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Lean Design of Alternative Packaging Cushion Material for Glass Bottles using Rice Husk and Coconut Fibre

Mahmod Abd Hakim Mohamad[1,*], Nurfarahin Onn[2], Muhammad Akmal Abdul Halim[2], Mohd Shahir Yahya[1], Nurul Amalina Farhanah Mohd Haidzir[3], Md Zin Ibrahim[3]

1 Sustainable Product Development (S-ProuD), Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia (Pagoh Campus), Pagoh Education Hub, Km 1, Jalan Panchor, 84600 Panchor, Johor, Malaysia
2 Department of Mechanical Engineering, Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia (Pagoh Campus), Pagoh Education Hub, Km 1, Jalan Panchor, 84600 Panchor, Johor, Malaysia
3 Department of Mechanical Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia (Pagoh Campus), Pagoh Education Hub, Km 1, Jalan Panchor, 84600 Panchor, Johor, Malaysia

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ABSTRACT

In recent years, rice husk and coconut fibre started to have substantial commercial value in the industry due to the research being conducted on these agricultural wastes as a new raw material consisting of high fibres and abundant resources. Therefore, this investigation determines the suitability of producing cushion packaging from rice husk and coconut fibre while reducing the amount of pulping material required from virgin wood and the usage of petroleum for making Polystyrene. This study aims to design cushion packaging from rice husk and coconut fibre using the lean concept while studying the compatibility of these cushions as primary packaging. The cushion is designed using AutoCAD software. Three types of cushion packaging models are created using different compositions of rice husk (RH) and coconut fibre (CF): Model 1 (100% RH 0% CF), Model 2 (50% RH 50% CF), and Model 3 (0% RH 100% CF). Each composition is combined with 450g of latex adhesive and 50g of water. The impact performances of cushions from different compositions are conducted using the Drop Tester Model AD-100 Design Series 4410 based on the Standard ASTM D 5276 (Drop Test of Loaded Containers by Free Fall 1998). Model 2 (50% RH 50% CF) gave the best performance in the capability to withstand the impact at a fixed height of 92 cm in the drop test compared to Model 1 (100% RH 0% CF) and Model 3 (0% RH 100% CF). Thus, the composition of rice husk and coconut fibre is the most suitable as packaging cushioning compared to the cushion with a single composition of rice husk or coconut fibre.

1. Introduction

The philosophy of lean design focuses on enhancing the value added by every activity carried out during the process in order to improve it. Activities that do not add value are considered Muda (in Japanese word) or waste. Lean techniques identify the activities that are not adding value and try to reorganize the process to eliminate or minimize them [1]. Lean methods identify activities that do

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

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not add value and try to align the process to eliminate or reduce them. Consequently, it will affect productivity, quality and competitiveness [2,3]. The philosophy of constant improvements, total quality assurance, the elimination of waste, utilization of all potential throughout the production chain and involvement of all workers is a pillar of lean manufacturing [4].

Package cushioning is used to help protect fragile items during shipment. It is common for a transport package to be dropped, kicked, and impacted. Cushioning is usually inside a shipping container such as a corrugated box. It is designed to deform or crush to help keep levels of shock and vibration below levels that may damage the product inside the box. Depending on the specific situation, package cushioning is between 50 to 75 millimetres thick. Internal packaging materials, sometimes the same ones used for cushioning are also used for other than cushioning. Some are used to immobilize the product, while others are used to fill the void and do not have a cushioning function [5]. One of the examples of worldwide package cushioning is Styrofoam.

Styrofoam in packaging systems has been widely used in the industry to cushion the product. Styrofoam, also known as Polystyrene, is a lightweight material, resistant to photolysis, not decomposed and decay, while usually remaining solid at room temperature yet melted to heat. The shipper and packaging industry find it as attractive to be used as it is cheap. However, these characteristics create problems for the environment regarding recycling, reuse and landfill operation, as the smoke emitted by Styrofoam is poisonous to humans and the surroundings when it is disposed of by burning them. The new material needed to substitute Styrofoam as package cushion as the petroleum oil source in making the Styrofoam is limited due to its unrenewable source.

Cushioning material is used to fill specs and to protect items from damage due to mechanical stresses such as impact, jolting or vibration during transportation. Cushioning material should be easy to remove and easy to dispose of. Where cushioning material is appropriate, it should be easy and quick to remove and recyclable. Loose-fill materials such as packaging chips, shredded materials, newspapers and others should be avoided [6]. As a primary packaging, the package cushion needs to contain the product and be attractive to the customer. Using natural materials as an alternative to synthetic materials has gained popularity in recent years across various industries. Agriculture waste material can be used as a cushion material to attract customers while protecting and reducing the environmental problem concerning agriculture waste management.

In past decades, a part of the from agricultural uses of the plants has been a viable source of raw materials for industrial purposes. Agricultural wastes such as rice husk and coconut fibre are renewable resources from nature and locally available, either purchased at low cost or for free. Rice husk and coconut fibre are the agriculture by-products obtained annually from the industry and small factories around Malaysia. The production of these agricultural wastes has been researched to be applied in packaging systems because this product is more environmentally friendly and does not take too long to process. Rice husk [7-9] and coconut fibre [10-13] are agriculture waste materials that have proven to be used as cushioning materials. Rice husk is a valuable natural resource obtained from agricultural waste and has an annual global quantity generated of around 137 million tons. Its production is in line with the rice production in the world, causing most of the rice husks to be unused or burned to reduce storage due to its unlimited resources [14]. Open burning is often used to dispose of the rice husk threatening the environment. In the research of cardboard making, the rice husk is chosen because of the unlimited fibres and lignin (15.20%) that can be obtained on the rice husk annually and give the best result in the cardboard paper test [15].

The coconut is a tropical fruit growing in the coastal area. Coconut fibre can be obtained anytime because the fruit has no annual seasons like rice husk. Coconut fibre materials are always used in studies for new packaging materials due to the high percentage of cellulose (26.6%), lignin (29.4%), and others found in the coconut fibre. The material used in many fibre applications such as ropes, brushes, and woven carpets, proved to be biodegradable when it was let in normal surroundings [16]. Meanwhile, the adhesive that binds these materials needs to be chosen based on its biodegradability to make a perfect biodegradable package cushion.

Thus, using the lean concept, this study utilizes agricultural wastes as alternative cushioning materials. The agricultural wastes used to produce a package cushion are rice husk and coconut fibre using Latex as an adhesive. These materials are biodegradable products that easily decompose in normal surroundings and are abundant in resources. The new cushion model is produced based on the design created in AutoCAD software to eliminate the use of corrugated boxes since using the corrugated box as the primary packaging. When using the primary packaging, more space is required during the shipping, and more cost material is needed to create those. Thus, these package cushions are designed to contain the product as a package cushion and act as primary packaging for the product.

2. Methodology

This section will discuss the methods of selecting and preparing the raw materials, designing and preparing the cushion mould, preparing the cushioning models, and the drop test.

2.1 Selection and Preparation of The Raw Materials

In the beginning, this study started with preparing the raw materials of rice husk and coconut fibre as shown in Figure 1. The coconut fibre is cut into approximately 2 inches and ground using a grinding machine. The rice husk and coconut fibre are then placed on a drying machine at 80°C for three days to ensure the raw materials are dry from moisture.

(a) (b)

Fig. 1. Raw materials: (a) rice husk (b) coconut fibre

2.2 Design and Preparation of The Cushion Mould

For testing purposes, the glass bottle is used as the product. The cushion design is developed using AutoCAD software based on measurements taken from the glass bottle. The details of the drawing and dimensions of the glass bottle and cushion are presented in Figure 2 below. Then, the cushion mould is prepared using PVC pipes with dimensions of 102 mm diameter pipe with 70 mm length and 20 mm diameter pipe with 25 mm length. Based on Figure 2, the two components of the cushion design are the upper cushion and the lower cushion, which act as cushions above and below the container.

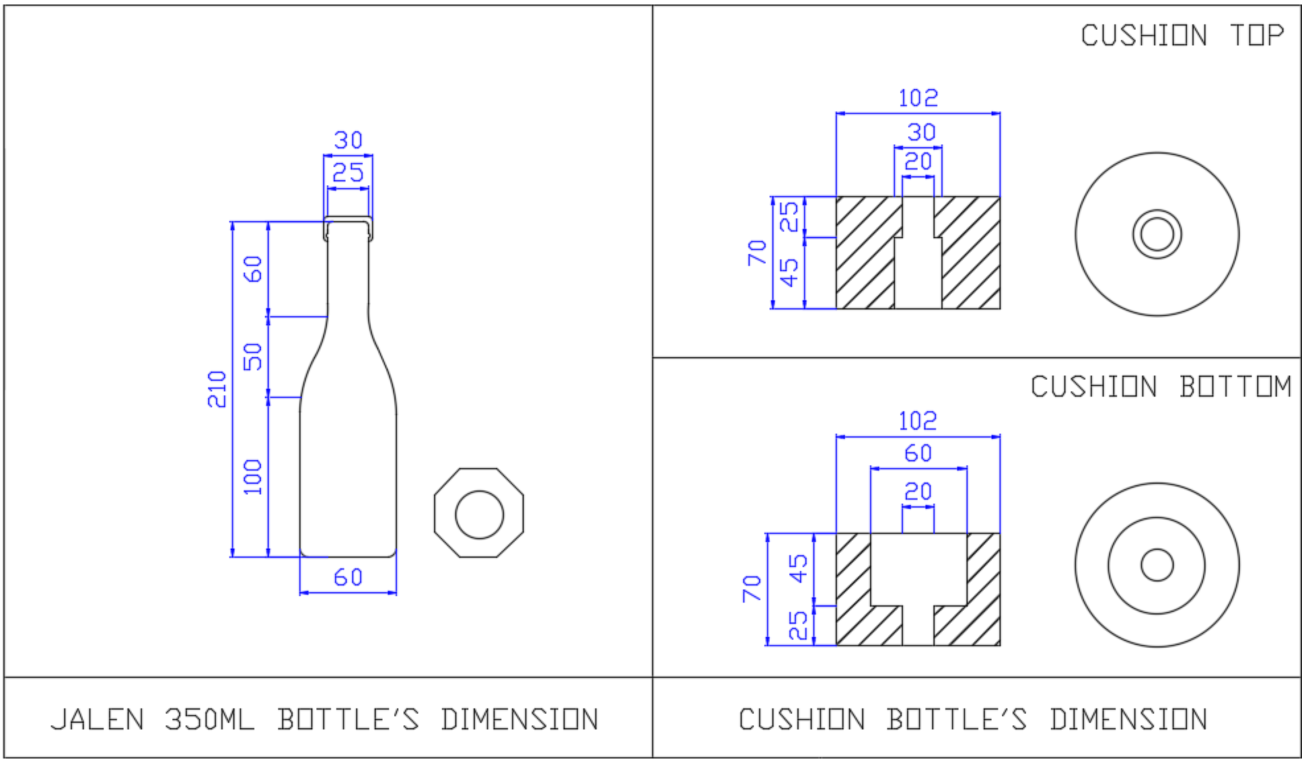


Fig. 2. Dimension of the glass bottle and cushioning model (all dimensions are in mm)

2.3 Preparation of The Cushioning Models

Three different cushioning models are provided based on the dried raw materials of rice husk (RH) and coconut fibre (CF) proportions as shown in Figure 3. Each model's total raw material weight is 200 g, divided equally between the upper cushion mould model and the lower cushion mould model.

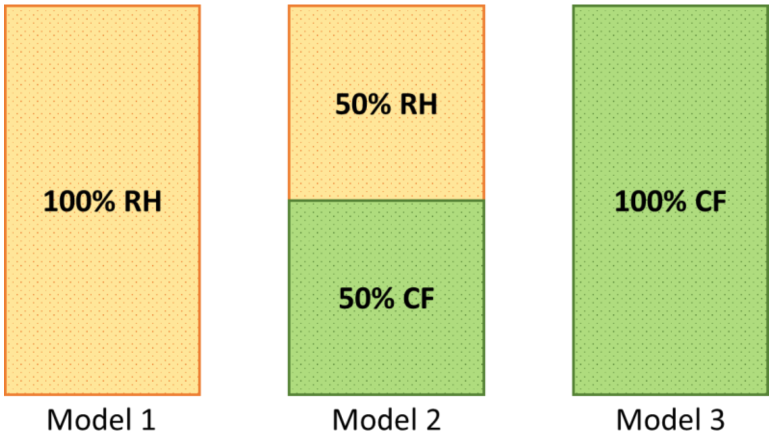


Fig. 3. Percentage of rice husk (RH) and coconut fibre (CF) in cushioning system models

Each sample was mixed with 450 g of liquid latex adhesive and 50 g of water. The process of selecting the weight of adhesive and water is repeated several times to obtain the results. Liquid latex adhesive is used to adhere the raw materials, while water ensures the mixture of raw materials and liquid latex adhesive is completely mixed [17,18].

The ingredients are mixed perfectly and put into the model mould that has been prepared. The mixture is added in stages where a 20 mm diameter PVC pipe is placed vertically in the center of a 102 mm diameter PVC pipe. The mixture was added progressively to fill the gap between the two PVCs until it reached a height of 25 mm. Pressure is applied during mixing to reduce entrapped air.

The glass bottle is positioned in the center of the mould vertically according to the position. The glass bottle cap is placed in the middle of the mould to make the upper cushion mould, while the base of the glass bottle is placed to make the lower cushion mould. The rest of the mixture is placed around the glass bottle and compressed by hand.

After pouring the mixture into the mould, the model is placed in a drying machine set at 80°C for four days to ensure that the cushion dries evenly. Figure 4 shows the product worn in the sample cushioning system for Model 1 (100% RH 0% CF composition), Model 2 (50% RH 50% CF composition), and Model 3 (0% RH 100% CF composition) that have been dried and the product used on each model's frame.

(a) (b) (c)

Fig. 4. Samples of cushioning systems: (a) Model 1 (b) Model 2 (c) Model 3

2.4 Drop Test

To determine the package cushion performances, the drop test is conducted on the package cushion in several orientations at several heights. The drop test is a test that drops a container of a load to determine its resistance to failure either breaks or leakage as required to produce a container through the appropriate specifications of the Department of Transportation. The free fall test is a simple and quick method for determining the motion and the critical acceleration (G) value that can be obtained using Eq. (1). Based on the free fall test, the object will experience an increase in velocity when it is dropped from a certain height. Furthermore, the velocity will be zero when the object touches the floor surface, which resulting shock [19].

$$G=\frac{\text{predicted acceleration}}{\text{gravity acceleration}} \tag{1}$$

The G value of the cushioned product is calculated to determine the degree of fragility of an object breaking when it experiences shock. The object will break or damage when a higher force acting on its structure. The package with a higher G factor will be able to withstand shock forces and have a low risk of falling damage. The classification of G factor is shown in Table 1 [20].

Table 1
Classifications of G factor values [20]

G factor value	Classification	Examples
15 – 25 G	Extremely fragile	Precision instruments, first generation of computer hard drives
25 – 40 G	Fragile	Benchtop and floor-standing instrumentation and electronics
40 – 60 G	Stable	Office equipment, cash registers, desktop computers
60 – 85 G	Durable	Television sets, appliances, printers
85 – 110 G	Rugged	Machinery, power supplies, monitors
110 G	Portable	Laptops, optical readers
150 G	Hand held	Calculators, telephones, radios, microphones

The equipment used in this study is a Drop Tester which is LAB Drop Tester Model AD-100 Design Series 4410. The three main components of the Drop Tester are the accelerometer, power source or coupler (Kistler Type 5134 A model), and computer. This machine is used to drop packages weighing less than 100 pounds (45 kg). The height of the fall must have an appropriate limit which is a minimum of 12 inches (30.5 cm) up to a maximum of 60 inches (152.4 cm). The height set for this test is dependent on the drop that normally occurs during the handling process. This test is carried out on each cushioning model based on the top, bottom, top angle, and bottom corner orientations according to ASTM D 5276 - Drop Test of Loaded Containers by Free Fall (1998) [21]. Figure 5 shows the free fall orientation positions in this study. Based from this figure, points 1, 3, 5, and 7 are the top orientation and points 2, 4, 6, and 8 are the bottom orientation of the cylinder of the cushioning system. Furthermore, the top corner orientation lies at between points 1 and 3, and the bottom corner lies between points 6 and 8.

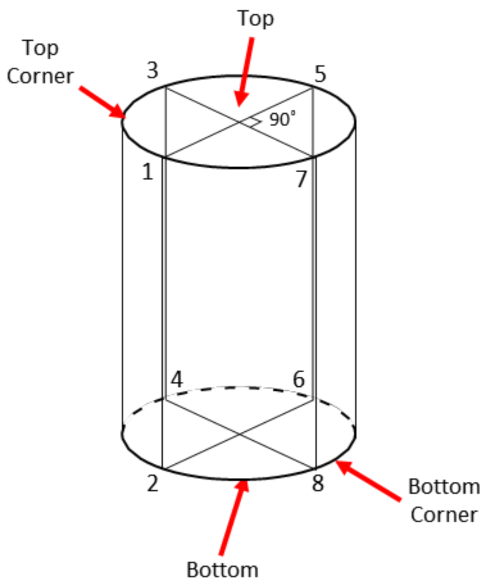
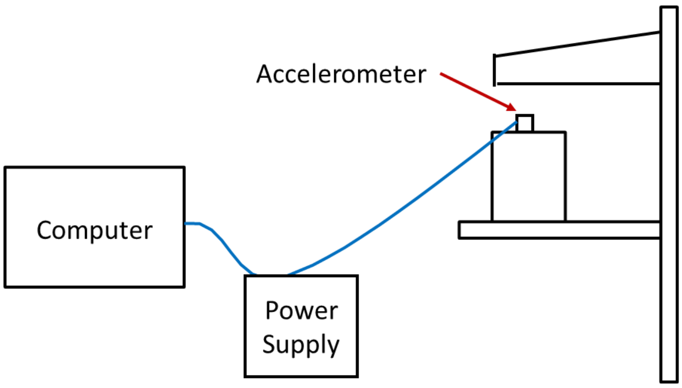


Fig. 5. Free fall orientation positions

D 5276 is appropriate for cylindrical packaging. The free fall test method is suitable for packaging that is handled manually during the distribution process. Environmental factors that need to be taken into account include where the surface falls needs to be flat, rigid, strong, and made of concrete or stone. If the falling surface is a steel plate, it should have a thickness of at least 13 mm. The size of each cushioning system is weighed, and the dimensions for cylinder cushion are 102 mm diameter × 260 mm height. The product used is a 350 ml of chili sauce in a glass bottle, and the average weigh is about 568 g.

Test Partner Three (TP3) software is used for this free fall test. All the power supply connections are on channel 1, and the accelerometer must always be in the correct condition so that the output is accurate. The accelerometer has a sensitivity of ±0.01 mV. The free fall test uses an accelerometer that will be attached to the cushion before the product is free dropped at the acceleration of gravity. The dropped object is connected to the power supply via a cable where the monitor will display a peak G curve versus time.

Before conducting the experiment, the free fall height is determined. The height is set by adjusting the fastening hinge on the drop tester. The model of the packaging system is to be tested so that it can detect the peak shock when the cushioning model drops and touches the plate. At the same time, the resulting shock is displayed in the form of a graph of peak acceleration versus time on a computer screen. Figure 6 shows the drop tester equipment's schematic diagram and machine.



(a)

(b)

Fig. 6. Drop Tester equipment: (a) schematic diagram (b) machine

The results from the free fall test are tabulated and analyzed. From the obtained table, the graph of the acceleration G against various packaging orientations is plotted for each cushioning system model. With these graphs, comparisons will be made between the three models. The graphs will show the packaging system model with best performance and most failure through the free fall test.

3. Results

This section will present the analysis of the free fall test and the graphs of peak acceleration value (G_P) versus orientation positions from the free fall test.

3.1 Analysis of The Free Fall Test

The sample model is divided into three sections with different compositions made from rice husk and coconut fibre. The sample cushioning system for Model 1 with a 100% RH 0% CF composition, Model 2 with a 50% RH 50% CF composition, and Model 3 with a 0% RH 100% CF composition. There are three different cushioning models in total, and the analysis will be split into free fall orientations for each model. This study focuses on the comparison of peak acceleration, G_P, and drop height values for each orientation of every cushioning model. The orientation condition is the condition that has been set on each sample to be dropped to obtain the peak acceleration value (G_P) when the cushioning system fails to be detected. The orientation of the drop is top, bottom, top corner, and bottom corner orientations.

Table 2 shows the effect of breakage on Models 1, 2, and 3 after drop test was performed in the top, bottom, top corner, and bottom corner orientations. When the sample is dropped, some small fragments is peel off from the cushion, especially for Model 1, because it is made entirely of rice husk. This indicates the characteristics of the rice husk that is fine, dry, and difficult to absorb water, prevents it from adhering to liquid latex adhesive perfectly. However, it still acts as a good cushioning system by absorbing shock energy and protecting the product from breaking even when it breaks during the second and third tests at the bottom corner orientation.

Table 2
The effect of the drop test on the sample

Test	Up			Down			Top corner			Bottom corner		
	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3
1	✓	✓	✓	✓	✓	✓	✓	✓	✕	✓	✓	✓
2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✕	✓	✓
3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✕	✓	✓

where ✓: not broken
✕: broken

3.2 Graphs of Peak Acceleration (G_P) Versus Orientation Positions from The Free Fall Test

Table 3 presents the data of the peak acceleration value (G_P) that are obtained from free fall tests for each orientation. The values found are in the range of 17 G to 23 G. The lowest G_P is 17.36 G, while the highest G_P is 23.87 G. The test is repeated three times, and the average value is calculated to obtain an accurate average value.

Table 3
Free fall test data

Test	Acceleration Peak, Gp											
	Up			Down			Top corner			Bottom corner		
	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3
1	22.83	23.14	23.18	22.61	22.80	23.40	23.16	20.96	23.31	23.10	23.13	22.53
2	23.87	23.11	23.36	23.66	23.19	23.73	22.85	23.30	23.26	19.78	23.44	23.07
3	23.33	23.88	23.85	23.67	23.58	23.62	22.46	23.42	17.36	18.89	23.47	23.25
Average	23.34	23.38	23.46	23.31	23.19	23.58	22.82	22.56	21.31	20.59	23.35	22.95

Referring to Figure 7, with three times of falls, the average peak acceleration value (G_P) is 23.34 G, 23.31 G, 22.82 G, and 20.59 G at the top, bottom, top corner, and bottom corner orientations. Based on the observation, the Model 1 cushion failed where the bottom corner of the cushion model was broken during the second and third drops at the bottom corner orientation. Still, the product is still in good condition since the cushion model has absorbed all the shock energy that occurs during the fall. The highest G_P occurs at the top orientation with 23.87 G, and the lowest G_P occurs at the bottom corner orientation with 18.89 G.

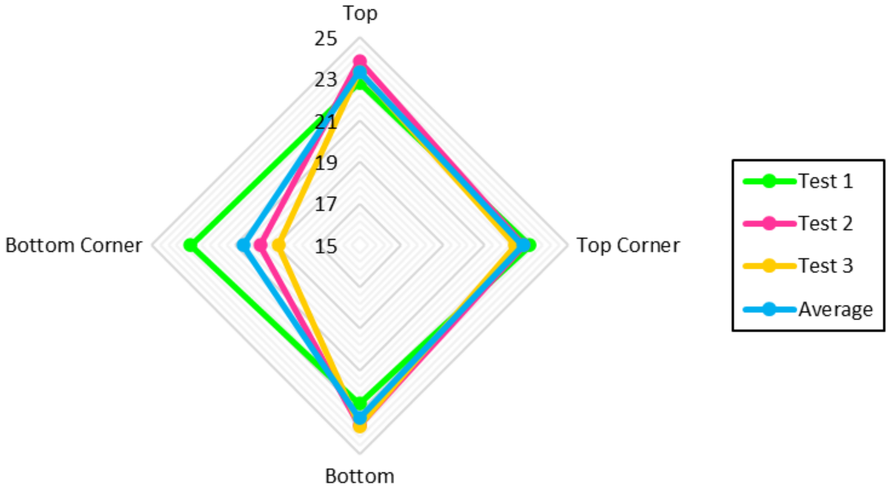


Fig. 7. Graph of peak acceleration (G_P) versus orientation positions for Model 1

Based on Figure 8, peak acceleration (G_P) has an average value of 23 G on top, bottom, and bottom corner orientations, while only the top corner has a low average value of 22.56 G. At this time, there was no break in the cushioning model after the drop test. However, there is some damage to the corner of the cushion during drop in the top corner orientation. The bottom corner orientation displayed a low G value in the first test but in the second and third tests, the G value was in the same range as the G value in the other orientation. It is may be due to a technical error that occurred during the first fall.

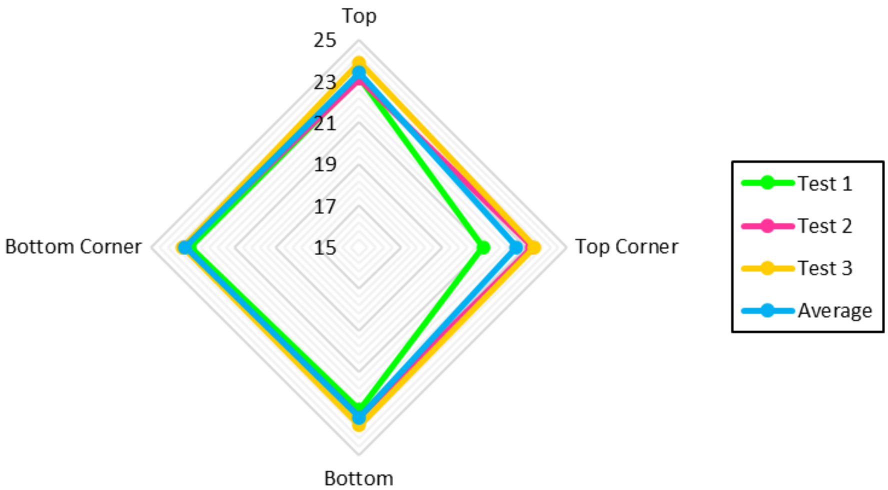


Fig. 8. Graph of peak acceleration (G_P) versus orientation positions for Model 2

As shown in Figure 9, the average acceleration value is slightly lower at the top corner orientation with a value of 21.31 G, while the other acceleration values are 23.46 G, 23.58 G, and 22.95 G at the top, bottom, and bottom corner orientations, respectively. At the top corner orientation, the cushioning model has broken in the third test a peak acceleration (G_P) of 17.36 G. The cushioning model has already suffered damage in the first and second tests causing the cushioning model break in the third test. Nevertheless, the product is still in good condition.

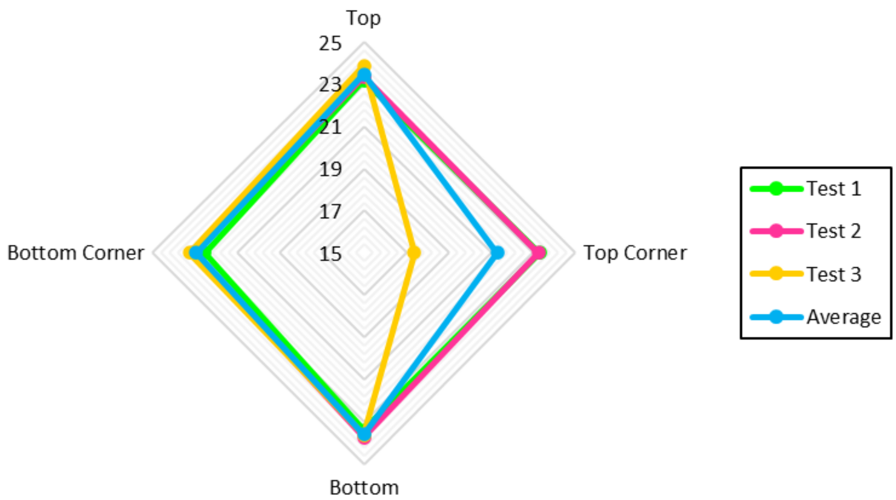


Fig. 9. Graph of peak acceleration (G_P) versus orientation positions for Model 3

Figure 10 compares the average of peak acceleration for three cushioning models at a fixed height of 92 cm and at the top, bottom, top corner, and bottom corner orientations. The average peak acceleration at the top orientation for Models 1, 2 and 3 are 23.34 G, 23.38 G, and 23.46 G, respectively. At the bottom orientation, the average peak acceleration for Models 1, 2, and 3 are 23.31 G, 23.19 G, and 23.58 G, respectively while at the top corner orientation, the average peak acceleration for Models 1, 2, and 3 are 22.82 G, 22.56 G, and 21.31 G, respectively. At the bottom corner orientation, the average values of peak acceleration for Models 1, 2, and 3 are 20.59 G, 23.35 G, and 22.95 G, respectively.

Referring to this graph, the peak acceleration (G_P) at the top, bottom, top corner, and bottom corner orientations of Model 2 gives higher values compared to the other models. The high and stable peak acceleration values show that Model 2, which is combination of two compositions of rice husk and coconut fibre, has a high ability to absorb shock energy when it is dropped from a height and touches the floor surface. In addition, the acceleration value of Model 1 shows a low acceleration value at the bottom corner orientation followed by Model 3 at the top corner orientation.

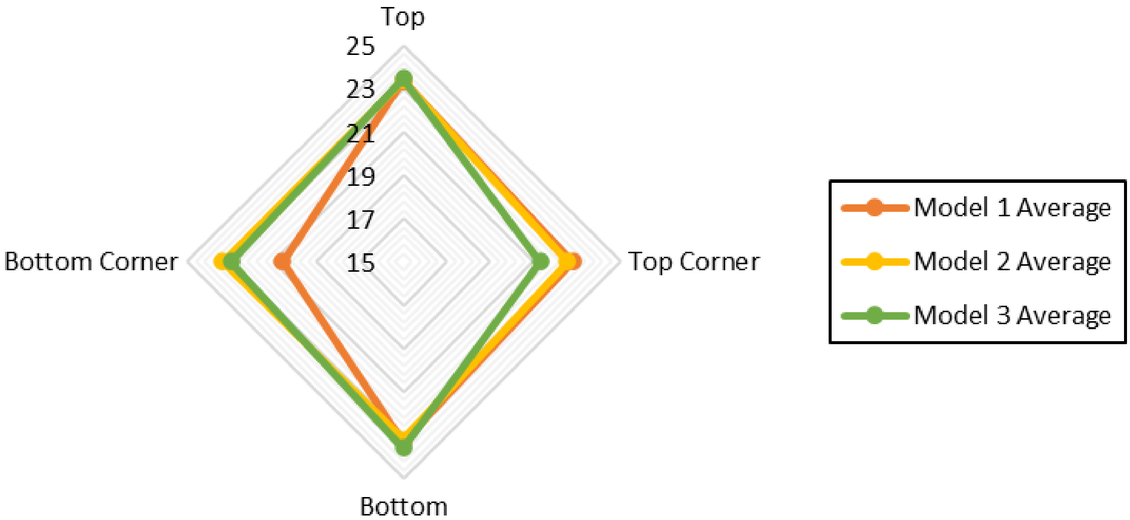


Fig. 10. Graph of average peak acceleration versus orientation positions of each model

4. Discussion

The free fall test can determine the performance of the cushioning materials and obtain the best type of cushioning material that can work in a variety of different conditions according to its needs. The performance of a cushion needs to emphasized to ensure that it protects the product when a fall occurs. Several aspects need to be considered in this free fall test, including the cushioning material's thickness, mass, and density. The materials used in this study are rice husk and coconut fibre that are designed cushions. The cushioning system keeps the products safe by absorbing and deflecting the shock forces on the cushion.

In observing the capabilities of the cushioning model, the shock force that occurs on the cushioning model has an impact on the model when it is dropped. One of the main functions of the cushion is to absorb and deflect the shock that occurs during a free fall. Through absorbing and deflecting the force on the cushion, every cushioning model in this study successfully protects the product from breaking during shock forces. The chipping and breaking effect that occurs indicates that the cushioning system is working as intended.

Model 2 was selected as the best cushioning model in terms of its ability to withstand the shock force of a free fall as a cushioning system. Model 1 is the model that produces the most debris when dropped, and Model 3 has the least debris compared to Models 1 and 2. It is due to the coconut fibre in Model 3 absorbing the latex liquid adhesive perfectly and its flexible characteristics that follows the shape of the mould perfectly. However, Model 2 was chosen because Model 3 broke on the first drop at the top corner orientation and its average peak acceleration values were less than Model 2 at the top, bottom, top corner, and bottom corner orientations.

In the free fall test, the forces resulting from acceleration and mass are the same for all samples, but the forces acting on each fall orientation is different. This situation is due to the area of the surface affected by the impact when drop is different for a package. The applied orientations for cylindrical packaging are the top, bottom, top corner, and bottom corner.

Based from the analysis has been carried out at the height of 92 cm, Model 2 gives average peak acceleration values of 23.38 G, 23.19 G, 22.56 G, and 23.35 G at orientations top, down, top corner, and bottom corner orientations, respectively. This was followed by the Model 3 with 23.46 G at the top orientation, 23.58 G at the bottom orientation, 21.31 G at the top corner orientation, and 22.95 G at the bottom corner orientation. Model 1 followed later with average peak acceleration values that are 23.34 G at the top orientation, 23.31 G at the bottom orientation, 22.82 G at the top corner orientation, and 20.59 G at the bottom orientation.

The overall test results show that Model 2 gives the best performance through this free fall test. The peak acceleration value (G_P) plays an important role in determining the ability of a cushioning to accommodate the product if subjected to continuous shock force. It is because the cushioning system model has a high peak acceleration explains that it is capable of absorbing the shock force applied to it. However, its ability to absorb shock forces decreases when the sample is dropped more often on the floor surface. The G_P display a minimum value if it is dropped in an unstable condition such as a shock at the top corner and bottom corner orientations. The higher G_P the means the higher the ability of the cushioning system to survive. This phenomenon explains that the cushioning system model has a higher average peak has higher strength characteristics compared to other models. It is explained that the ability of a cushioning material in terms of its strength will decrease as the shock force is continuously applied. It can be concluded that Model 2 is better than Models 1 and 3 to be used as a cushioning system on glass bottles through normal transport handling because it has good cushioning characteristics from the aspect of energy absorption.

5. Conclusion

In conclusion, this study is successful because it has achieved the desired objective of identifying the appropriate cushioning model (designed using the lean concept) for glass bottles for transport purposes through free fall tests. The free fall tests are conducted to meet the complementary test specifications. This test aims to evaluate the properties and characteristics of various materials and determine the performance of the best cushioning material that can work in the most optimal conditions in different situations. Based on the data collected, Model 2 (50% RH 50% CF composition) is the best sample cushioning model. Therefore, it is the most suitable for packaging cushioning compared to the sample cushioning model with only a rice husk (Model 1) or coconut fibre (Model 3) composition.

The G factor concept is a dimensionless value that is used to predict the ability of cushioning materials to accommodate shock forces through tests. This concept can theoretically help in achieving the objectives of the study. However, there are several factors that can be considered to improve the results of this study:

i. Design a thick rectangle cushion to facilitate its manufacture and its application into tertiary packaging.
ii. Compare the impact of shock with the Impact Test on the models of cushioning materials so that the relationship between the test results can be identified and obtain more accurate results.
iii. The test should be conducted in a real environment.
iv. Conduct free fall experiments at various heights to determine the free fall height relationship.

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