Single-step production of Compressed Stabilized Sludge Blocks (CSSB) using sludge from water treatment plants as the sole raw material

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ABSTRACT The utilization of sludge derived from water treatment plants as a viable material in Compressed Stabilized Earth Blocks (CSEB) production has attracted significant interest among researchers mainly due to escalating challenges associated with sludge management, which not only pose environmental concerns but also entail substantial financial burdens. Currently, researchers use sludge only as a substitute of raw materials in CSEB manufacturing processes. However, this approach is not only complicated due to mixing ratio of many raw materials but also not fully minimized the production cost. This paper presents a pioneering approach towards Compressed Stabilized Sludge Blocks (CSSB) production utilizing a single-step method involving sludge as the sole raw material. The sludge sourced from the water treatment plant serves as the primary ingredient, blended solely with cement. Initially, the dried sludge undergoes crushing to achieve the desired particle size. Subsequently, it is evenly mixed with cement and a controlled amount of water to form a homogeneous mixture. The resulting blend is then poured into interlocking brick molds and subjected to automated compression. Following the molding process, the CSSB undergo a curing period, during which they are intermittently sprinkled with water twice daily. Finally, the CSSB are subjected to compressive strength test. Remarkably, the findings reveal that the CSSB produced using this single-step method exhibit strength that comply to standard requirement for building construction. This approach not only presents a straight-forward solution for addressing the challenges associated with sludge but also underscores its potential for sustainable sludge management while yielding multiple financial benefits.

KEYWORDS: Sludge-derived CSEB; Sustainable construction; Compressive strength; Resource conservation; Waste management
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INTRODUCTION

The escalating volumes of sludge generated by water treatment plants pose significant environmental and logistical challenges globally. In Brazil, for example, an estimated 78 million tons of sludge are generated annually (Fiore *et al.*, 2022), with similarly substantial figures in other countries such as Australia (43,500 tons; Maiden *et al.*, 2015), the UK (131,000 tons; Finlay, 2015), and Malaysia (5,500 metric tons daily; Nambiar, 2021). Conventional disposal methods for sludge often entail considerable financial expenditures and environmental risks, prompting the exploration of innovative strategies for its management.

In recent years, attention has turned towards repurposing sludge as a valuable resource in various industrial applications, including its use in the production of clay bricks (Ahmadi *et al.*, 2023), as a geotechnical component in road construction (Nguyen *et al.*, 2023; Fiore *et al.*, 2022), and in the manufacturing of Compressed Stabilized Earth Blocks (CSEB) (Asrah *et al.*, 2020; Samsudin *et al.*, 2017; Ratnayake & Kasthuriarachchi, 2015). However, studies such as that by Ratnayake & Kasthuriarachchi (2015) have concluded that dried sludge alone is not suitable for CSEB production due to insufficient fines content, while others have proposed using sludge as a minor substitute for traditional CSEB formulations, resulting in reduced compressive strength (Asrah *et al.*, 2020; Samsudin *et al.*, 2017). Unfortunately, this approach is complicated by the need to manage multiple raw materials and does not fully minimize costs.

Considering these limitations, this paper presents a pioneering approach to Compressed Stabilized Sludge Blocks (CSSB) production using single-step method utilizes sludge as the sole raw material, mixed only with cement and water. Conventional CSEB manufacturing typically relies on natural materials such as clay and shale, which are subject to extraction-related environmental impacts and resource depletion. Using sludge as the sole raw material in CSSB production not only fully mitigates the burden of sludge disposal but also offers a sustainable alternative that aligns with principles of circular economy and resource efficiency. By addressing pressing environmental challenges and driving positive socio-economic impacts through resource conservation and sustainable development, this approach represents a significant advancement in CSSB production. It should be noted here the introduction of new terminology which is Compressed Stabilized Sludge Blocks or CSSB instead of the conventional terminology of Compressed Stabilized Earth Blocks or CSEB to emphasis the use of sludge from water treatment plant instead of soil in ordinary CSEB production.

METHODOLOGY

As previously mentioned, this paper presents a straightforward approach to manufacturing CSSB using sludge as the sole raw material, mixed only with ordinary Portland cement (OPC) and water. Given the pioneering nature of this work in single-step CSSB production, the test results are limited to the assessment of compressive strength only. However, it is recognized that higher compressive strength in CSEB typically corresponds to better performance in all other required parameters and thus for CSSB. It should be noted that due to the nature of the project, certain sensitive parameters are not provided in this paper. Interested parties may request this information from the corresponding authors through private communication.

Sludge Sample and Its Preparation

The raw sludge sample was collected from the Jetama Water Sdn. Bhd. water treatment plant, which is a government-linked company (GLC) in Sabah. Jetama Water manages six water treatment plants along the West Coast of Sabah, providing potable water to over one million people. The two plants in Penampang District alone produce approximately 40 tons of sludge monthly, contributing to a current backlog of over 12,000 tons, illustrated in Figure 1. The sample used in this study was obtained from the Kasigui water treatment plant in Penampang, Sabah, Malaysia. Subsequently, the sample was air-dried, as depicted in Figure 2.

(a) Accumulated sludge in the treatment pond (b) Backlog of sludge nearby the pond

Figure 1. Backlog and accumulated sludge at Kasigui treatment plant taken on June 2024

Figure 2. Open space drying of the sludge sample

Sample Mixing

The dried sludge was subsequently crushed to achieve suitable particle size using a crusher machine. It was then dry-mixed with OPC in an electric mixer at a weight-to-weight cement:sludge ratio of 15:85. During the mixing, water was gradually added until a homogeneous cement-sludge-water mixture was formed.

CSSB Forming

The mixture was poured into interlocking brick mold with dimensions of 250 mm x 125 mm x 100 mm (Length x Width x Height) with one rectangular and two circular hollow and then subjected to automated compression at preset maximum loads to produce finished interlocking CSSBs shown in Figure 3. The CSSB underwent a curing period, during which they were intermittently sprinkled with water twice daily. Finally, the CSSBs were subjected to compressive strength testing at 14 and 28 days of curing.

Figure 3. The finished interlocking CSSB bricks

RESULT AND DISCUSSION

As previously mentioned, the primary objective of this paper is to demonstrate the viability of utilizing sludge from water treatment plants as the sole raw material for producing CSSB with sufficient compressive strength as opposed to what has been reported in the literatures. The compressive strength of the CSSB samples was assessed using an automated hydraulic compressive strength testing machine with a maximum load of 5,000 kN (Figure 4). Prior to testing, the sample dimensions of the samples were carried out and input into the control panel of the machine to obtain the compressive strength value upon completion of the test.

On day 14, the CSSB samples exhibited a compressive strength of 5.458 MPa (Figure 5a), meeting the minimum requirement of 5 MPa for fully cured bricks, set by BS3921:1985 for clay bricks as building construction material. Upon full curing on day 28, the compressive strength increased to 8.182 MPa (Figure 4b), representing an almost 50% increment compared to the half-cured samples. These results demonstrate the potential of sludge-derived CSSB to meet the strength requirements for building construction materials.

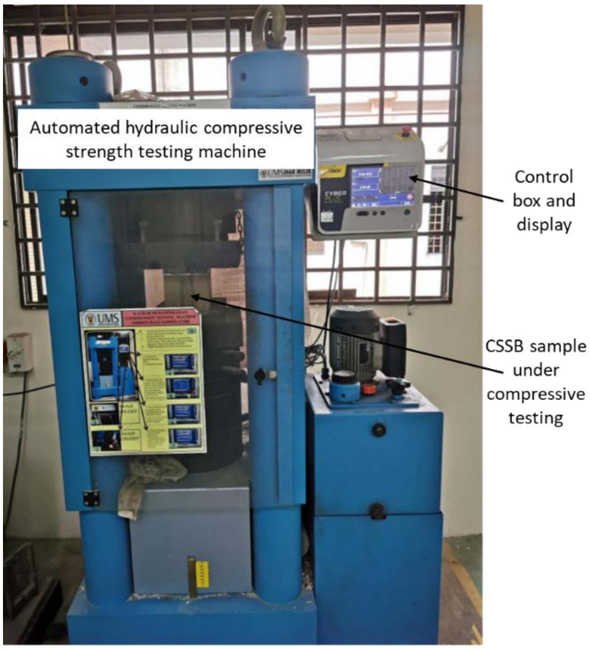
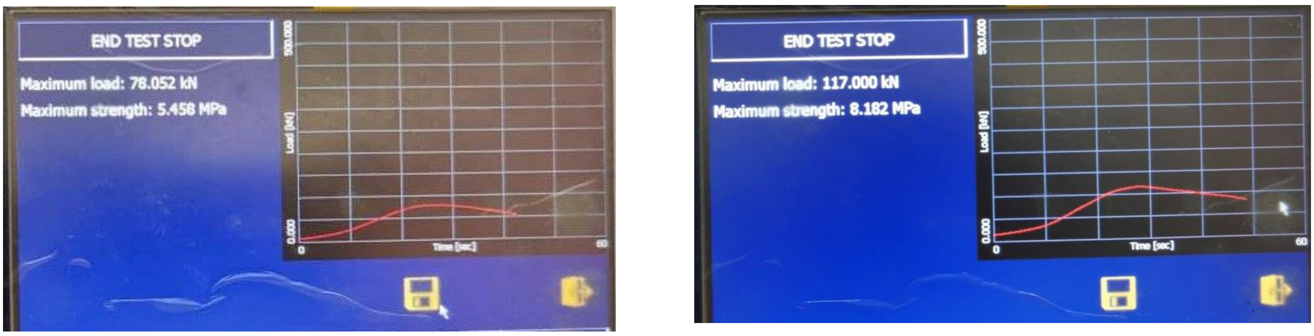


Figure 4. Compressive strength testing of CSSB sample



(a) Compressive strength reading at 14 days (b) Compressive strength reading at 28 days

Figure 5. Compressive strength of the CSSB with water treatment sludge as sole raw material

Although only the compressive strength of the CSSB is presented here, it is logical to compare the obtained results with those reported by other researchers. To start with, this paper presents findings that diverge from the conclusions by Ratnayake & Kasthuriarachchi (2015), who suggested that sludge alone cannot be used for CSEB production. In contrast, our study demonstrates that sludge as the sole raw material complies with standard requirements, even at half the curing age, particularly in terms of compressive strength.

Vishwajith *et al.* (2023) incorporated sludge as an additive in fired clay bricks and achieved a compressive strength of 5.98 MPa with 25% sludge content. Basu *et al.* (2022) observed a reduction in brick strength with increasing sludge content as a component in brick formulation. Similarly, a collaborative study involving universities in Vietnam and Thailand found that the highest brick strength (4.0 MPa) was achieved using combinations of sludge with cement or with cement and fly ash (Trang *et al.*, 2021). Asrah *et al.* (2020) recommended 50% sludge substitution to sand in weight-to-weight soil:sand:cement ratio of 1:2:3, while Samsudin *et al.* (2017) reported that substitution of sludge to soil with maximum weight-to-weight sand:cement:(soil:sludge) ratio of 2:1:(1:3) are still acceptable as building construction brick in reference to BS3921:1985 as standard. It is notable that the majority of these studies utilized sludge only as an additive rather than as the sole material in brick production.

CONCLUSION AND FUTURE RECOMMENDATIONS

This study challenges the prevailing belief among researchers and industrial practitioners that sludge from water treatment plants is unsuitable to produce CSSB on its own. Contrary to this perception, the findings demonstrate that sludge can indeed serve as the sole raw material for producing CSSB with acceptable strength. By simplifying the CSSB production process which also means minimizing overall production costs, this approach offers a promising solution to the dual challenges of sludge disposal and sustainable construction.

The next phase of the research focuses on further characterizing the physical and durability properties of sludge derived CSSB. This includes investigations into wet compressive strength, stress-strain behavior, thermal conductivity, acoustic isolation, water absorption rate, efflorescence, and erosion resistance. By comprehensively evaluating these aspects, the single-step production technique presented in this paper is further refined to achieve CSSB with strengths exceeding 20 MPa, facilitating widespread adoption in various construction applications including residential buildings, commercial structures, infrastructure projects, and sustainable housing initiatives. Additionally, other associated aspects such as economic benefits, life cycle analysis, greenhouse gas emissions, and overall sustainability of the CSSB production process are also explored. Ultimately, widespread adoption of sludge-derived CSSB in various construction applications is anticipated to materialize in the near future, contributing significantly to sustainable development and resource conservation in the construction industry.

As previously mentioned, the two Jetama Water Sdn. Bhd. water treatment plants located in the Penampang District alone produce 40 tons of sludge byproduct monthly and currently have over 12,000 tons of accumulated sludge. Using the conventional method of sludge disposal, which involves landfilling, would cost over RM12 million a year (equivalent to over USD2.5 million) to be paid to an authorized sludge removal company. Turning sludge into bricks, as discussed in this paper, would not only save on disposal costs but also generate financial gains.

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