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Evaluation of Corrugated Board and Polystyrene as Cushioning Material in Packaging

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This project is to identify the most suitable material for cushioning and choose a better partition design for cushioning purposes in packaging. This study involves the characteristics of corrugated board and polystyrene. The cushion test was carried out using ASTM 1596-97, using Lansmont Cushion Tester where the product is protected by corrugated board and polystyrene made partition. A constant load with a fixed position was dropped at various heights of 20, 25, 30, 35, and 40 inches. The result of the study was shown in waveform on the screen through Test Partner 3 (TP3) software. The G peak value and height change of partition after load drop were analysed. The comparison between the cross and square partition was done. The comparison for G peak value results in the cross partition possesses 10.7% vibration less than square partition. Cross partition of the corrugated board can withstand higher vibration of 9.6% compared to square partition. In terms of height change, the corrugated board form cross partition is better than polystyrene form cross partition by 13%. Referring to the standard of fragility, the corrugated board made square and cross partition is suitable for packaging glass and pottery containers. The polystyrene-made partition is more suitable to be used for electronic equipment.

Keywords: Corrugated board; polystyrene; cushioning; packaging

I. INTRODUCTION

In this modern era, packaging is mostly used to package a product and to protect the product from hazards like shock, vibration, compression, humidity, and extreme temperature changes during product handling and during the transportation process. When the package is dropped or kicked, the product will suffer shock and impact that have probably caused damage to the product. This will cause loss to both manufacturer and consumer.

Cushioning plays an important role to protect products, especially fragile products in the package from damage during the transportation process. There will always be some undesired shock, vibration which can cause accidents and losses. The shock and vibration effect can be controlled and by an adequate cushion in the package (Hanlon *et al.,* 1998). The cushion used is commonly the corrugated board, polystyrene, bubble wrap, and many more. Several studies on the physical properties of the corrugated board by considering the air flow of flute design structure. The cushion has more ability to absorb shock and protect package after fatigue (Li *et al.,* 2009). Xu *et al.* (2011) had tested honeycomb paperboard for cushioning packaging. From the study, the thickness of honeycomb affects the performance of dynamic performance. As the thickness of the structure increases, the lower peak acceleration so the product is more protected by the honeycomb package. Chen *et al.* (2015) had studied the usage of expanded polystyrene (EPS) in various applications in order to know the strength of polystyrene. The energy absorption is higher in high-

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density EPS as well as higher ability to withstand compression stress.

Several studies on the structural design of corrugated boxes are performed. Pathare and Opara (2014) had conducted research on corrugated board uses in packaging industries. Pathare *et al.* (2012) stated that vents on corrugated board will reduce the mechanical strength of it and vents should be placed away from the vertical corners and less than five percent of the total box wall area which the strength loss can be reduced. Box partition or box divider is an inner packaging that separates the products and protects the product from crashing and colliding into each other. To prevent the products from bearing too much compression stress, the insertion of box partitions is important. The box partition can strengthen the top and bottom of the package and can ensure the package arrives at the consumer safely. Partitions are made of custom sizes and designs to serve the products perfectly.

There are a few reports about polystyrene and corrugated board as cushioning material to the environmental aspect. Both of these materials are mostly used in industries due to the best ability in absorbing shock and providing a cushion to the product. However, the usage is too much and causes cost increment. Therefore, partition in packaging can be designed to reduce costs. Through this way, the package system will be lighter, which can reduce the transportation costs, lessen the capital and increase the net profit. The most important is that the wastage will be less which contributes to fewer environmental problems.

II. MATERIALS AND METHOD

A. Sample Design

The test specimens were the corrugated board and polystyrene as cushioning materials. There were two types of comparison that were the cushioned material comparison and types of the package system. The size of the package used in the research is 8.0 cm x 8.0 cm x 8.0 cm (Joongmin, 2004). The current research done here was only a simulation or it is called in-house simulation, the size of the package sample was used according to ratio. The corrugated box of the package was at dimension 22.0 cm x 21.5 cm x 8.0 cm which the ratio of length was 1:2.75, the ratio of width was 1:2.7 and the height was at a ratio of 1:1. Figure 1(a) shows the design of the cross partition. Figure 1(b) shows the design of the square partition. The size of partition used is 8.0 cm x 5.0 cm x 1.5 cm (Joongmin, 2004). Taking the ratio as a reference, the dimension of the partition in this research was 22.0 cm x 21.5 cm x 8.0 cm.

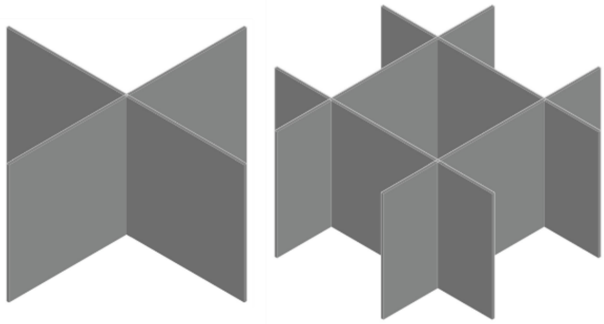

Figure 1. (a) Cross partition design and (b) Square partition design

B. Testing

Lansmont cushion tests were conducted following the ASTM 1596-97: Dynamic Shock Cushioning Characteristics of Packaging Material using cushion tester in UTHM Packaging Lab as shown in Figure 2(a). For this purpose, the cushion tester was connected with both accelerometer and TP3 software to conduct a shock test. The cushioning material was studied to compare the ability to absorb shock. The partitions of the package were made of corrugated board and polystyrene. A fixed mass load was positioned and dropped at five heights of load that were 20, 25, 30, 35, and 40 inches from the package. The package was tested five times. The G peak value was noted and the measurement of the height changes of partition was taken. The manipulated variables were included in tabulation for a clearer picture of the comparison purpose. The results are shown in the TP3 software (as shown in Figure 2(b)) used for tabulation of data purposes. Only the maximum G value and the height changes of partition were considered as the result and used to compare the efficiency and suitability of the materials to be used as a cushion.

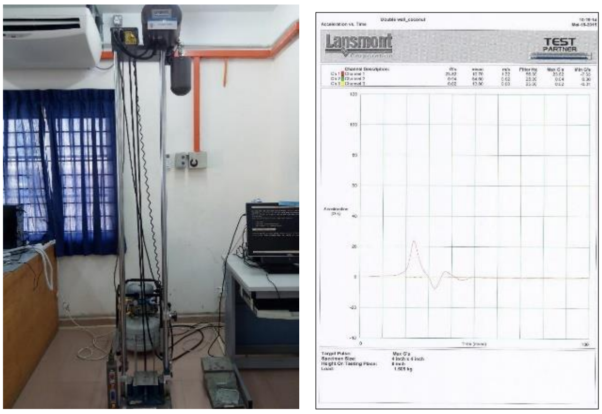

Figure 2. (a) Cushion Tester and (b) TP3 software data

III. RESULTS AND DISCUSSIONS

A. Relation Between G Peak Value Against Drop Height of Load

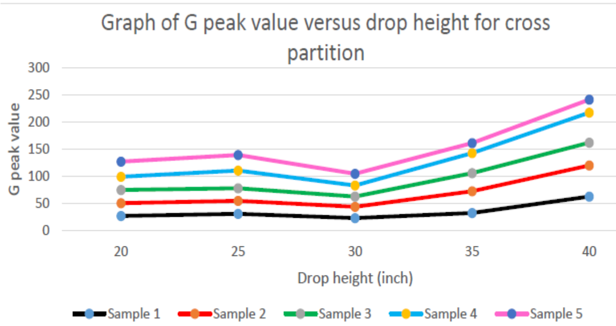

Figure 3. Graph of G peak value versus drop height for cross partition made of polystyrene

Figure 3 shows the graph of G peak value versus drop height for cross partition made of polystyrene. From the graph shown, the comparisons between the five samples at five drop heights can be observed. Using sample 5 as an example, the line graph shows an inclined curve until the third drop which shows a sudden incline till the fourth drop then incline again in the last drop height which is 40 inches. This may cause by the fatigue of the partition during the third shock. The fatigue of partition causes the reading of G peak value to be inconsistent. Using sample two as an example, the reading of G peak value after the first drop is 23.47 G. The difference is about 33.6 G or 143.2% compare to the fifth reading, 57.08 G concerning the first reading. Comparing the fifth drop of samples 2 and 5, sample two shows a reading of 57.08 G, whereas sample five shows 24.19 G. The difference between them is 32.9 G or 57.6% concerning sample 2. By analysing all the graphs, it can be concluded that the cross partition made of polystyrene fatigue after the third drop.

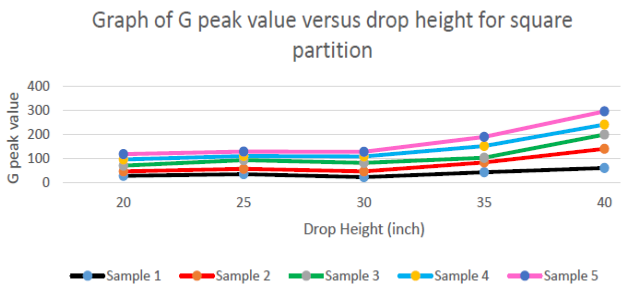

Figure 4. Graph of G peak value versus drop height for square partition made of polystyrene

Figure 4 shows the graph of G peak value versus drop height for square partition made of polystyrene. From the graph shown, the comparisons between the five samples at five drop heights can be observed. Using sample 5 as an example, the line graph shows the decline curve at the second drop then increases again after the third drop. This phenomenon shows the fatigue of the partition after the second drop. Besides that, by studying samples 4 and 5, both of these samples fatigue after the second drop. Comparing samples 3 and sample 4, sample 3 fatigue after the third drop, whereas sample 4 fatigue after the second load. This might be due to the unsymmetrical load distributed on the partition. Taking sample 1 as an example, the reading for the first drop is 26.01 G, whereas, for fifth drop, the reading is 58.85 G. The gap is about 32.8 G or 126.3% for the first drop. Comparing the first reading for samples 1 and 5, the reading of sample one is 26.01 G and sample five is 22.66 G. The difference of the same height is 3.35 G or 12.8% for sample 1. From the graph, we can conclude that polystyrene-made square partition can fail at the second drop that is at 25 inches.

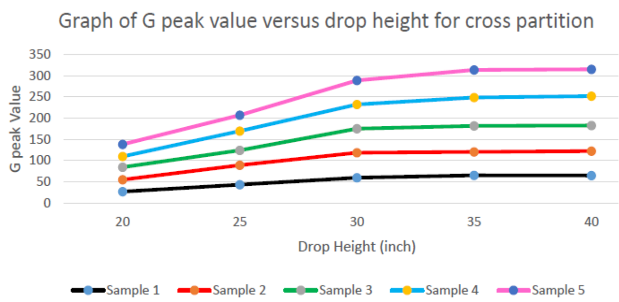

Figure 5. Graph of G peak value versus drop height for cross partition made of corrugated board

Figure 5 shows the graph of G peak value versus drop height for cross partition made of corrugated board. From the graph shown, the comparisons between the five samples at five drop heights can be observed. Using sample 1 as an example, the line graph shows the incline curve after the first drop till after the fourth drop. It declined after the fifth drop. This phenomenon shows the fatigue of the partition after the fifth drop. Besides that, by studying the 4th and 5th samples, sample four does not fall fatigued, whereas the 5th sample fatigue after the 5th drop, same as sample 1. Comparing samples 2 and 3, sample 2 fatigue after the fourth drop whereas sample 3 fatigue after the fifth drop load. This might be due to the unsymmetrical load distributed on the partition. Taking the reading of sample 3, compare the reading of the first and fifth drop. The first drop shows 29.24 G, whereas the fifth drop shows 59.92 G. The two readings differ about 30.7 G which is equal to 105% for the first drop. Comparing the fifth reading of sample 2 and 4, at the same height, the two samples shows 57.84 G and 69.11 G, respectively. Both of the readings differ about 11.3 G or 19.5% for sample 2. From the graph, it can conclude that the corrugated board made cross partition fatigue after the fifth drop that is at 40 inches.

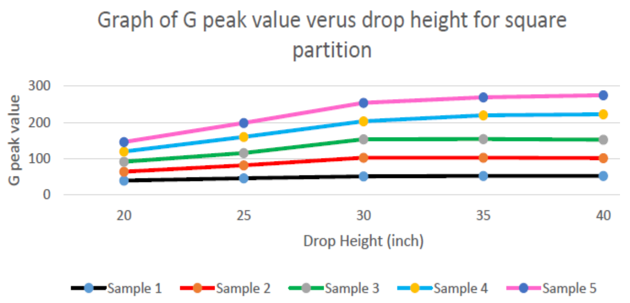

Figure 6. Graph of G peak value versus drop height for square partition made of corrugated board

Figure 6 shows the graph of G peak value versus drop height for square partition made of corrugated board. From the graph above, the comparisons between the five samples at five drop heights can be observed. Using samples 1 and 4 as an example, the line graph shows the incline curve from the first drop till the last drop. This phenomenon shows that the partition did not fatigue even after the 40-inch load drop. Besides that, by analysing samples 2 and 5, both samples fatigue at the same drop load height that is at 35 inches. In addition, sample 1 and sample 4 shows the same trend, while sample 2, 3, and 5 poses almost the same graph pattern. The trend is not uniform might cause by the unequal shock and stress distributed on the partition. Using sample 2 as an example, the reading for the first drop shows 24.61 G and the fifth drop shows 49.19 G. The readings differ about 24.6 G which is 100% for the first drop. Study sample 2 and 5, the first drop contrast about 1.77 G or 7.2% for sample 2 when sample 2 shows 24.61 G and sample 5 shows 26.38 G. From the graph, it can conclude that the corrugated board made square partition fatigue after the fourth drop that is at 35 inches.

B. Comparison Between Design of Corrugated Board

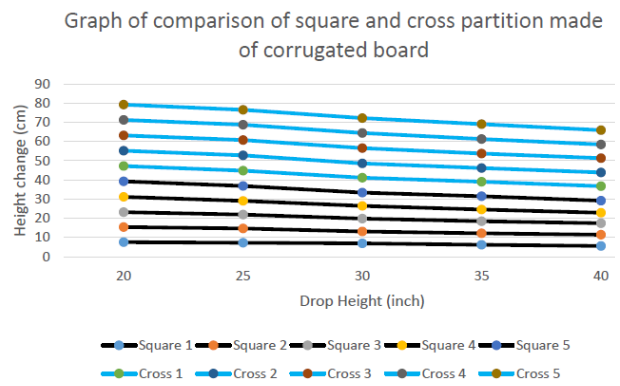

Figure 7. Graph of comparison of square and cross partition made of corrugated board

Figure 7 shows the graph of the comparison of square and cross partitions made of corrugated board. From the graph shown, the comparisons between the types of partitions made of the corrugated board can be observed clearly. Discussing the square partition, after the first drop, sample 1 decreased 0.5 cm, 6.3% compared to the original height. Sample 1 cross partition does not change the height after the first drop. After the fourth drop, the square partition starts to fail at 6.2 cm, whereas the cross partition remains as a good partition at 7.5 cm. The difference between these two partitions is 1.3 cm, 21% for the square partition. From the graph, it can be concluded that a corrugated board made cross partition can absorb more shock compared to the square partition.

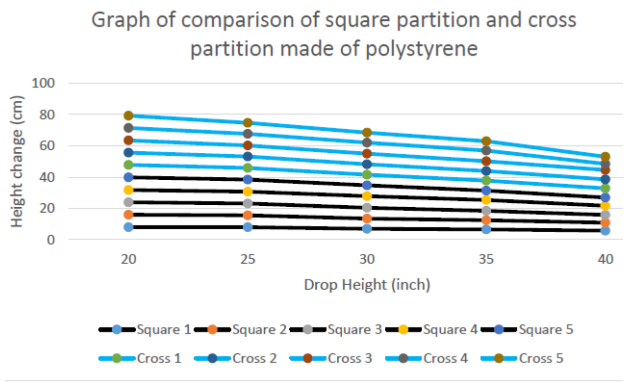

Figure 8. Graph of comparison of square and cross partition made of polystyrene

Figure 8 shows the graph of the comparison of square and cross partitions made of polystyrene. From the graph shown, the comparisons between the two materials made partition can be observed clearly. Taking the reading of sample 1 of square and cross partition, after the first drop, the height of the partition remained unchanged. However, after the third drop, all of the samples of square partition started to fail at a minimum of 7.0 cm. After the third drop, the cross-partition height changed is in the range of 6.4 to 7.0 cm, and all the partitions are not failed. By comparing the reading of the last drop of sample 1 for both square and cross partition, the square partition showed a reading of 5.8 cm which is already a failed partition. The cross partition shows a reading of 5.9 cm which is still in good condition. The difference between both partitions is only 0.1 cm which is around 1.7% but the end condition is totally different. From the graph, it can be concluded that polystyrene-made cross partition is able to absorb more shock compared to the square partition.

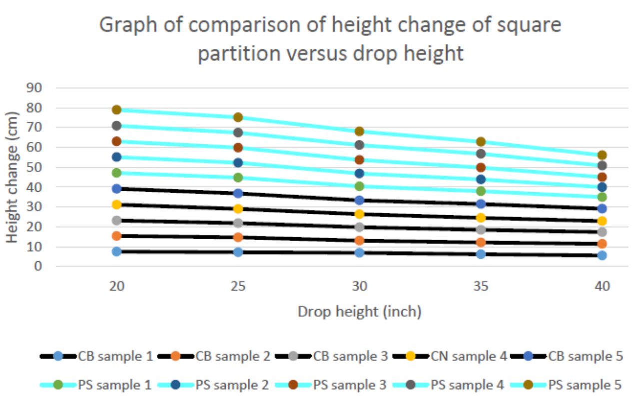

Figure 9. Graph of comparison of square partition for polystyrene and corrugated board

Figure 9 shows the graph of the comparison of square partition for polystyrene and corrugated board. From the graph above, the comparisons between the two materials made partition can be observed clearly. From the first drop of all samples of corrugated board and polystyrene made partition, the range of height change does not vary too wide. The range is between 7.5 cm to 8.0 cm. The corrugated board samples pose more changes in height compared to the polystyrene. Using sample 1 as an example, the corrugated board sample changes 0.5 cm, 6.25%, whereas polystyrene has no changes after the first drop. There is a significant difference between both samples. However, polystyrene made square partition started to fail after the third drop. Using sample 1 as an example, the partition failed at 7.0 cm while the corrugated board made partition remains as an adequate cushion at 7.2 cm. By comparing the failure rate of both materials, polystyrene-made partition tends to fail at a higher range of height that is a minimum of 7.4 cm. The corrugated board-made partition failed after the fourth drop which is at a minimum height of 6.2 cm. The minimum failure rate between the two materials differs about 1.2 cm, 16.2% with respect to the polystyrene minimum failure height. From the graph above, it can be justified that a corrugated board made square partition possesses a higher ability to absorb shock.

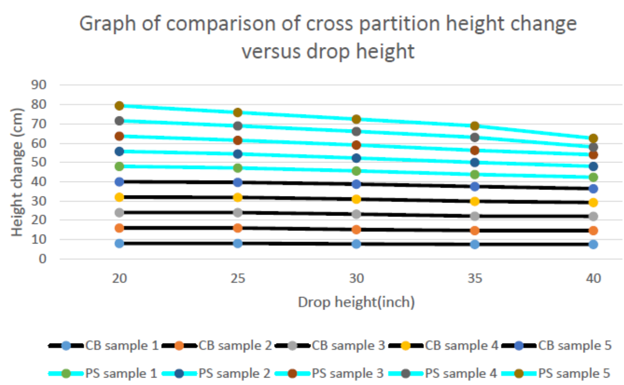

Figure 10. Graph of comparison of cross partition for corrugated board and polystyrene

From Figure 10, the comparisons between the two materials made partition can be observed clearly. From the first drop of all samples of corrugated board and polystyrene made partition, the range of height change does not vary too wide. The range is between 7.8 cm to 8.0 cm. The corrugated board samples do not undergo height change after the first drop, whereas the polystyrene undergoes a slight change in height. Using sample 2 as an example, the polystyrene sample changes 0.2 cm, 2.5%, whereas the corrugated board has no changes after the first drop. There is a significant difference between both samples. Using sample 1 of corrugated board, the second drop does not affect the height as well, until the third drop. It changed to 7.7 cm, decreased about 0.3 cm, 3.8% compared to the original height. By comparing to the polystyrene, sample 1, after undergoing a second drop, at 25 inches, the height changed to 7.5 cm which declined about 0.5 cm, 6.3% compared to the original height. By checking sample 5 for both the materials, at the same drop height, 40 inches, the corrugated board, and polystyrene partition pose a height of 7.2 cm and 4.5 cm, respectively. The difference is about 2.7 cm, 37.5% with respect to the corrugated board-made partition. From the graph, it can be concluded that a corrugated board made cross partition is able to absorb more shock compared to the polystyrene.

Hence, the summary of average readings of G peak value and the average readings of height change for cross partition made of corrugated board and polystyrene as shown in Table 1 and Table 2. Based on the average readings of G peak value, it can be concluded that the corrugated board made square and cross partition is suitable for packaging glass and pottery containers. The polystyrene-made partition is more suitable to be used for electronic equipment.

Table 1. Summary of average readings of G peak value of corrugated board and polystyrene made partition

Corrugated board partition	Average five readings	Polystyrene partition	Average five readings
Square	45.66	Square	34.26
Cross	50.49	Cross	30.95

Table 2. Summary of average readings of final height of cross partition

Types of cross partition	Average five readings (cm)
Corrugated Board	7.7
Polystyrene	6.7

IV. CONCLUSION

Adequate packaging is very important in protecting products from hazards during transportation and handling. The corrugated board shows a better cushioning material compared to the polystyrene. Besides, the cross partition is able to absorb more shock and more protection towards the product compared to the square partition which is slightly not suitable in protecting the product from a big impact.

In general, this study shows that corrugated board and polystyrene have different properties based on the design and material. Both of the materials are potentially to be used as cushioning material in packaging. There are some suggestions to improve further the protecting performance of cushioning materials.

i. Investigate obtaining the critical thickness of cushioning material for each load applied.
ii. Use different orientations/design of cushioning material in order to identify the highest performance.

V. ACKNOWLEDGEMENT

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