Progress in Engineering Application and Technology Vol. 3 No. 1 (2022) 104-111

PEAT

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/peat
e-ISSN : 2773-5303

A Comparison of Properties Between Eco-Brick and Lightweight Brick by Using SolidWorks Software

Lim Mei Chien[1], Roslinda Ali[1]*, Noraini Marsi[2]

[1]Department of Civil Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, MALAYSIA

[2]Department of Mechanical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, MALAYSIA

*Corresponding Author Designation

DOI: https://doi.org/10.30880/peat.2022.03.01.012
Received 17 January 2022; Accepted 11 April 2022; Available online 25 June 2022

Abstract: One of the most common construction materials used in building construction is brick. Even though there are many advantages of using brick in building construction, the production of brick also brings disadvantages to the environment and human health. Eco-brick has been identified as one of the instruments that can be used to replace the use of brick in construction. An eco-brick is a Polyethylene Terephthalate (PET) bottle filled up with mixed inorganic waste such as plastics, foams, packaging, and cellophane. The aim of this study is to investigate the characteristics and properties of an eco-brick as a replacement for a building block. Five samples of eco-bricks with different density ratios (0.15 g/m^3, 0.35 g/m^3, 0.55 g/m^3, 0.75 g/m^3, and 0.95 g/m^3 respectively) together with a lightweight brick control sample were prepared and tested by using SolidWorks software. The samples are tested by conducting the compressive strength test, drop test, and failure analysis. From the result, it can be said that the compressive strength of eco-brick increases as its density increases. In addition, as the density of eco-brick and the drop height increase, the impact strength of the eco-brick also increase. Lastly, it can be concluded that the eco-brick with a density ratio of 0.95 g/m^3 is the best and suitable to be used as a replacement brick because it gives the optimum strength in the compressive strength test and drop test compared to the conventional lightweight brick.

Keywords: Eco-Brick, SolidWorks Software, Density Ratio, Compressive Strength Test, Drop Test

Corresponding author: linda@uthm.edu.my

1. Introduction

Eco-brick has been identified as one of the instruments that can be used to replace the use of brick in construction. According to [1], an eco-brick is a Polyethylene Terephthalate (PET) bottle filled up with mixed inorganic waste such as plastics, foams, packaging, and cellophane which is used as building blocks in construction. The majority of the eco-brick building projects are community-based programs in which the societies cooperate to build educational centers and leisure spaces in Latin America, Africa, and South Asia.

Recent studies have shown that the eco-bricks have several advantages as a replacement for the building blocks. One of the advantages is that the eco-bricks can be used in modular units, furniture, and open spaces in a short term period. Meanwhile, they can also be used to construct earthen gardens and buildings in the long-term period [2]. Besides, the manufacturing process of eco-bricks is simple with regulated weight and packaging. Therefore, the use of eco-bricks helps in minimizing the total cost of building construction. Even though the eco-bricks are lighter than conventional brick, they are strong for the weight they bear [3]. Hence, the wall constructed using eco-bricks is less expensive but more stable than a conventional brick wall. On top of that, the eco-brick walls are lighter, which make them more resistant to earthquakes [4].

Therefore, this study is interested to investigate the characteristics and properties of an eco-brick as a replacement for a building block. In order to achieve the aim of this study, three objectives were formulated. The first objective is to determine the optimum strength of different density ratios of eco-brick as a building block by using SolidWorks software. The second objective on the other hand, is to investigate the failure analysis of different density ratios of eco-brick as a building block by using SolidWorks software. The last objective of the study is to compare the properties of the optimum density of the eco-brick with the conventional brick. Three tests were conducted to achieve these objectives, namely the compressive test, drop test and failure analysis test.

1.1 Compressive strength test

Compressive strength is defined as the highest compressive stress that a material can sustain without fracturing. The equation that is used to determine the compressive strength of brick is stated below [5]:

$$\text{Compressive strength of the brick } (\text{N/mm}^2) = \frac{\text{Maximum load applied to the brick (N)}}{\text{Cross} - \text{sectional area of the brick } (\text{mm}^2)} \quad Eq. 1$$

In general, the past researches that have been conducted on replacement bricks using various waste materials such as stone dust bottle brick revealed that the compressive strength of the replacement brick increases as the size and weight of the brick increases [6], [7].

1.2 Drop test

Impact resistance is a critical property for assessing the dynamic performance of the brick under impact load [8]. Since the impact strength of bricks is vital for assessing their performance, many types of impact tests have been used to determine the impact resistance of brick and other construction materials including drop-weight test, weighted pendulum Charpy-type impact test, constant strain-rate test, projectile impact test, split-Hopkinson pressure bar (SHPB) test, explosive test and instrumented pendulum impact test. As a result, the drop-weight impact test is frequently used due to its straightforward and inexpensive test method to determine the brick's strength [8].

1.3 Failure analysis

Failure analysis is a process of interpreting the implications of unexpected process or product risks and failures [9]. It aimed to determine the actual cause of problems and propose recommendations for changes that would prevent a similar failure in the future. Therefore, there are various common failure analysis techniques have been used, including Failure Modes Effect Analysis (FMEA), Fault Tree Analysis (FTA), Hazard Operability Analysis (HAZOP) and the Root-Cause Analysis (RCA). Among the failure analysis technique, the Root-Cause Analysis (RCA) is commonly used in finding the physical cause of failure, such as human and latent root causes.

1.4 SolidWorks CAD

SolidWorks CAD is a mechanical design automation software that allows designers to map out designs easily, experiment with features and measurements, and generate models, simulations, and informative sketches. A SolidWorks model is made up of 3D solid geometry in the form of a component or assembly file that specifies their edges, faces, and surfaces [10]. After the model is designed, the simulation of the model is conducted by using SolidWorks Simulation to obtain the mechanical properties of the model. SolidWorks Simulation is a simple set of structural analysis tools that employ Finite Element Analysis (FEA) to simulate CAD models and anticipate a product's real-world physical behavior. Finite element analysis (FEA) simulates how a product will react to forces, vibration, heat, fluid movement, and other physical influences in the actual world [11]. In general, the processes required in finite element analysis are stated below:

i. Choose appropriate field variables and elements.
ii. Critique the continuation.
iii. Choose an interpolation function.
iv. Determine the attributes of the element.
v. Assemble element properties to obtain global properties.
vi. Establish the boundary conditions.
vii. Determine the nodal unknowns by solving the system equations.
viii. Perform any extra computations necessary to get the appropriate numbers.

2. Materials and Methods

Five samples of eco-bricks namely Sample A, Sample B, Sample C, Sample D and Sample E with different density ratios (0.15 g/m^3, 0.35 g/m^3, 0.55 g/m^3, 0.75 g/m^3 and 0.95 g/m^3 respectively) were prepared by using SolidWorks software. In addition, a lightweight brick sample acting as a control sample is also designed by using the software. Next, the physical and mechanical properties of an eco-brick were tested by using SolidWorks Simulation. The tests involved are compressive test, drop test and failure analysis. The data obtained are recorded and analyzed by using Microsoft Excel. Last but not least, the optimum eco-brick that has been identified will be compared with the lightweight brick control sample to see its characteristics or properties. The flowchart of the research methodology is presented in Figure 1.

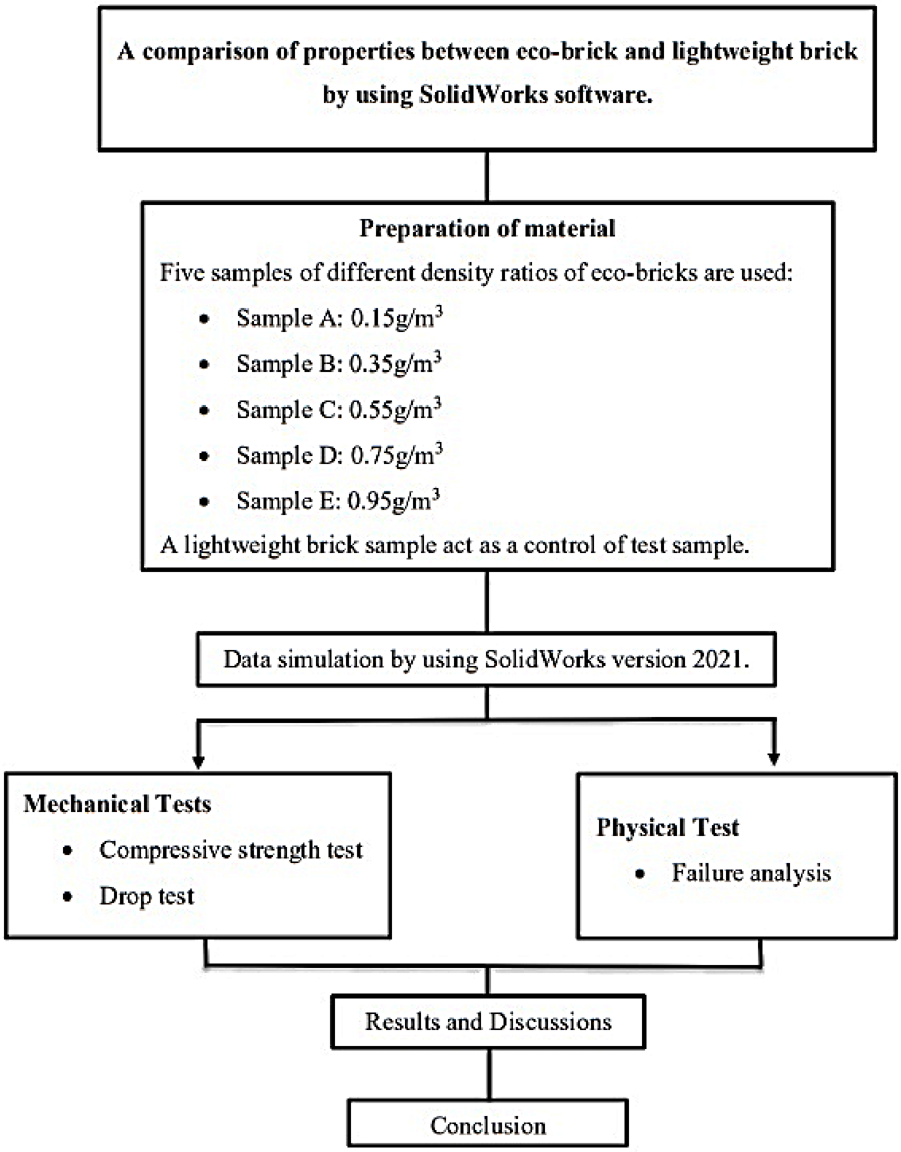

Figure 1: Flowchart of Research Methodology

3. Results and Discussion

3.1 Compressive strength test

Table 1 reveals the compressive test result of five samples which is A, B, C, D and E with different density ratios. The data indicated that samples with higher density ratios have higher values of compressive strength compared to samples with low density ratios. The higher the density of the samples, the higher the compressive strength value.

Table 1: Data of compressive strength test

No	Sample	Density (g/m^3)	Compressive strength (N/mm^2)
1	A	0.15	0.0058
2	B	0.35	0.0059
3	C	0.55	0.0060
4	D	0.75	0.0061
5	E	0.95	0.0062

The graph in Figure 2 shows that there was a steady increase in its strength as the density of the samples increased. Based on the results, it can be concluded that sample E with a density ratio of 0.95 g/m^3 is the best and most suitable to be used as a replacement brick since it has the highest compressive strength value of 0.0062 N/mm^2. This is because eco-brick with a higher density is able to perform better since it has stronger physical and mechanical features such as volume stability, elastic modulus, and elastic-plastic recovery behavior compared to a less dense sample [1]. This finding is also in line with research works conducted by [12] that claimed samples with higher density often has stronger strength and fewer voids and porosity.

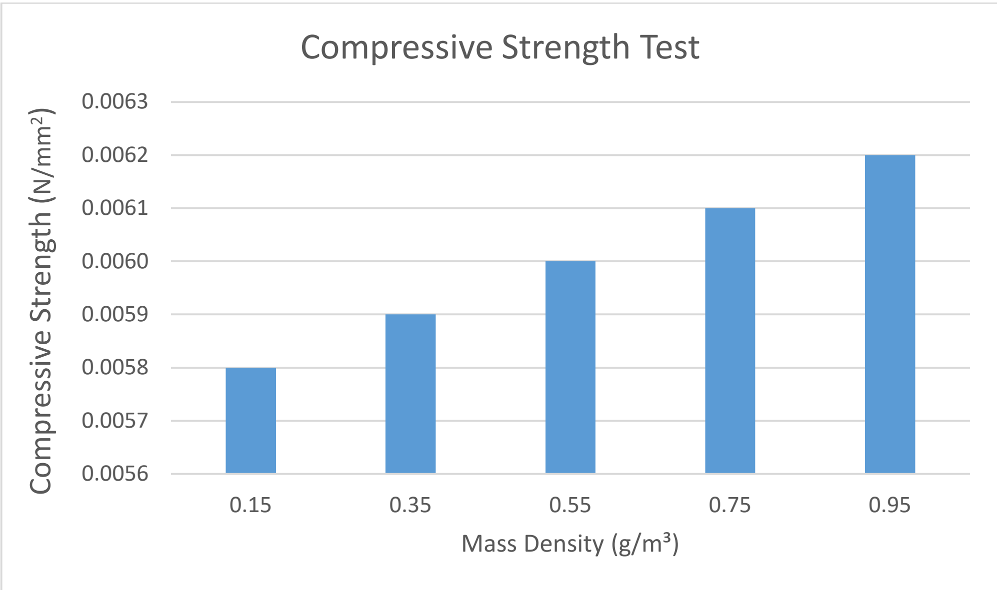

Figure 2: Compressive strength against mass density

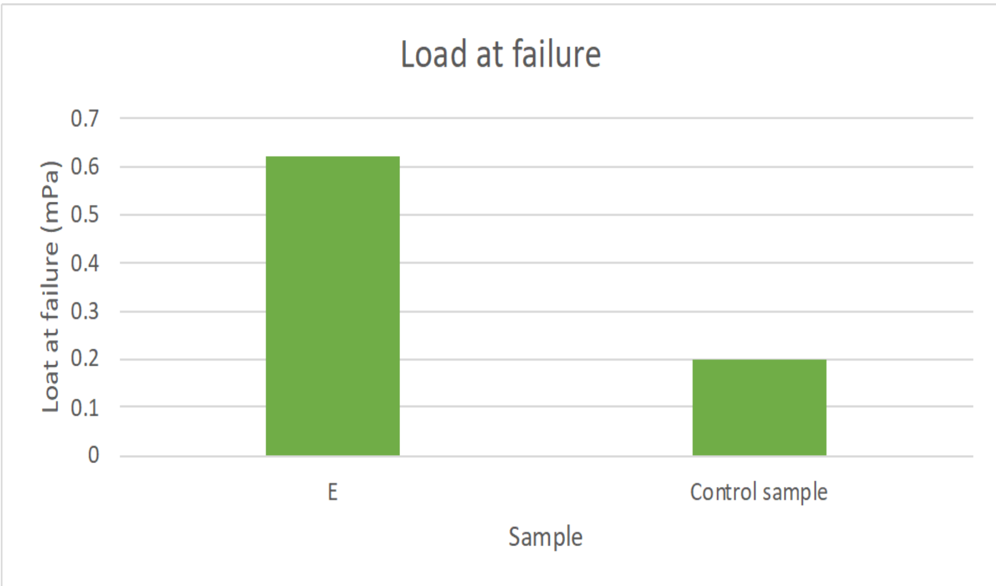

Figure 3: Comparison of compressive strength test simulation result between control sample and sample E

Failure analysis is a process of interpreting the implications of unexpected process or product risks and failures [9]. In terms of failure analysis for the compressive strength test, Figure 3 demonstrates the comparison of the compressive strength test between the control sample and the optimum sample

(sample E). From the graph, it can be said that a load of failure for sample E (0.62 MPa) is higher than the control sample (0.20 MPa). The voids within sample E are lesser than the control sample as it has a larger volume of filler compared to the control sample. In addition, sample E is able to withstand higher stress values in the compressive strength test compared to the control sample.

3.2 Drop Test

Table 2 shows the drop test result of five eco-brick samples with different density ratios by using SolidWorks simulation. Four different drop heights are chosen for the analysis including 0.5 m, 1.0 m, 1.5 m and 2.0 m. The results revealed that the impact strength for all samples increase when the drop height and the density of the sample increase.

Table 2: Data of drop test

Sample	Density	Drop Height (m)	Result (N/mm^2)
A	0.15	0.5	0.0565
		1.0	0.0798
		1.5	0.0978
		2.0	0.1128
B	0.35	0.5	0.0615
		1.0	0.0854
		1.5	0.1045
		2.0	0.1182
C	0.55	0.5	0.0820
		1.0	0.1160
		1.5	0.1420
		2.0	0.1640
D	0.75	0.5	0.1305
		1.0	0.1845
		1.5	0.2260
		2.0	0.2609
E	0.95	0.5	0.1467
		1.0	0.2077
		1.5	0.2545
		2.0	0.2940

The graph in Figure 4 shows that the impact strength is affected by the drop height and density of the sample. From the result, it can be concluded that sample E with the highest density ratio (0.95 g/m^3) has the highest impact strength whereas sample A with the lowest density ratio (0.15 g/m^3) has the lowest impact strength for every drop height. Therefore, it can be said that sample E gives the optimum results in the drop test. This finding is in line with previous research works conducted by [13] in which their results indicated that the impact strength of the sample will be increased with the addition of filler. The filler particles can reduce fracture propagation of the sample via a crack pinning and lead to an increase in impact resistance of the sample.

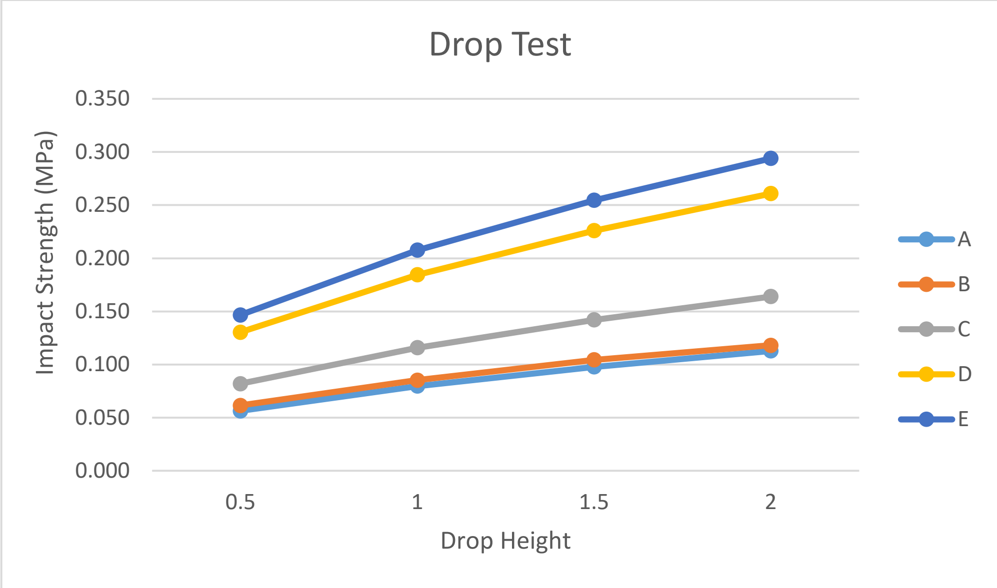

Figure 4: Impact strength versus drop height

In terms of failure analysis for drop test, Figure 5 reveals the comparison of the drop test between the control sample and the optimum sample (sample E). From the graph, it can be said that the impact strengths of both the control sample and sample E show an increasing trend with the increasing drop heights. The sample E with a density ratio of 0.95 g/m³ also has higher impact strength compared to the control sample at every drop height in the drop test. This is because the brick with the addition of polystyrene had fewer fragments compared to the conventional brick after dropping from a drop height of 1m. According to [14], bricks with fewer fragments after dropping is more durable.

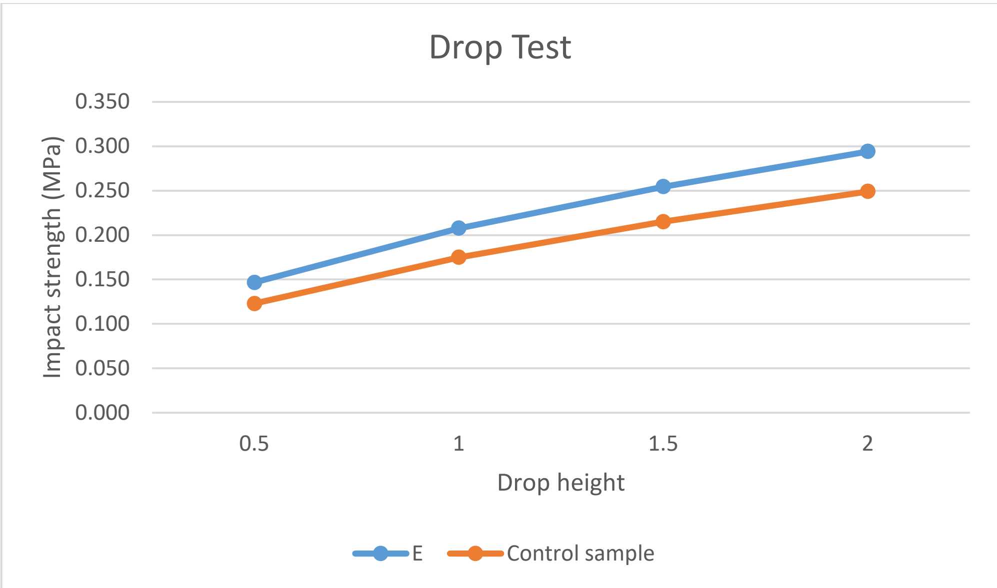

Figure 5: Comparison of drop test result between the control sample and sample E

4. Conclusion

One of the biggest limitations that derived while conducting this research is lack of accuracy in the simulation tests that were carried out. This makes it difficult for the researcher to verify the precision of the result. This is because SolidWorks software can only generate simulation results that cannot fully present the real-life situation of the object. Therefore, to overcome the limitation of the research, experimental tests must be conducted in order to determine the results obtained from the simulation study. In addition, by conducting experimental testing, the accuracy of the results can be determined.

Acknowledgement

The authors would like to thank the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia for its support.

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