Sri-Lanka. The pit was excavated with the aid of an excavator.

2.1.2. Rice husk ash

The rice husk ash was collected from the waste of a brick kiln.

2.1.3. Water

Fresh, colourless, odourless and tasteless potable water that was collected from water distribution of National Water Supply and Drainage Board (NWS&DB) was used. Water was free from organic matters of any type.

2.2. Manufacturing of bricks

Clay was mixed with the RHA. The handmade bricks of dimensions 195 mm × 95 mm × 50 mm were prepared using the molds under local brick production workmanships, where bricks were cast within molds without applying pressure over them. The materials were measured using weighing balance. The clay bricks were dried under the warm weather condition (35 °C, and 60% relative humidity), prevailing in dry zone in Sri Lanka. The clay bricks were fired between 600 and 850 °C in a brick kiln, which is the industrial scale manufacturing process of fired clay bricks in Sri Lanka.

When preparing the clay for the brick casting, first, clay was mixed with water. Different RHA percentages: 0% (control specimen), 2%, 4%, 6%, 8% and 10% by weight of the brick (Table 1) was thoroughly mixed with clay and a graded addition of water until proper mixing was reached. The mix was separated to 2.5 kg samples and each sample was