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Lightweight rPPU Eco-block Using Recycled Plastic (rP) and Polyurethane (PU) for Soft Subgrade Soil Stabilisation

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Abstract

The stability of the soil plays a crucial role in the safety and longevity of various civil engineering structures. However, problematic soil conditions, such as clay soil and peat soil, often pose challenges due to their high-water content, poor strength, low bearing capacity, and high compressibility. This research focuses on addressing these challenges by utilizing lightweight fill materials as an effective solution for backfilling applications. The study aims to investigate the characteristics and performance of a novel lightweight fill material using recycled plastic (rP) and polyurethane (PU) known as rPPU ecoblock. The eco-block is mainly fabricated using recycled plastic bottles, recycled plastic packaging, and polyurethane, offering a sustainable approach to waste management and construction materials. To achieve the research objectives, a series of experiments will be conducted. The strength and density of plastic bottles filled with recycled plastic packaging will be analyzed, providing insight into their mechanical properties. Furthermore, the water absorption and buoyancy of the lightweight rPPU eco-block are evaluated, considering its suitability for various construction scenarios. The research findings contribute to the understanding of the physical and mechanical characteristics of the rPPU eco-block, providing valuable information for its potential application as a backfill material. The compressive strength, water absorption, and buoyancy tests conducted per ASTM standards provide quantitative data on the eco-block's performance. The use of lightweight fill materials, particularly the rPPU eco-block, offers benefits such as reduced embankment self-weight, improved stability, and minimized environmental impact. Moreover, the recycling of plastic waste contributes to the circular economy and aligns with sustainable development goals (SDG): SDG9 and SDG11. The results of this research provide valuable insights for engineers, construction professionals, and stakeholders involved in geotechnical and civil engineering projects.

1. Introduction

In the realm of civil engineering, the stability of soil plays a critical role in ensuring the safety, stability, and longevity of various structures, including foundations, buildings, embankments, and others. However, there are instances where the natural soil conditions pose significant challenges, particularly in areas with problematic soil.

Such problematic soil can be prone to settlement, and erosion, or have a poor load-bearing capacity, making it unsuitable for construction projects [1] In recent years, numerous soil stabilizers have been developed and emerged as effective solutions to address these issues by considering both the load imposed by the structure itself and the ground condition underneath. It can be achieved by modifying the embankment load, utilizing concrete slabs under the embankment [2] implementing a nailed-slab system [3], using lightweight fill materials [4], and enhancing structural support through pile support [5].

One promising approach is the use of lightweight fill materials, particularly in problematic soil conditions, which effectively reduce the overall embankments self-weight. There are various benefits of using lightweight fill materials. By doing so, the stress on the underlying soil is alleviated, reducing settlement issues and improving the overall stability of the embankment [6].

Additionally, the use of lightweight fill materials can lead to cost savings. Since these materials are lighter, they require less energy and resources for transportation, handling, and construction. This can result in reduced construction costs and shorter construction timelines [7].

In the past few years, there has been a growing trend in the civil engineering industry to utilize various by-products as lightweight fill materials, such as expanded polystyrene [8], blast furnace slag [9], waste tires [10], lightweight aggregates [11], and plastic waste [12]. The use of these by-products aligns with the circular economy and sustainable development. It helps divert waste from landfills, reduce resource consumption, and minimize the environmental impacts of traditional construction materials.

Since the mid-twentieth century, plastic materials have been critical to the advancement of science, technology, and nearly all facets of modern progress. According to the National Oceanography Centre (2022), every year, about 300 million metric tons of plastic are generated, 10 million of which end up in the water stream. The European Commission released the EU Strategy for Plastics in the Circular Economy in 2018 to tackle this problem. It outlines the key objectives for plastic design, production, usage, re-use, and final disposal by 2030 [13]. Since plastic products have a relatively short lifespan and a high demand [14], plastic has become a part of everyday life, and its disposal is one of the biggest environmental issues. Plastic harms the environment throughout both the production and disposal processes.

Reusing plastic bottles in the construction sector has been regarded, and there are existing studies on productive brick [15], replacing concrete [16], and flake aggregate replacement [17]. However, the use of plastic bottles themselves as a supplement to conventional building materials has received a lot of attention, but little research has been done to determine whether the bottles themselves can be used in construction or not, and there is even less effort to characterize such solutions. Despite that, there are still research studies on the use of plastic bottles as building materials such as eco-brick for construction purposes [18]. It is critical to learn more about the physical and mechanical characteristics of eco-block since there is a growing tendency to see them as a solution for two connected issues: recycling inorganic waste materials and affordable sustainable structures.

In this study, a series of basic experiments are performed to analyze the correlation between the strength and density of plastic bottles filled with plastic waste, tire waste, and sand. A laboratory-scale model of a lightweight rPPU eco-block is also built to study its characterization on Eco-blocks, which are simply empty mineral bottles filled with waste plastic bags and plastic packaging. Following an analysis of the trial findings, it is decided if the lightweight rPPU eco-block should be used as a soft subgrade soil stabilization.

2. Materials and Methods

The subsequent stage involves the material collection and preparation as well as the fabrication of the rPPU eco-block. In the initial fabrication phase, the plastic bottle is prepared by filling it with sand and two waste materials respectively: plastic waste and rubber tires. The performance evaluation of the bottle focuses on density, Young's Modulus, and compressive strength.

The next stage involved the preparation of the rPPU eco-block using the plastic bottle that was previously prepared. The void space between the bottles will be filled with PU. Finally, the performance of the rPPU eco-block as a lightweight fill material for road embankments or slopes will be evaluated through water absorption, density, buoyancy, and compressive strength. The findings obtained from these studies will provide conclusive evidence regarding the viability of the rPPU eco-block as a lightweight, sustainable, and cost-effective fill material, relative to existing lightweight fill materials such as sawdust, fly ash, blast furnace slag, and waste tires.

The physical model testing as shown in Fig. 1 will be prepared according to the proposed size. The proposed size of the fabrication rPPU eco-block is 205 × 205 × 205 mm and will be used for the rPPU eco-block. The plastic bottles will be filled with filler material and subsequently placed within the fabrication rPPU eco-block. The mold will accommodate a total of 3 × 3 plastic bottles, so there will be 9 plastic bottles containing filler in one fabrication rPPU eco-block. Prior to the final product, any void between bottles was filled with PU.

For the preparation of PU to fill the void, 300g of PU was needed for each rPPU eco-block. The PU was mixed with 30g of distilled water (10% of the PU weight) until the color of the PU was slightly changed to light yellow. It can expand about 3000% when reacting with water. After the color changes, immediately pour the PU into the mold that has been filled with bottles. For the PU foam to fully expand, at least took 10 minutes.

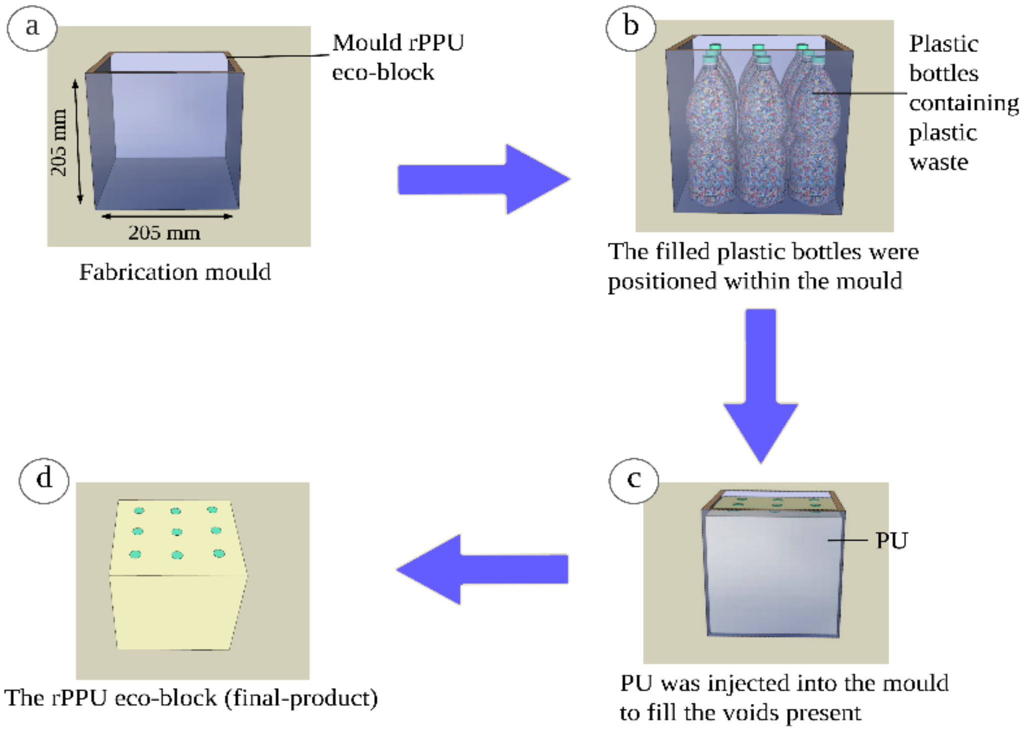

Fig. 1 *The process of preparation of the rPPU eco-block*

3. Result and Discussion

3.1 Density Measurement

Tables 1 and 2 outline the density of both bottle-filled plastic and the rPPU eco-block, respectively. The bottle-filled plastic samples were prepared with densities of 0.25, 0.35, 0.40, and 0.55 g/cm^3, corresponding to weights of 125, 175, 225 and 275, respectively. While, the densities of the 205 mm times 205 mm rPPU eco-block are 0.17, 0.22, 0.28, and 0.34 g/cm^3 respectively. Notably, a decrease in density was observed in the block samples. This contributes to the overall lower density of the block. Moreover, it was shown that the density of rPPU eco-block increases linearly with the quantity or amount of bottle-filled plastic used in its composition.

Table 1 *Density measurement for bottle-filled plastic*

	Sample code / Properties	125g	175g	225g	275g
Bottle-filled plastic	Mass (g)	125	175	225	275
	Volume ml (cm^3)	500 (500)	500 (500)	500 (500)	500 (500)
	Density (g/cm^3)	0.25	0.35	0.45	0.55

Table 2 *Density measurement for rPPU eco-block*

	Sample code / Properties	125 rPPU	175 rPPU	225 rPPU	275 rPPU
rPPU eco-block	Mass (g)	1.334	1.792	2.248	2.684
	Volume ml (cm^3)	7985.25 (7985.25)	7985.25 (7985.25)	7985.25 (7985.25)	7985.25 (7985.25)
	Density (g/cm^3)	0.17	0.22	0.28	0.34

3.2 Water Absorption Test

Water absorption test results are presented in Fig. 2. When observing the graph, the most identical was observed, all the samples had a similar percent of intake water, where the average value is 17.29%. The sample with the lowest water absorption is 0.28 g/cm^3 at 17.26% while 0.17 g/cm^3 has the highest water absorption at 17.32%, followed by 0.22, 0.34, and 0.28 g/cm^3 at 17.30%, 17.29%, and 17.26%, where the difference is not significant for these three samples. From the same figure, the lower the density, the lower the water absorption ability. The finding was noted in a past study by Beju and Mandal, (2017), where the water absorption of EPS geofoam decreased as its density increased. The rPPU eco-block showed higher water absorption ability even though the density was nearly the same. The main material for the sample is plastic bottles, which do not absorb water at all. The material that absorbs the most water is the PU foam, which is about 17.29%.

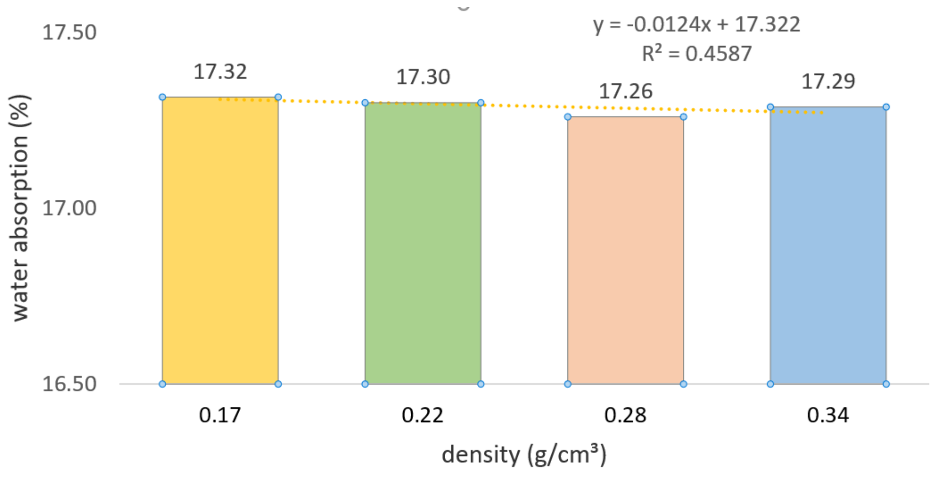

Fig. 2 *Water absorption for 24 hours*

3.3 Buoyant Force

Archimedes' principle was carried out to determine the buoyant force for the rPPU eco-block. From Fig. 3, as the density of the rPPU eco-block increases, so does the magnitude of the buoyant force. It confirms a positive correlation between density and buoyant force, suggesting that a higher density rPPU eco-block displaces more fluid and experiences a greater buoyant force. The rPPU eco-block has a density that is less than half that of water, buoyant forces will be present if the eco-block is immersed. This might be a big issue for an application like fill material for river embankments; if river banks increase, buoyant forces can push the eco-block higher, causing disturbance and collapse of the pavements and buildings above [19].

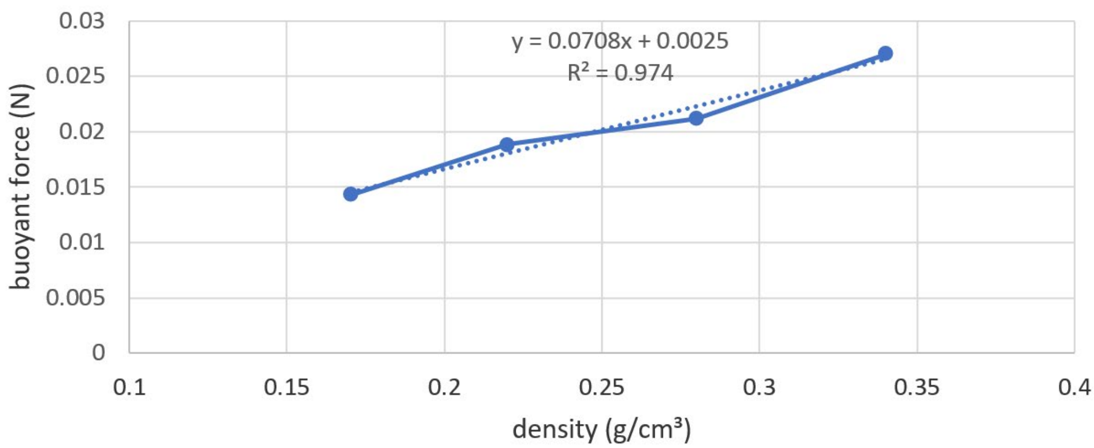

Fig. 3 *Linear relationship between the density the density of rPPU eco-block*

3.4 Strength Characteristics of rPPU Eco-block

Fig. 4 shows the effect of rPPU eco-block at different densities on compressive strength. The results indicated better vertical orientation for the rPPU eco-block. The results also showed that the compressive strength significantly increased with the increase in density of the rPPU eco-block. Besides, this indicated that different densities had influenced the compressive strength of the sample. The Young's modulus of the rPPU eco-block is shown in Fig. 5. The relationship between Young's Modulus and density is not straightforward and depends on the material being considered. However, in general, the Young's modulus of a material tends to increase with increasing density [20].

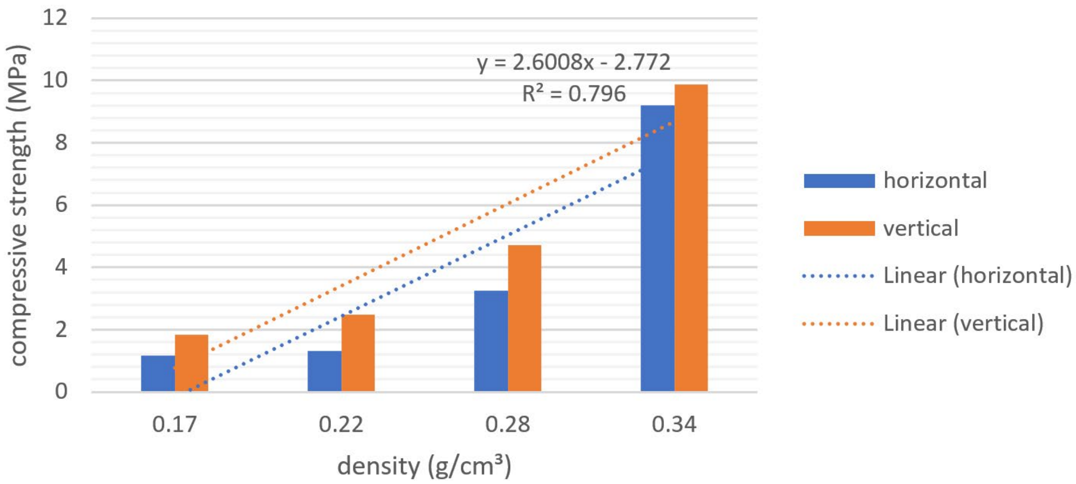

Fig. 4 *Compressive strength at different densities*

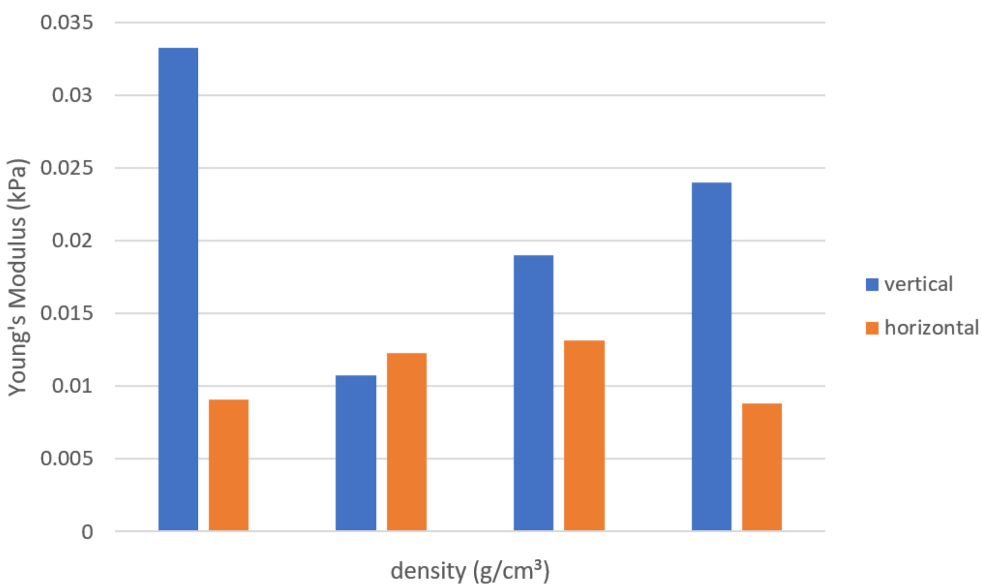

Fig. 5 *Young's Modulus for variation densities and orientation*

4. Conclusion and Recommendation

- The density determination revealed a linear increase in the density of rPPU eco-block with the increase in EcoFiller. As EcoFiller content rose, the density of the rPPU eco-block consistently increased.
- Water absorption tests demonstrated a consistent pattern across samples, showing similar percentages of water intake. The plastic bottles, comprising the main material, exhibited negligible water absorption. PU foam within the samples absorbed the most water at approximately 17.29%.

- Analysis based on Archimedes' principle indicated a direct correlation between the density of rPPU eco-block and the buoyant force. Higher-density blocks displaced more fluid, resulting in increased buoyant forces, showcasing a positive relationship between density and buoyant force.
- Observations from compressive strength tests illustrated improved vertical orientation for the rPPU eco-block. The results indicated a significant enhancement in compressive strength corresponding to the density increase in the rPPU eco-block. Different densities exerted varying influences on the sample's compressive strength.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm their contribution to the paper as follows: ***study conception and design:*** *Akma Qistina, Tuan Noor Hasanah, Roslinda;* ***data collection:*** *Akma Qistina;* ***analysis and interpretation of results:*** *Akma Qistina, Tuan Noor Hasanah;* ***draft manuscript preparation:*** *Akma Qistina, Tuan Noor Hasanah. All authors reviewed the results and approved the final version of the manuscript.*

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