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Evaluation of the Performance Enhancement of Clay Bricks by Incorporating Coal Fly Ash Generated from a Thermal Power Plant

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Abstract- Energy generation in coal power plants generates Fly Ash and bottom ash as byproducts. The disposal of fly ash is a significant environmental concern in Sri Lanka, due to the absence of a sustainable solution for the management of fly ash generated at the Lakwijaya Thermal Power Plant. This study was conducted to evaluate the feasibility of producing fly ash incorporated clay bricks as a sustainable waste management option for fly ash management at the Lakwijaya Coal Power Plant. The clay soil was acquired from a commercial brick production site and mixed with fly ash at various ratios, including 0% (Control), 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, and 50%. Five bricks were manufactured from each treatment, and their physical properties were evaluated. The General Linear Model (GLM) was employed to assess the significance of variations in studied physical properties of bricks produced under different treatments at 95% level of confidence. The results revealed that the dry weight and compressive strength of bricks varied significantly among the treatments ($P<0.05$). The highest dry weight (1.59±0.38 Kg) was observed from the control, while treatment 10 reported the lowest dry weight (1.38±0.25 Kg). Bricks produced under treatment 6, which contained 25% of fly ash, showed the significantly highest compressive strength (2.95±0.55 N/mm^2). However, no significant differences were observed in density, impervious portion and apparent porosity ($P>0.05$). Based on overall properties, treatment 6 could be recommended as the best treatment. In conclusion, this study demonstrated that fly ash generated from the Lakwijaya Coal Power Plant can be utilized to produce clay bricks, which can be used as a sustainable waste management option**.**

Keywords: Brick, Coal Power Plants, Fly Ash, Performance Enhancement, Sri Lanka

I. INTRODUCTION

Various energy sources are employed globally to meet the energy requirements of modern civilizations. These sources can be broadly categorized as renewable and non-renewable sources. Among the energy sources, coal power is a prominent one that is used in different countries, including Sri Lanka (Cui *et al.*, 2012). High availability, easiness of supply, and affordable price have made coal-based power generation more popular than other energy sources. Coal-fired power plants generate various byproducts, including flue gases, soot particles, and contaminated water, which require proper treatment and management (Henneman *et al.*, 2023).

In essence, thermal power plants rely on coal as their primary fuel source for generating electricity. The total process of power generation involves pulverizing coal and incinerating it under a sufficient supply of oxygen within the incineration chamber of the boiler, releasing heat (Gimhan *et al.*, 2017). The produced heat is extracted by the boiler tubes, while the flue gases with fine ash particles are allowed to flow and cool down. At the bottom of the incineration chamber, coal slag/bottom ash is collected (Gimhan *et al.*, 2017; Shearer *et al.*, 2017). A variety of flue gas treatment techniques are used to remove coal fly ash from the flue gas (Fediuk and Yushin, 2015).

In the case of shape, fly ash particles remain spherical, with diameters ranging from < 1 μm up to 150 μm (Fisher *et al.*, 1978). High levels of lime are associated with tan or light colours in fly ash, while high iron content results in a brownish hue. Elevated unburned carbon content often causes fly ash to appear dark grey to black in colour (Gimhan *et al.*, 2017). Fly ash is usually containing oxides of a variety of metals including, Si, Al, Fe, Ca, Mg, K, Na, Ti, and S (Zierold and Odoh, 2020). Often, the minerals included in fly ash result in colour, which can vary from tan to dark grey. The presence of different heavy metals, pollutants, and contaminants necessitates the treatment of fly ash to avoid potential adverse effects on the ecosystems. Therefore, environmentalists tend to pay close attention to the impacts of fly ash on ecosystems and human health over the last few decades (Ghazali *et al.*, 2019).

The Lakwijaya Coal Power Station, located in Sri Lanka, currently caters for approximately 50% of the daily electricity demand, making it a critical component of the nation's power infrastructure. As a result of the coal burning, both fly ash and bottom ash are produced and the fly ash production is about four times greater than coal slag. Currently, the produced fly ash is collected and deposited in a dump yard. According to the estimates, around 150,000 tons of fly ash are produced annually by the Lakwijaya thermal power plant (Gimhan *et al*., 2017). Presently, the continued dumping of fly ash has led to various environmental and social issues arising due to the spreading and deposition of fly ash with the wind. Consequently, residents from surrounding areas have voiced their concerns by registering complaints and staging protests against the emission of fugitive dust particles (Gimhan *et al*., 2017). Therefore, a viable solution to address this issue is needed.

The civil engineering industry relies on bricks for a variety of engineering purposes, including building construction, insulation and masonry projects. Clay is the primary material used in brick production, which is extracted from the land. The formation of clay is a slow process resulting from the weathering and erosion of rocks containing minerals. Clay has a high plasticity due to its particle size and water content, but once dried or fired, it becomes hard and brittle (Bergaya and Lagaly, 2006). Clay is known for its smoothness to the touch, low sand or gravel content (less than 35%), compactness to soft materials, and ability of particles for intermediate to plasticity. The clay used for brick production must possess specific qualities such as durability, aesthetic nature, higher energy efficiency, and thermal and sound insulation ability (Murmu and Patel, 2018). Recently, extensive clay mining has led to several environmental concerns, such as pollution, breeding of potential vectors, promotion of soil erosion, and degradation of the aesthetic beauty (Koroneos and Dompros, 2007).

Several recent studies have evidenced that the physical and mechanical characteristics of bricks can be successfully enhanced by integrating different materials in brick production (Parashar and Parashar, 2012; Zhang *et al*., 2018). Under this, a variety of materials such as fly ash, rice husk, waste sludge and wood ash materials have been used in different ratios to produce enhanced clay bricks (Zhang *et al*., 2018). Meanwhile, fly ash generated from different sources such as coal power plants, industrial processes and waste incineration has been incorporated as a partial auxiliary material in brick production (Abbas *et al*., 2017; Sutcu *et al*., 2019).

Fly ash has been found to have a variety of potential uses, ranging from the manufacturing of bricks to the synthesis of zeolite (Ghazali *et al*., 2019). Among these reuse options, coal fly ash is widely utilized in the construction industry, especially for cement production, development of construction materials, road construction and the synthesis of geo-polymer (Jayaranjan *et al*., 2014). The use of coal fly ash to make bricks can provide a sustainable waste management option, along with a beneficial use for this byproduct. Several studies have evidenced for the applicability of coal fly ash as a partial replacement material in brick production (Eliche-Quesada *et al*., 2018). Therefore, the current study was conducted to investigate the potential of manufacturing a coal fly ash incorporated clay brick as a sustainable waste management option for fly ash generation at the Lakvijaya thermal power plant.

II. MATERIALS AND METHODS

A. Study Location

The current study was conducted at a clay brick manufacturing plant located in Gonawilla, North Western Province of Sri Lanka. The required coal fly ash was acquired from the Lakwijaya coal power plant, while clay soil was obtained from the “Waruna Tile Factory”.

B. Mixture Formation

The clay was initially weighed and divided into ten equal parts, each weighing 10 Kg. Fly ash was incorporated into the clay as shown in Table 1. From every treatment, five samples of clay mixtures were manufactured as replicates. The fly ash, clay, and water were mixed together in the prescribed ratio, and each mixture was heaped separately. Bricks were formed using a standard wooden block (180 × 90 × 50 mm).

The bricks were separated based on the treatment and were stored, separately. Coconut branches were utilized for the purpose of providing shade. Subsequently, the bricks were arranged in stacks to ensure proper air circulation within the heaps, with the objective of reducing the moisture content of the bricks. After 21 days, thoroughly dried bricks were subjected to a continuous 48-hour heating process at a temperature of 300 °C. The burnt bricks were then allowed to cool down in the furnace for a period of seven days.

Table 1. Treatment Design

Treatment	Percentage of Fly Ash Added (%)	Percentage of Clay Added (%)
Treatment 1 (T1)	5	95
Treatment 2 (T2)	10	90
Treatment 3 (T3)	15	85
Treatment 4 (T4)	20	80
Treatment 5 (T5)	25	75
Treatment 6 (T6)	30	70
Treatment 7 (T7)	35	65
Treatment 8 (T8)	40	60
Treatment 9 (T9)	45	55
Treatment 10 (T10)	50	50

C. *Curing of Bricks*

The bricks that had been produced under each treatment were stored under a canopy for three days, during which they were repeatedly sprinkled with water (Figure 1). Subsequently, the bricks were completely covered with polyethylene for 25 days to facilitate the curing of bricks.

Figure 1. Produced Bricks Stacked for Drying

D. *Assessment of Mechanical and Physical Characteristics of Bricks*

Following mechanical and physical characteristics of the bricks manufactured under different treatments were monitored and calculated using standard methods, as described below. From each treatment, five bricks were considered for measurements.

1) *Dry, Saturated, Suspended and Wet Weights of Bricks*

The weight of individual bricks was measured separately as the Wet Weight (WW). Subsequently, the bricks were heated in an oven at 105°C until reaching a constant weight and the Dry Weight (DW) was measured after allowing the bricks to reach the room temperature. Then, the dried bricks were fully inundated in water, followed by boiling the water container for two hours. It was made sure that the bricks are not in direct contact with the bottom of the container. Following the boiling process, the test specimens were allowed to cool up to room temperature, while still being submerged in water. After the specimens were cooled, they were left submerged in water for around 12 hours. The weight of the submerged bricks was measured as the Suspended Weight (SW). After that, the Saturated Weight (SW2) of the bricks was measured after wiping the bricks with a smooth cotton cloth to remove all water droplets from the surface.

2) *Density, Apparent Porosity and Impervious Portion of Bricks*

The equation 1 indicated below was used to calculate the bulk density of the bricks.

$$\text{Density} = \frac{\text{Dry weight (DW)}}{\text{Volume of the brick}} \ldots\ldots \text{ Eq. 1}$$

The volume of the Impervious Portion refers to the amount of space within the brick that is filled with solid material and does not allow water to pass through it. Meanwhile, the Apparent Porosity refers to the measure of its pore space or voids, as a percentage of its total volume. The Impervious Portion and Apparent Porosity were calculated using Equations 2 and 3, respectively.

$$\text{Volume of Impervious Portion} = \text{Dry Weight (DW)} - \text{Saturated Weight (SW2)} \text{ .. Eq. 2}$$

$$\text{Apparent Porosity} = \frac{[\text{Suspended Weight (SW)} - \text{Dry Weight (DW)}]}{\text{Exterior volume (V)}} \text{X } 100 \ldots \text{ Eq. 3}$$

3) *Specific Gravity and Water Absorption Capacity of Bricks*

Equations 4 and 5 were used to calculate and determine the Specific Gravity and Water Absorption Capacity of bricks produced under different treatments.

$$\text{Specific Gravity} = \frac{\text{Dry Weight (DW)}}{[\text{Saturated Weight (SW2)} - \text{Dry Weight (DW)}]} \ldots\ldots \text{ Eq. 4}$$

$$\text{Water Absorption Capacity} = \frac{[\text{Suspended Weight (SW)} - \text{Dry Weight (DW)}]}{\text{Dry Weight (DW)}} \text{X } 100 \ldots \text{ Eq. 5}$$

4) *Compressive Strength of Bricks*

Two sides of the clay bricks were layered with a thin layer of cement mortar (with a mixing ratio of 1:3 for cement and sand) and the bricks were allowed to dry for three days. The bricks were placed among two steel plates of the compressive strength testing machine and load was applied at incremental levels to identify the maximum load bearable by the bricks prior to cracking (Figure 2). Based on the maximum load, Equation 6 was used to calculate the compressive strength of the bricks.

$$\text{Compressive Strength} = \frac{\text{Maximum Applied Load (N)}}{\text{Area of Bed Face}} \quad \ldots \text{Eq. 6}$$

Figure 2. Monitoring the Compressive Strength of Bricks

E. *Statistical Analysis*

All the recorded mechanical and physical properties were entered into SPSS (Version 23), adhering to quality control procedures. The statistical significance in variations of the studied mechanical and physical characteristics of bricks produced under different treatments was evaluated using the General Linear Model (GLM) followed by Tukey's pairwise test, at a 95% level of confidence.

III. RESULTS AND DISCUSSION

A. *Dry Weight of Bricks*

The dry weight of bricks displayed significant variations among different treatments (P<0.05). Bricks of the control treatment (T1) exhibited the highest mean dry weight of 1.59±0.38 kg, whereas the lowest mean dry weight (1.38±0.25 kg) was observed in the bricks manufactured under the Treatment 10. Furthermore, an inverse relationship was noted between the percentage of fly ash and the dry weight of the bricks, suggesting that the increase in the fly ash proportion in bricks leads to a gradual reduction in the dry weight of bricks (Figure 3). A similar study has shown that the incorporation of around 25% of fly ash can result in a weight reduction of 18% in bricks, leading to the production of lighter bricks (Abbas *et al.*, 2017).

B. *Bulk Density of Bricks*

There was no significant difference among the mean bulk density of bricks produced under different treatments (P>0.05). However, it was observed that the control treatment (T1) had the highest mean bulk density value (1.96±0.41 kg/m^3). On the other hand, treatment 10 (T10) exhibited the lowest mean bulk density value of 1.70±0.35 kg/m^3, as shown in Figure 4. These findings suggest that the incorporation of fly ash into bricks results no significant effects on bulk density.

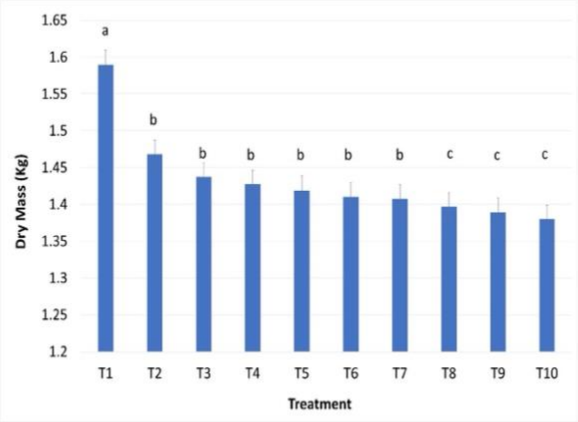

Figure 3. Dry Weight of Bricks under Different Treatments

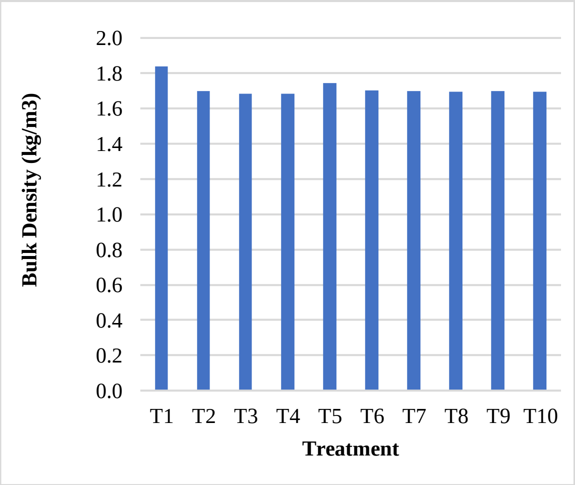

Figure **4.** Bulk Density of Bricks Produced under Different Treatments

C. *Impervious Percentage and Apparent Porosity of Bricks*

Both impervious percentage and the apparent porosity of bricks did not report any significant variations among the treatments (P>0.05). Bricks produced under T10 treatment reported the highest mean impervious percentage of 70.8±3.5%, while the lowest mean impervious percentage (67.6±2.8%) was found in the bricks produced under the control treatment, as shown in Figure 5. In the case of the apparent porosity, the highest mean value was observed in bricks produced under T10 treatment as 29.2±4.1%. Meanwhile, bricks produced under the control treatment reported the highest mean apparent porosity as 32.4±3.7% (Figure 5). This suggests that the bricks produced under T1 treatment are relatively more porous than the bricks incorporated with coal fly ash.

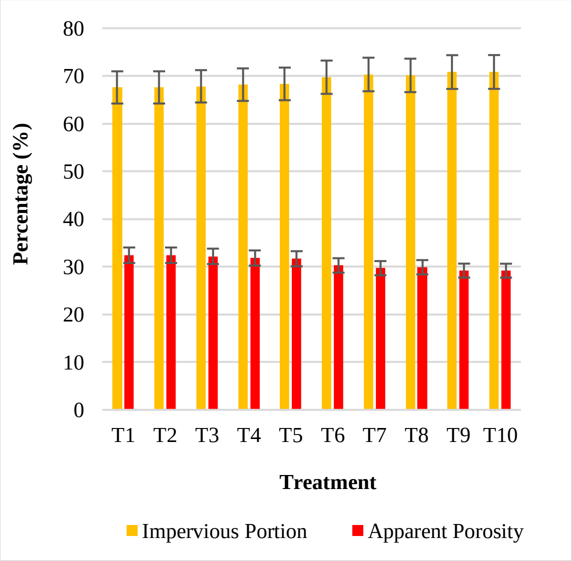

Figure 5. Impervious Portion and Apparent Porosity of Bricks

D. Compressive Strength of Bricks

The highest mean compressive strength of 2.95±0.55 N/mm^2 was reported from bricks produced under treatment 6, followed by the bricks produced under treatment 7 (2.91±0.62 N/mm^2), as shown in Figure 6. Meanwhile, the lowest mean compressive strength (2.65±0.81 N/mm^2) was reported from the bricks produced under the control treatment. The statistics of the GLM suggested that the compressive strength of bricks denoted significant variations among different treatments ($P<0.05$).

According to the recommendations of the Sri Lankan standards for clay bricks, the mean compressive strength of bricks should be higher than 2.8 N/mm^2 (Perera *et al.*, 2015). A previous study by Islam *et al.* (2020) has suggested that the compressive strength of bricks tends to decrease with the increase of fly ash level. In a similar study conducted by Abbas *et al.* (2017), clay bricks incorporated with 20% of coal fly ash has reported to adhere with the minimum compressive strength requirements in Pakistan. However, findings of this study evidence that the compressive strength of brick gradually increases until T6 (25% of fly ash) and gradually decrease thereafter. Based on the findings, the coal fly ash incorporated bricks produced under treatments 6 (25%), T7 (30%) and T8 (35%) adhere to the desired standards.

A. Water Absorption

The statistics of GLM, suggested that the mean water absorption capacities of bricks are not denoting any significant variations among different treatments ($P>0.05$). The highest mean water absorption capacity was reported from the bricks produced under Treatment 3, with a value of 19.7±2.9%. Meanwhile, the lowest mean water absorption capacity was reported from the bricks produced under Treatment 9 (17.4±2.5%), as shown in Figure 7. According to Perera *et al.* (2015), the clay bricks should indicate a water absorption capacity of less than 28% and any increase in water absorption capacity can indicate less recrystallization. This suggests a poor strength in clay bricks. Therefore, a lower water absorption capacity is desirable in clay bricks to ensure a satisfactory level of strength and durability (Perera *et al*., 2015). The bricks produced under different treatments reported lower water absorption capacity levels, suggesting that the incorporation of coal fly ash results in a desirable strength.

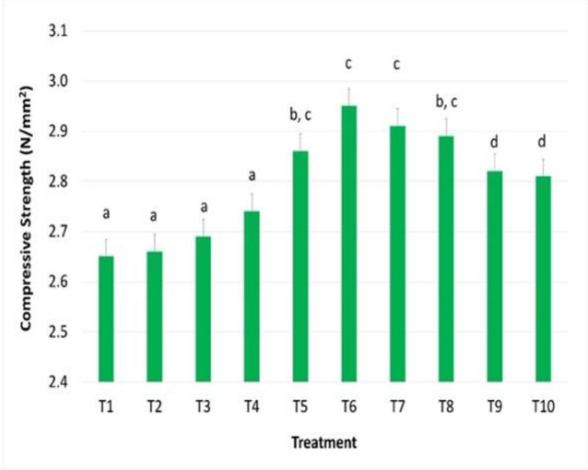

Figure 6. Compressive Strength of Bricks

B. Specific Gravity of Bricks

The mean specific gravity values of bricks produced under different fly ash ratios reported significant variations among different treatments ($P<0.05$). Bricks produced under treatments 6 and 10 reported the lowest specific gravity of bricks as 2.20±0.34. On the other hand, bricks produced under treatment 1 (Figure 8) reported the highest mean specific gravity as 2.80±0.91, followed by treatment 5 (2.60±0.45). The bricks incorporated with fly ash exhibited a lower specific gravity, indicating that they were lighter in weight compared to ordinary bricks.

The specific gravity of clay bricks has been reported to range from 1.8 to 2.2 (Ukwatta *et al.*, 2016). These findings suggest that the incorporation of fly ash in brick production could potentially result in lighter-weight bricks, which may have important practical applications in the construction industry.

Notably, the bricks produced with 25% (T6) and 50% (T10) of coal fly ash demonstrated adhered to this recommendation, as shown in Figure 8.

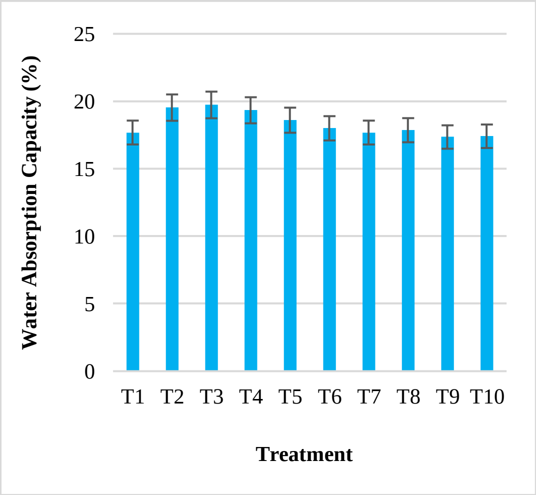

Figure 7. Water Absorption Capacity of Bricks

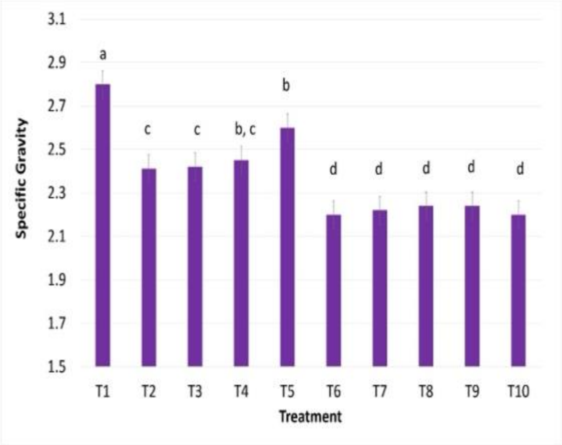

Figure 8. Specific Gravity of Bricks

IV. CONCLUSIONS

The present study aimed to evaluate the effect of incorporating different levels of fly ash on the physical and mechanical properties of bricks. Results revealed no significant differences in bulk density, impervious portion, apparent porosity, and water absorption capacity of the bricks produced under different treatments. However, the dry weight, compressive strength and specific gravity of bricks demonstrated significant differences among the treatments. The findings suggested that the addition of fly ash as a replacement material for clay in the brick-making process could have a positive impact on the dry weight and compressive strength of the bricks. Specifically, the T6 treatment, in which fly ash was used at a rate of 25%, exhibited the best overall performance among all of the treatments. Overall findings of the current study suggest that the mechanical and physical characteristics of bricks can be enhanced through the addition of fly ash, producing sustainable and cost-effective building materials.

The incorporation of coal fly ash into brick production could be recommended as a viable option for the management of coal fly ash generated at the Lakwijaya Power Plant in Sri Lanka, while avoiding detrimental impacts on the environment and human health. However, further studies are recommended to investigate the radiation emission levels and customer preference of fly ash incorporated clay bricks.

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Conflicts of Interest: The authors declare that they have no competing interests.

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