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Development of Eco-Efficient Interlocking Bricks using Water Treatment Sludge

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Abstract - The issue of water treatment plant (WTP) sludge disposal became one of the important environmental concerns due to the growing need for drinking water supply and the increased sludge amount. Such disposal methods as landfilling and open dumping require large disposal sites and can negatively impact the quality of soil and underground water. This research analyzes the possibility of using WTP sludge as a material for making interlocking bricks as a partial substitute of other building materials in order to contribute to sustainability in waste management and recycling of resources. Sludge samples obtained from a plant that produces drinking water were analyzed using SEM and XRD. Then five brick samples with sludge amount 30%, 35%, 40%, 45% and 50% were made. Their properties such as compressive strength, water absorption, density and efflorescence were analyzed. The research results revealed that with the increased amount of sludge, the compressive strength and density decreased whereas the water absorption was increased. From all brick mixtures, the one with 30% of sludge proved to be the best, achieving the highest compressive strength 10 N/mm², water absorption 3.4%, density 1539.5 kg/m³. The efflorescence in the test pieces was insignificant, which means the level of soluble salts is acceptable. It was found that the WTP sludge could be used for producing interlocking bricks at proper rates.

Keywords: Water treatment plant sludge; Sustainable construction; Interlocking bricks; Waste utilization; Compressive strength; Circular economy.

1. INTRODUCTION

Rapid With the exponential growth of the population and the increasing urbanization, there has been an increase in the need for clean water and construction materials. In addition, there is a large amount of sludge that is generated from the process of water treatment and it poses serious disposal challenges around the world. Conventionally, sludge is either used in the landfills or is dumped in the aquatic environment causing environmental pollution and increased disposal costs (Dahhou et al., 2024; Mattoso et al., 2024).

The sludge produced from the treatment plants consists of fine particles and a number of chemical elements such as aluminum, silica, and iron among others. Accumulation of this sludge has become a major issue across the world due to the unavailability of sufficient landfills and stringent environmental regulations (Dahhou et al., 2024).

Recently, many researchers have studied various methods for utilizing the sludge in order to convert them into construction materials that would be beneficial for both the environment and sustainable development. Construction industry is considered to be one of the major consumers of raw materials and it becomes a platform for the sludge utilization. The inclusion of sludge in bricks, concrete, and other cementitious materials will not only decrease the environmental problems but will also help in sustainable development (Mattoso et al., 2024; Ceren et al., 2024; Liu et al., 2023).

There are many studies reporting the use of water treatment sludge and alum sludge as partial replacements of the cement, fine aggregates, fly ash, limestone, and other construction materials. Specifically, treated alum sludge was found to act as a partial replacement of cement and fine aggregates in concrete showing increased durability and good performance of its strength properties (Ching et al., 2022; Kaish et al., 2023). Moreover, water treatment sludge when used as a partial replacement of cement showed the pozzolanic activities and improved microstructure density (Hai He et al., 2023). In particular, interlocking bricks are gaining popularity because of their low costs, easy construction process, and lower demand of motor; therefore,

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incorporation of waste sludge into these bricks helps in sustainability through reduction of the usage of natural materials like clay and sand (Nontananandh et al., 2025; Mattoso et al., 2024).

2. MATERIALS AND METHODOLOGY

2.1 Cement

Regular Portland cement was used as the main bonding agent in the production of the interlocking bricks. The cement helps to bond the aggregate and sludge particles together and also greatly helps in developing the strength of the brick. In the process of making the interlocking bricks, the cement helps form hydrates when mixed with water. These hydrates fill the spaces between particles and hence strengthen the brick.

2.2 Water Treatment Plant Sludge

Sludge from the water treatment plants is one of the major by-products encountered in the purification of raw water. It is primarily made up of fine suspended solids, leftover coagulants, organic material, and mineral compounds including silica, alumina, and iron compounds. When this sludge is not disposed of properly, it can cause environmental problems such as accumulating solid waste or causing land and water pollution. The processed water treatment sludge was partially used to replace the conventional materials for producing interlocking bricks in this study. The sludge was sun-dried to remove moisture and then crushed and sieved to ensure uniform particle size and a fine consistency for use in mixing. Use of sludge in brick production will contribute to sustainable waste management and minimize natural construction materials usage. Too much sludge can lead to increased porosity and water uptake that may negatively impact brick performance, however. So, suitable replacement levels were chosen to balance the environmental benefits and appropriate engineering properties of the interlocks.

2.3 Coarse Aggregate

The coarse aggregate used in all the experiments was crushed coarse aggregate of nominal maximum size of 6 mm. It provided the main structural framework for the interlocking bricks, enhancing their strength, stability, and load-bearing capacity. The dimensional stability and overall brick durability was also enhanced by the use of well graded coarse aggregate.

2.4 Mix Proportion

Five different mix proportions were formulated, using partially replaced the conventional materials to processed water treatment plant (WTP) sludge, by maintaining the content of coarse aggregate at 15%. To achieve this, the sludge content was varied from 30% to 50% with the corresponding reduction in cement content. The mix design enabled a systematic evaluation of the impact of incorporating sludge into the bricks on their physical, mechanical and durability properties.

Table 1: Mix proportions adopted in the study

MIX ID	Cement (%)	Aggregates (%)	Sludge (%)
M1	55	15	30
M2	50	15	35
M3	45	15	40
M4	40	15	45
M5	35	15	50

3.RESULTS AND DISCUSSION

3.1 Characterization of Water Treatment Plant Sludge

For the production of interlocking brick, the processed water treatment plant (WTP) sludge was characterized in order to evaluate its suitability as a construction material. The surface morphology and particle structure of the sludge was investigated by Scanning Electron Microscopy (SEM), and the mineralogical composition and the main crystalline phases of the sludge was investigated by X-ray Diffraction (XRD) analysis.

3.1.1 Scanning Electron Microscopy (SEM)

SEM images showed the presence of irregularly shaped particles of different sizes and surface features in the processed WTP sludge. The particles were found to be agglomerated particles (flocs) with compact and porous parts, suggesting the heterogenic structure of the sludge. The large flocculated structures seen in some of the micrographs indicate that sludge formation was achieved via typical coagulation and flocculation processes used in the drinking water treatment industry.

Fig 1: large agglomerated sludge particles indicating flocculated bulk structure.

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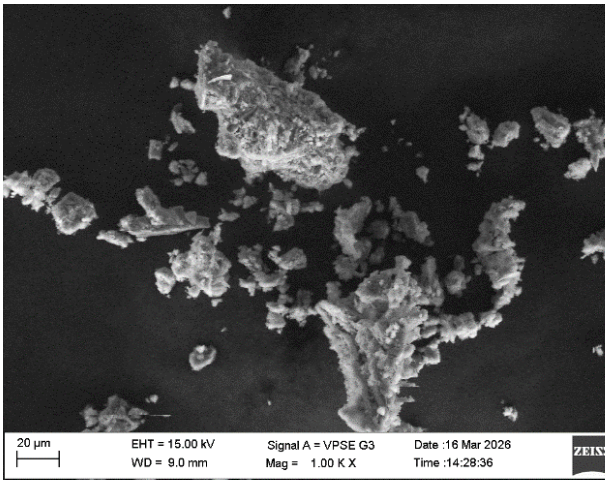
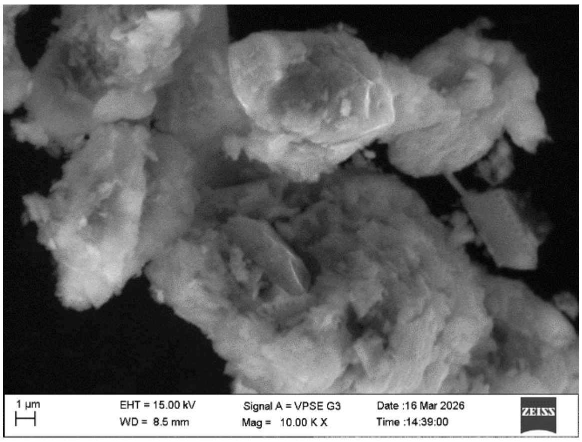


Fig 2: reveals porous and fine particles indicating higher surface area and absorption capacity.



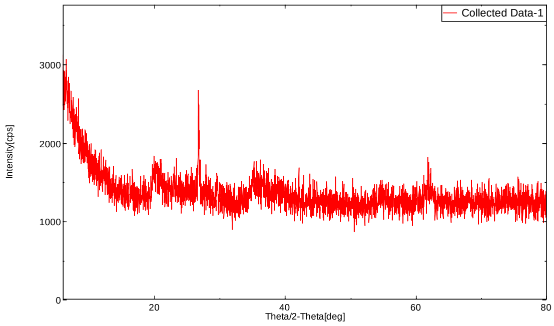
In general, the SEM images show that the processed sludge has morphological features suitable for the partial use of it as a constituent of interlocking bricks made of cement. However, since adding too much sludge can cause the hardened matrix to become porous, therefore reducing mechanical strength, it is important that the sludge content be within the optimum range.

3.1.2 X-ray Diffraction (XRD)

XRD pattern of the sludge processed showed a broad diffuse background with limited number of diffraction peaks indicating that the material is mainly amorphous and moderately crystalline. This sort of diffraction effect is normally related to water treatment sludge with hydrated metal hydroxides, aluminosilicate compounds and organic components.

The diffraction pattern indicated the presence of silica- and alumina-rich phases and minor amounts of crystalline compounds. Weak diffraction peaks at 20°, 28°, 35°, 55°, and 62° (2θ) suggest the presence of minerals like quartz, kaolinite, illite, calcite, and iron-bearing compounds. These minerals are basically the result of the raw water suspended solids or from the coagulants used in the treatment process.

Fig 3: XRD graph of sludge sample.



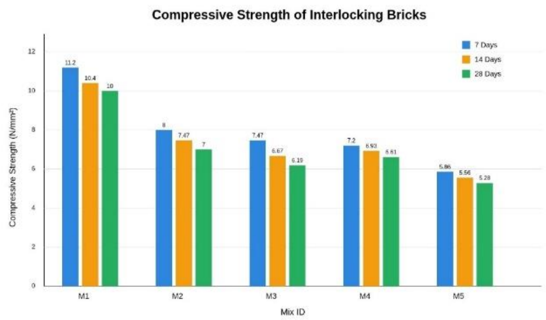
3.2 Performance Evaluation of Interlocking Bricks

Three different tests were conducted to analyze the manufactured interlocking bricks: compressive strength, water absorption, and density test, and efflorescence test. A series of experiments was conducted to evaluate the effect of the sludge replacement on the engineering properties of bricks and to make an optimum replacement value for the sludge which is suitable in practical construction applications.

3.2.1 Compressive Strength

The most important parameter that determines the structural properties of interlocking brick is its compressive strength. The compressive strength results after 7, 14 and 28 days cure is summarized in Table 2.

Fig 4: Graphical representation of Compressive strength of bricks.



3.2.2 Water Absorption

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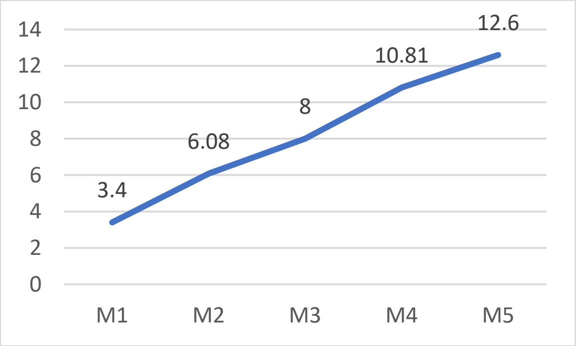
Water absorption is an important indicator of brick durability because it reflects the volume of interconnected pores within the material. Lower water absorption generally corresponds to improved durability and resistance to moisture penetration.

Fig 5: Graphical representation of Water absorption of interlocking bricks

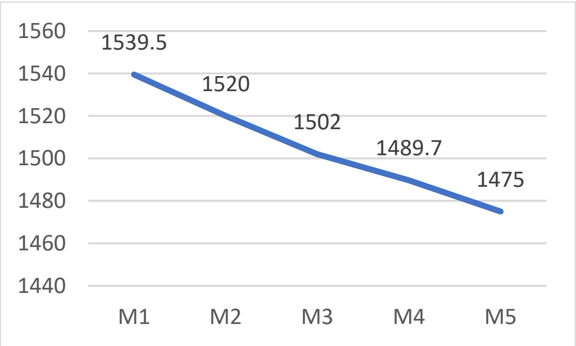


The results indicate that lower sludge replacement levels produce denser bricks with improved resistance to moisture ingress.

3.2.3 Density

The density measurements demonstrated a gradual reduction with increasing sludge content. The highest density of 1539.5 kg/m³ was obtained for Mix M1, while Mix M5 exhibited the lowest density of 1475 kg/m³.

Fig 6: Graphical representation of density of Interlocking Bricks



3.2.4 Efflorescence

Efflorescence testing was performed to evaluate the presence of soluble salts on the surface of the manufactured interlocking bricks after repeated wetting and drying cycles.

There was a very thin coating of white deposits (efflorescence) on less than 10% of the exposed surface of the specimens. The test did not show any indications of surface cracking, flaking or deterioration.

Fig 7: Images of Interlocking Brick after Efflorescence Test

4.CONCLUSION

The present study investigated the feasibility of utilizing water treatment plant (WTP) sludge as a partial replacement material in the production of cement-based interlocking bricks. The sludge was processed and characterized using Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD), which confirmed the presence of predominantly amorphous aluminosilicate materials with irregular and porous particle morphology, indicating its suitability for incorporation into cement-based construction materials.

Five interlocking brick mixtures containing 30–50% WTP sludge were manufactured and evaluated for compressive strength, water absorption, density, and efflorescence. The experimental results demonstrated that sludge content significantly influenced the engineering properties of the bricks. An increase in sludge replacement resulted in a gradual reduction in compressive strength and density, accompanied by an increase in water absorption. This behavior is primarily attributed to the porous nature of the sludge particles and the corresponding increase in internal voids within the cementitious matrix.

Among the investigated mixtures, Mix M1 containing 30% WTP sludge exhibited the most satisfactory overall performance, achieving a 28-day compressive strength of 10 N/mm², water absorption of 3.4%, and a density of 1539.5 kg/m³. The specimens also exhibited only slight efflorescence, indicating that the concentration of soluble salts was within acceptable limits and did not adversely affect the surface quality of the bricks.

The findings demonstrate that processed WTP sludge can be successfully incorporated into interlocking bricks at an appropriate replacement level, providing an environmentally responsible alternative for managing sludge generated during drinking water treatment. The reuse of sludge not only reduces the burden on landfill disposal but also decreases the consumption of conventional construction materials, thereby supporting sustainable resource utilization and circular economy principles.

Based on the experimental investigation, 30% WTP sludge replacement is recommended as the optimum proportion among the mixtures studied, as it provided the best balance between mechanical performance, durability, and material sustainability. The results indicate that WTP sludge possesses considerable potential as an alternative construction material and can contribute to the development of eco-friendly interlocking bricks suitable for sustainable construction applications.

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