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Effect of waste rice husk ash on structural, thermal and run-off properties of clay roof tiles

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HIGHLIGHTS

- Waste rice husk ash contains 84% of silica, which are more amorphous and reactive.
- 10% replacement of clay shows 45.97% increment in the transverse breaking load.
- Light-weight roof tiles could be achieved by replacing clay with RHA.
- With 10% RHA mixed clay tiles, indoor temperature is reduced by 4 °C.
- Rain water harvested from RHA mixed clay roof tiles can be utilized.

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ABSTRACT

Rice Husk Ash (RHA), a waste from firing process of clay products, has no proper usage. For this study, roof tile specimens were manufactured by replacing clay with different RHA percentages (i.e., 0%, 5%, 10%, 15% and 20%) in an industrial scale plant, so as to determine the effect of waste RHA from a brick firing process on structural, thermal properties and run-off qualities of clay roof tiles. For 10% replacement of clay with RHA, transverse breaking load was increased by 45.97% indicating higher ductility compared with that of the conventional tiles. Bulk density is reduced with the percentage of RHA added, promising a light-weight roof tile, a favourable tile for a roofing material. With increasing RHA content, water absorption increases. RHA replacement up to 15% is desirable, satisfying the water absorption limit according to standards. RHA replacement up to 20% doesn't affect on the water penetration property. RHA mixed roof tiles can reduce the indoor temperature, feeling more comfortable for inhabitants. Collected runoff coming along the 10% RHA mixed clay roof tiles has a pH value of 7.22 and total solid concentration of 118.67 mg/L, indicating RHA mixed roof clay tile will not cause any severe impact on the runoff. Hence this harvested runoff can still be utilized for non-potable activities while enhancing the strength and thermal properties of clay roof tiles.

1. Introduction

Rice is the staple food in many countries, resulting to produce a large amount of rice husk. For example, out of 579, 476, 722 tons of world annual paddy production in 2002, Sri Lanka produces 2, 794,000 tons was placed at the 18th highest paddy producing country in the world [1]. Husk to paddy ratio is 0.1 by weight and about 20% of rice husk becomes RHA [2], as a result 279,400 tons of rice husk are produced by rice milling industry.

Rice husks are often used as a fuel in brick manufacturing industry; as a result, a considerable amount of rice husk ash (RHA) accumulates in the environment without having a proper usage. Rice husk ash (RHA), a waste of brick firing process, is unusually high in silica (around 90%), highly porous and light weight, with a large external surface area [3]. Its absorbent and insulating properties are being used in many industrial applications, including acting as a strengthening agent in building materials.

Possible enhancement of properties of civil engineering construction materials, namely, high strength concrete, normal concrete, masonry blocks and bricks with the addition of RHA have been previously studied. For example, high strength Grade 80 concrete is relatively easy to be produced by adding controlled

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burnt RHA and that concrete has resulted similar strength and durability properties as in concrete with silica fume [4]. With the addition of RHA by 20–30% replacement, the permeability of concrete with Ordinary Portland Cement can be reduced by 3–7 times [5]. The optimal replacement percentage of RHA in concrete was found to be varied from 10% to 20% [6]. Production of RHA by the control burning process is expensive; as a result, attempts have been recently given to utilise RHA collected from brick firing process to enhance the properties of building materials. Optimum percentage of RHA that could be added to brick masonry is about 4% [7] to 5% [8]. Adding 5% waste RHA to cement-sand masonry blocks showed better compressive strength and thermal performances, compared to the convention cement-sand blocks [9]. With the addition of lime, utilization amount of waste RHA could be increased up to 10%, in order to achieve optimum compressive strength [9]. Effects of waste RHA on properties of clay roof tiles have not investigated previously.

Asbestos sheet roof covering becomes more popular among people mostly because of easiness in handling, cost effectiveness and high strength when compared with the conventional clay tiles. The World Health Organization (WHO) has found that use of asbestos as roofing material, cause cancer of the lungs, larynx and ovary, mesothelioma, and asbestosis (fibrosis of the lungs). In addition, several thousands of deaths can be attributed to other diseases related to asbestos, as well as to other exposures to asbestos which are non- occupational [10]. Due to these reasons, many countries have already banned the use of asbestoses. Clay roof tiles can be a better alternative to asbestos roofing, considering several advantages of roof tiles over asbestos roofing: health favourability, better appearance, thermal absorption. Main disadvantage of clay roof tile over asbestos is lesser strength, manufacturing cost, difficulty in handing. Manufacturing cost of clay tiles can also be minimized by utilising waste RHA as a material to manufacture clay roof tiles, while preventing environmental pollution caused by open dumping of rice husk. Light weight roofing tile that would be achievable by using highly porous, light weight material like RHA [3], will overcome the difficulty in handling roofing tiles.

In terms of sustainability, not only the structural performances but also the thermal properties and run-off qualities of the roof tiles are increasingly important. As the roof generates the significant heat loading when compared to other building components due to its vast surface area and the orientation which is directly facing to the sky, the indoor thermal environment is greatly affected by the roofing material [11]. Hence, it is required to study the thermal performances of RHA mixed roof tiles. The runoff coming along the roof, which is common in urban environment, can be carried several miles away. Specially in urban areas, roofs act as primary storm water pollutants [12], roof surfaces in urban areas are efficient catchment surfaces for the deposition of fine particles which can travel over long distances along with storm water. Rainwater harvesting is suitable practice and popular way of saving water in many countries. Therefore, harvested roof runoff is primarily used for some of non-potable purposes. Utilizing of harvested storm water, especially in dry zones in Sri Lanka, is becoming a new trend in order to find solutions for water scarcity. Therefore, investigating the effect of RHA mixed clay roof tiles on properties of the harvested roof runoff is increasingly important.

On the other hand, the most of the investigation on performances of tiles (or blocks) manufactured with waste were limited to laboratory scale investigations. Application of waste RHA in industrial scale is necessary to understand actual performances of the product. Findings from the industrial scale investigation would be more practicable and hence, they will contribute to introduce a new trend of producing efficient clay roof tiles, uplifting the clay tile industry.

Investigating the effect of waste rice husk ash (RHA) on structural properties (transverse breaking load, bulk density, water absorption, water penetration) is one of the objectives in this study. Chemical and physical properties of raw materials were examined. Thermal properties of roof tiles and the properties of harvested roof runoff were investigated so as to find the sustainable use of RHA mixed clay roof tiles.

2. Materials and methodology

2.1. Materials

2.1.1. Raw materials

Clay was collected from Bangadeniya area, located in Puttlam District (North Western Province of Sri Lanka), where clay roof tile production has been well established. RHA was collected from an industrial scale brick kiln.

2.1.2. Preparation of roof tile specimens

Required amount of water was gradually added into the clay to make the mixture to mould the tiles. This mix proportion is mostly used in clay roof tile manufacturing industry in Sri Lanka. Five clay mixtures were prepared by replacing clay with different amount of RHA contents: 0%, 5%, 10%, 15% and 20% (by weight). Clay and RHA amounts for each clay mixture are shown in Table 1.

Clay and RHA were mixed by trampling. Further mixing was achieved with the help of a machine; the mixture was ground, well mixed and became almost a homogeneous material. The mixture was excreted to clay plates which had slightly larger dimensions than the dimensions of a tile. These plates were kept on the lower part of the mould of the electrically driven pressing machine and pressed the required shape with the upper part of the mould. The moulded tile was then shaped with small knives by removing excessive material hanging around. Tiles were stacked on shelves inside sheds for 4 days so as to make sure they got sufficient time to dry enough to burn. The tiles were packed as closely as they lied on edge, on the brick laid floor of the kiln in which burning was initially done with wood. When the kiln was full, the doorways were bricked up and plastered with mud minimizing the heat loss.

Initially in the kiln, only smoke was allowed to pass through the flues with a gentle heat transferred inside for 12 h until the disappearance of the white steam which indicated tiles were fully dried. Fire was then gradually increased within 72 h and was allowed to go inside from bottom to top after the interior of the flues got red heat and maintained the high temperature condition for 24 h. The temperature inside the kiln was maintained at 850 °C. Doorways were opened after 24 h and the temperature of the furnace was gradually reduced to room temperature before removal of the fired roof tiles. The roof tile specimens in this study were cast and fired in a roof tile factory at Waikkal, in Puttlam District (Fig. 1).

2.2. Laboratory experiments

Laboratory experiments were performed to investigate properties of raw materials and properties of tiles.

2.2.1. Raw materials

2.2.1.1. Sieve analysis. Sieve analysis for RHA was conducted as specified in [13]. Wet sieve analysis was conducted for clay in accordance with [14].

2.2.1.2. Specific gravity and Atterberg's limits. Specific gravity test for both RHA and clay was performed as in [15]. Atterberg's limit tests for clay samples mixed with RHA (of 0%, 5%, 10%, 15% and 20%) were carried out as specified in [16].

2.2.1.3. Chemical analysis. X-ray Fluoresce (XRF) test for both clay and RHA samples was performed according to the process described by [17]. The amorphous nature of the rice husk silica was examined by X-ray Diffraction (XRD) analysis [18]. Further, the "soluble fraction of silica" as described by [18] was investigated to determine the amount of amorphous silica in the waste RHA.

Table 1
Clay and RHA amount in different tile mixture (amount is given for one tile).

Mixture	RHA (%)	Clay (kg)	RHA (kg)
Mixture 1	0	5	0
Mixture 2	5	4.75	0.25
Mixture 3	10	4.5	0.5
Mixture 4	15	4.25	0.75
Mixture 5	20	4	1