A Study of the Effect of Squareness of the Corrugated Box on its Box Compression Strength

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***Abstract*— Packaging plays a significant role to provide safety to the products. At the time of storage and transportation, cartons are stacked one above the other and subjected to compressive forces which lead to the crumbling of corrugated boxes. Box design is an important perimeter to consider while manufacturing of the boxes to make sure the box compression strength of the boxes satisfies the requirement. In this paper, we study the effect of keeping the box square in shape irrespective of the height, on the compression strength of the box when compared to a rectangular box (non square) of the same perimeter. This may help us in making a more informed design decision when it comes to production of corrugated boxes.**

***Keywords*— Box compression strength, Box design, Box Squareness, Corrugated boxes, Box failure**

I. INTRODUCTION

The box compression strength (physical protection) depends on a number of factors:

- The structural design of the carton, i.e. size and dimensions, supporting elements in the carton design, flap design, and loading direction.
- Whether the contents support the package or not.
- Types of secondary (transport) packaging.
- Transport, storage methods and conditions (palletisation, stacking, climatic conditions).
- Material properties such as stiffness and compression strength of the paperboard [3].

While some of the points above point to the conditions which occur after the delivery of the manufactured box to the client- like weather conditions, shipping method or type of secondary package and may not be in control of the industry that is in charge of manufacturing the carton boxes, the first and last points, which correspond to the box shape and material properties respectively are among the key things over which the box manufacturer can have control in the industry itself.

Precision of the design of the box and more control over the material properties of the raw goods used to manufacture the boxes can lead to an increase in the box compression strength of the box which signifies better box performance in the practical scenarios.

II. LITERATURE REVIEW

A. Packaging and Corrugated Boards

According to ISO standards, paperboard is a paper with a basis weight (grammage) above 224 g/m2, but there are exceptions. It can be single- or multi-ply and can be easily cut and formed. It is lightweight and strong and hence is used in packaging. Corrugated board is made from the combination of two sheets liners glued to a corrugated inner medium called the fluting.

Flutes are the S shaped waves/arches of a corrugated box that makes up the board. This is called the board's corrugation. Flutes are essentially the reinforcement that make up the board. They run parallel to the depth of the container and give it its rigidity and crushing/stacking strength.

Table 1 Standard US Corrugated Flutes

Flute Designation*	Flutes per Linear Foot	Flutes Thickness (in.)	Flutes per Linear Foot
A Flute	33+3	3/16	
B Flute	47+3	1/8	
C Flute	39+3	5/32	
E Flute	90+4	1/16	

The types of fluting vary depending upon how many flutes are included per foot, and how thick the fluting is. By experimenting with flute profiles, designers can vary compression strength, cushioning strength and thickness. Flutes come in several standard sizes such as A, B, C, E, and F. Different flute profiles can be combined in one piece of combined board [1].

B. Conversion of Corrugated Boxes

Separate liner material and fluting material is bought in the form of rolls of packaging boards. The process starts with **corrugation** i.e. the conversion of the fluting stock into the fluted board using a machine called the corrugator. These fluted rolls are then **pasted** with liner material/ other fluted boards to achieve desired number of plies. The rolls are then **cut into sizes** using manual, rotary and slot cutting operations. The open box is **stitched** using metal wires on a stitching machine to complete the conversion process.

C. Box Design

Box design, both graphical and structural plays an important role when talking about the usability of a box. While it is important for a box to be appealing in looks and graphics to attract customers in today's supermarket scenario, it is also equally important for the box to be structurally well built so as to give the maximum performance in the practical usage. Following are some critical requirements, structurally to be taken care of to optimize the box strength.

- L:W:H ratio or Length : width : height ratio of the box which also affects the resistance to buckling. Uneven L:W:H ratios are theoretically said to show a lower value to buckling resistance and stacking strength.
- Gap between contents of the package and walls of the box. It is usually kept as small as possible, but it depends on the type of packaging used- manual or automatic.
- Headspace left in the package; weather the contents of the package share the load which will be kept over the package.
- How well is the package optimized for stacking (pallet utilization), for material usage in production and for cost requirements.

D. Principle of Box Failure

Boxes are said to have "failed" when they exhibit buckling upon being stacked. In the practical usage of the corrugated boxes, it is fairly obvious that they will be stacked for storage one over the other to use the storage space optimally. This will lead to the damage to the boxes if proper care is not taken and factors like the compression strength of the box are ignored.

General principle of load distribution on the perimeter of the package upon stacking says that the maximum load will always be taken by the corners of the box. This is depicted in the diagram below.

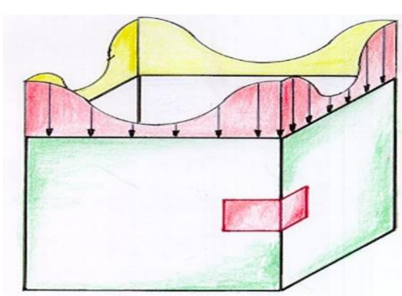

Figure 1 Load Distribution along the Perimeter of the Box

E. Box Compression Strength (BCS)

Box Compression strength (BCS) or Compression strength can be defined as the measure of the maximum compressive force per unit width that a paper board box can withstand during a compression test till it reaches the buckling stage. It is expressed in kN/m. It is one of the most important property of the paper board package and it helps in determining the staking limitations as well as the overall strength of the package [1].

Once the conversion of the box is complete, the next biggest task is to check if the quality of the box is up to the mark. This is generally done by finding out the box compression strength of the box using a box compression tester or theoretically, by using the simplified McKee formula [2].

III. METHODOLOGY

1. The materials used for the experiment were virgin kraft for the liner part of A, B and E flute boards, semi kraft for the fluting part of the E flute boards and recycled stock for the fluting part of A and B flute boards.
2. The box shape was designed as depicted below.

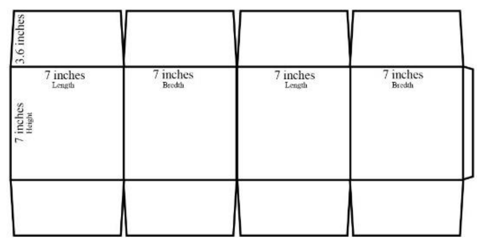

Figure 2. Development Diagram of the Boxes to be Converted.

3. 15 rectangular (not square) boxes were converted (three for each perimeter; one for each flute) using the same method as discussed in the literature [box height was kept constant]. The dimensions of the boxes are as follows.

Table 2. Perimeter and Dimensions of the Rectangular Boxes

Box Perimeter (inches)	Dimensions [LxBxH] (inches)	Type of fluting
30	8x7x7	A, B, E
32	9x7x7	A, B, E
34	10x7x7	A, B, E
36	11x7x7	A, B, E
38	12x7x7	A, B, E

4. These 15 boxes were tested for their box compression strength (BCS) using an industrial grade box compression tester and the BCS readings were recorded.
5. Now, 15 more boxes were converted (three for each perimeter; one for each flute) for the same five perimeter values using the same method as discussed in the literature but this time the box shape was kept square each time [box height was kept constant]. The dimensions of the boxes are as follows.

Table 3. Perimeter and Dimensions of the Square Boxes

Box Perimeter (inches)	Dimensions [LxBxH] (inches)	Type of fluting
30	7.5x7.5x7	A, B, E
32	8x8x7	A, B, E
34	8.5x8.5x7	A, B, E
36	9x9x7	A, B, E
38	9.5x9.5x7	A, B, E

6. BCS readings were again taken out for these square boxes and were recorded. These BCS readings were compared with the BCS readings of the rectangular boxes.

IV. Research Findings and Analysis

Following readings of box compression strength were recorded for boxes of varying perimeter for each fluting style.

Table 4. Difference between BCS Values of Square Boxes and Rectangular Boxes for A Flute Boxes.

Box perimeter (inches2)	Box compression strength (Kgf)		Difference (BCS square boxes- BCS rectangular boxes)
	Square boxes	Rectangular boxes	
30	311.3	289.5	21.7
32	314	312.6	1.4
34	383.9	330.7	53.2
36	382.6	328.9	53.7
38	429.2	332	97.2

Table 4. Difference between BCS Values of Square Boxes and Rectangular Boxes for B Flute Boxes.

Box perimeter (inches2)	Box compression strength (Kgf)		Difference (BCS square boxes- BCS rectangular boxes)
	Square boxes	Rectangular boxes	
30	279.3	230.9	48.4
32	309.1	265.4	43.7
34	285.4	279.1	6.3
36	289	285.8	3.2
38	293.3	286.4	6.9

Table 4. Difference between BCS Values of Square Boxes and Rectangular Boxes for E Flute Boxes.

Box perimeter (inches2)	Box compression strength (Kgf)		Difference (BCS square boxes- BCS rectangular boxes)
	Square boxes	Rectangular boxes	
30	117.6	66.7	50.9
32	119.2	69	50.2
34	119.9	59	60.9
36	119.4	67.9	51.5
38	120.1	82.2	37.9

Above tables indicate that the box compression strength values of the square boxes for all the perimeters and for all the fluting styles were found to be more than the box compression strength values for rectangular boxes of the same perimeters (Value of BCS of square boxes – BCS of rectangular boxes always gave a positive resultant).

V. Conclusion

In this paper, we tried to study the importance of keeping the box shape a perfect square instead of a rectangle for a 3 ply board box of various fluting profiles (A, B and E). We practically proved, under a limited scope, that the square boxes of any fluting variety will perform better than the other rectangular boxes of the same perimeter given that the material remains same. The reason behind this may be that in case of square boxes, the load distribution along the perimeter is more uniform when compared to other rectangular perimeters as discussed in literature under the principle of box failure. This knowledge may help industries in future in making a more informed decision when it comes to carton box design.

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