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Assessing the Feasibility of 3D-Printed Moulds in Sustainable Plastic Brick Fabrication

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Abstract

Sustainable water-based food production systems are essential to meet the growing demand for food while preserving water resources and ecosystems. These systems should integrate practices that manage water efficiently, such as green water management. Such practices conserve water and ensure the production of nutritious food, contributing to food and water security. The correlation between these systems and the production of wave breakers moulds to produce plastic waste bricks lies in the shared goal of environmental sustainability. Plastic waste bricks, created by repurposing plastic waste into durable building materials, offer a solution to plastic pollution. These bricks can be used to construct wave breakers, which protect shorelines and prevent erosion. This project aimed to fabricate a 3D-printed wave breaker mould for sustainable plastic bricks. Experimental testing was carried out to investigate this mould's feasibility. It has been deduced that using 3D-printed moulds for wave breakers can lead to innovations in coastal engineering, potentially improving the efficiency and effectiveness of wave energy dissipation and offering economic and environmental benefits. It is recommended that surface modification could be an alternative to improve the mould's wear and friction impact.

Keywords: Sustainability, wave breaker, impact forces, intensities

INTRODUCTION

Earlier studies have found that the size and distribution of wave forces on coastal structures account for the significant impact of wave breaker design. It is hypothesised that the design of wave breakers can be inferred solely from the impact load characteristics [1]. Traditional wave breakers are often expensive and time-intensive to build. Thus, it is essential to look for more efficient alternatives. A study by Liu et al. (2022) compared the environmental impact of 3D printing and conventional casting methods for concrete products, particularly when using industrial wastes as materials [2]. It concludes that 3D printing offers potential sustainability benefits, such as improved resource efficiency and increased construction productivity, especially when utilizing waste materials like fly ash and slag. Another study by Dunn et al. (2019) explored the design and testing of sustainable recycled materials for large-scale 3D printed construction in marine environments [3]. It highlights the Bio Shelters Project, which aims to enhance seawalls by promoting biodiversity, providing seawater filtration, and supporting fisheries productivity through innovative 3D printed structures. Raut and Kolekar (2023) investigated the impact strength of 3D printed specimens using different printing parameters such as infill density, printing orientation, and infill pattern [4]. The study concludes that finer layer thicknesses and higher infill densities generally result in improved impact resistance. Additionally, a numerical modelling study by Tan et al. (2022) presents an analysis of the impact of green-water overtopping flow on pedestrians on the crest of sloped coastal structures [5]. The study examined the flow characteristics and forces exerted on pedestrians, highlighting the potential risks and safety concerns under various wave conditions.

A review by Mohammed (2016) discussed the diverse applications of 3D printing technologies in oceanography, including the production of components for autonomous underwater vehicles, replicas of marine organisms for biomechanics studies, and coral reef structures for ecosystem restoration [6]. It highlights how 3D printing enhances research capabilities and promotes the understanding and restoration of marine ecosystems. Palaniyappan et al. (2024) carried out a study on recycling and cleaner conversion of crab shell waste into polylactic acid (PLA) biocomposite filaments for 3D printing applications [7]. The study identified optimal extrusion parameters and demonstrated that adding 7% crab shell particles to PLA significantly improves tensile and flexural strength, making it suitable for sustainable bio-scaffold and bone graft material production. Raju and Arockiasamy (2022) introduced an innovative concept for coastal protection by integrating mangroves with floating barges [8]. The approach involves mooring barges to the seafloor, planting mangroves along the shore, and then unmooring the barges once the mangroves are well-rooted, providing natural wave attenuation and environmental benefits. Repurposing construction waste into high-performance 3D printing materials for renewable energy infrastructure has been an increasing concern. These materials were reported to achieve superior compressive and flexural strengths, reduce carbon emissions by 20%, and enhance resource efficiency by 85%, making them a sustainable alternative to conventional building materials [9]. Using 3D printing technology to create wave breaker moulds could be cost-effective. However, understanding impact loads at and near the vertical wall boundary of wave breakers made from 3D-printed moulds remains unexplored. Therefore, this innovation aims to fabricate a 3D-printed wave breaker mould for sustainable plastic bricks, where experimental testing was carried out to investigate this mould's feasibility.

RESEARCH METHODS

The prototype of the 3D-printed mould for sustainable plastic bricks was developed, as shown in **Fig. 1.**

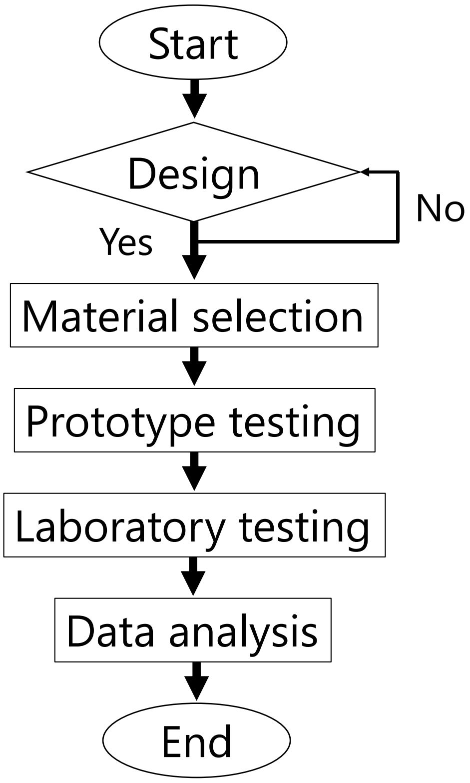

Fig. 1. Methodology flow chart

The innovation development began with optimising various wave breaker mould designs for 3D printing. **Fig. 2** shows the mechanical drawing of the 3D-printed mould of the optimised design. This mould consists of three unique structures, i.e. interlocking and cylinder shape, as well as the function of stacking mould. Following the confirmation of the optimised design, the 3D printing material was selected based on the capability of forming complex shapes. Small-scale prototype was printed, and lab tests were performed to assess their structural integrity and durability. **Fig. 3** shows the experimental model in the wave flume [10]. Physical model simulations were conducted at a 1:100 geometric scale under standard wave conditions to evaluate different impact forces and intensities. Finally, sensors were analysed to gather data on wave force reduction, mould integrity, and environmental impact.

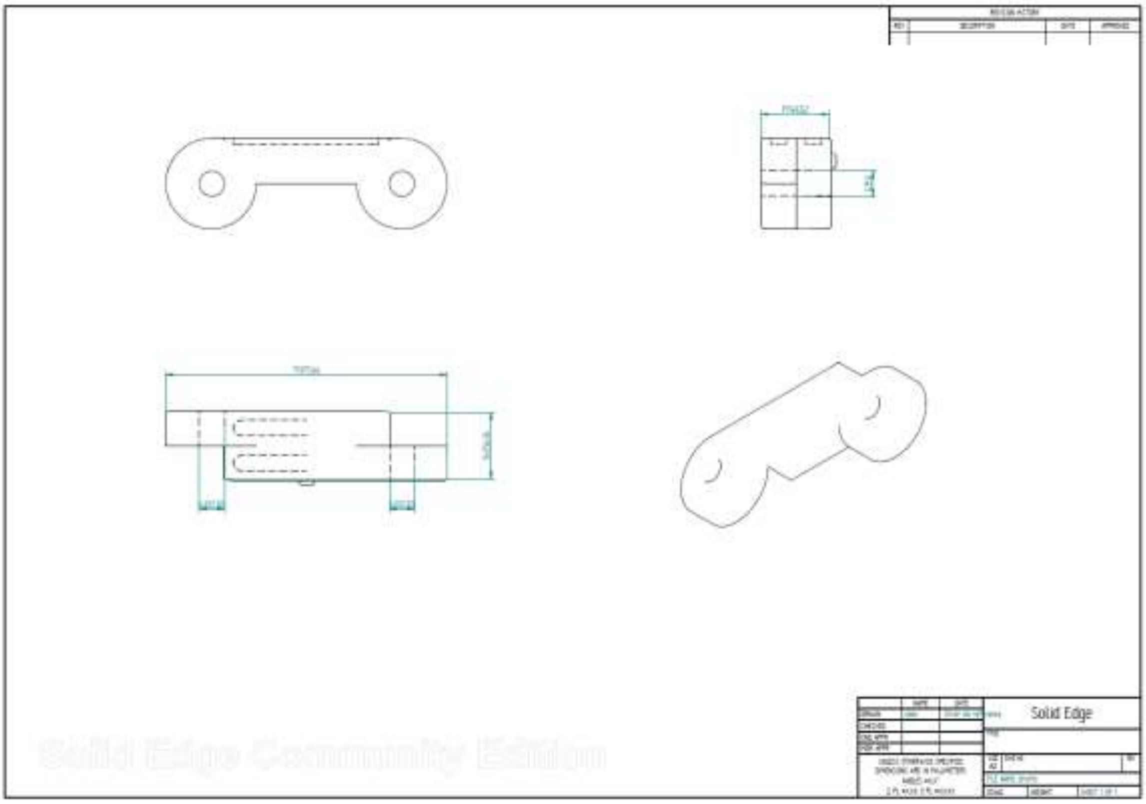

Fig. 2. Mechanical drawing of the 3D-printed mould by Solid Edge

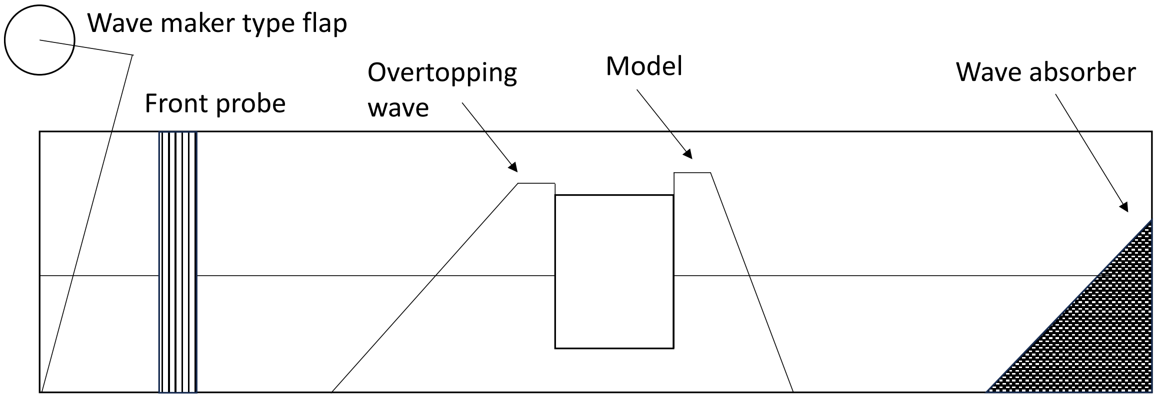

Fig. 3. The experimental model in the wave flume [10]

RESULTS AND DISCUSSION

Fig. 4 shows the wave impact forces as time progresses. It shows that the 3D-printed wave breaker mould design induces impact forces with different intensities and durations. The impact force with the highest intensity of 73608 N was found at the early stage of the experiment (i.e. before 30 s). The next most significant impact force was shown after 42 s with an intensity of 59298 N, followed by an impact force of 14286 N after 50 s. A decreasing trend of the wave impact forces was observed with an increase in the duration. This indicates that the 3D-printed wave breaker mould design is feasible for reducing the impact force of the incoming wave energy [11-15]. The cylinder shape of the stacking mould has effectively dissipated wave energy and reduced displacement due to its interlocking nature. A gradual decrease of the incident wave height (in the same time duration of 1.2 s) can be observed in Fig. 5 (a) – (c). The intensity's width widened due to the impact pressures shifting down the wall, resulting in reflected wave interferences [16-18].

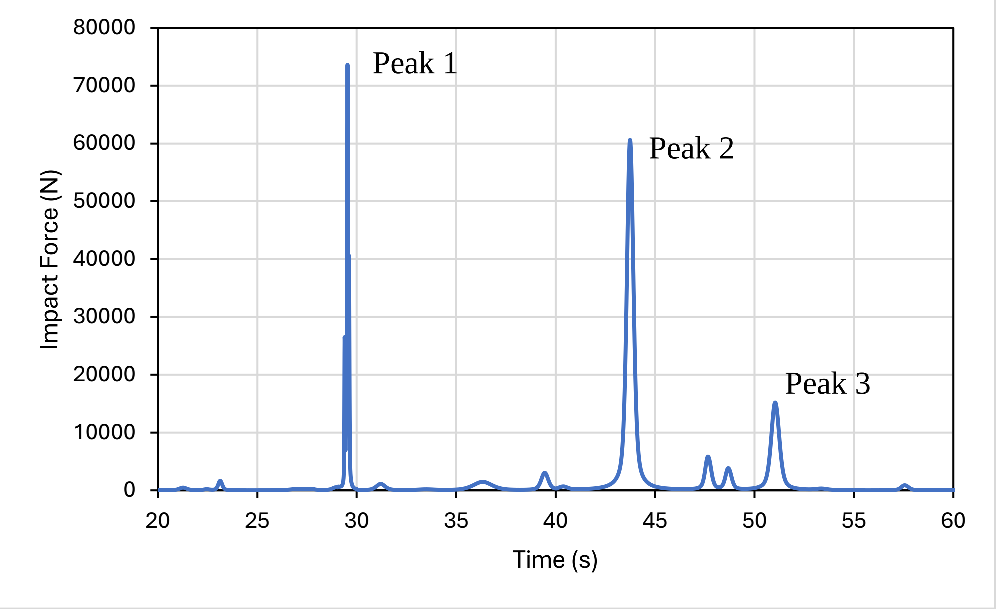

Fig. 4. The wave impact forces after progressing for 60 s

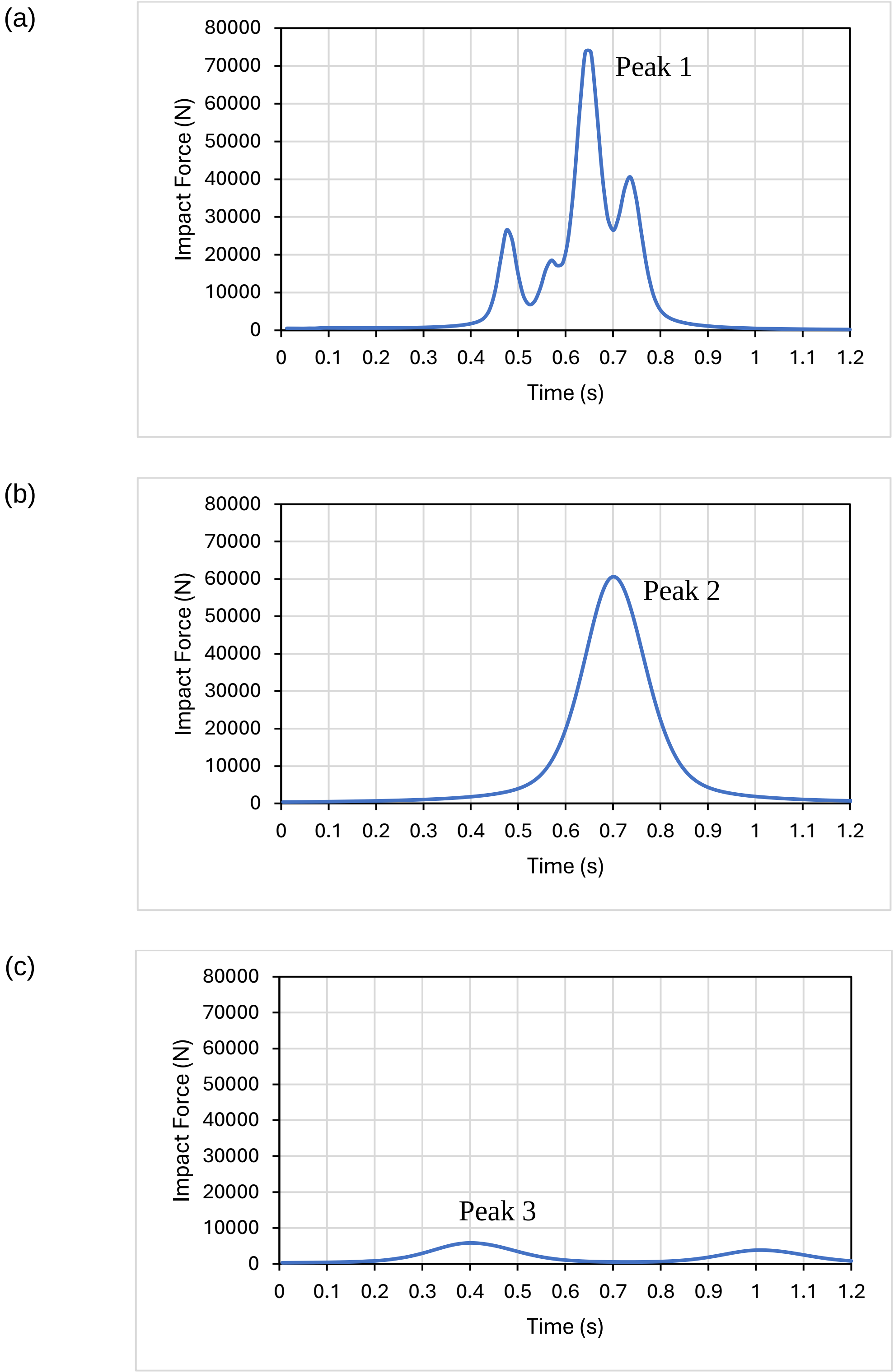

Fig. 5. The incident wave height for Peak 1 (a), Peak 2 (b) and Peak 3 (c) in the same time duration of 1.2 s

The design of the wave breaker mould is crucial as it determines the shape and interlocking capabilities of the final wave breaker product (i.e. the plastic waste bricks). This design uses the concept of stacking mould, which produces a two-cylinder structure that interlocks with others to form a sturdy barrier against waves, as shown in **Fig. 6.** The cylinder shape of the stacking mould allows water to flow around rather than against it, effectively dissipating wave energy and reducing displacement due to its interlocking nature [19-20]. This 3D-printed wave breaker mould significantly enhances the compressive strength efficiency of traditional cylindrical moulds. The wave breaker design improves mechanical interlocking and stress distribution, resulting in enhanced load-bearing capacity. **Fig. 7** shows the compressive strength of plastic bricks using cylinder-shaped mould at various curing day intervals. The highest compressive strength of 29.76 MPa was found after 28 curing days. **Fig. 8** shows a significant increase in compressive strength for the plastic bricks, with the highest compressive strength of 78.80 MPa found after curing days for 28 days using 3D-printed wave breaker mould. These findings indicate that plastic bricks produced with wave breaker moulds can exhibit up to 30% (as shown in **Fig. 9**) higher compressive strength than those with cylindrical moulds. This increase is due to the optimised geometry, which better resists deformation and evenly distributes forces.

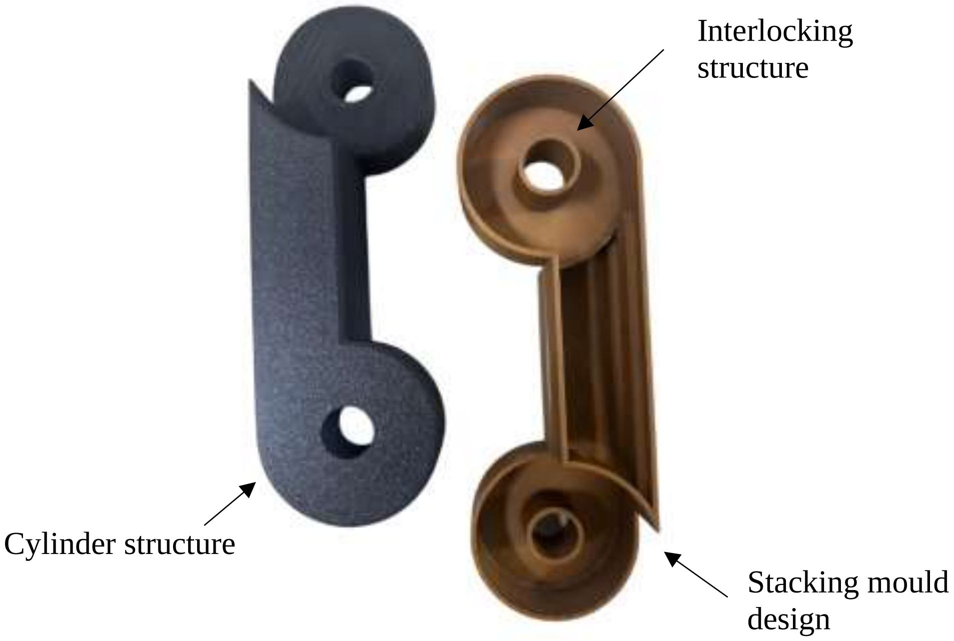

Fig. 6. The 3D-printed wave breakers are designed based on three criteria

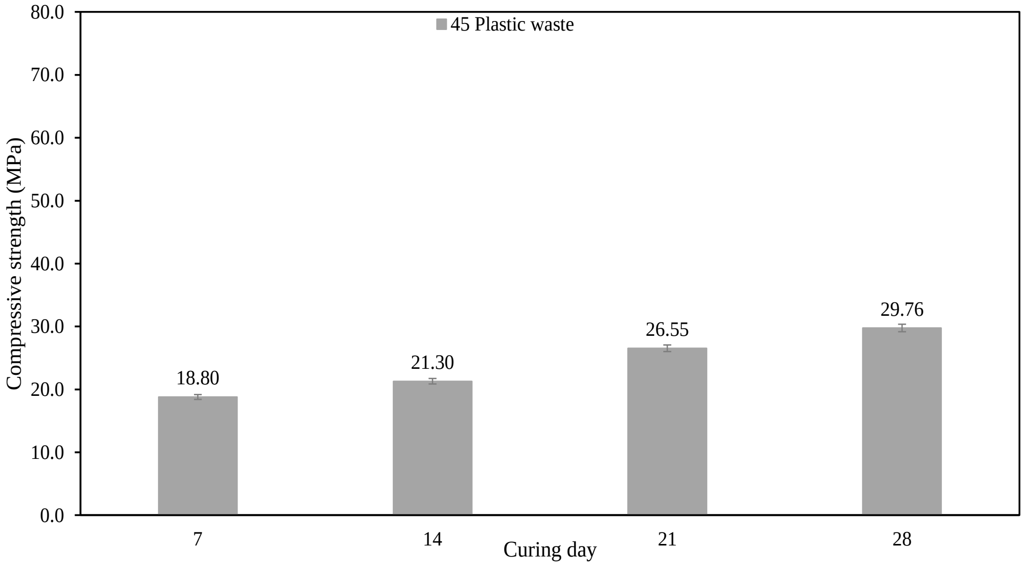

Fig. 7. Compressive strength of the plastic bricks using cylinder-shape mould

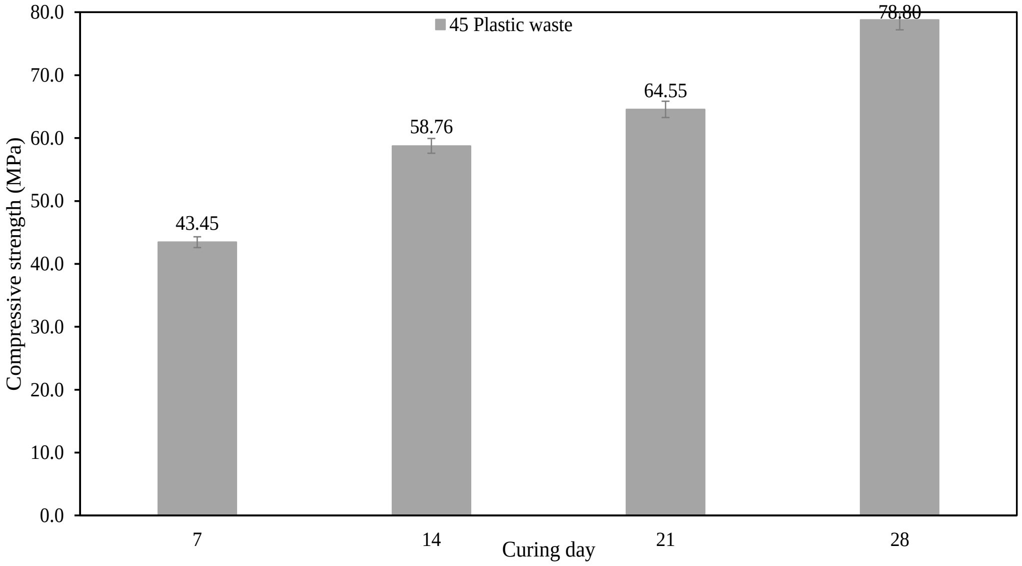

Fig. 8. Compressive strength of the plastic bricks using 3D-printed wave breaker mould

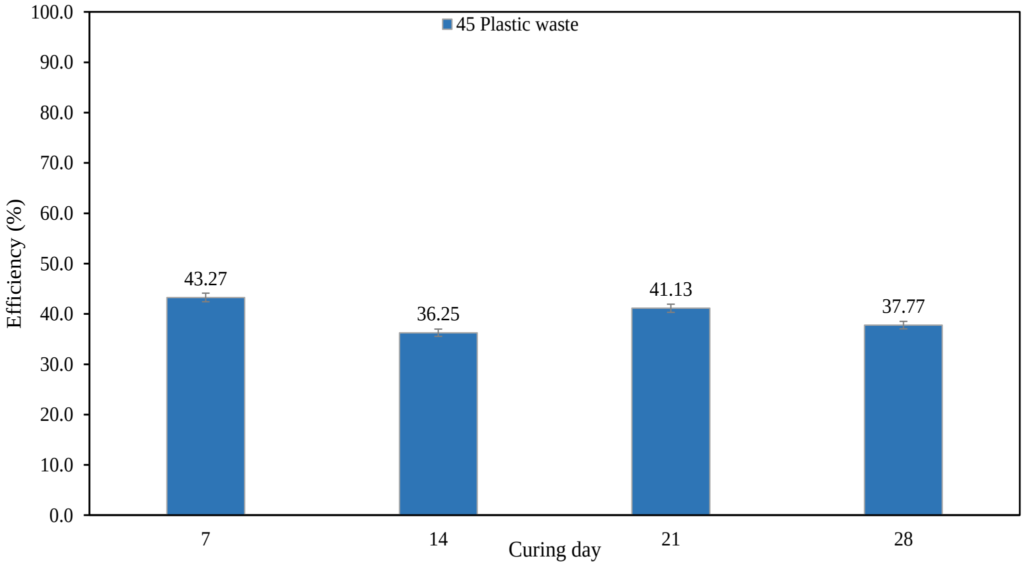

Fig. 9. The increased efficiency of compressive strength using 3D-printed wave breaker mould compared to cylinder shape mould

The impacts of the innovation, i.e. 3D-printed mould for sustainable plastic bricks proposed as an alternative design for wave breaker fabrication include:

a) Cost efficiency: 3D printing technology can reduce the cost and time required to produce wave breaker moulds.
b) Design flexibility: Complex and intricate designs that are difficult to achieve with conventional methods can be created. This allows for the optimisation of wave breaker designs for better performance.
c) Environmental friendly: It allows for the use of materials that can be recycled or are biodegradable.
d) Customisation: Each mould can be easily customised to meet specific requirements, beneficial for experimental designs or regions with unique coastal characteristics.

Albeit the aforementioned advantages of the 3D-printed mould for sustainable plastic bricks, a suggestion for improvement is proposed to increase the feasibility of the mould. It is suggested that suitable surface modifications might reduce the impact of wear, friction, and heat, thereby increasing mould life and performance. This can lead to longer-lasting moulds that require less frequent replacement.

CONCLUSIONS

In conclusion, using 3D-printed moulds for wave breakers can lead to innovations in coastal engineering, potentially improving the efficiency and effectiveness of wave energy dissipation and offering economic and environmental benefits.

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