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RESEARCH ARTICLE

Influence of Fiberboard Container Design on Compression Bulge Displacement

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ABSTRACT

Bulge effect is the out-of-plane displacement of a panel of a corrugated fiberboard box from its original position. This bulge effect often is the result of excessive weight being placed on a box that rests at the bottom of a palletized load. Panels that are out-of-plane reduce the stacking strength of the box and can result in damage to products inside the containers. This study was designed to find the influence of fiberboard container design on its bulging performance when under compression. The objective of the study was to determine if change in height of a regular slotted container will affect the bulging performance in relation to different environmental conditions. For this study, three heights were selected based on the market study of the fresh produce sector and testing was conducted in accordance to American Society for Testing and Materials (ASTM) standards. All the samples were conditioned in accordance to ASTM and Technical Association of the Pulp and Paper Industry (TAPPI) standards. Data analysis for the three box heights suggests that compression bulge displacement may be affected in some scenarios..

KEY WORDS

corrugated fiberboard, bulge; RSC; compression.

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INTRODUCTION

The transportation of products to consumers is a complex process. Product damage can arise from various areas such as "physical, chemical, microbiological and climatic sources" [1]. Due to the risk of product damage, it is critical that the selected container provides sufficient protection from the distribution environment. Compression and shock performance have received attention from the packaging industry, but there is limited research on bulging performance. Container bulging has the potential to cause damage to the product inside due to material fatigue. This effect is commonly observed when the containers have a load stacked on top of them for a long period of time, causing material deformation over time referred to as fatigue [2]. A variety of environmental climates may also be present during the transportation process. This provides further complications. For example, an increase in humidity will cause water absorption in paper-based materials leading to a loss in strength [3]. While increasing product headspace would most likely minimize product damage due to compressive forces it would not solve pallet load destabilization and would decrease the amount of product that could be shipped. A regular slotted container (RSC) C-flute single wall corrugated fiberboard box is one of the most common container styles in the packaging industry. As such, increasing performance on this design allows for optimization of improvement in the packaging industry.

Corrugated Fiberboard Container

A regular slotted container (RSC) is the most common box style. It is identified by European Federation of Corrugated Board Manufacturers (FEFCO) as FEFCO code 0201 (Figure 1). All flaps of the box are the same length and the two outer flaps meet at the center of the box when folded. This design minimizes manufacturing waste by using as much area of the blank size as possible [4].

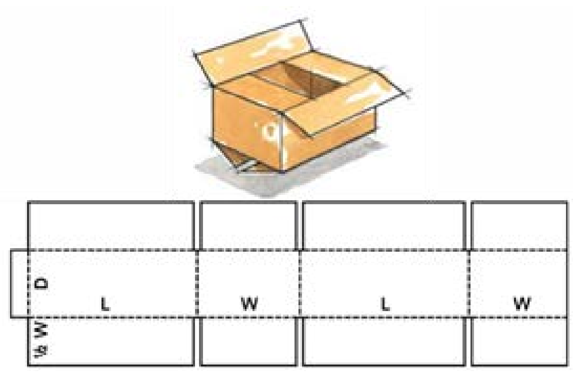

Fig. 1: Regular Slotted Container [4]

Basis weight is used to express the amount of fiber in a sample of paper or paperboard. In the United States, basis weights are indicated as pounds per 1000 or 3000 square feet depending on the application of the paper or paperboard [5]. For corrugated fiberboard, combinations of basis weights are expressed by writing the basis weights of each layer from outside to inside and separating the basis weight of each layer with a forward slash. In single-wall corrugated fiberboard, this expression would be the combined weight of facings and fluted medium as shown in Table 1.

The grades of corrugated fiberboard can be defined either by the Mullen Test or the Edge Crush Test. The Mullen Test is used to determine the force needed to rupture the board. The Edge Crush Test refers to the stacking strength of the box before it crushes at its edges. Boxes use different grades of corrugated fiberboard depending on the weight of the product inside and the desired stacking strength of the box to resist compressive loads. Grade of the paper used for liners on the corrugated board can be identified by the box manufacturer certificate printed on a box, as seen in the examples in Figure 2. Boxes designed to transport fresh produce use higher grade corrugated fiberboard to prevent produce damage. Fruits and vegetables are easily

Table 1: Mullen and ECT Test with Corresponding Weight of Layers in Corrugated Fiberboard [6]

Fiberboard [6]	
Single Wall	
Mullen	Combination
125	26/26/26
150	33/26/33
175	42/26/42
200	69/26/42
250	69/26/69
275	90/26/90
350	90/26/90

ECT	Combination
32	35/26/35
40	35/26/55
44	55/26/55

bruised or crushed in loading and transportation. Use of high-grade corrugated fiberboard improves the stacking strength by improving the performance of the walls of the box that bear vertical load. Boxes that can bear greater vertical loads are less likely to be crushed in transit. High-grade corrugated fiberboard boxes also exhibit less bulge than corrugated fiberboard made from lower grade paper. Fresh produce near panels that exhibit bulge are more likely to be damaged. Boxes designed for agricultural use should have minimal bulge [7].

The basic types of board include single face, single wall, double wall, and triple wall corrugated board are shown in Figure 3. These types of board consist of different numbers of liners and fluted mediums. Single face board is used as a wrapping material for fragile products. Single wall a popular corrugated board used for various boxes. Double wall and single wall are used when extra padding, stacking strength,

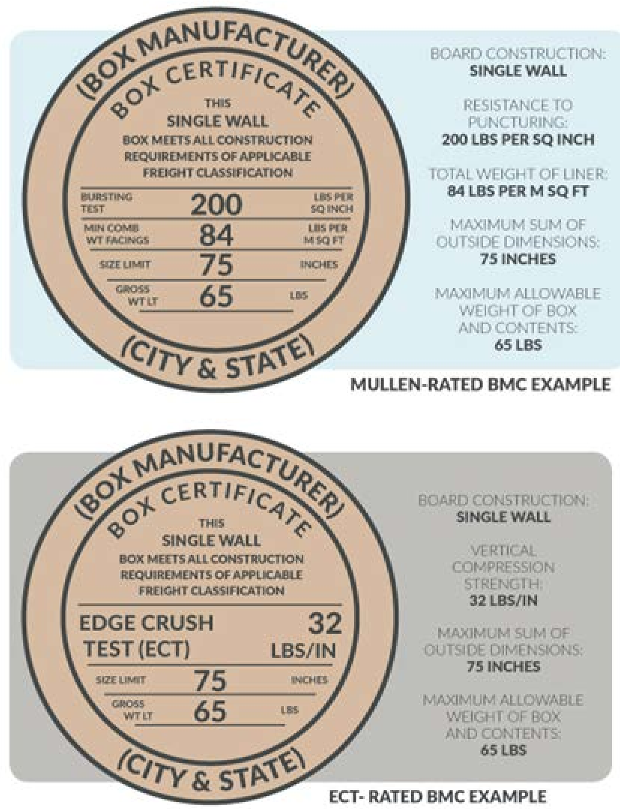

Fig. 2: Mullen and ECT-rated Box Manufacturer Certificates [8]

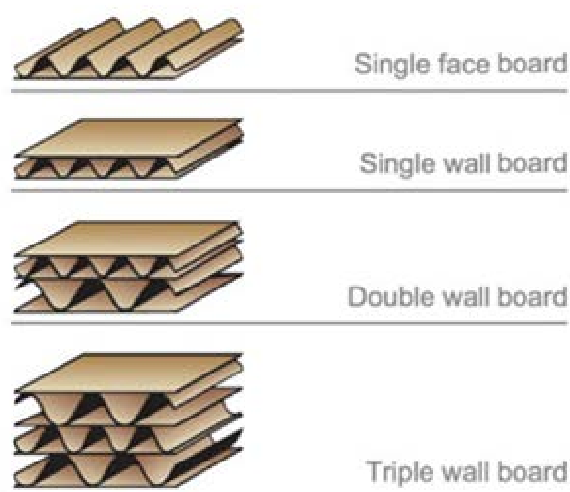

Fig. 3: Board Types [10]

Table 2: Common flute sizes [11]

Flute Type	Flute Thickness (in)	Flutes Per Foot
A-flute	1/4"	33
B-flute	1/8”	47
C-flute	3/16”	39
E-flute	1/16”	90

and crush resistance are needed [9] (Pro Pac, 2019). Another characteristic of corrugated fiberboard is the size of the flutes in the medium as shown in Table 2. Boxes use different flute sizes depending on the performance needs of the package. Thicker flute sizes have stronger stacking strength when used in boxes. Thinner flute sizes are used when the quality of graphics is a priority due to the flatter surface made when more flutes per foot are utilized [10] (Pro Pac, 2019).

Corrugated Common Print

The most common pallet used is the Grocery Manufacturers Association (GMA) pallet. While pallets used in distribution have been standardized to use GMA (40” x 48”) dimensions, the length and width of boxes can vary to fit the needs of containment for different products [12]. However, a common footprint for corrugated fiberboard boxes has been established by The Fibre Box Association. The dimensions and layout for boxes using this standard are shown in Figure 5. Either five or ten boxes can fit a standard GMA pallet without overhang or under-hang using these standardized dimensions. Container dimensions that allow for five corrugated fiberboard boxes to sit on one layer are referred to as “5-Down” and container dimensions that allow for ten corrugated boxes to sit on one layer are referred to as “10-Down” [4].

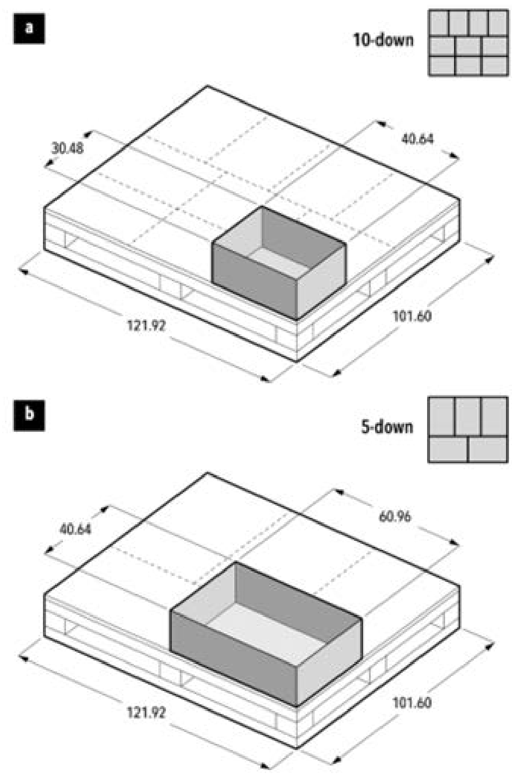

Fig. 5: (a) Half-size (b) Full-size Corrugated Common Footprint (CCF) Containers [12]

Corrugated Container Bulge

Bulge effect refers to the displacement of a panel of a container from its original plane (Figure 6). Loose content inside of a container exerts a pressure that pushes the container panels away from the center of the box. The amount of bulge observed may be increased or reduced depending on the bending stiffness of the corrugated fiberboard used. Bending stiffness is inversely proportional to

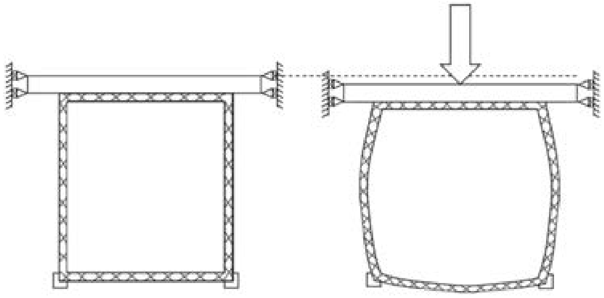

Fig. 6: Container Bulge of an Empty Container Under Compression [13]

bulge effect, as an increase in stiffness will yield a decrease in bulge effect. The bending stiffness of a panel is determined by the grade of linerboard, size of the flutes, overall box dimensions, orientation of the fluted medium, and the surrounding environment of the box. Containerboard with larger flute sizes have greater bending stiffness relative to containerboard with smaller flute sizes. However, the tradeoff is higher material costs which are amplified with economies of scale.

The overall box dimensions will change the panel span, or distance between the corners of the box. Most of the rigidity of a box stems from the edges and corners where panels meet. In order to increase bending stiffness, the overall dimensions of the box should be reduced. Although the dimensions of the box can be reduced to increase bending stiffness, the box still needs to be large enough to contain the product or item inside. [13].

Bulge effect is reduced in the direction of the flutes on corrugated fiberboard due to the shape of the flutes. The surrounding environment of the box will also determine the bending stiffness of the box panels. Water or water vapor can increase the moisture content of the containerboard. This is especially true in fiberboard packaging for fresh produce, as fresh produce contains a lot of water. Increasing the moisture content in the material breaks the bonds between cellulose fibers, reducing the rigidity of the panel. Thus, an increase in moisture content of the containerboard will lead to a decrease in bending stiffness.

Compression bulging occurs due to the external downward compression load on the box. In the real world, this kind of compression can occur in this distribution environment due to the weight of the different containers on top of the container getting bulged. In the lab environment, this bulging is simulated using a compression testing machine.

Initial bulge, sometimes referred to as filling bulge, is the bulge of the panels of a corrugated fiberboard box during and immediately after the filling process (Figure 7). The contents filling a container apply a pressure to the inside walls of the box and push the panels out-of-plane from their original position. Initial bulge is only measurable during the filling of the box up until the filling process is completed. Due to initial bulge being observable for only a short duration, it is classified as a time-dependent bulge. Time-dependent bulge can measure the displacement of the panels of the boxes as a function of time [13] (Peleman, 2018).

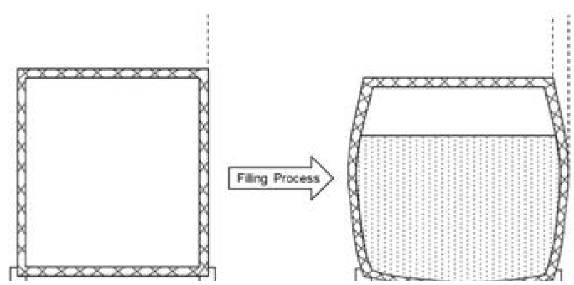

Fig. 7: Initial Bulge of a Container During Filling Process [12]

There are two different types of compression happening in the distribution environment, Static Compression and Dynamic Compression. Static

Fig. 9: Ten-Down Box Design Example – 9.5-inch height (241.3 mm) [All dimensions are in millimeters]

compression is when the pallet loads are stored in a warehouse or distribution center and measured by dead-load stacking tests. On the other hand, Dynamic Compression is when the pallet load is in motion. The compression strength is directly related to the stacking strength of the box. The compression strength can be found out using two methods, either by using the McKee formula or by lab testing. Stacking strength is not the same as the compression strength of a box and cannot be used in a packaging system to determine the top load. Stacking strength is lower than the compression strength because it takes into consideration the distribution hazards and environmental impacts. Some of the different factors which are involved in this calculation are stacking duration (number of days), stacking pattern – columnar or interlocked, relative humidity and excessive handling.

This study examines the effect container height on bulge of filled containers under a compression load. Six different container designs, based on the regular slotted container style (RSC, FEFCO Code 0201), were analyzed in this study. Each design varies based on corrugated common footprint and container height. These containers were tested under three different environmental conditions - ambient, tropical and refrigerated, using environmental chambers for pre-conditioning and conditioning [14,15]. A compression testing system in combination with a patented container bulge measuring fixture were used to quantify the maximum compression bulge under a top-to-bottom static compression load. The findings of this study should be of value for packaging engineers involved in managing the potential reduction of material usage while maximizing the stacking strength and rigidity of corrugated fiberboard containers.

MATERIALS, PRE-CONDITIONING AND CONDITIONING

In order to analyze the relationship between bulging performance impacted by compression and fiberboard container design regular slotted container adhering to the common footprint (Figure 9 and 10) were constructed using a single wall C-flute with a board combination of 43/26/43. The six design parameters were 5-Down and 10-Down footprint, with heights of 9.5-inch, 11.5-inch and 13.5-inch (241.3 mm, 292.1 mm and 342.9 mm) for both footprints. All the samples were pre-conditioned in accordance to the Technical Association of the Pulp and Paper Industry (TAPPI) 402 SP-13 (Standard Conditioning and Testing Atmosphere for Paper, Board, Pulp Hand

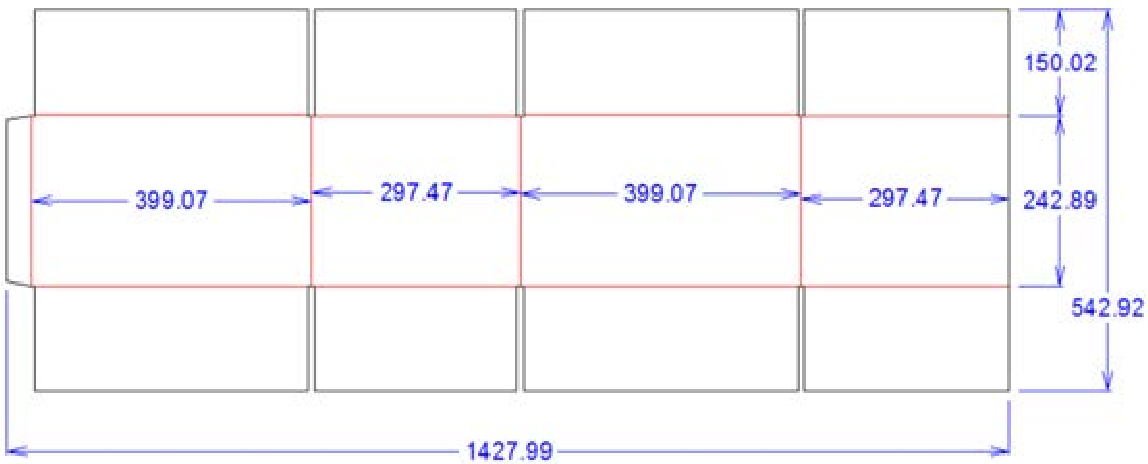

Fig. 9: Ten-Down Box Design Example – 9.5-inch height (241.3 mm) [All dimensions are in millimeters]

sheets and Related Products)[14] and then conditioned in accordance with the ASTM D4332-14 (Standard Practice for Conditioning Containers, Packages, or Packaging Components for Testing Conditioning) [15] for ambient, tropical and refrigerated conditions. A Darwin environmental room (Darwin Chambers Company, USA) was used to precondition and condition the samples before testing. EXTECH Data Logger SD700 [16] Barometric Pressure, Humidity and Temperature data recorders were used to track the different temperature and relative humidity values as a function of time. When conditioning containers, temperature and humidity are key factors and tracking these factors can identify undesired causes of variance in this experiment.

Bulge Measurng Apparatus and Setup

A patented bulge measuring apparatus invented by Singh and Kutz [17] is used to measure the out-plane displacement of the side faces and the bottom faces of a container. To measure the bulge, the container is placed within the extensible frame of this apparatus which allows to measure the bulge for three axes. The apparatus has an inner ledge helping to snug fit the testing sample. Assemblies of sensors are grouped to measure container bulging. The assemblies include a platen which measures out-of-plane displacement of panels from their original positions. The platen initiates contact with the center of the panel as this is the point of the panel that should exhibit the most out-of-plane displacement. The frame and measuring platens of the bulge measuring apparatus can be seen in the perspective view in Figure 11. The out-of-plane displacement of the panels is measured while a force is applied to the top of the box as seen in Figure 12.

The displacement values displayed on a digital

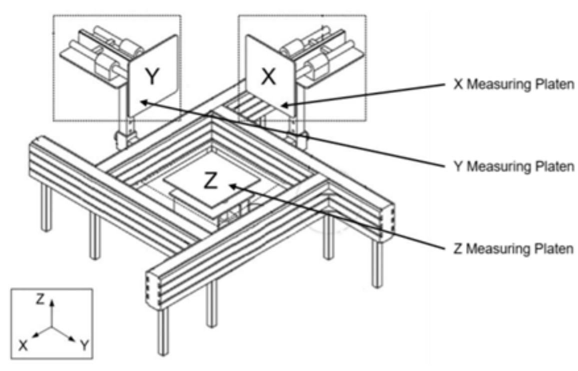

Fig. 11: Perspective View of the Bulge Measuring Apparatus [Adapted from US Patent US8746085B2] [17]

read output attached to the bulge measuring apparatus. The displacement values from each of the three axes are shown on the Easson ES-10, 3-axis digital reader attached to the apparatus as seen in Figure 13.

The X platen is used to measure the long face of the container, the Y platen for the short face and the Z Platen for the bottom face respectively (Figure 11). The X and Y measuring platens used to measure the bulge of the side faces of the container remain at the maximum displacement after performing the compression bulge test to note the final readings. The Z platen is spring returned measuring platen. A Lansmont Compression Tester (Lansmont Corporation, USA), as shown in Figure 16, was used as an external compressive force to create the bulge effect on the containers.

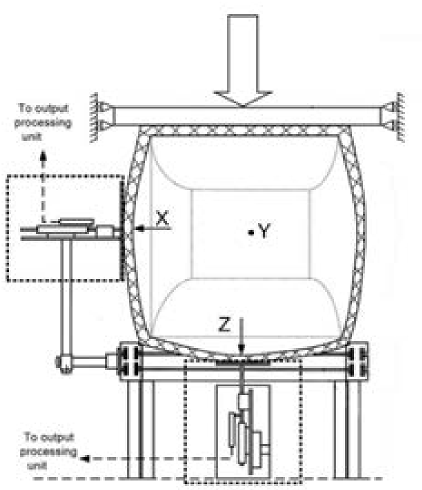

Fig. 12: Cross Sectional View of a Container During Compression Bulge Test

[Adapted from US Patent US8746085B2] [17]

Fig. 13: Bulge Measuring Apparatus and Lansmont Compression Tester

METHODS

A preliminary study was conducted to gauge bulging performance prior to the main study by testing five conditioned RSC containers for all the two heights for ambient and tropical environmental conditions to validate the design of the experiment

Table 3: Experimental Design for Preliminary Study

	Ambient Conditions 23°C and 50% Relative Humidity	Tropical Conditions 40°C and 70% Relative Humidity
Heights (inches or mm)	**Five Down (Replicates)**	**Ten Down (Replicates)**
9.5 / 241.3	5	5
12 / 304.8	5	5

(Table 3). The study involved testing five samples in accordance to ASTM D642 (Standard Test Method for Determining Compressive Resistance of Shipping Containers, Components, and Unit Loads)[18] for two heights under the theoretical best case and worst-case environmental conditions, Ambient and Tropical Conditions. The preliminary study data were used to determine the number of samples needed to be tested in the main experiment. The bulge performance was measured using a Bulge Tester Apparatus. To simulate the bulging effect on the box, a compression tester was used in accordance to the ASTM D642. The results of the preliminary study and the experimental design of the main study are shown in the results section (Tables 4 and 5).

A standard operating procedure was created to conduct the Compression Bulge Test for the preliminary and main study:

1. Place the bulge tester under the compression tester, under the center of the platen.
2. Adjust the extensible frame to snuggly receive a container within a rectilinear aperture formed by the interior walls of the extensible frame. For this experiment, adjust it to fit either five down or ten down footprints prior to testing.
3. Label all the faces of the container as per the Procedure ISTA 1A [19]. For this experiment, label all the faces of the regular slotted container as shown in Figure 14.
4. Tape the face 3 of the boxes in accordance to ASTM D1974 [20] in the environmental chamber to minimize exposure to regular environmental conditions.
5. Fill the sample with HDPE plastic pellets, approximately seventy five percent of the container (Figure 15) and tape the face 1 of the sample.
6. Position the container within the rectilinear aperture such that upright panels of the container are encompassed by the extensible frame and the bottom panel is flush with the interior ledge (Figure 16).

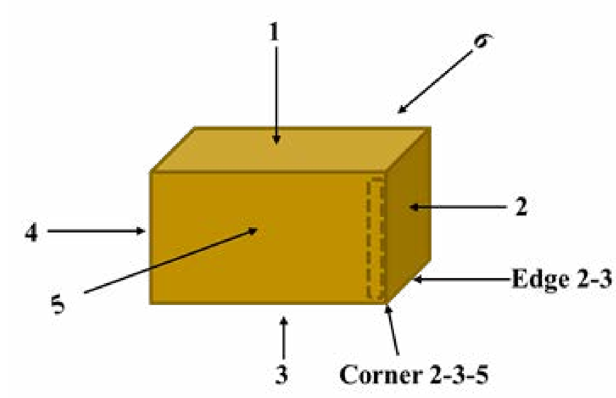

Fig. 14: Box Face Identification [19]

Fig. 15: Corrugated Container Containing HDPE Pellets

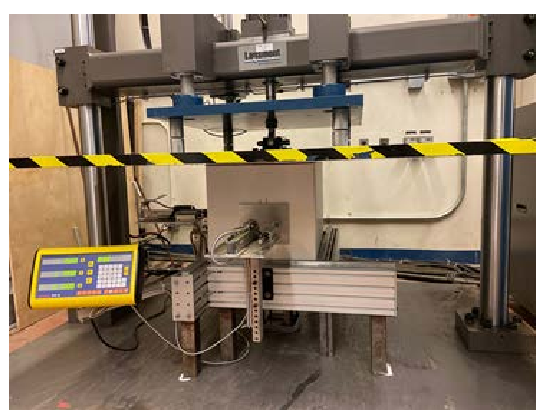

Fig. 16: Compression Bulge Displacement Test Set-Up

As shown in Figure 16 bring down the compression tester platen till its barely touching the top of the container.

8. Position the platens about centroidal areas of the container (Figure 16).

9. On the ES-10 Digital reader, zero out the three axes.

10. Start a compression test till failure. Compression tester settings included a preload of 50 pounds, test speed of 0.5 inch/minute, and stop of test at a 10% compression force yield.

11. Record the peak force, deflections and the XYZ values from the digital reader.

12. Use a camera or recording device to observe and record the Peak Z value as it is a spring return.

RESULTS AND DISCUSSION

The impact of height and pallet footprint dimensions on bulge amount were analyzed in three environmental conditions, ambient, tropical and refrigerated for the main study. Bulge amount in the X and Y axes were observed and recorded at the peak load. From the preliminary study data, a general full factorial power analysis was conducted with a target power level of 80%. 'Effect Size' is a measure of how large a difference in data needs to exist to be considered meaningful and standard deviation of bulge amount were the inputs. As seen in Table 4, a maximum replicate amount of 3 was required to reach the 80% power level. Therefore, for the main study had three replicates for all treatments (Table 5). Additionally, bulge amount in the Z axis was minimal thereby it was not observed in the main study

The results of the main study are shown in Figures 17-20. A one-way analysis of variance (ANOVA) was conducted for both X (Long face) and Y(Short face) panel bulge in each pallet footprint

Table 4: Preliminary Study Power Analysis

Panel	Effect Size (in.)	Standard Deviation	Replicates Needed
X	0.167	0.149	3
Y	0.326	0.058	2
Z	0.013	0.008	2

Table 5: Experimental Design for Main Study

	Refrigerated Conditions 12°C and 85% Relative Humidity	**Ambient Conditions 23° C and 50% Relative Humidity**	**Tropical Conditions 40° C and 70% Relative Humidity**
Heights (inches or mm)	**Five Down and Ten Down (Replicates)**	**Five Down and Ten Down (Replicates)**	**Five Down and Ten Down (Replicates)**
9.5 / 241.3	3	3	3
11.5 / 292.1	3	3	3
13.5 / 342.9	3	3	3

and environmental condition. A general linear model ANOVA was conducted for both X and Y panel in each pallet footprint across all environmental conditions. The data had equal variances and normal distribution which are the two requirements needed in order to run the general linear model.

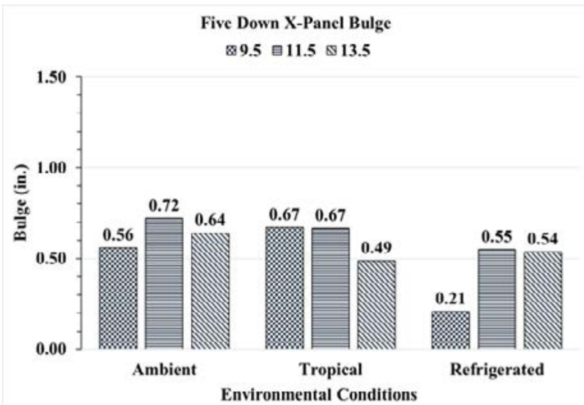

Fig. 17: 5-Down RSC's Compression Bulge Displacement along X Panel (Long face)

Compression Bulge Displacement-Five Down

The out of plane or bulge displacement observed on the varying heights of Five down RSC containers as affected by environmental conditions are shown in Figures 17 and 18. ANOVA analysis for 5-Down RSC containers stored in ambient, tropical and refrigerated conditions did not indicate any significant effect ($p > 0.05$) on X-panel's (Long face) bulge displacement across all three box heights (Figure 17). Similarly, 5-Down RSC containers stored in tropical and refrigerated conditions did not have a significant effect on Y-panel's (Short face) bulge displacement across all three box heights (Figure 18).

However, 5-Down RSC containers stored in ambient conditions indicated that there was a significant effect ($p \leq 0.05$) on Y-panel's (Short face) bulge displacement (Figure 18) across the three box heights. Subsequently, a Fisher's LSD was performed on the Y-panel compression bulge displacement. Which revealed that the RSC container with 13.5 in. height had a significantly higher bulge on the Short face compared to the box heights of 11.5 in. and 9.5 in (Figure 18).

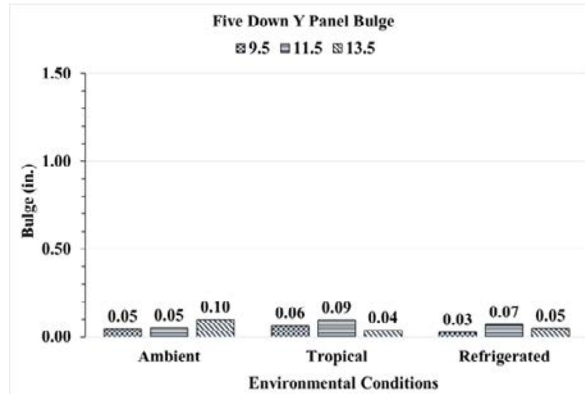

Fig. 18: 5-Down RSC's Compression Bulge Displacement along Y Panel (Short Face)

A general linear model analysis was conducted which allows the ANOVA procedure to analyze interactions between variables. It was observed that there were not any significant differences ($p > 0.05$) in compression bulge displacement across X and Y panels for all box heights and environmental conditions in 5-down footprint. Indicating that for a 5-down footprint there was no interaction between the variables box heights and different environmental conditions towards compression bulge displacement on both Long (X-Panel) and Short faces (Y-Panel). It should be noted that this finding is limited to the box heights considered in this study.

Compression Bulge Displacement-Ten Down

The out of plane or bulge displacement observed on the varying heights of Ten down RSC containers as affected by environmental conditions are shown in Figures 19 and 20. ANOVA analysis for 10-Down RSC containers stored in tropical and refrigerated conditions did not indicate any significant effect ($p > 0.05$) on X-panel's (Long face) bulge displacement across all three box heights (Figure 19). Similarly, 10-Down RSC Containers stored in ambient, tropical and refrigerated conditions did not have a significant effect on Y-panel's (Short face) bulge displacement across all three box heights (Figure 20).

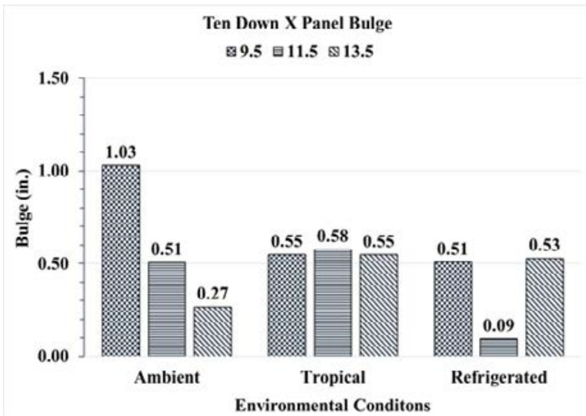

Fig. 19: 10-Down RSC's Compression Bulge Displacement along X Panel (Long Face)

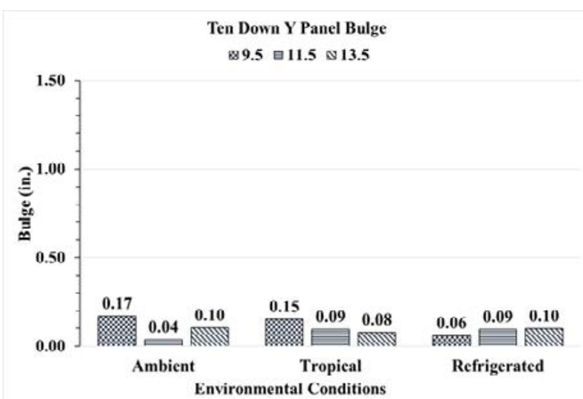

Fig. 20: 10-Down RSC's Compression Bulge Displacement along Y Panel (Short Face)

However, 10-Down RSC containers stored in ambient conditions indicated that there was a significant effect ($p \leq 0.05$) on X-panel's (Long face) bulge displacement across the three box heights (Figure 19). Subsequently, a Fisher's LSD was performed on the X-panel compression bulge displacement. Which revealed that the RSC container with 9.5 in. height had a significantly higher bulge followed by box heights of 11.5 in. and 13.5 in (Figure 19).

A general linear model (GLM) analysis was conducted which allows the ANOVA procedure to analyze interactions between variables. Corresponding GLM analysis did not find any significant differences ($p > 0.05$) in compression bulge displacement across Y-panels (Short face) for all box height and environmental conditions in 10-down footprint (Figure 20).

However, a GLM analysis indicated that there was a significant difference ($p \leq 0.05$) across X-panel compression bulge displacement for all box heights and environmental conditions in 10-down footprint. In addition, a two-way interaction between height and environmental conditions was observed. As shown in Figure 19, X-panel compression bulge displacement steadily decreases with increasing box heights in ambient condition but is relatively unaffected in tropical condition and is lower in refrigerated condition for the 11.5 in. samples. Therefore, it can be said X-panel (Long face) compression bulge displacement is different across all heights in 10-down and the type of differences are also dependent on the specific environmental condition. Indicating that for a 10-down footprint the box heights and different environmental conditions are significantly contributing to compression bulge displacement on Long face (X-Panel). It should be noted that this finding is limited to the box heights considered in this study.

CONCLUSIONS

The results from this study showed that in some scenarios RSC box height is significantly affecting compression bulge displacement. To some extent it can be ascertained that for an RSC box with a 5-down footprint tends to have higher compression bulge displacement on the Short face with increasing box heights under ambient conditions. However, from statistical analysis it is not evident that this trend is applicable under tropical and refrigerated conditions. Thereby it can be surmised that regardless of the box height (considered in this study) a palletized load with a 5-down footprint should not be significantly affected by compression bulge displacement under tropical and refrigerated conditions.

Similarly, an RSC box with a 10-down footprint tends to have reduced compression bulge displacement on the Long face with increasing box heights under ambient conditions. This observed trend is in contradiction to 5-down footprint where increasing box height contributed to higher compression bulge displacement. It is possible due to a smaller load bearing area of a 10-down RSC container compared to a 5-down RSC container could have led to this trend. However, the current study's data analysis cannot confirm this rationale. Therefore, it would of interest to further study this matter.

Overall findings of this study suggest that while RSC dimensions may affect compression bulge displacement in some scenarios. However, it seems that it is mostly affected by material properties of the corrugated fiberboard such as board grade, basis weight, moisture content, and other properties. This is consistent with past research findings for RSC bulge reduction trends with internal sesame tape in the corrugated board [13]. Further research should be conducted on these material properties to investigate their relation to compression bulge displacement for Regular Slotted Container.

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