Evaluation of a Bulge Reduction Technology for Corrugated Fiberboard Containers Under Static Compression

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ABSTRACT

This research examines the effect of top-to-bottom static compression load on the bulge of RSC containers. The study compares a control regular slotted container (RSC) constructed with corrugated fiberboard to tape-reinforced designs. The bulge reduction, achieved using various tape placements and conditioning environments, were measured. Currently, no research on the effect of reinforcement tape towards reduction in the out-of-plane displacement (bulging) of the corrugated fiberboard panels has been undertaken. Samples related to four different container designs, varying by presence, quantity and the position of the reinforcement tape on the vertical panels, were tested and analyzed. The study involved the use of a prototype cutting table, environmental conditioning chambers, a compression testing system and a patented container bulge measuring fixture. The statistical analysis of the observations confirms that the reinforcement tape significantly reduces the out-of-plane displacement of the container side panels under ambient environmental conditions (23 ± 1 °C, 50 ± 2% relative humidity). In tropical and refrigerated conditions (40 ± 2 °C, 90 ± 5% relative humidity and 5 ± 2 °C, 85 ± 5% relative humidity) it was observed that the reinforcement tape has potential in reducing bulge. The findings of this study should be valuable to packaging engineers towards the potential reduction of material usage while improving the stacking strength and rigidity of an optimized corrugated fiberboard containers.

KEY WORDS

corrugated fiberboard, bulge reduction; RSC; reinforcement taperesistance.

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INTRODUCTION

Since they were first slotted and cut in 1894 and approved as a valid shipping material in 1903, corrugated fiberboard containers have grown into the dominant form of transport packaging [1]. With an annual growth between 2014-19 of 1.3%, the global Cardboard Box & Container Manufacturing Industry generated a total revenue of $333 billion in 2019 [2].

Ideally, corrugated fiberboard containers are durable enough to withstand standard distribution related logistical activities. However, if non-optimally designed and validated towards the anticipated application in commercial use, corrugated fiberboard containers can damage the product carried within. The most common types of damage experienced by such containers are deformation related and include creasing, crushing and out-of-plane displacement (bulging).

Bulging may be described as a type of deformation containers experience when subjected to compressive forces such as superimposed stacking or internal forces due to the nature and bracing of the product carried within. Both compressive and internal forces can accelerate the failure of a container by causing panels to flex and flutes to buckle,
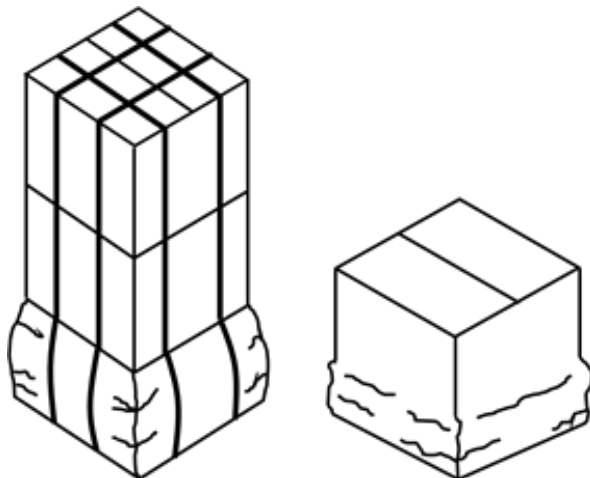

Figure 1: Compression (left) and Filling (right) Bulge [3]

thereby compromising its structural integrity. As part of unit loads, corrugated fiberboard containers are stacked onto pallets to facilitate both transportation and storage activities during distribution. During such applications, these containers exhibit a tendency towards deformation of their vertical panels due to the compressive forces placed on them. The outward deformation, or bulging, of a corrugated fiberboard container also has the tendency to destabilize the pallet loads. Due to the bulging, a container's original geometric shape is likely to change, causing the palletized load to take up more space than anticipated. For the pallet load, changes in geometric dimensions may result in unanticipated cube utilization issues. In more extreme cases, the pallet's unitization film may be forced to contact other surfaces during transit leading to wear and tear of the film and thus to further unit load destabilization.

Currently, there are no studies available specific to the performance of corrugated fiberboard containers towards evaluating their bulging characteristics. Validation tests such as those used for compression strength, impact resistance, and vibration challenges are examples of standardized tests related to corrugated fiberboard box that are most commonly undertaken by researchers. However, these tests do not provide sufficient focus on the bulging issue inherent to corrugated fiberboard containers. The Rail Committee on Information Standards provides a basic distinction between two types of bulge effects, namely compression bulge and filling bulge as shown in Figure 1 below [3]. Compression bulge is defined as the expansion of the original outside dimensions of a container as a result of external downward pressure caused by the strapping of the unit-load or by the weight of other superimposed packages, or a combination of both. Filling bulge is defined as the expansion of the original outside dimensions of a container during the filling process
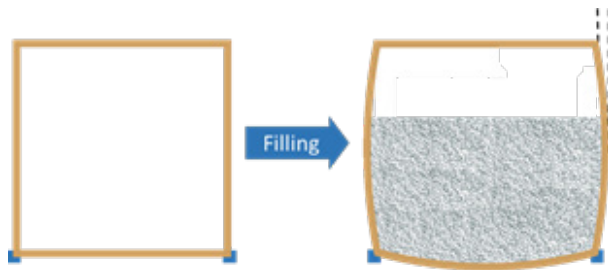
Figure 2: Concept of Initial Bulge

This research aims at defining and evaluating bulging of corrugated fiberboard containers. Towards the definitions, compression bulge has been further subdivided into regular compression bulge, maximum compression bulge and residual compression bulge. It may be noted that bulging issue is more pronounced for products that tend to "free-flow" i.e. they tend to settle to the bottom of the containers due to distribution related activities.

Initial bulge (IB) or filling bulge (FB), is the difference of out-of-plane displacement of the panels of a container before and immediately after the filling process (Figure 2). Both the filling process and the container's content results in its panels being pushed outward, i.e. changing the container's original shape due to internal pressure. It may be mentioned here that containers prior to being filled may already have considerable imperfections such as panels not being completely plane.

Compression bulge (CB) is the out-of-plane displacement of the panels of a container caused by an external top-to-bottom compression load (Figure 3). The out-of-plane movement of the panels of a filled container as a result of external loads can be caused by strapping the unit load, by superimposing other containers, or a combination of both. Maximum compression bulge (MCB) is the difference of out-of-plane displacement of the panels of a container at the start of the compression bulge test and the moment of maximum compression load (Figure 3). During the execution of a compression bulge testing, the out-of-plane displacement of the panels of the container increases as the top compression load is applied. With the choice of a stop force under the compression strength, or by recording the value of the bulge when the compression strength is reached, the value for the maximum compression bulge can be read. Residual or relaxation compression bulge (RCB), is the remaining difference of out-of-plane displacement between the start and the end of the compression bulge test (Figure 3). During the execution of a compression bulge test, the out-of-plane displacement of the container's panels increases with increasing compression load. If the compression bulge test is terminated and the compression load is removed, the container panels return over a certain distance in the direction of the original shape of the container. This returning out-of-plane displacement is called the returning bulge. Ideally, the residual compression bulge is equal to the maximum compression
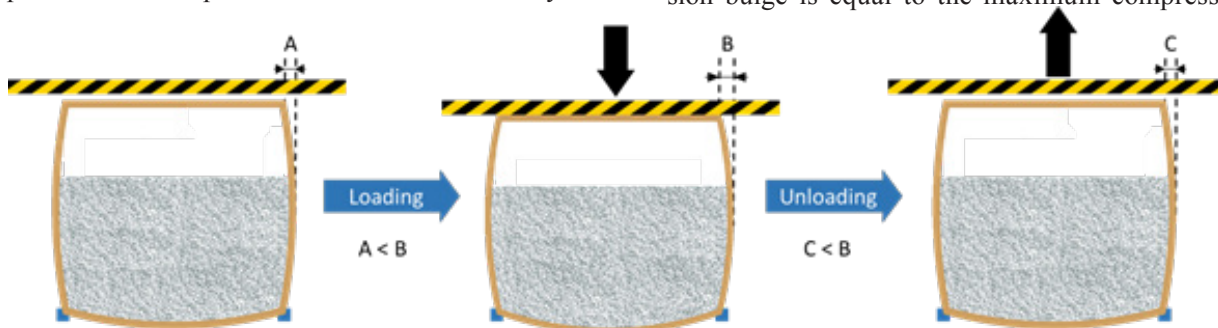

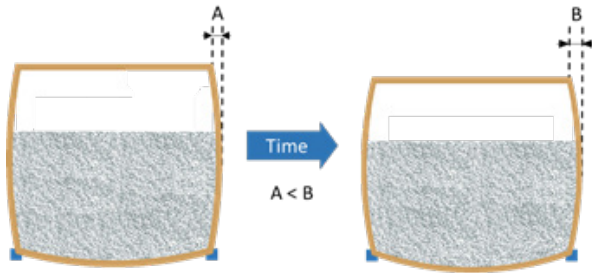*Figure 3: Concept of Compression Bulge*

Figure 4: Concept of Time-Dependent Bulge

bulge minus the returning bulge.

Time-dependent bulge (TDB) is the out-of-plane displacement of the panels of a filled container as a function of time (Figure 4). This bulge effect is generally due to the creep phenomenon which generally occurs as a result of long-term exposure to high levels of stress which are still below the yield strength of the material. Due to internal pressure caused by the content of the container, the container panels undergo an outward deformation. However, the container continues to bulge after having been filled and without applying an external compression load. In this study, this type of bulge is referred to as time-dependent bulge. Since the container filling process and execution of a compression bulge test is not instantaneous, TDB is always present.

As previously stated, information on methods to reduce the bulging effect is lacking. There are mainly three categories of bulge reducing methods, namely corrugated board selection and container design, interior components and reinforcement materials. All three categories focus on increasing the stiffness of the corrugated fiberboard panels.

While corrugated board can be stiffened by increasing the caliper and basis weight of the panel, these options go against the trend of right-weighting and more specifically light-weighting, where the focus is on using less material while targeting a comparable physical performance [4, 5]. Another option is to optimize the moisture content of the corrugated fiberboard. Moisture content is primarily dependent on the ambient environment of the container during its distribution which is typically uncontrollable to the optimal conditions. Surface treatments to increase the moisture resistance do exist but are expensive and may have environmental implications such as reduced recyclability. Another option considers the difference in bending stiffness of a combined board across the machine direction (MD) or the cross direction (CD). Since the MD bending stiffness is greater than the bending stiffness across the CD bending stiffness [6], minimizing the container depth dimension which is typically aligned in the CD direction, could be a bulge-reducing opportunity. However, this dimension may not be modifiable due to its relationship to the content dimensions.

The dynamics of a container under physical stresses during distribution can also be changed by connecting the internal packaging components, such as dividers, to the side panels of the container. This connection normally increases the resistance to bulge and increases the box compression strength [7, 8], but is dependent on the contents to be placed inside the container. Another strategy to reduce the bulge effect, is through applying reinforcement materials such as polymer strips, continuous filament strings or tapes into or onto the corrugated fiberboard. According to the Fiber Box Handbook [1], reinforcement materials do little to reduce bulge since paper structure fails earlier than the reinforcement. However, the ability of reinforcement to influence the external dimensions of a container is now reconsidered.

This study examines the effect of reinforcement tape on the bulge reduction of filled containers under a compression load. Four different container designs, based on the regular slotted container style (RSC, FEFCO Code 0201), were analyzed in this study. Each design varies based on the presence, the number and the position of the reinforcement tape on the vertical panels of the containers. These containers were tested under three different environmental

conditions - ambient, tropical and refrigerated, using environmental chambers for pre-conditioning and conditioning [9, 10]. A compression testing system in combination with a patented container bulge measuring fixture were used to quantify 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, TESTING APPARATUS AND METHODOLOGY

2.1 Materials

The reinforcement tape applied around the containers was a filament tape (Sesame® Tape, H.B. Fuller Company, St. Paul, Minnesota, USA). The tape consists of filament fibers coated with a hot melt adhesive on both sides. The tape is typically applied in the corrugated structure using a dispensing system at the wet end of a corrugator. Tape bonds to the linerboard and medium as the corrugator heat activates the hotmelt. The tape used in this study had a width of 1.1 cm (0.43 in) and a minimum breaking strength of 333 N (75 lbs) [11]. Figure 5 illustrates the two different placements of the tape included in this study. The tape as applied to the outside of the outer linerboard is referred to as out-board placement and as applied to the inside of the outer linerboard as in-board placement.

Figure 5: Out-Board Placement (left) and In-Board Placement (right) of Reinforcement Tape

Four different container designs composed of C-flute single wall corrugated sheets were included in this study. The basis weight of the sheets used was 205/112/205 g/m2, ECT value was 7.36 ± 0.18 kN/m and the burst strength was 0.98 ± 0.32 kgf/cm2. The internal dimensions of the RSC containers were 45.7 cm (length) x 35.4 cm (width) and 30.5 cm (depth) (18 in x 10 in x 12 in).

The various designs included in this study varied by the presence, the quantity and the position of the tape on the vertical panels of the containers. Below are the designs used in this study (Figure 6):

1. RSC: Regular Slotted Container with no reinforcement tape and used as a benchmark for performance comparisons

2. STC: Single Tape Container (RSC) with the reinforcement tape applied in-board across the circumference of the container at 50% height level

3. DTC-30-70: Double Tape Container (RSC) with the reinforcement tape applied out-board across the circumference of the container at 30% and 70% height levels.

4. DTC-20-80: Double Tape Container (RSC) with the reinforcement tape applied in-board across the circumference of the container at 20% and 80% height levels.

Figure 6 illustrates the different container designs with dashed lines indicating in-board placement of the tape and a solid lines indicating out-board placement of tape. It should be noted as a limitation in this study that the tape placement variables for this study were selected randomly to represent a few possible placements. Tapes are normally placed inside the board between the medium and outer liner. This study evaluated tapes placed on the outside of the board for one configuration to get a relative understanding of the placement since in board samples were not available. In addition, it should be noted that the containerboard was not
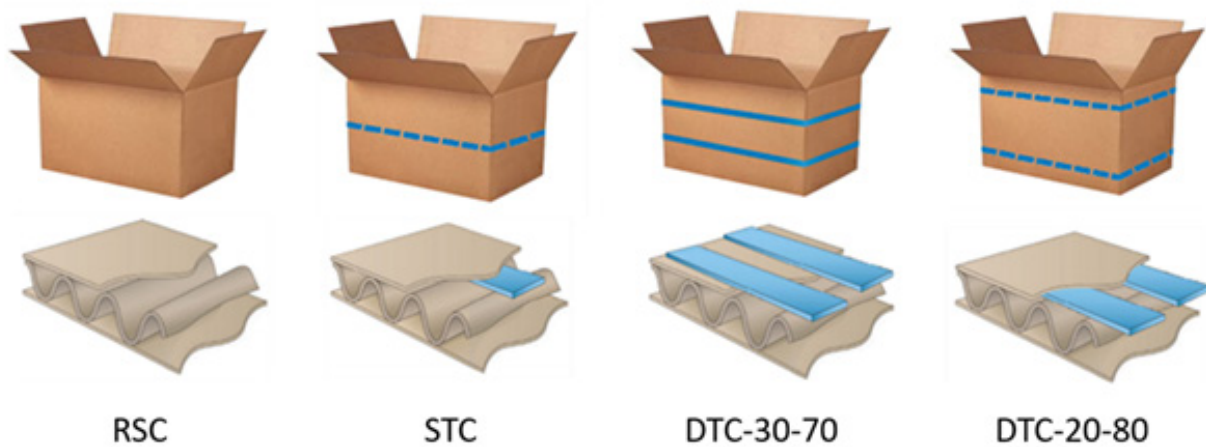
Figure 6: Representation of the Four Container Designs Studied

designed to withstand high humidity environments and did not have any moisture resistant properties.

Since bulging is more pronounced for free-flowing products, HDPE pellets (density of 0.941 g/cm3) were selected as the dead weight in this study. The presence of the pellets in the container ensures that the out-of-plane displacement of the side panels of the containers under compression load occurs in the outward direction. The container was filled with HDPE pellets to approximately 75% of the depth resulting in a total weight of 18 kg (Figure 7).
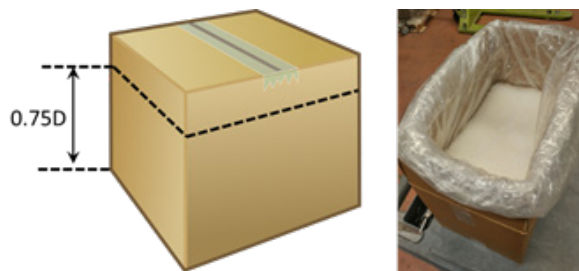

Figure 7: Filling Setup of Experimental ContainersDesigns Studied

2.2 Testing apparatus and fixture

An environmental chamber meeting the requirements of ASTM standards (Darwin Chambers Company, Saint Louis, Missouri, USA) was used to both precondition and condition the containers. The

standard practices recommended by ASTM D685 and ASTM D4332 were used towards identifying the prescribed temperature and humidity conditions as well as the associated durations to reach equilibrium with the respective environments [9,10]. A humidity/temperature datalogger (Model EXTECH SD700, FLIR Commercial Systems Inc., Nashua, New Hampshire, USA) was used to confirm that the tolerances recommended by the ASTM standards were met throughout the experimentation.

A servo-hydraulic compression tester designed to evaluate the compressive strength of individual shipping containers (Model 152-30, Lansmont Corporation, Monterey, California, USA) as shown in Figure 8 was used. The out-of-plane displacement (bulge) of the vertical panels of the containers was measured by a patented bulge measuring fixture (Cal Poly Corporation, San Luis Obispo, California, USA) (Figure 9). To conduct bulge testing, the bulge test fixture was placed under the test platen of the compression tester and loaded with the experimental containers (Figure 8). As the compression platen was vertically lowered onto the top panel of the containers, the downward forces caused the vertical panels of the containers to buckle and deflect outward (i.e. bulge). The quantity of bulge for the vertical panels was then directly displayed by the

precision measurement reader (Model ES-10, The EASSON Company, Vacaville, California, USA) attached to the bulge test fixture [12]. Throughout this manuscript, the X measurements represent bulging along the container's vertical panels along the length and the Y measurements represent the vertical panels along the width. During bulge testing, the location of the manufacturing (MFG) joint was always opposite of the corner where the X-Y bulge reading was captured (Figure 10).
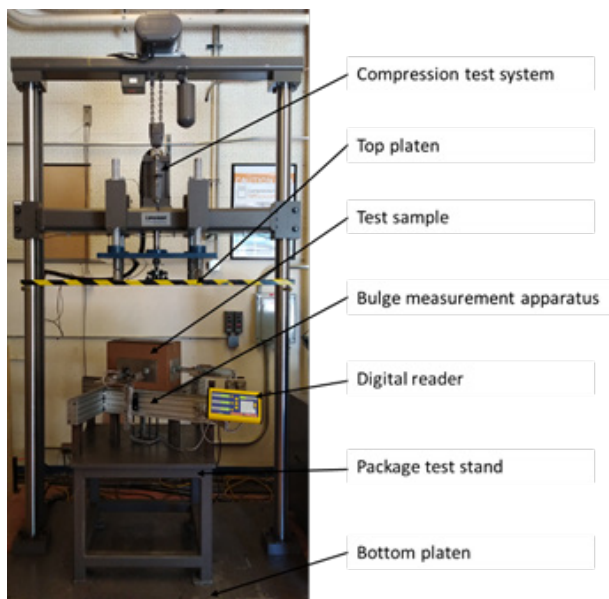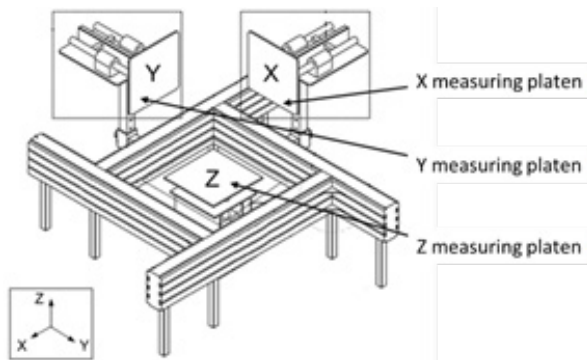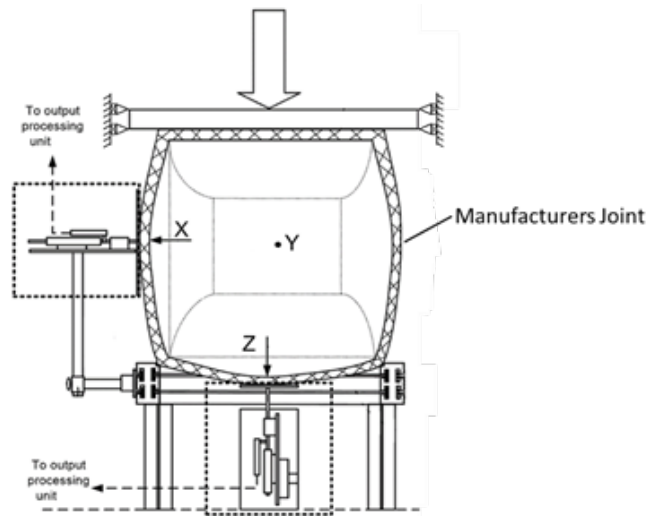

Figure 8: Compression Tester Setup

Figure 10: Manufacturer Joint in Relation to Compression Test Set Up

2.3 Methodology

As previously mentioned, all containers included in this study were both preconditioned and conditioned prior to any testing. The values for the temperature, relative humidity and durations to reach equilibrium were selected according to ASTM D685 (Standard Practice for Conditioning Paper and Paper Products for Testing) and ASTM D4332 (Standard Practice for Conditioning Containers, Packages, or Packaging Components for Testing) [9, 10]. While the preconditioning

Figure 9: Bulge Measurement Apparatus

	Pre-conditioning	Conditioning		
		Ambient	*Tropical*	*Refrigerated*
Temperature (°C)	30 ± 2	23 ± 1	40 ± 2	5 ± 2
Relative Humidity (%)	20 ± 5	50 ± 2	90 ± 5	85 ± 5
Time (hours)	72	24	24	24

Table 1: Preconditioning and Conditioning Specifications Note: "±" values indicate tolerances

requirements were adopted from ASTM D685, the three conditioning requirements, i.e. ambient, tropical and refrigerated, were adopted from ASTM D4332. Table 1 provides the conditioning specifications used for this study.

In compliance with ASTM D685's recommendation of the temperature between 22 °C-40 °C, a relative humidity range between 10-35% and a conditioning period between 24-72 hours, this study selected 30 °C, 20% and 72 hours respectively [9]. After the preconditioning, all containers are conditioned for three different environments, namely ambient, refrigerated and tropical, for a duration of 24 hours as reflected in Table 1 [10].

The compression tester settings were based on the ASTM D642 practice which provides the procedure for measuring the ability of the container to resist external compressive loads applied to its faces, to diagonally opposite edges, or to corners [13]. All compression testing was conducted using a preload of 222 N, a yield detection at 20%, a stop force of 133,000 N, a stop deflection of 1.27 cm and a constant rate test speed of 1.27 cm/min.

With eight replicates for each of the four designs and the three environmental conditions, a total of 96 experimental containers were tested in this study.

RESULTS AND DISCUSSION

The test data available are analyzed by performing three statistical analysis procedures:

Analysis of Variance (ANOVA), Dunnett's comparisons and Tukey's comparisons. In essence, the ANOVA determines whether at least one of the group/treatments means is significantly different from the others. Dunnett's test - also called Dunnett's Multiple Comparison - compares group means from several container design groups with a control group mean. The Dunnett tests (family-wise error rate at 5% and RSC as the control group) identifies which condition(s) yielded a significant difference(s) from the RSC mean. Tukey's test, also called Tukey Kramer's Honest Significant Difference test, is a post-hoc test based on the studentized range distribution and looks at all pairwise difference in group means, to determine which specific group means are different when compared with each other.

3.1 Maximum compression bulge

Figure 11 provides the overview chart of the means of the maximum compression bulge in the X and Y directions presented by conditioning environment and container design. Each bar is constructed using the mean of the bulge based on eight samples and each error bar is constructed using one standard deviation from the mean. The overview chart shows that the X bulge is clearly higher than the Y bulge which is due to the longer panel span. In the ambient environment, the X bulge of the RSC container is distinctly higher than the X bulge in the tape designs. However, in the following sections
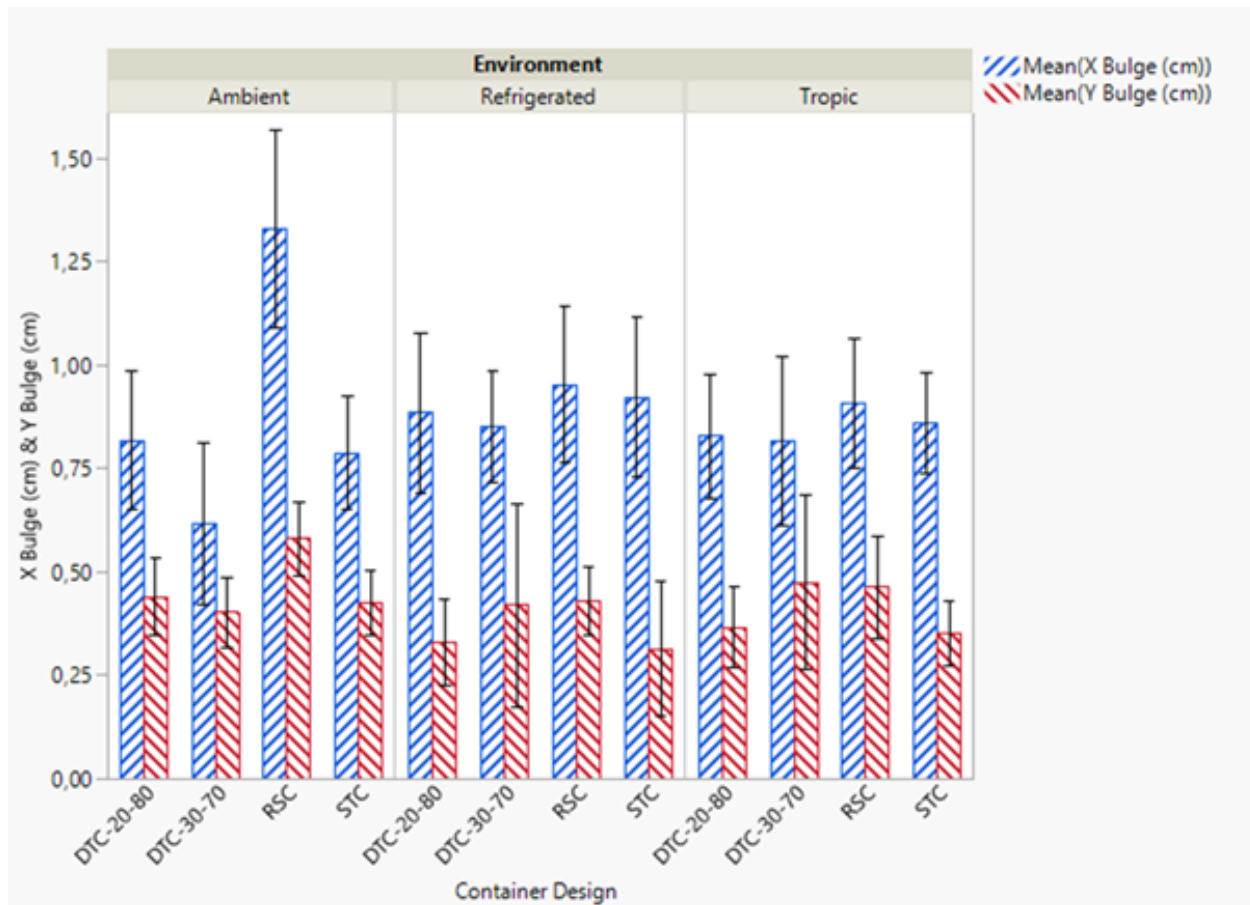
Figure 11: Overview Chart of Mean (±Standard Deviation) of Bulge by Container Design and Environment

a Dunnett's test is performed to examine whether the X and Y maximum compression bulge for the containers with tape are significantly different compared to the reference container.

The Dunnett test, with RSC as the control group, results for the X and Y bulge in an ambient environment are shown in Figure 12. The bar chart shows that the out-of-plane displacement in both the X and Y direction is significantly reduced for all tape-reinforced containers. In comparison to RSC design, the mean out-of-plane displacement is significantly lower for the containers with tape, namely the DTC-20-80 containers (X p-value < 0.0001 and Y p-value = 0.0076), the DTC-30-70 containers

(X-p-value < 0.0001 and Y-p-value = 0.0006) and the STC containers (X-p-value < 0.0001 and Y-p-value = 0.0026). Therefore, the tape reduces the bulging effect in both directions with an ambient conditioning environment. To examine whether the average values of the maximum compression bulge for the containers differ significantly from each other, a Tukey Kramer's test is performed. The results are shown in Table 2 as a connecting letters report whereby container designs not connected by the same letter have means that significantly differ from each other. The report shows the mean X out-of-plane displacement for the RSC containers with the corresponding letter "A" is significantly higher
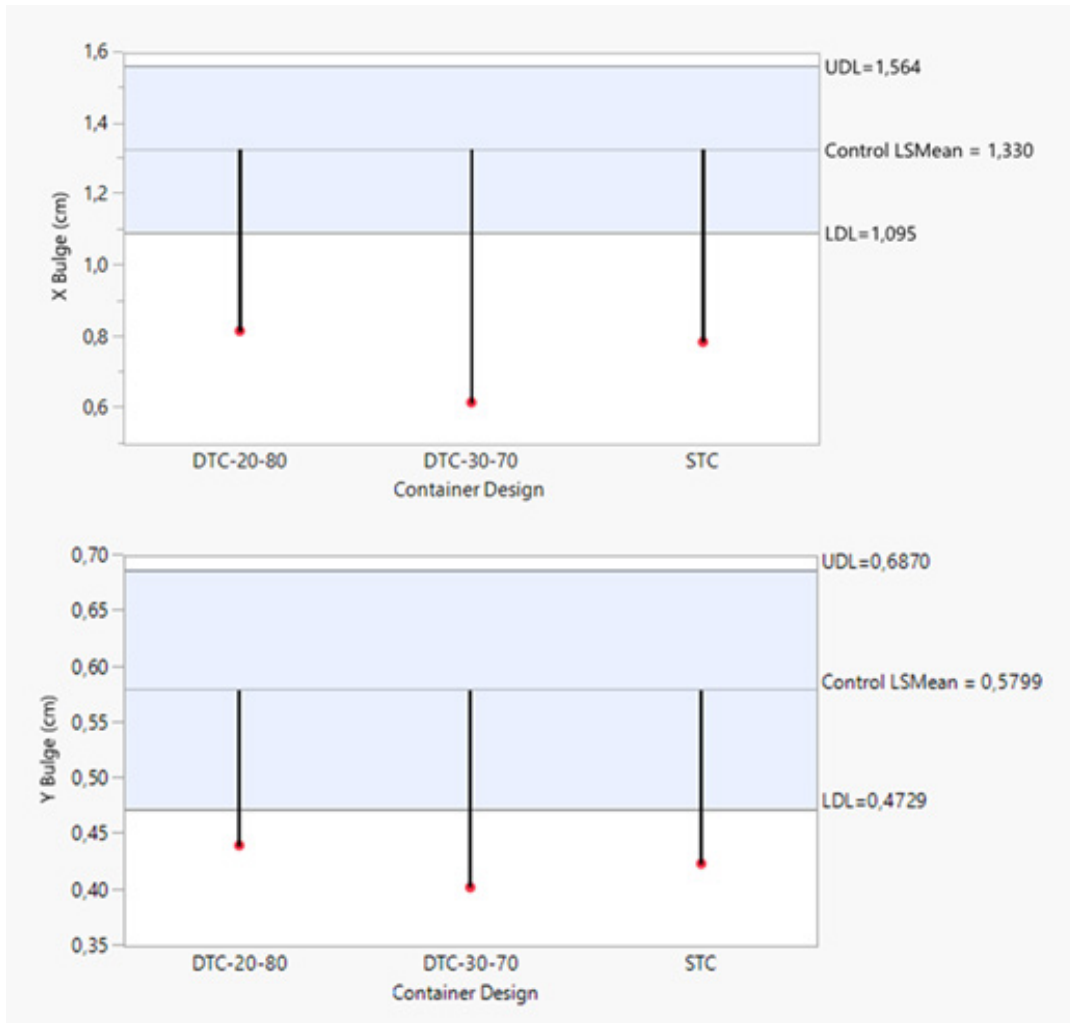
Figure 12: X and Y Bulge Means Comparison for Ambient Environment Using Dunnett's Method, with RSC as the Control Group

Container design	X Bulge		Y Bulge	
	Letters	Mean (cm)	Letters	Mean (cm)
RSC	A	1.378	A	0.601
DTC-20-80	B	0.848	B	0.456
STC	B	0.816	B	0.439
DTC-30-70	B	0.640	B	0.417

Table 2: X and Y Bulge Means Connecting Letters Report Using Tukey Kramer's Method

than the mean value of the X out-of-plane displacement for containers with tape, with corresponding letters "B", which is confirmed by the Dunnett test. Similarly, it indicates that the mean Y
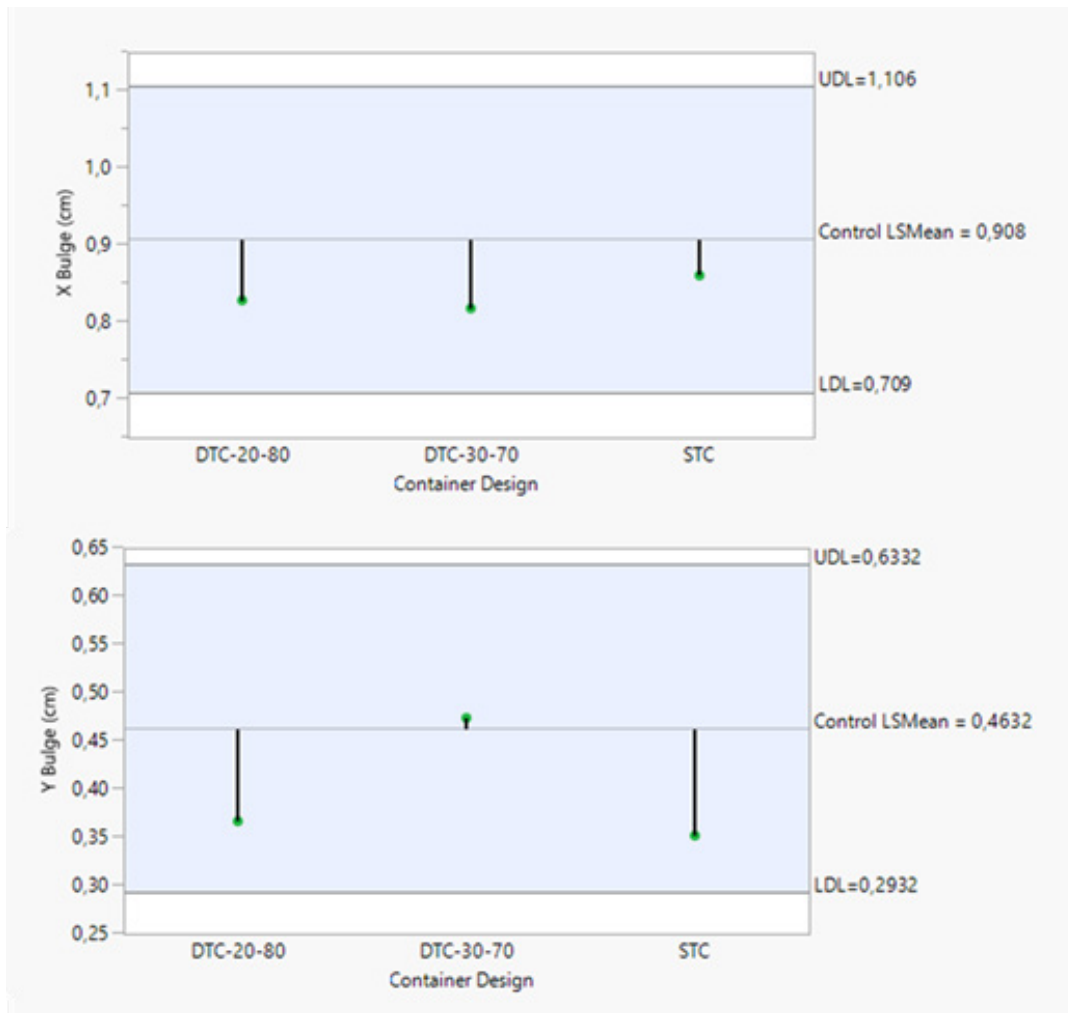
Figure 13: X and Y Bulge Means Comparison for Tropical Environment Using Dunnett's Method, with RSC as the Control Group

out-of-plane displacement for the RSC containers, with the corresponding letter "A", is significantly higher than the mean value of the Y out-of-plane displacement for containers with tape, with corresponding letter "B" which is also confirmed by Dunnett's test. However, the connecting letters report shows that there is no significant difference in mean Y out-of-plane displacement between the different container designs with tape, since these are all assigned the letter "B".

In Figures 13 and 14 , the Dunnett test using RSC as the control group, shows results for the X and Y bulge in a tropical and refrigerated environment. The charts show (Figure 12) that compared to RSC containers, there is a decreasing trend in the mean out-of-plane displacement in the X and Y direction for tropical environment but is not significantly different from the control group. The tropical X and Y bulge differences for the DTC-20-80 containers (X-p-value = 0.6812 and Y-p-value = 0.4151), the DTC-30-70 containers (X-p-value = 0.5857 and Y-p-value = 0.9995) and the STC containers
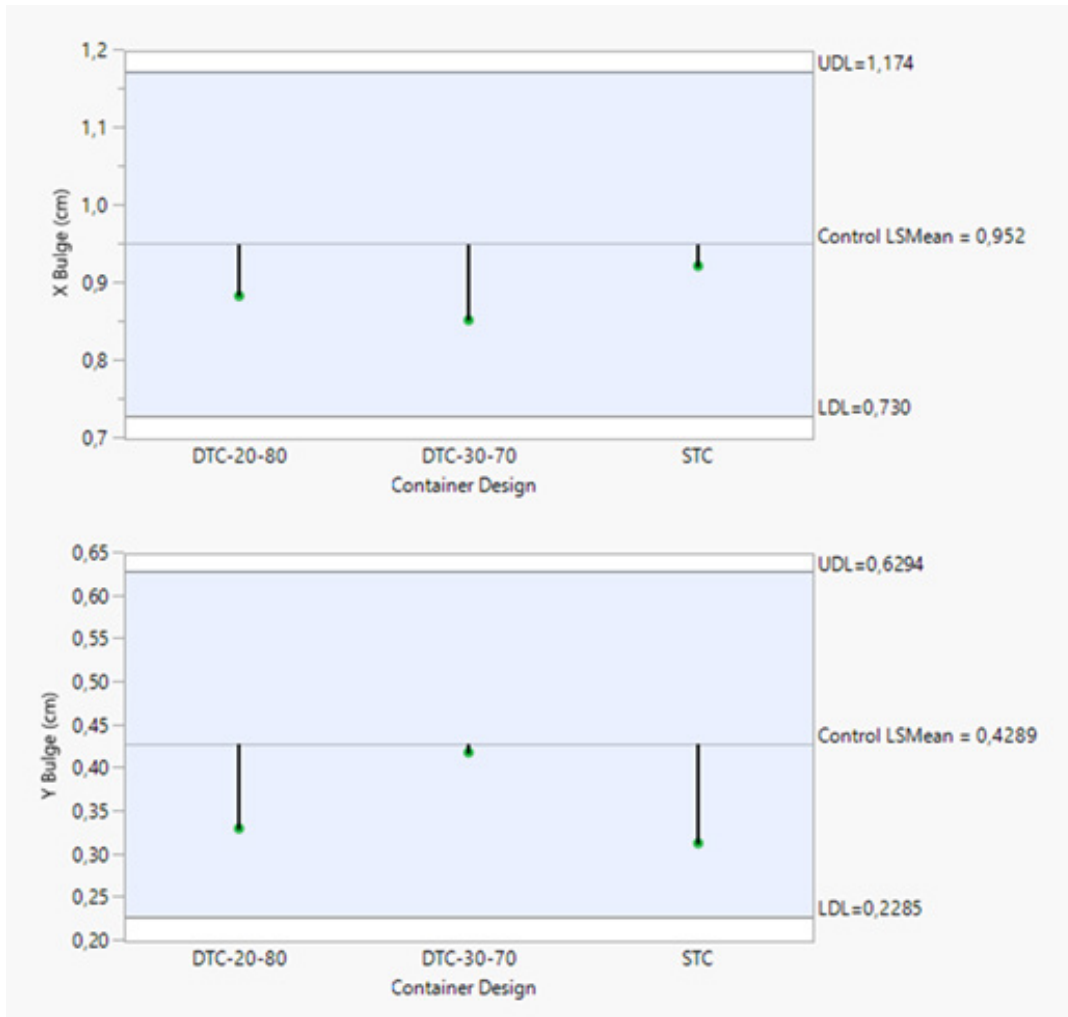
Figure 14: X and Y Bulge Means Comparison for Refrigerated Environment Using Dunnett's Method, with RSC as the Control Group

(X-p-value = 0.9255 and Y-p-value = 0.2930) are not significant.

Similarly, in Figure 14 the charts show that compared to RSC containers, there is a decreasing trend in the mean out-of-plane displacement in the X and Y direction for refrigerated environment but is not significantly different from the control group. The refrigerated X and Y bulge differences for the DTC-20-80 containers (X-p-value = 0.8519 and Y-p-value = 0.4948), the DTC-30-70 containers (X-p-value = 0.6207 and Y-p-value = 0.9998) and

the STC containers (X-p-value = 0.9916 and Y-p-value = 0.3551) are not significant.

In both tropical and refrigerated environments, tape-reinforced containers show potential to reduce the bulge in both directions but are not statistically different from the control group RSC. In an ambient environment however, all tape reinforced containers could reduce the bulge considerably.

CONCLUSION

This study examined the effect of top-to-bottom static compression load on the bulging of filled regular slotted containers with reinforcement tape. Four different container designs, the RSC, the STC, the DTC-30-70, the and the DTC-20-80, were tested under three different environmental conditions, ambient, tropical and refrigerated.

The implementation of Sesame® Tape resulted in significant bulge reduction in standard conditions. Under ambient conditions, there was a significant decrease in out-of-plane displacement of container's side panel caused by compression. In tropical and refrigerated conditions, a general trend was observed where the reinforcement tape in unmodified/standard containerboard did reduce the out-of-plane displacement of container side panels for three of the container designs, but it was not statistically significant. It can be inferred that by optimally increasing board stiffness and/or adding moisture resistance along with embedding reinforcement tape, a container's resistance against compression bulge can be customized. Therefore, there is potential in reducing compression bulge and further research will be necessary to identify the optimal board stiffness to be effective in tropical and refrigerated conditions. This study will be useful for packaging engineers to identify effective usage of reinforcement tape to reduce compression bulge.

In addition, further study is needed to determine optimal tape placement for each specific box configuration.

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ACKNOWLEDGMENT