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Strength, durability, thermal and run-off properties of fired clay roof tiles incorporated with ceramic sludge

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HIGHLIGHTS

- Clay can be replaced with industrial ceramic sludge (optimum of 20%) for manufacturing fired clay roof tiles.
- Lighter weight tile, compared with conventional tile, can be achieved by replacing clay with ceramic sludge.
- With 20% sludge, transverse breaking load was improved by 22.9%.
- At this sludge level, water absorption was found to be 11.8% and indoor temperature could be reduced by 2.8 °C.

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ABSTRACT

This study explores the possibility of substituting clayey raw materials using ceramic sludge in clay roof tile production. The tile specimens were manufactured in an industrial scale plant by replacing clay with ceramic sludge: 0%, 10%, 15%, 20% and 25% (by weight). Strength properties (transverse breaking strength, modulus of rupture, bulk density), durability properties (water absorption, water penetration, salt crystallization, efflorescence, acidic and alkaline resistances) and run-off qualities (Ph, total solids, BOD, heavy metal concentration) were examined. Thermal properties of the sludge incorporated tiles were investigated and compared with the conventional tiles. Bulk density reduces with increasing the sludge content, which is a favorable property of roof tiles. Transverse breaking strength was optimum at 20% sludge, indicating 22.9% increment compared to the conventional tile. Clay replacement up to 20% is acceptable, satisfying water absorption and penetration in standards. No efflorescence and Sulphuric acid attack were disturbed for any specimen. At 12:00 noon, the tile with 20% sludge reduced indoor temperature by 2.8 °C, providing more comfortable shelter compared to the conventional roof tiles. For the 25% sludge incorporated tiles, run-off showed 120.2 mg/l total solid concentration, 7.36 Ph value and 5 mg/l BOD5 value, 0.01 mg/l, 0.05 mg/l, 0.06 mg/l, 0.04 mg/l Cd, Cu, Pb and Zn concentrations, respectively; while for the other tiles, run-off had lesser concentrations, which are favorable for rain water harvesting process. With 20% sludge, tiles achieved better structural, durability and thermal properties compared with the conventional tiles while satisfying the standard limits of run-off qualities.

1. Introduction

Necessity in expanding clay roof tile production and attention in increasingly important environmental problems have demanded to use several natural and synthetic raw materials as a substitute of laterite clay [1]. These additives may influence on the clay roof tile properties such as strength, durability, thermal performances and quality of run-off.

Uplifting of the clay roof tile as an alternative for asbestos roofing is an urgent need, especially in Asian countries, where use of asbestos roof has been restricted. The World Health Organization (WHO) [2] has found that use of asbestos, which is popular among people and contractors as roofing material, causes cancer of the lungs, larynx and ovary, mesothelioma, and asbestosis (fibrosis of the lungs). Restricting the use of asbestos will help revive the roof tile manufacturing industry to a greater level than in today. However, the operations of more than 60% of brick and roof tile manufacturing factories in Sri Lanka were closed down, probably due to not satisfying the strength and other requirements given in standards. There is an urgent necessity to uplift the clay roof tile industry by introducing alternative materials to improve tile properties. Clay roof tiles have several advantages compared with other roof materials [3], consequently, clay roofing tile is demanding in the

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construction industry. This demand will be further increased with the expansion of world population and the tendency of having an own house by each family.

With the increase in the tile production, exponential increase in the consumption of laterite clay is inevitable. Although clay is naturally available, there are difficulties in finding clay for the industry, mainly due to environmental impact on river banks, and in certain areas excavation of clay has not been allowed. As a result, incorporation of different types of residues (i.e., waste sugarcane bagasse, waste rice husk ash, sewage sludge) in the manufacturing of traditional ceramic products (clay bricks, floor tiles and roof tiles) has been investigated in last few decades. For example, sustainable clay bricks have been previously produced by utilizing waste: 4% waste rice husk ash [4] 5% waste sugarcane bagasse and 5% rice husk ashes [5]; industrial ceramic sludge [6]. Ceramic floor tiles with 7% (maximum) sewerage sludge was recommended in [7]. For roof tiles, optimum usage of waste RHA was found to be 10% while enhancing structural, thermal and run-off performances of fired clay roof tiles [8]. Addition of 4% sewage sludge for roof tiles is acceptable regarding the compliance with the flexural rupture strength and absorption with the current standards [9]. The possibility of producing roof tiles by waste addition up to 40% rock dust [10], up to 10% glass waste [11] up to 40% granite waste [12], has been previously reported. However, in these studies [9–12], investigations were limited to determine the ways to improve strength properties, and no study was found on incorporation of ceramic sludge into fired clay roof tiles.

Ceramic sludge, which is a residue from a wastewater treatment plant of ceramic tile production, can be transformed from residues into secondary raw materials in fired clay roof tile production, providing a solution for disposal of large amounts of industrial ceramic sludge directly into the environment. Substitution of laterite clay with industrial ceramic sludge causes a reduction in the environmental damage while saving energy and natural resources. Annual ceramic sludge production is found to be about 60,000 tons at about 100 top rates ceramic factories in Sri Lanka. Ceramic sludge consists with mainly more than 50% from weight of silico-aluminous based components and with low content of heavy metals [1]. However, the sludge received after purifying process may increase the presence of certain number of compounds due to flocculation process in which ferric and aluminous salts are incorporated [13]. Proper SiO_2/ Al_2O_3 can improve the strength characteristic of clay mixtures [14]. A several number of reactions and transformations are subjected in the firing process and causes decisive in governing the final properties of ceramic products [15]. Therefore, investigation on strength properties of the ceramic sludge based fired clay roof tile is necessary.

Nowadays, analysis of rainwater, is becoming increasingly important as a sustainable, alternative source of water with reduced impact on the environment [16]. Roof surfaces in urban areas are efficient catchment surfaces in the deposition of fine particles which can travel over long distances along with storm water [8]. About half of the world population (47%) expected to be experienced severe water scarcity in 2030 if new water management policies are not introduced [17]. This threat of global water shortage is exacerbated by global warming which is expected to make summer droughts more frequent and cause water scarcity even in developed countries. Especially in dry zones or dry seasons, utilization of rainwater in non-potable activities gives a solution for water scarcity, leads to an approach in water management and increases the potential for alternative sources. In this context, the quality (Ph, BOD, total solid (TS) concentration) of run-off water should be known. Several types of chemicals are added in manufacturing and treatment processes in ceramic industry, as a result, run-off collected from the roof tile incorporated with ceramic sludge may have heavy metal, whose concentration need to be investigated.

On the other hand, higher contribution for the internal thermal environment is supported by roofing material compared with other building materials due to its direct exposure to the sunlight and high surface area [18]. With the urbanization global warming affected seriously for the human comfort and people are seeking for costly artificial thermally comfortable mechanisms such as air conditioning. The fineness of the industrial ceramic sludge particles are less compared to laterite clay used in ceramic tile production [13]. These coarse sludge particles may contribute to make the clay tile more porous compared to the conventional tile, as a result, the tiles incorporated with the sludge perform differently, during exposure to the direct sunlight. Thermal performance of the developed tile needed to be investigated because the sole purpose of the use of roofing material is to protect occupants from rain and direct sunshine while providing thermally comfort indoor environment.

The roof structures, especially in the marine environment, are in a high risk of decaying due to the salt crystallization. The efflorescence, which is governed by external agents such as climate and land conditions [19] is not only an aesthetic problem but can also cause serious microstructural damage [20]. In addition, acid rain is an increasing environmental problem especially in Asian countries [21], demanding for resistance of roof tile for aggressive environmental conditions. Although the strength, thermal and run-off properties of roof tiles have been studied [8] durability performances including acid /alkaline resistance, salt crystallization on waste added porous roof tiles were rarely investigated. Hence the durability performance of the clay roof tiles with additive of the ceramic sludge needs to be investigated.

In this study, laterite clay used for clay roof tiles, was partially replaced by ceramic sludge, transforming a residue into secondary raw materials in fired clay roof tile production. Five sludge proportions (i.e., 0%, 10%, 15%, 20% and 25% by weight) were used and strength properties (Transverse breaking strength, modulus of rupture, bulk density) of tiles were compared with those of the tile without substitution of clay. With the competitiveness of clay roof tiles with the other roofing materials, not only the mechanical strength but also durability properties, thermal properties and run off qualities of roof tiles were investigated. Roof tiles with actual dimensions produced at an industrial scale roof tile manufacturing plant, leads to understand the performance of the tiles at mass scale production while making a contribution for expanding and uplifting clay roof tile industry.

2. Experimental methods

2.1. Characterization of raw materials

Laterite clay was collected in Anamaduwa and Bangadeniya areas (North Western Province in Sri Lanka). Ceramic sludge was collected from a ceramic factory located in Dankotuwa (North Western Province). Raw materials were subjected to X-ray Florescence (XRF) using ARIL 9800 Simultaneous XRF machine to investigate chemical composition of raw materials. Grain size distribution was determined by wet sieve size analysis and hydrometer analysis as specified in ASTM C 325 [22] and ASTM D 422 [23], respectively. Specific gravity of raw materials was determined as

Table 1
Clay and ceramic sludge percentages in different mixtures (% by weight).

Mixture	Ceramic sludge	Laterite clay
Mixture 1	0	100
Mixture 2	10	90
Mixture 3	15	85
Mixture 4	20	80
Mixture 5	25	75