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A STUDY ON THE RELATIONSHIP BETWEEN CORRUGATED BOX PERIMETER AND ITS COMPRESSION STRENGTH FOR 3 PLY BOX OF A, B & E FLUTE PROFILE USING SIMPLIFIED MCKEE FORMULA AND MINI CARTON COMPRESSION TESTER

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ABSTRACT

Box Compression Strength (BCT) 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.

Usually, a box compression tester is required for conducting the BCS test but within this paper, an effort has been made to find a more accurate BCS (box compression strength) reading by just using the simplified McKee formula. An average difference value was found out between the BCS readings obtained by the tester and the values calculated using the simplified McKee formula for square boxes of increasing perimeter. The fluting used were A, B and E. If this average difference in incorporated in the formula, it may end up increasing the accuracy and hence the functionality of the formula.

Keywords- Compression strength, McKee formula, Simplified McKee, Fluting, Compression strength tester

1. Literature review

1.1 Packaging 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. Sometimes it is referred to as cardboard, which is a generic, lay term used to refer to any heavy paper pulp–based board [1].

1.2 Corrugated boards

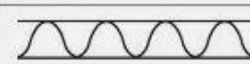
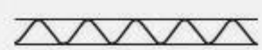
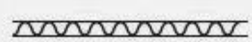
Corrugated board is made from the combination of two sheets liners glued to a corrugated inner medium called the fluting. These layers of paper are assembled in a way which makes the overall structure much more robust than each layer taken separately.

Corrugated packaging is a versatile, economic, light, robust, recyclable, practical and yet dynamic form of packaging [1].

1.2.1 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. As well as providing stacking strength, flutes also provide insulation that protects products from sudden temperature changes [3]. Usually, it can be said that larger flutes like ‘A’ flute & ‘B’ flute profile provide greater strength and cushioning to the containment, while finer flute profiles like ‘D’ & ‘E’ (mini) provide better ability to be printed and folded.

Table 1.1 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 [4].

1.3Conversion of corrugated boxes

Separate liner material and fluting material is bought in the form of rolls of packaging boards. The grammage of this stock depends on the final strength expectation from the converted corrugated box. The process starts with the conversion of the fluting stock into the fluted board using a machine called the corrugator. Then, these fluted rolls are cut and stuck to the liner material to form corrugated board. This board is die cut or slot cut in the desired shape and the open end is stitched to seal the box.

1.3.1 Corrugation

A typical 52 inches corrugator has three fluting rollers- two of these are for fluting the material and one is pressure roller to press the liner with the glued flute. These fluting rollers are iron coated and heated. Iron rods, as many as 27 per cylinder, are used to heat these rollers. These rods can be individually switched on and off to control the temperature of the rollers. The glue that is used is obviously heat-set.

1.3.2 Pasting

Pasting of the single face corrugated board to another corrugated board or liner material is facilitated by the dual roll pasting machine. The machine has a large glue roller that runs inside the glue tank. The pressure rollers squeeze a thin layer of this glue and apply it on to the surface of the material. Viscosity of the glue depends on the paper grammage (G.S.M.). Grammage also governs the speed at which the machine has to be run. If the gluing does not properly happen in the pass, it is manually applied in hope of recovering the board.

1.3.3 Cutting

Using manual cutter- it is done on a manual cutting table which, on one end, is fixed with a knife arm. The machine is used to manually cut the board material to desired size when the automatic cutting machine is occupied or dysfunctional. It does not give quality as good as the automatic cutting machine and gives uneven fibrous edges.

Using rotary cutter- it has rolling blades that cut lengths and breaths of the board. It also has creasing rolls that crimps the board to help in folding it.

Slot cutting machine is for making slots in the board so that it can be assembled in the shape of a carton after folding

1.3.4 Stitching

Stitching machine is used to create manufacturer's joints to seal the cartons from the open end. The stitching wire used can be rust free quality or normal quality based on the customer's requirement. It is a function of the life expected out of the carton.

1.4 Box compression strength

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 as illustrated below [6].

$$\mathbf{BCS = 0.6 \times ECT \times \sqrt{t} \times \sqrt{Z}}$$

This is known as the simplified McKee formula. Here, 'BCS' refers to box compression strength, 'ECT' refers to edge compression strength, 'Z' refers to the box perimeter and 't' refers to the thickness/caliper of the board used.

If the box compression performance does not satisfy the standards of its end use, it calls for an internal audit of the quality standards maintained in the import of raw material, the processes of conversion, the storage of both the raw and finished undelivered produce and the transport of the material in and out of the industry. In such cases, other properties of the board that can affect the box compression strength are examined and adjusted.

1.4.1 Edgewise Compression Strength (ECT)

It is defined as the strength displayed by the corrugated board while being subjected to a constant compressive stress in the direction of the flutes. It is considered to be of significance mainly because of its high impact on the box compression strength value [1].

According to the McKee formula mentioned above, edge compression strength is concluded, theoretically to be directly proportional to the box compression strength.

1.4.2 Ring Compression Strength (RCT)

The ring crush test (RCT) is used to determine the ring crush strength or the ring crush resistance of a paper strip formed into a ring with a standard length and width. The standards and procedures are followed as per ISO 12192 and TAPPI T 822.

ECT = 1.28 (RCT of liner material 1 + m RCT of fluting material + RCT of liner material 2)

Here, 'ECT' refers to edge compression strength, 'RCT' refers to the ring compression strength value and 'm' refers to the take-up factor of the board used.

Thus, it can be theoretically concluded that ring compression strength is directly related to the edge compression strength which, in turn is directly related to box compression strength.

2. Methodology

2.1 Conversion of boxes

The materials used for the experiment are 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.

A total of 18 square boxes were converted as per the procedure mentioned above for this particular experiment. Only 3 ply board was used for converting these boxes. A development diagram is given below for reference.

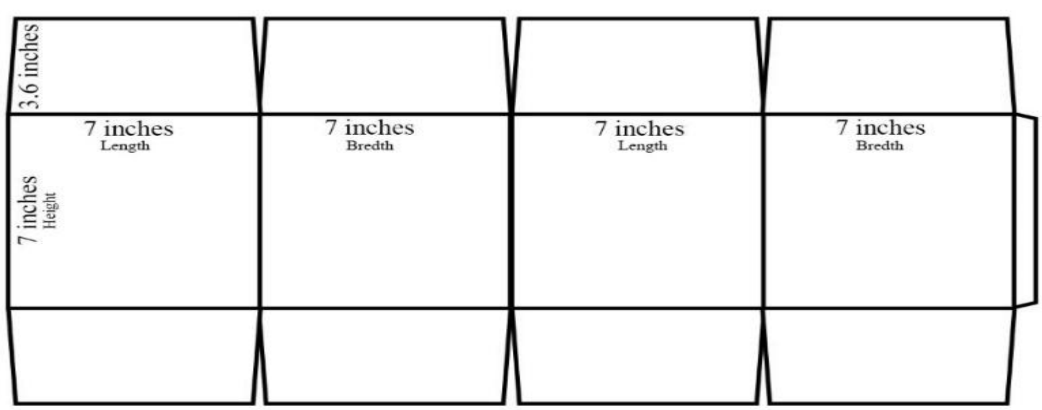


Figure 2.1 Development diagram of the boxes to be converted

- Paper rolls are loaded on a 52 inch corrugator machine to accomplish the fluting of the paperboard and blade auto cutter along with dual roll pasting machine is used to prepare the 3 ply packaging board roll.
- To cut these 3 ply sheets into the size of the box, a rotary cutting machine used.
- Now this cut and crimped sheet of the box size is taken to the slot cutter to make the slots which help the flaps of the box fold inwards and so that the stitching flap gets to its normal size (smaller than the box height).
- Rust free quality stitching wire is used on the stitching machine for stitching the open box.
- The box is folded appropriately according to the crimps formed by rotary cutting machine and the upper and lower flaps are taped using regular brown tape.

2.2 Conducting the compression test

- 18 fair square boxes were used to conduct the box compression test using an industrial grade compression tester. The dimensions used are as follows.

Table 2.1 Perimeter and dimensions of the boxes that are prepared for each fluting.

Box Perimeter (inches)	Dimensions (LxBxH)	Type of fluting
28	7x7x7	A,B and E
30	7.5x7.5x7	A,B and E
32	8x8x7	A,B and E
34	8.5x8.5x7	A,B and E
36	9x9x7	A,B and E
38	9.5x9.5x7	A,B and E

2.3 Calculating BCT using McKee formula

- On the same 3 ply board material which was used for the conversion of boxes, ring compression strength test (RCT) was done. The RCT values obtained were then used to calculate ECT using the formula mentioned in 1.4.2.

- The following values of material take-up factor (m) was used for calculating the ECT values.

Table 2.2 Fluting styles and their take-up factors

Fluting style	Material take-up factor
A	1.54
B	1.32
E	1.27

- Box compression strength was then, theoretically calculated using the simplified McKee formula as illustrated in section 1.4.

3. Research findings and analysis

Following values of box compression strength were observed when the boxes were tested on an industrial grade box compression tester which had been calibrated as per the TAPPI standards.

Table 2.3 Box compression tester values for different fluted boxes

LxBxH (inches)	Box perimeter (inches)	Box compression strength (BCT) in Kgf		
		A	B	E
7.5x7.5x7	30	311.3	279.3	117.6
8x8x7	32	314	309.1	119.2
8.5x8.5x7	34	383.9	285.4	119.9
9x9x7	36	382.6	289	119.4
9.5x9.5x7	38	429.2	293.3	120.1

Following was the thickness of the 3 ply boards that were used to make boxes

Table 2.4 Noted thickness of the boards with the above three flutes

Fluting style	Thickness (mm)
A	3.9
B	2.9
E	2.01

Following RCT values were obtained in KN/m from the Ring compression tester

Table 2.4 Fluting styles and their ring compression strength values

Fluting style	Ring compression test (RCT) values in KN/m	
	Liner material	Fluting material
A	3.5	2.76
B	3.5	2.76
E	1.31	5.5

Following values of ECT were obtained by using the formula in section 1.4.2

Table 2.4 Fluting styles and their edge compression strength values

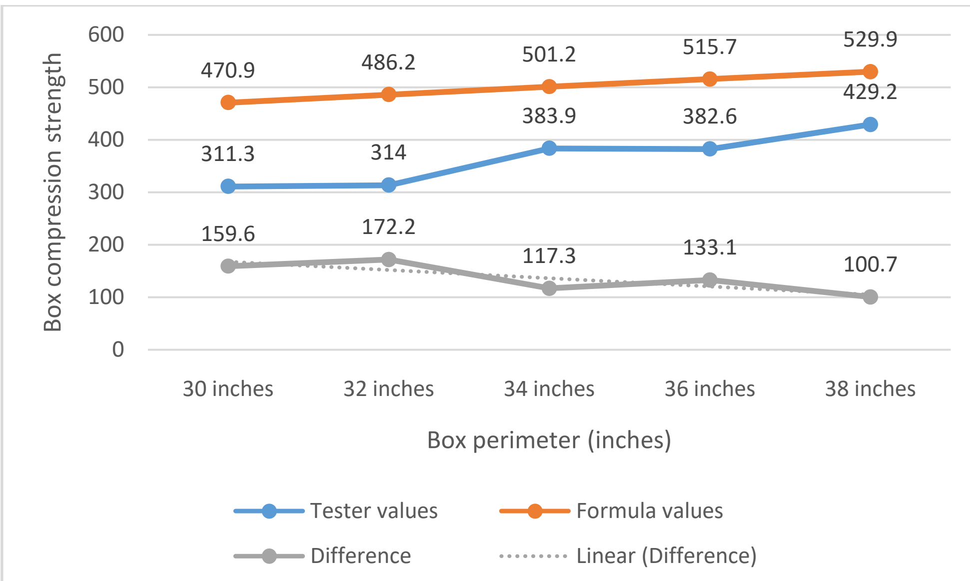
Fluting style	Edge compression strength (ECT) in KN/m
A	14.40
B	13.63
E	4.25

Using above observations and simplified McKee formula, following BCS values were calculated for each perimeter of each fluting style of the box.

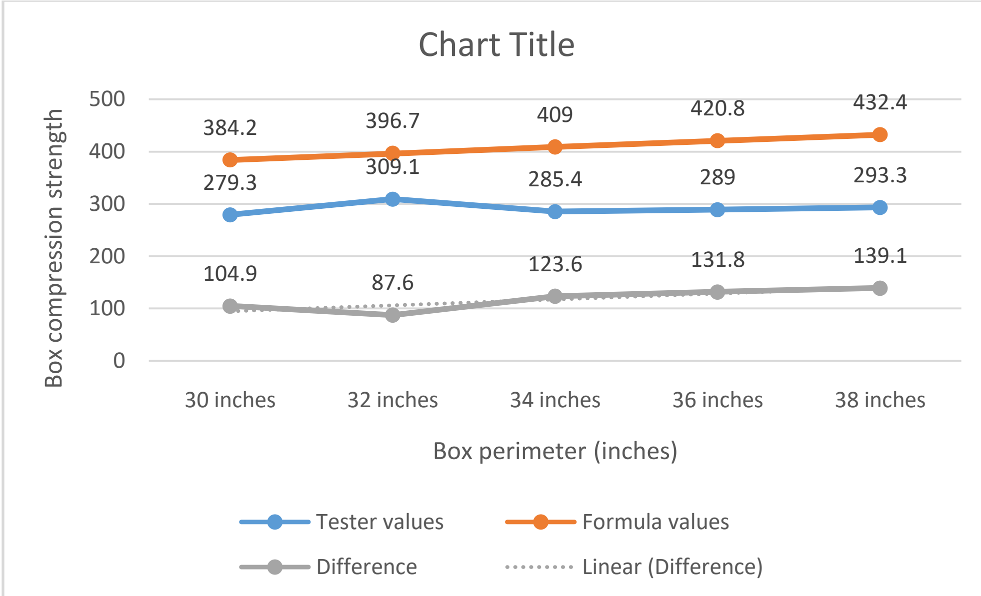
Table 2.5 Calculated values for different fluted boxes

LxBxH (inches)	Box perimeter (inches)	Box compression strength (BCT) in Kgf		
		A	B	E
7.5x7.5x7	30	470.9	384.2	99.6
8x8x7	32	486.2	396.7	102.9
8.5x8.5x7	34	501.2	409	106.1
9x9x7	36	515.7	420.8	109.1
9.5x9.5x7	38	529.9	432.4	112.1

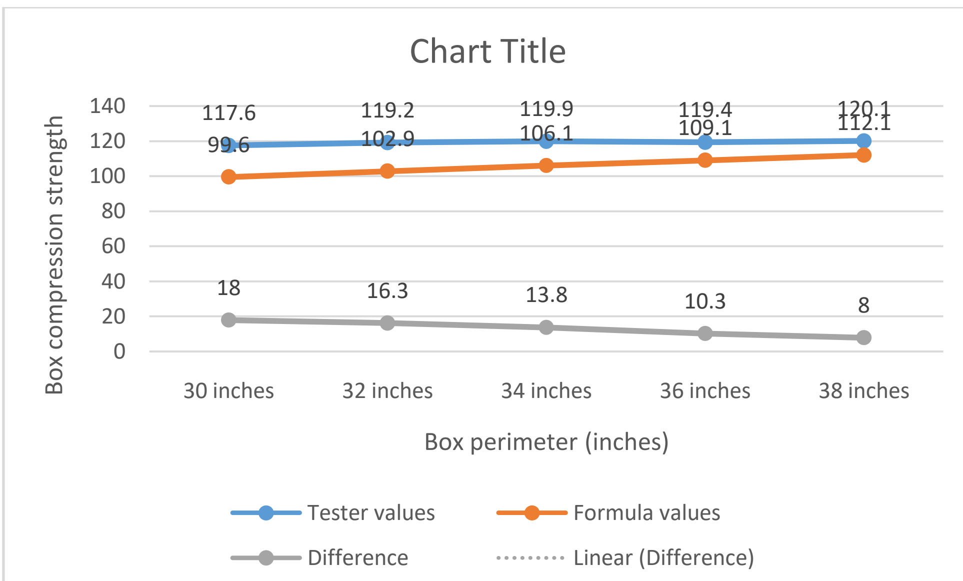
3.1 Comparing the tester values with the formula values



Average of the difference between the BCS values found out by the tester and the values calculated by the formula came out to be 136.6 for the fluting style A.



Average of the difference between the BCS values found out by the tester and the values calculated by the formula came out to be 117.4 for the fluting style B.



Average of the difference between the BCS values found out by the tester and the values calculated by the formula came out to be 13.28 for the fluting style E.

From the charts, it was clearly indicated that there was a general increase in the BCS value as per the increase in the value of the box perimeter. This is well reflected by the BCS values obtained by the tester as they follow a general increasing trend which is similar to that of the BCS values which were calculated using the simplified McKee formula.

Also, it can be noticed from the above graphs that the line of difference between the tester values of BCS and the values calculated using the simplified McKee formula is almost horizontal in nature. This depicts that there resides an almost constant factor that is the difference between the practical BCS value (found experimentally using a compression tester) and the BCS values calculated using the formula. This factor is the average of the difference between the two BCS values and it was found out to be 136.6 for A fluting, 117.4 for B fluting and 13.28 for E fluting.

Slight variations in the values and the reason behind the line not being completely horizontal is the atmospheric condition (temperature and relative humidity), inconsistency in the similarity of raw material and error margin of the equipment used which was beyond the computational scope of this paper.

4. Conclusion

The theoretical relation of the box perimeter with the box compression strength for a 3 ply board box of various fluting profiles (A, B and E) was studied in this paper using the calculated values from simplified McKee formula and mini box compression strength tester. These readings were then compared and the average deviation difference value was found out. This can be the first step towards eliminating the need of a box compression tester to find BCS for the boxes and to make the simplified McKee formula more accurate. This might help small industries and startups, for whom purchasing a box compression tester right away is impractical, in maintaining the quality of the boxes manufactured.

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