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Utilising Different Ratios of Plastic Waste Composition to Produce an Ecobrick as a Sustainable Building Material

Sharon Ting Shu Sze[1], Roslinda Ali[1,*], Noraini Marsi[2], Mimi Suliza Muhamad[1], Nor Hazren Abdul Hamid[1], Hasnida Harun[1], Muhammad Bakhtiar Azni[3]

1 Department of Civil Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Panchor, 84600 Muar, Johor, Malaysia
2 Department of Mechanical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Panchor, 84600 Muar, Johor, Malaysia
3 SWM Johor North Regional Office, SWM Environment Sdn. Bhd., 83300 Batu Pahat, Johor, Malaysia

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ABSTRACT

One of the most important building materials in construction is brick. Nevertheless, the production of brick brings more disadvantages than advantages to the environment and human health. Ecobrick has been identified as one of the tools that can be used as a sustainable building material in construction. In general, an ecobrick is a recycled Polyethylene Terephthalate (PET) plastic bottle filled with mixed inorganic waste such as used plastic, packaging or other wastes to a set density. The aim of this research is to determine the best ratio of plastic waste in PET bottles to produce ecobrick as a construction material. This research was conducted to evaluate the strength of the different density ratios of plastic waste in PET bottles in terms of compressive strength, drop impact resistance and flexural strength. A total of seven ecobrick samples with density ratios of 0 g/ml, 0.15 g/ml, 0.25 g/ml, 0.35 g/ml, 0.45 g/ml, 0.55 g/ml and 0.65 g/ml were prepared. The samples were tested using compressive tests, drop tests, flexural tests and failure analysis. The tests revealed that the optimum density ratio of an ecobrick is 0.45 g/ml. Subsequently, 3-unit and 6-unit blocks were developed to test the strength of the ecobrick with a density ratio of 0.45 g/ml. This was done to investigate the feasibility of ecobrick as a construction material. The compressive strength for the 6-unit ecobrick was 9272.13 N while the compressive strength for the 3-unit ecobrick was 3649.03N. It can thus be concluded that a combination of ecobrick units provides greater compressive strength which makes it suitable as construction material.

1. Introduction

Construction is the process of assembling and erecting structures, mainly those that function to provide shelter and protection in ancient times [1]. As time went by, the construction industry expanded into large structures such as road construction, railway development, house design and so on [2]. This indicates that the construction industry brings a lot of advantages to a nation and its

* *Corresponding author*
E-mail address: linda@uthm.edu.my

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citizens. The construction industry plays a vital role in stimulating economic growth. It creates job opportunities, generates revenue and contributes to the overall gross domestic product (GDP) of a country [3]. In addition, the construction industry also boosts the development of infrastructure by building and maintaining essential infrastructure such as roads, bridges, airports, railways, schools, hospitals and residential buildings. These structures provide a foundation for economic activities and social development, improving the quality of life for communities. Therefore, it cannot be denied that the construction sector is a significant source of employment.

According to the Malaysian Public Works Department [4], brick is one of the most important building materials in construction. Bricks are used for a wide range of construction projects, including walls and structural elements because of their long-term performance in terms of their strength, efficiency, durability and to ensure a wholesome and cosy environment [5]. There are various types of bricks available on the market, each with its own characteristics and uses. The choice of brick type depends on factors such as intended application, aesthetic preferences and environmental considerations. Some common types of bricks include common bricks, fire bricks and lightweight bricks. In general, common bricks are the most basic and standard type of bricks used in construction projects such as walls, foundations or decorative elements.

Nevertheless, even though the use of brick in the construction industry is advantageous, it also has some inherent disadvantages to the environment and human health, primarily due to the resource-intensive nature of brick manufacturing. Brick production requires natural resources such as clay, shale and other raw materials. The extraction of these materials can lead to habitat destruction, soil erosion, loss of biological diversity and the depletion of non-renewable resources [6]. In some regions, wood or other biomass materials are used as fuel in traditional brick kilns, leading to deforestation and loss of biodiversity. In terms of human health, during the production of bricks, dust and airborne particles may be released. There is strong evidence that particulate matter (PM), carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) are public health concern [7]. Prolonged inhalation or exposure to high levels of these particles can irritate the respiratory system and potentially lead to respiratory problems, particularly for individuals with pre-existing respiratory conditions.

As brick has been found to have negative effects on the environment and human health, research studies have been conducted by scholars over the years to find alternative materials that can be used to produce brick. Most of the past research has used waste materials in the production of bricks. Among the waste materials used include waste clay bricks [8], autoclaved aerated concrete brick trash [9], cement kiln dust and grated polystyrene [10], agricultural waste [11-14], cigarette butts [15,16], glass waste [17-19] and plastic waste [20-22]. In general, these researchers found that waste materials can be used to produce brick. Bricks made from waste materials provide greater strength and performance than conventional bricks. For example, bricks made from plastic waste have a greater compressive strength at 8.16 N/mm^2 compared to conventional soil bricks with a compressive strength of 2.16 N/mm^2 [23].

Meanwhile, studies have been conducted on the use of plastic PET bottles to replace brick as a construction material. These researchers used different types of inorganic waste materials as filler content to produce PET bottle brick or also known as ecobrick. Some of the inorganic waste filler content materials used include plastic waste [24], sand or soil [25-27] and waste glass [17-19]. To date, the use of only plastic waste as filler content material in producing ecobrick is minimal and almost non-existence. The strength properties of ecobrick with plastic waste filler content have only been proven in simulation studies by Lim *et al.,* [28] and Ali *et al.,* [29]. Even though plastic waste is a widely used material in any industry due to its elasticity and durability, it takes approximately 450 years to biodegrade [30]. Therefore, this study aims to investigate the feasibility of ecobrick produced using plastic waste as construction material. It is hoped that at the end of this study, not only an innovative solution to produce a cheaper, environmentally friendly and competent brick can be achieved, but the problem of the increasing amount of plastic waste disposed of in landfills can also be addressed.

1.1 Ecobrick

Ecobricks are recycled Polyethylene Terephthalate (PET) plastic bottles filled with mixed inorganic waste such as used plastic, packaging or other types of waste to a set density [31]. Ecobricks serve as reusable basic components to create a wide range of products such as furniture, walls and other construction structures. Besides, ecobricks are a low-cost building material that can also be recycled to reduce waste disposal in places where industrial recycling is still lacking. As a result, ecobricks have driven the innovation and technology that support a clean future for our nation. The potential of ecobricks which give value to something that is once worthless is a step away from the outdated paradigm of waste and garbage.

The concept of ecobricks was founded in 2000 by a German architect Andreas Froese, who used sand as filler material in PET bottles [32]. Froese discovered 10,000 bottles as he volunteered to clean up after an event in Honduras. He introduced the initial plastic bottle house project in the village of Yelwa, Nigeria. Since then, he has built parks, schools, residences, water reservoirs and other structures out of plastic bottles filled with sand. Since then, the use of ecobricks as a sustainable building material has become an inspiration to the world.

Furthermore, the use of ecobricks has also been initiated in Guatemala, through the Philippines to South Africa by an environmental activist, Susanna Heisse. Heisse was outraged by the amount of plastic trash surrounding Lake Atitlán in Guatemala and she later found that ecobricks could be a solution towards reducing plastic pollution [33]. Heisse used them to construct a wall, which served as an example to people all across the world. Through this project, Hug It Forward, Vida Atitlan (Susanna's organisation) and other groups have already built 38 ecobrick schools in Guatemala and many more are being planned.

1.2 Compressive Strength Test

Compressive strength refers to the capacity of a material to withstand pushing forces from an axial direction without any crack or deflection [34]. With the aid of a compression testing machine, a compression strength test is performed on bricks to evaluate their load-carrying capacity. The compressive strength test is a fundamental indicator for building units from a material’s flexibility, workability and load-displacement properties. The minimum permissible average compressive strength is 5.2 N/mm2 for bricks and 2.8 N/mm^2 for hollow blocks per 10 samples chosen randomly from the Contractor’s stock pile of 1000 or part thereof [4].

1.3 Drop Test

An impact strength test is usually used to determine the performance of bricks on site. Various forms of impact tests can be conducted to measure the impact resistance of bricks such as drop-height test, drop-weight test, projectile impact test, instrumented pendulum impact test and weighted pendulum Charpy-type impact test [28]. In general, a drop-weight impact test is recommended to determine the strength of the tested material as it is the easiest, most straightforward and most cost-efficient method [35]. The drop test determines an object’s ability to withstand a defined amount of physical impact by dropping it from a specified height onto a hard surface or floor [36]. During the drop test, the tested material should maintain its shape after dropping on the ground surface without any damage.

1.4 Flexural Test

Flexural strength is one of the parameters to indicate how strong a material is against breaking or cracking under bending stress. When force is applied in tension or compression, a material with high flexural strength may sustain bending, stretching, twisting and other forms of stress without deforming [37]. Flexural test findings for bricks are represented as a rupture modulus, abbreviated as (MR) in megapascals (MPa) or newtons per square millimetre (N/mm²). Either the three-point load test (ASTM C78) or the centre point load test can be used to perform flexural tests on brick (ASTM C293) [38]. For example, ASTM C78 is typically used for smaller specimens while ASTM C293 is used for larger specimens. It should be noted that taking into account the bigger size of specimen's results in a low modulus of rupture. Additionally, the modulus of rupture accounts for 10-15% of the material's compressive strength.

1.5 Failure Analysis

Failure analysis is a process of collecting, identifying and investigating the reason for a failure to prevent similar failures for the next generation [39]. A comprehensive failure analysis needs to present a well-supported chain of evidence that either rebuts or supports a potential analysis of the damage evidence. The most important rule in identifying the existing cause of problems is analysing the cause of failures. Subsequently, the problems are be determined and suitable recommendations can be proposed for changes that cannot be avoided [40]. Some of the general failure analysis techniques that have been implemented include root-cause failure analysis (RCFA), failure modes and effects analysis (FMEA), fault tree analysis (FTA) and hazard and operability study (HAZOP). One of the most common failure analysis techniques that can be applied in this study is the root cause failure analysis (RCFA) [41].

2. Methodology

2.1 Determination of Different Density Ratios of the Sample Size

A literature search was carried out to determine the density ratios of the sample size. For the literature search, past studies were analysed in terms of the density ratio of sample size and research methodology. A table was constructed to compare how previous studies selected their samples to conduct experimental work. This information was used to determine the optimum sample size for this research.

From the literature search conducted, the density ratios from Lim *et al.,* [28] and Ali *et al.,* [29] were adopted as sample size. Firstly, both studies used a range of density ratios as their sample size. In contrast to other studies, the sample size is determined based on the weight of the bottle and the percentage of plastic waste as a filler content. The use of density ratio for calculating the mass of an ecobrick is a more accurate measure of its strength than the weight of the bottle or the percentage of plastic waste [42]. This is because density ratio takes into account the volume of the bottle as well as the weight of plastic waste. A higher density ratio indicates a stronger ecobrick [43]. Therefore, density ratio is used to determine the sample size in this research. A total of seven samples of ecobricks with different density ratios were prepared. A summary of the samples used in this research is shown in Table 1.

Table 1
Preparation of samples

Sample	Density ratio (g/ml)	Weight of sample
A	0.0	15g (empty bottle without plastic filler content)
B	0.15	0.15 g/ml x 500 ml = 75g
C	0.25	0.25 g/ml x 500 ml = 125g
D	0.35	0.35 g/ml x 500 ml = 175g
E	0.45	0.45 g/ml x 500 ml = 225g
F	0.55	0.55 g/ml x 500 ml = 275g
G	0.65	0.65 g/ml x 500 ml = 325g

2.2 Preparation of Ecobrick Samples

After the sample size was determined, ecobrick samples were prepared based on the density ratios that have been identified prior to laboratory testing. The preparation of ecobrick samples consisted of PET bottles and non-biodegradable plastics. In general, the process of making ecobrick samples requires a few steps, the:

i. collection, cleaning and drying of PET bottles
ii. selection of PET bottles
iii. preparation of plastic as filler content
iv. process of making ecobricks. It is important to note that the preparation of ecobrick samples is based on the standard guidelines of ecobrick production from the Global Ecobrick Alliance [43].

In this study, 500ml PET bottles were used to make ecobricks. This is because the size of a 500 ml PET bottle is similar to the size of a conventional brick. The 500 ml PET bottle has a length of 200 mm and a diameter of 65 mm. Meanwhile, the conventional brick measures 190 mm in length, 90 mm in width and 90 mm in height. The bottles chosen to make ecobrick samples come from the same brand.

In terms of filler content, the plastic waste chosen is made up of a mixture of hard and soft plastic such as bottle caps, soap refill packages, grocery bags and biscuit packets. This mixture was used as filler content as hard plastic materials are lightweight but have high impact strength and rigid while soft plastics have low material weight but high impact strength with high recyclability. A mixture of these plastics can result in strong and rigid ecobrick samples. All plastic materials were washed, dried and cut into smaller pieces before being compacted into the PET bottle. A sample of a completed ecobrick is shown in Figure 1.

Fig. 1. Completed ecobrick sample

2.3 Laboratory Testing on Ecobrick Samples

The ecobrick samples with different density ratios underwent laboratory testing to determine their strength and durability as a construction material. Among the laboratory tests conducted include:

i. compressive strength test
ii. drop test
iii. flexural test.

Finally, a failure analysis was carried out on the samples after the laboratory tests.

3. Results and Discussion

3.1 Strength Properties of Different Densities of the Sample Size

3.1.1 Compressive strength test

The graph in Figure 2 shows the average compressive results of seven samples which are A, B, C, D, E, F and G with different density ratios. In Figure 2, the graph shows that there is steady increment in compressive strength as the sample density increases. The trend illustrates that Sample A (density ratio 0 g/ml) has the lowest compressive strength values of 0.39 N/mm^2 whereas Sample G (density ratio 0.65 g/ml) has the highest compressive strength value of 53.09 N/mm^2. The greater the density of the samples, the greater the compressive strength [44].

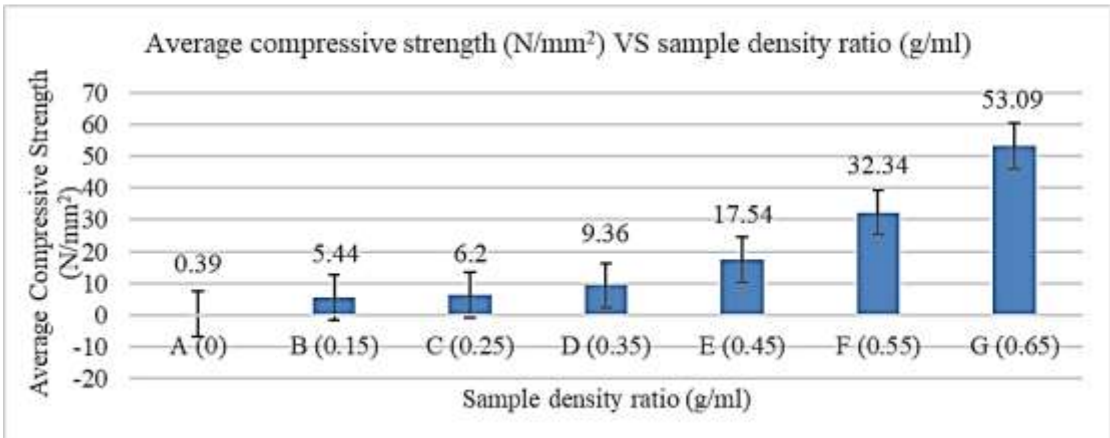


Fig. 2. Graph of average compressive strength against each density ratio of the ecobrick

In terms of failure analysis, the results indicate that Sample A failed more obviously than Sample G. In Figure 3, the samples are arranged from Sample A (left) to Sample G (right). Sample A suffered from great deformation after being compressed. Ecobrick samples with a lower density ratio tend to show higher damage, with more visible fractures and buckling compared to higher density ratio samples. This is likely due to the fact that low-density ratio samples are not able to withstand the given load, resulting in more prominent failure modes. In addition, low-density ecobrick samples may have more voids compared to high-density ecobrick samples due to lower filler content [45].

(a) (b) (c) (d) (e) (f) (g)

Fig. 3. Ecobrick sample after compressive test (a) Sample A (b) Sample B (c) Sample C (d) Sample D (e) Sample E (f) Sample F (g) Sample G

3.1.2 Stress and strain

A stress-strain curve is a graphical representation of the relationship between stress (force per unit area) and strain (deformation) of a material. Figure 4 shows a graph of the yield strength of ecobrick samples at different density ratios. From the results, it can be concluded that Sample G (0.65 g/ml) resulted in the greatest force at 17188.33 N with an elongation of 30 mm in the compression test. Meanwhile, Sample A (0 g/ml) experienced the least elongation with 26.1 mm at 927.21 N.

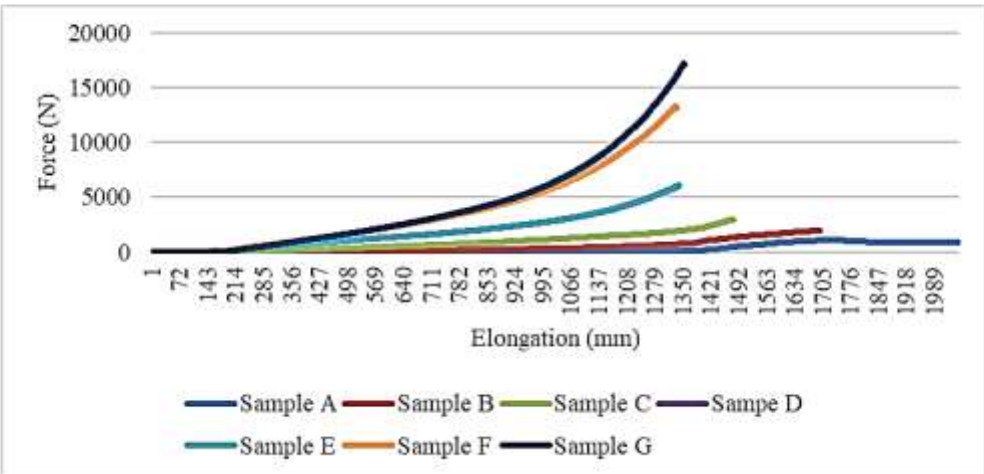


Fig. 4. Stress-strain curve after compressive strength test

3.1.3 Drop test

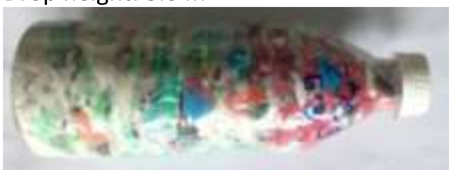
The results of the drop test indicate that the higher the weight of a sample, the better the appearance of the sample after being dropped at the height of 1.0 m, 2.0 m and 3.0 m (Table 2). For Sample A, significant sunken areas were found on the PET bottle after being dropped at a height of 3.0m. In contrast to Samples E, F and G, the bottles did not break and fail on the surface after being dropped from a height of 1.0 m, 2.0 m and 3.0 m respectively. Therefore, it can be said that the more a bottle is compacted thoroughly with plastic waste, the more solid and rigid it becomes.

In terms of failure analysis, at 1.0 m, Sample A showed the most defects on its surface while Sample G showed no defect on its surface. Sample F presented less failure than Sample E, Sample D, Sample C and Sample B. At 2.0 m, Sample A also showed the most defeats on its surface while Sample G showed no failure on its surface. At this height, Sample F also experienced less deformation than Sample E, Sample D, Sample C and Sample B. Last but not least, at 3.0 m, Sample A also showed the most defects on its surface than 1.0 m and 2.0 m, while Sample G showed no failure on its surface even though the drop height increased. The results of failure analysis for Samples A to G are shown in Table 2.

Table 2
Drop test results (a) Samples before drop (b) Samples after drop

Sample	Before drop	After drop
A	Drop height: 1.0 m  (a)	Drop height: 1.0 m  (b)
	Drop height: 2.0 m  (a)	Drop height: 2.0 m  (b)
	Drop height: 3.0 m  (a)	Drop height: 3.0 m  (b)
B	Drop height: 1.0 m  (a)	Drop height: 1.0 m  (b)
	Drop height: 2.0 m  (a)	Drop height: 2.0 m  (b)
	Drop height: 3.0 m  (a)	Drop height: 3.0 m  (b)
C	Drop height: 1.0 m  (a)	Drop height: 1.0 m  (b)

	Drop height: 2.0 m  (a)	Drop height: 2.0 m  (b)
	Drop height: 3.0 m  (a)	Drop height: 3.0 m  (b)
D	Drop height: 1.0 m  (a)	Drop height: 1.0 m  (b)
	Drop height: 2.0 m  (a)	Drop height: 2.0 m  (b)
	Drop height: 3.0 m  (a)	Drop height: 3.0 m  (b)
E	Drop height: 1.0 m  (a)	Drop height: 1.0 m  (b)
	Drop height: 2.0 m  (a)	Drop height: 2.0 m  (b)

	Drop height: 3.0 m  (a)	Drop height: 3.0 m  (b)
F	Drop height: 1.0 m  (a)	Drop height: 1.0 m  (b)
	Drop height: 2.0 m  (a)	Drop height: 2.0 m  (b)
	Drop height: 3.0 m  (a)	Drop height: 3.0 m  (b)
G	Drop height: 1.0 m  (a)	Drop height: 1.0 m  (b)
	Drop height: 2.0 m  (a)	Drop height: 2.0 m  (b)
	Drop height: 3.0 m  (a)	Drop height: 3.0 m  (b)

3.1.4 Flexural test

Figure 5 shows the flexural strength of each density ratio at three different parts of the ecobrick. From the results, it can be said that as the density ratio increases, the body part supports more

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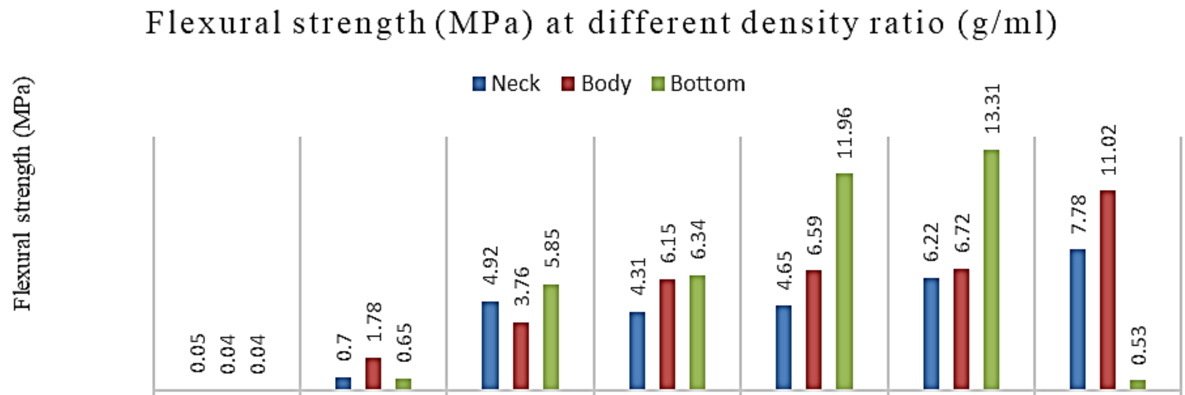
flexural strength than the neck and bottom effectively. In general, the flexural strength of samples with greater recycled filler content is weaker than samples with lower filler content. This is in line with the previous study from Tesfaw *et al.,* [46] that proved that recycled high-density polyethylene scrap (rHDPE) has weaker bond strength than virgin high-density polyethylene (vHDPE) materials. As the molecular weight of virgin HDPE is large, it contributes to very strong bond strength. Therefore, with a higher load, bond strength is allowed to break.



	A	B	C	D	E	F	G
Neck	0.05	0.7	4.92	4.31	4.65	6.22	7.78
Body	0.04	1.78	3.76	6.15	6.59	6.72	11.02
Bottom	0.04	0.65	5.85	6.34	11.96	13.31	0.53

Sample

Fig. 5. Flexural strength (MPa) at different density ratios (g/ml)

The samples are arranged from Sample A (left) to Sample G (right) (refer to Figure 6). Based on Figure 6, in terms of failure analysis, it was observed that Sample E cracked more insignificantly than Samples A, B, C and D. In contrast, Sample F ruptured more than the Sample E. Meanwhile, Sample G deformed more completely than the other sample. The samples cracked and failed at the maximum point after the flexural test. This is because the plastic content in the PET bottle reached the maximum bending point and is unable to provide flexural strength for the PET bottle [47].

(a) (b) (c) (d) (e) (f) (g)

Fig. 6. Ecobrick sample after the flexural test (a) Sample A (b) Sample B (c) Sample C (d) Sample D (e) Sample E (f) Sample F (g) Sample G

3.2 Ecobrick Application

After the optimum density ratio in producing ecobrick is obtained, the ecobrick block was designed in units of 3 and 6 to determine the strength properties of ecobrick as a construction material. Figure 7 shows the force applied to the 3-unit and 6-unit ecobrick blocks. For the 3-unit ecobrick block, the maximum compressive strength was 3649.03 N. Meanwhile, the 6-unit ecobrick block reached a peak force at 9272.13 N. This demonstrates that ecobrick blocks consisting of plastic waste can be used as construction material due to surprisingly high strength [48].

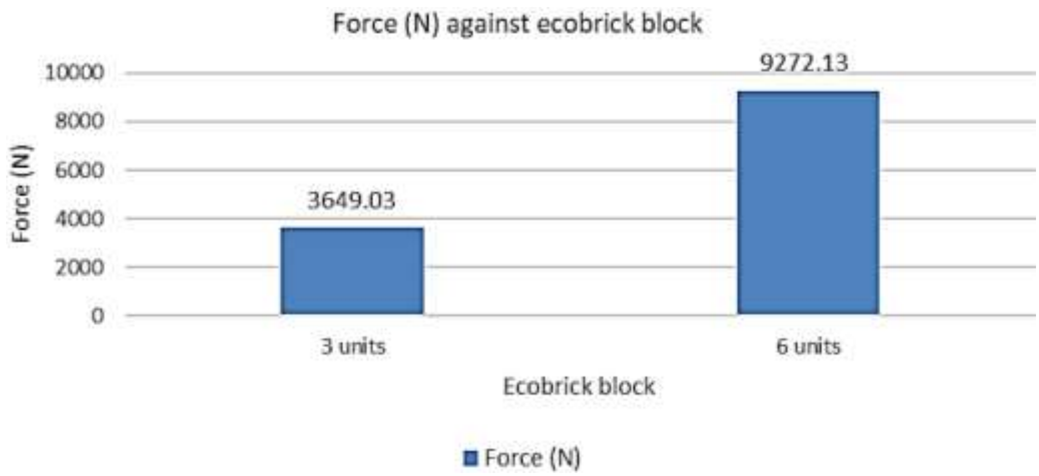


Fig. 7. Ecobrick blocks after compressive test

4. Conclusions

In conclusion, this research has achieved all the objectives of the study. From the research, the optimum density ratio of plastic waste composition to produce an ecobrick as a sustainable building material is 0.45 g/ml, which is Sample E. Based on the overall strength testing, Sample E with a density ratio of 0.45 g/ml reaches a significant flexural value and did not experience breaking or cracking under bending force. Besides, Sample E also obtained a compressive strength of 17.54 N/mm^2 which exceeds the minimum recommended brick compressive strength of 5.2 N/mm^2 as regulated by the Malaysian Public Works Department. Subsequently, ecobrick blocks have been designed in 3 units and 6 units to determine its strength properties as a building material. From the laboratory tests, the 6-unit ecobrick block (9272.13 N) provides greater strength compared to the 3-unit ecobrick block (3649.03 N). As a result, it can be concluded that ecobrick made of plastic waste as a filler content is feasible as construction material. The production of ecobrick is an innovative approach which brings various benefits to the environment and to the society by reducing the use of natural resources and plastic waste disposal in landfills.

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References

[1] Swenson, Alfred and Pao-Chi Chang. *Construction. Encyclopaedia Britannica, 10 January*. 2020.
[2] Dina, El Chammas Gass. “Construction: Definition & Types - Video & Lesson Transcript.” (2022).

[3] Saka, Najim. "An assessment of the impact of the construction sector on the gross domestic product (gdp) of nigeria." *Journal of Surveying, Construction and Property* 13, no. 1 (2022): 42-65. https://doi.org/10.22452/jscp.vol13no1.4

[4] Malaysian Public Works Department. "JRK 20800: Standard Specifications for Building Works." (2005).

[5] Homes. "10 Types of Bricks Used in Construction." Homes247.In. (2020).

[6] Enshassi, Adnan, Bernd Kochendoerfer and Ehsan Rizq. "An evaluation of environmental impacts of construction projects." *Revista ingeniería de construcción* 29, no. 3 (2014): 234-254. https://doi.org/10.4067/S0718-50732014000300002

[7] Manisalidis, Ioannis, Elisavet Stavropoulou, Agathangelos Stavropoulos and Eugenia Bezirtzoglou. "Environmental and health impacts of air pollution: a review." *Frontiers in public health* 8 (2020): 14. https://doi.org/10.3389/fpubh.2020.00014

[8] Hussein, Yasser M., Mohamed Abd Elrahman, Yara Elsakhawy, Bassam A. Tayeh and Ahmed M. Tahwia. "Development and performance of sustainable structural lightweight concrete containing waste clay bricks." *Journal of Materials Research and Technology* 21 (2022): 4344-4359. https://doi.org/10.1016/j.jmrt.2022.11.042

[9] Murthi, P., N. Veda Sri, Mirza Mudassir Baig, Mohammed Abdul Sajid and S. Kaveri. "Development of green concrete using effective utilization of autoclaved aerated concrete brick trash as lightweight aggregate." *Materials Today: Proceedings* 68 (2022): 1599-1608. https://doi.org/10.1016/j.matpr.2022.07.316

[10] Saleh, Hosam M., Aida A. Salman, Abeer A. Faheim and Abeer M. El-Sayed. "Influence of aggressive environmental impacts on clean, lightweight bricks made from cement kiln dust and grated polystyrene." *Case Studies in Construction Materials* 15 (2021): e00759. https://doi.org/10.1016/j.cscm.2021.e00759

[11] Al-Sabaeei, Abdulnaser M., Amin Al-Fakih, Sajjad Noura, Ehsan Yaghoubi, Wesam Alaloul, Ramez A. Al-Mansob, Muhammad Imran Khan and Nura Shehu Aliyu Yaro. "Utilization of palm oil and its by-products in bio-asphalt and bio-concrete mixtures: A review." *Construction and Building Materials* 337 (2022): 127552. https://doi.org/10.1016/j.conbuildmat.2022.127552

[12] Liu, Hua-Yueh, Han-Sheng Wu and Chen-Pei Chou. "Study on engineering and thermal properties of environment-friendly lightweight brick made from Kinmen oyster shells & sorghum waste." *Construction and Building Materials* 246 (2020): 118367. https://doi.org/10.1016/j.conbuildmat.2020.118367

[13] Tayeh, Bassam A., Samir M. Ahmed and Radwa Defalla Abdel Hafez. "RETRACTED: Sugarcane pulp sand and paper grain sand as partial fine aggregate replacement in environment-friendly concrete bricks." (2023): e01612. https://doi.org/10.1016/j.cscm.2022.e01612

[14] Vigneshwar, P. V., B. Anuradha, K. Guna and R. Ashok Kumar. "Sustainable eco-friendly fly ash brick using soil filled plastic bottles." *Materials Today: Proceedings* 81 (2023): 440-442. https://doi.org/10.1016/j.matpr.2021.03.573

[15] Gokulnath, M., P. Hari Krishnan, S. Jayashree, J. Julia Caroline and N. Arun Prakash. "Utilisation of cigarette butts in clay bricks." *Int Res J Eng Technol* 6, no. 3 (2019): 3240-3242.

[16] Kurmus, Halenur and Abbas Mohajerani. "Recycling of cigarette butts in fired clay bricks: A new laboratory investigation." *Materials* 13, no. 3 (2020): 790. https://doi.org/10.3390/ma13030790

[17] Munir, Muhammad Junaid, Syed Minhaj Saleem Kazmi, Osman Gencel, Muhammad Riaz Ahmad and Bing Chen. "Synergistic effect of rice husk, glass and marble sludges on the engineering characteristics of eco-friendly bricks." *Journal of Building Engineering* 42 (2021): 102484. https://doi.org/10.1016/j.jobe.2021.102484

[18] Xin, Yuecheng, Dilan Robert, Abbas Mohajerani, Phuong Tran and Biplob Kumar Pramanik. "Transformation of waste-contaminated glass dust in sustainable fired clay bricks." *Case Studies in Construction Materials* 18 (2023): e01717. https://doi.org/10.1016/j.cscm.2022.e01717

[19] Ursua, John Rogel S. "Plastic wastes, glass bottles and paper: Eco-building materials for making sand bricks." *J. Nat. Allied. Sci* 3, no. 1 (2019): 46-52.

[20] da Silva, Tulane Rodrigues, Afonso Rangel Garcez de Azevedo, Daiane Cecchin, Markssuel Teixeira Marvila, Mugahed Amran, Roman Fediuk, Nikolai Vatin, Maria Karelina, Sergey Klyuev and Maciej Szelag. "Application of plastic wastes in construction materials: A review using the concept of life-cycle assessment in the context of recent research for future perspectives." *Materials* 14, no. 13 (2021): 3549. https://doi.org/10.3390/ma14133549

[21] Hameed, Awham Mohammed and Bilal Abdul Fatah Ahmed. "Employment the plastic waste to produce the light weight concrete." *Energy Procedia* 157 (2019): 30-38. https://doi.org/10.1016/j.egypro.2018.11.160

[22] Kulkarni, Prathik, Vikas Ravekar, P. Rama Rao, Sahil Waigokar and Sanket Hingankar. "Recycling of waste HDPE and PP plastic in preparation of plastic brick and its mechanical properties." *Cleaner materials* 5 (2022): 100113. https://doi.org/10.1016/j.clema.2022.100113

[23] Maneeth, P. D., K. Pramod, Kishor Kumar and Shanmuka Shetty. "Utilization of waste plastic in manufacturing of plastic-soil bricks." *Int. J. Eng. Res. Technol* 3, no. 8 (2014): 530-536.

[24] Ariyani, Dwi, Niken Warastuti and Resti Arini. "Ecobrick method to reduce plastic waste in Tanjung Mekar village, Karawang regency." *Civil and Environmental Science* 4, no. 01 (2021): 022-029. https://doi.org/10.21776/ub.civense.2021.00401.3
[25] Pradha, S. Subha and K. Saranya. "Recycling plastic waste into construction materials for sustainability." In *IOP Conference Series: Earth and Environmental Science*, vol. 1210, no. 1, p. 012016. IOP Publishing, 2023. https://doi.org/10.1088/1755-1315/1210/1/012016
[26] Puri, Vishal, Satyam Kumar, Khushi Grover and Mukul Sharma. "Development of Eco-Friendly Bricks for Sustainable Construction." In *IOP Conference Series: Materials Science and Engineering*, vol. 1248, no. 1, p. 012109. IOP Publishing, 2022. https://doi.org/10.1088/1757-899X/1248/1/012109
[27] Chhazed, Abhishek, Manisha V. Makwana, Neeraj Chavda and Aman Navlakhe. "Utilization of PET waste in plastic bricks, flexible pavement & as alternative constructional material—A review." *Int. J. Appl. Eng. Res* 14, no. 3 (2019): 616-620.
[28] Lim, Mei Chien, Roslinda Ali and Noraini Marsi. "A comparison of properties between eco-brick and lightweight brick by using SolidWorks software." *Progress in Engineering Application and Technology* 3, no. 1 (2022): 104-111.
[29] Ali, Roslinda, Noraini Marsi, Nur Fatin Izzaty Mustafa Kamal, Mimi Suliza Muhamad, Norshuhaila Mohamed Sunar, Hasnida Harun, Nor Hazren Abdul Hamid and Nuramidah Hamidon. "A Study on The Characteristic of An Eco-Brick as A Replacement to The Conventional Brick." *Progress in Engineering Application and Technology* 1, no. 1 (2020): 22-29.
[30] Gammage, Emmanuelle. “How Long Does It Take for Plastic to Biodegrade?” (2022).
[31] Patel, Monalisa. “Eco-Bricks: Much-Needed Solution to Plastic Pollution.” (2021).
[32] Arulraj, Prince, G., Illamathi and Jayashree. “An experimental reasearchon piers made with waste plastic bottles.” *International Journal of Recent Technology and Engineering 8* 1, no. 4 (2019): 1010–13.
[33] Hopkins, Rob. "EcoBricks and education: how plastic bottle rubbish is helping build schools." *Retrieved from theguardian. com: https://www. theguardian. com/lifeandstyle/2014/may/29/ecobricks-and-education-how-plastic-bottle-rubbish-is-helping-build-schools* (2014).
[34] Krishna. “Compressive strength test on bricks and its importance.” *CivilRead*. (2020).
[35] Zhu, Xue-Chao, Han Zhu and Hao-Ran Li. "Drop-weight impact test on U-shape concrete specimens with statistical and regression analyses." *Materials* 8, no. 9 (2015): 5877-5890. https://doi.org/10.3390/ma8095281
[36] Jayaprakash. “Testing Bricks at Site | Quality of Clay Bricks | Visual and Experimental Tests for Quality Bricks.” *CivilDigital*. (2019).
[37] Jamal, Haseeb. “Tests Applied on Bricks.” *Civil Engineering*. (2023).
[38] Hamakareem, Madeh Izat. “Flexural Test on Concrete - Significance, Procedure and Applications.” (2017).
[39] Bose-Filho, Waldek Wladimir, José Ricardo Tarpani and Marcelo Tadeu Milan. "General Aspects of Failure Analysis." (2008). https://doi.org/10.31399/asm.tb.fahtsc.t51130111
[40] Zerbst, Uwe, Christian Klinger and R. Clegg. "Fracture mechanics as a tool in failure analysis—Prospects and limitations." *Engineering Failure Analysis* 55 (2015): 376-410. https://doi.org/10.1016/j.engfailanal.2015.07.001
[41] Hussin, Hilmi, Umair Ahmed and Masdi Muhammad. "Critical success factors of root cause failure analysis." *Indian J Sci Technol* 9, no. 48 (2016): 1-10. https://doi.org/10.17485/ijst/2016/v9i48/90706
[42] Ryan, Michael. “The Relationship Between Mass, Volume & Density.” *Sciencing*. (2022).
[43] Alliance, Global Ecobrick. *Step Guide to Making an Ecobrick| Ecobricks. org*. 10.
[44] Othman, Rokiah, Ramadhansyah Putra Jaya, Khairunisa Muthusamy, MohdArif Sulaiman, Youventharan Duraisamy, Mohd Mustafa Al Bakri Abdullah, Anna Przybył *et al.,* "Relation between density and compressive strength of foamed concrete." *Materials* 14, no. 11 (2021): 2967. https://doi.org/10.3390/ma14112967
[45] Antico, Federico C., María J. Wiener, Gerardo Araya-Letelier and Raúl Gonzalez Retamal. "Eco-bricks: A sustainable substitute for construction materials." *Revista de la Construcción. Journal of Construction* 16, no. 3 (2017): 518-526. https://doi.org/10.7764/RDLC.16.3.518
[46] Tesfaw, Solomon, Teshome Mulatie Bogale and O. Fatoba. "Evaluation of tensile and flexural strength properties of virgin and recycled high-density polyethylene (HDPE) for pipe fitting application." *Materials Today: Proceedings* 62 (2022): 3103-3113. https://doi.org/10.1016/j.matpr.2022.03.385
[47] Al-Darzi, Suhaib Yahya. "The effect of using shredded plastic on the behavior of reinforced concrete slab." *Case Studies in Construction Materials* 17 (2022): e01681. https://doi.org/10.1016/j.cscm.2022.e01681
[48] Jalaluddin, Mohammed. "Use of plastic waste in civil constructions and innovative decorative material (eco-friendly)." *MOJ Civil Engineering* 3, no. 5 (2017): 359-368. https://doi.org/10.15406/mojce.2017.03.00082