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Experimental Verification of McKee Formula

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Abstract Seventy RSC single-wall 200# corrugated boxes, of seven different sizes from the same manufacturer, were compressed. Actual box compression strengths were compared with those computed using the McKee formula. The ratios of side-loading to top-loading box compression strengths for 3”x3”x3”, 5”x5”x5”, and 7”x7”x7” were found to be 30%, 46%, and 62% below those derived from the formula, while the box compression strengths (top loading) were 18%, 45%, and 63% higher. Bigger boxes yielded wider discrepancy between the actual compression strength value and that predicted by the McKee formula. A similar conclusion was made with three other box sizes with the same height (4”x4”x12”, 5”x5”x12”, and 6”x6”x12”). The effect of box height (which is not included in McKee formula) on its compression strength was also investigated using three box sizes, 5”x5”x5”, 5”x5”x12”, and 5”x5”x48”. As expected, the box became weaker as the height increased due to the wall buckling. The compression strength dropped 62% from the 5” to 48” box heights. Overall, the box compression strengths (BCT) predicted by the McKee formula were off anywhere from 50.48% overestimate for the 5”x5”x48” box size to 69.36% underestimate for the 6”x6”x12” box size.

Keywords *McKee Formula; Box Compression Strength; Corrugated Boxes; Edge Compression Test (ECT)*

1. Introduction

Corrugated boxes are the most commonly used secondary packaging for shipping goods. The McKee formula has been widely used to predict the compression strength of corrugate boxes. The formula is defined as [1]:

$$BCT = 5.876 \times ECT \times \sqrt{U \times d} \qquad \text{..... Equation 1}$$

where *BCT* = Box compression test/strength (lb), *ECT* = Edge crush test (lb/in), *U* = Footprint perimeter (in), and d = Wall thickness (in).

In this study, a verification of McKee formula compression strength was done experimentally by crushing a total of 70 RSC (regular slotted container) single-wall 200# corrugated boxes of seven different sizes from the same manufacturer. The effects of loading direction, footprint perimeter, volume, and height on the boxes' compression strength were investigated.

2. Materials and Methods

The following RSC box sizes were used in this study: 3"x3"x3", 4"x4"x12", 5"x5"x5", 5"x5"x12", 5"x5"x48", 6"x6"x12", and 7"x7"x7". They were grouped for various studies, as shown in Table 1. Eighteen measurements of wall thickness were made from various boxes (Table 2). Edge crush tests were performed on 2"x2" specimens cut from various boxes using the Clamp Method in accordance to TAPPI T839 [2], as shown in Table 2 and Figure 1. Specimen orientations for top and side loadings are shown in Figure 2.

Table 1: *Box Grouping for Various Studies*

Group	Box Size	Study
1	3"x3"x3", 5"x5"x5", 7"x7"x7"	• Effect of Load Direction • Effect of Footprint Perimeter (Cube Shape) • Effect of Volume (Cube Shape)
2	4"x4"x12", 5"x5"x12", 6"x6"x12"	• Effect of Footprint Perimeter (Same Height) • Effect of Volume (Same Height)
3	5"x5"x5", 5"x5"x12", 5"x5"x48"	• Effect of Height

Table 2: *Wall Thickness & ECT*

No.	Wall Thickness (in)
1	0.112
2	0.124
3	0.104
4	0.101
5	0.090
6	0.100
7	0.102
8	0.095
9	0.114
10	0.115
11	0.128
12	0.094
13	0.108
14	0.109
15	0.088
16	0.110
17	0.115
18	0.126
Avg (in)	*0.108*
SD (in)	*0.012*
SD (% of Avg)	*11.02*

No.	ECT (lb)	
	Top Load	Side Load
1	63.94	35.43
2	76.91	40.44
3	71.61	38.94
4	74.03	33.39
5	61.56	37.89
6	67.69	37.48
7	59.72	45.82
8	53.67	36.31
9	60.88	37.81
10	62.39	32.39
11	52.52	34.51
12	50.21	31.93
13	62.06	36.77
14	47.62	37.48
15	48.39	32.05
16	56.8	38.69
17	47.91	38.73
18	59.55	33.26
Avg (lb)	*59.86*	*36.63*
SD (lb)	*8.88*	*3.48*
SD (% of Avg)	*14.84*	*9.51*
Side/Top	*0.61*	
ECT (lb/in)	*29.93*	*18.31*

Figure 1: *ECT Using Clamp Method Per TAPPI T839*

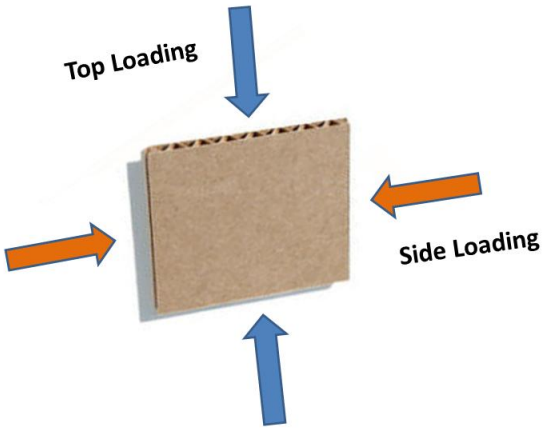

Figure 2: *ECT Specimen Orientations for Top and Side Loadings*

Boxes were crushed on a compression table and maximum/failure loads were recorded, as shown in Figure 3 and Table 3.

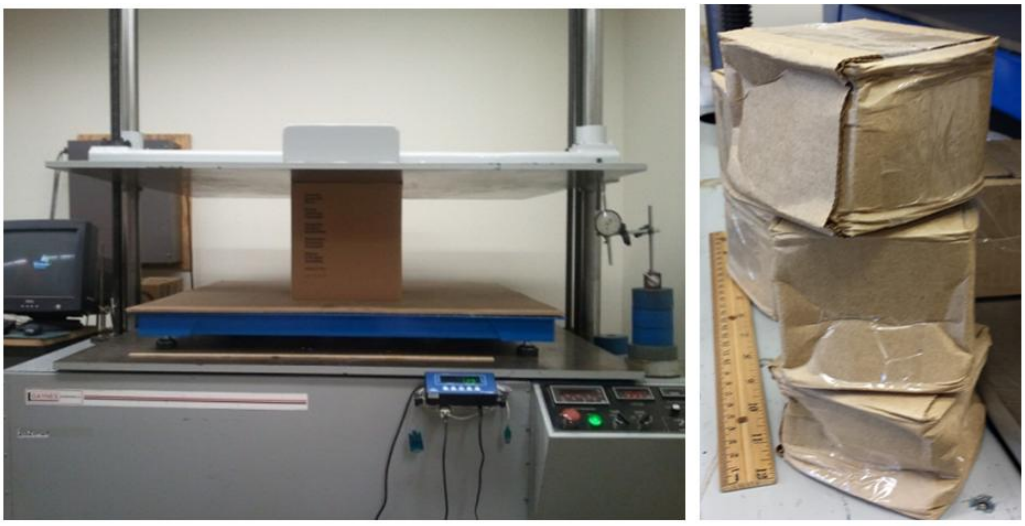

Figure 3: *Compression Test of Boxes*

Table 3: *Compression Test Data*

LxWxH	3"X3"X3"	5"X5"X5"	4"X4"X12"	5"X5"X12	7"X7"X7"	6"X6"X12"	5"X5"X48"
Height, H (in)	3	5	12	12	7	12	48
Footprint Perimeter, U (in)	*12*	*20*	*16*	*20*	*28*	*24*	*20*
Volume (in^3)	*27*	*125*	*192*	*300*	*343*	*432*	*1200*
No.	**Box Compression Strength, Top Load (lb)**						
1	262	326	304	317	509	460	139
2	293	394	316	286	521	482	120
3	268	352	313	313	522	487	139
4	263	331	291	316	504	500	118
5	242	342	274	327	528	461	106
6	269	332	279	305	533	441	137
7	224	327	298	289	491	506	132
8	218	350	293	301	517	479	128
9	236	342	278	308	518	477	141
10	241	311	304	325	485	491	117
Avg (lb)	*252*	*341*	*295*	*309*	*513*	*478*	*128*
SD (lb)	*23*	*22*	*15*	*14*	*16*	*20*	*12*
SD (% of Avg)	*9.24*	*6.57*	*4.98*	*4.48*	*3.03*	*4.13*	*9.32*

3. Results and Discussion

3.1. Effect of Load Direction

Three box sizes (3”x3”x3”, 5”x5”x5”, and 7”x7”x7”) were used. For each size, 10 boxes were crushed by top loading and another 10 boxes by side loading. ECT of 29.93 and 18.31 lb/in from Table 2 were used in BCT calculations from the McKee formula (Equation 1) for top and side loadings, respectively. Results were summarized in Table 4 and Figure 4. Side/Top BCT ratio was constant at 0.61, which was the Side/Top ECT ratio. However, when the trend line equation of actual compression data in Figure 4 was used, Side/Top ratios from the experiment were 0.43 for U = 12” (3”x3”x3” box size) and 0.23 for U = 28” (7”x7”x7” box size), respectively. This represents 30% and 62% below the 0.61 ratio obtained from the McKee formula.

Table 4: *Effect of Load Direction*

	Top & Side Max Load (lb), 200# Single Wall					
	3"x3"x3"		5"x5"x5"		7"x7"x7"	
No.	**Top Load**	**Side Load**	**Top Load**	**Side Load**	**Top Load**	**Side Load**
1	262	118	326	106	509	126
2	293	95	394	112	521	139
3	268	116	352	105	522	132
4	263	106	331	108	504	134
5	242	103	342	103	528	130
6	269	114	332	107	533	119
7	224	98	327	111	491	128
8	218	118	350	120	517	107
9	236	108	342	104	518	114
10	241	112	311	98	485	103
Avg	*252*	*109*	*341*	*107*	*513*	*123*
SD	*23*	*8*	*22*	*6*	*16*	*12*
SD (% of Avg)	*9.24*	*7.55*	*6.57*	*5.56*	*3.03*	*9.73*
BCT (lb)	*200*	*122*	*258*	*158*	*305*	*187*
U (in)	***12***		***20***		***28***	
Side/Top (Actual)	***0.43***		***0.32***		***0.24***	
Side/Top (BCT)	***0.61***		***0.61***		***0.61***	

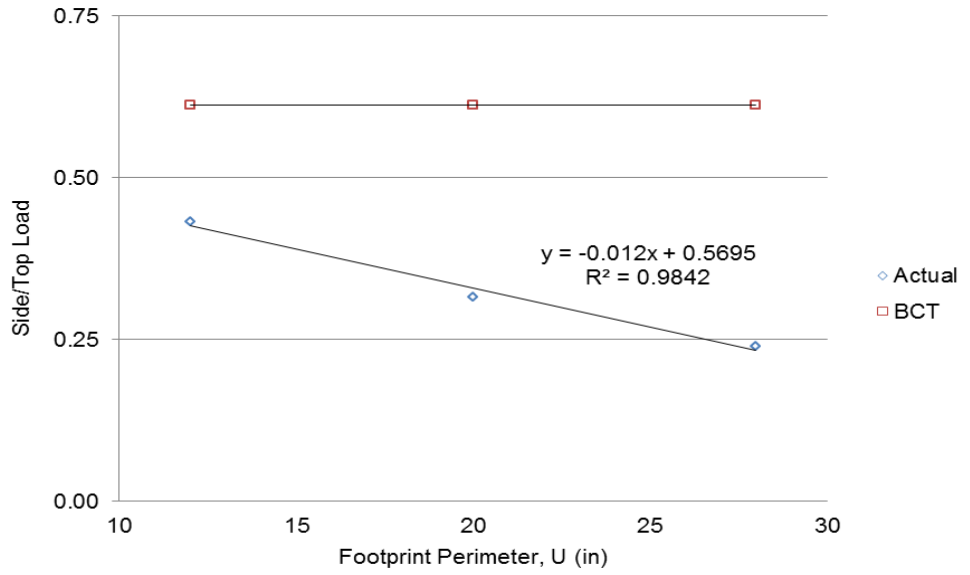

Figure 4: *Side/Top Load Ratio versus Footprint Perimeter*

3.2. Effect of Footprint Perimeter and Volume

In this experiment, two sets of boxes were used. The first set consisted of three cube boxes; 3”x3”x3”, 5”x5”x5”, and 7”x7”x7”. The data for this set was presented in Table 4 and only top-load data was used in this analysis. The second set consisted of three box sizes with the same height of 12”; 4”x4”x12”, 5”x5”x12”, and 6”x6”x12”. Results were summarized in Table 5 and Figures 5 and 6. Using trend line equations from Figure 5, the box strengths from experiment were 18% and 63% over those obtained from the McKee formula (BCT) for U = 12” (3”x3”x3” box size) and U = 28” (7”x7”x7” box size), respectively. Similarly, trend line equations from Figure 6 yielded 16% and 60% over BCT for U = 16” (4”x4”x12” box size) and U = 24” (6”x6”x12” box size), respectively.

Table 5: *Effect of Footprint Perimeter and Volume*

No.	Box Compression Strength (lb)					
	Same Box Proportion, Cube			Same Box Height, 12"		
	3"x3"x3"	5"x5"x5"	7"x7"x7"	4"x4"x12"	5"x5"x12"	6"x6"x12"
1	262	326	509	304	317	460
2	293	394	521	316	286	482
3	268	352	522	313	313	487
4	263	331	504	291	316	500
5	242	342	528	274	327	461
6	269	332	533	279	305	441
7	224	327	491	298	289	506
8	218	350	517	293	301	479
9	236	342	518	278	308	477
10	241	311	485	304	325	491
Avg (lb)	***252***	***341***	***513***	***295***	***309***	***478***
SD (lb)	*23*	*22*	*16*	*15*	*14*	*20*
SD (% of Avg)	*9.24*	*6.57*	*3.03*	*4.98*	*4.48*	*4.13*
BCT (lb)	***200***	***258***	***305***	***231***	***258***	***282***
U (in)	***12***	***20***	***28***	***16***	***20***	***24***
Volume (in^3)	***27***	***125***	***343***	***192***	***300***	***432***

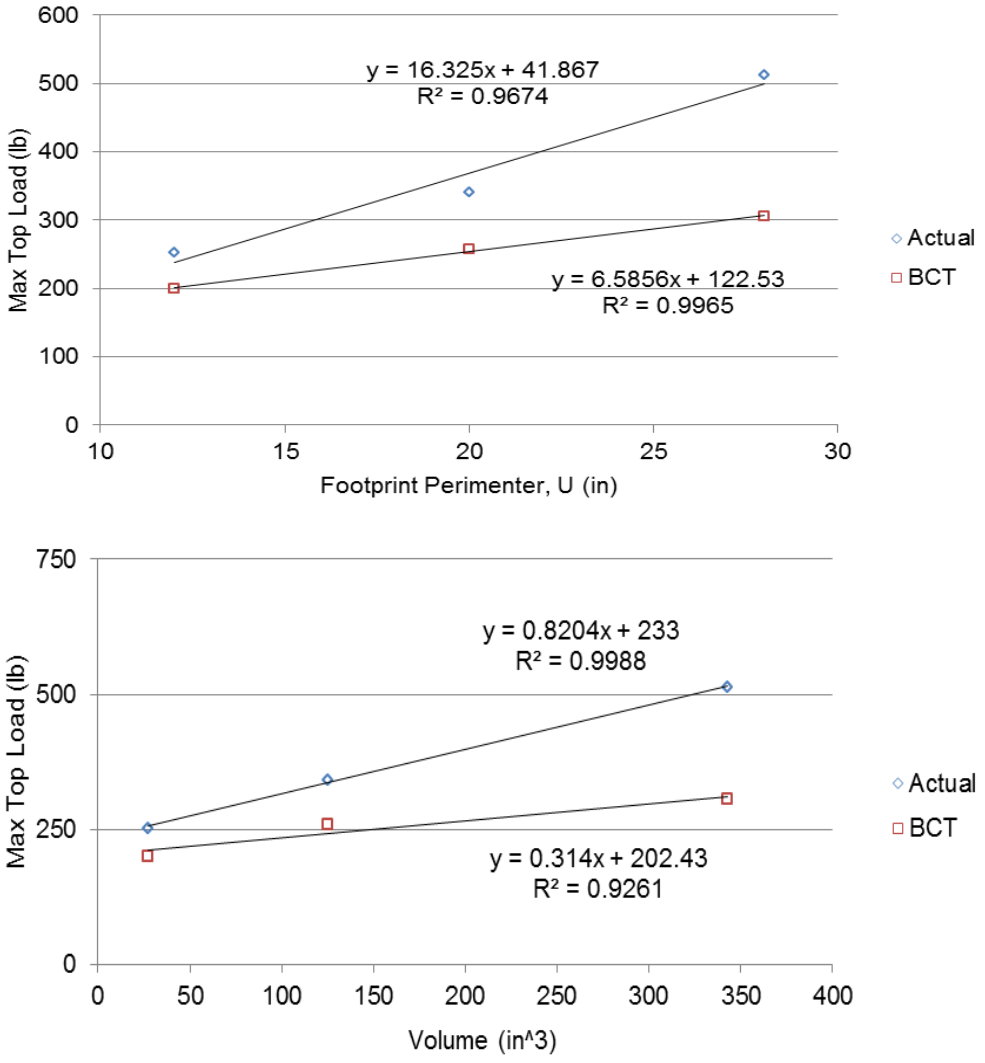

Figure 5: *Effect of Footprint Perimeter and Volume – Cube Boxes*

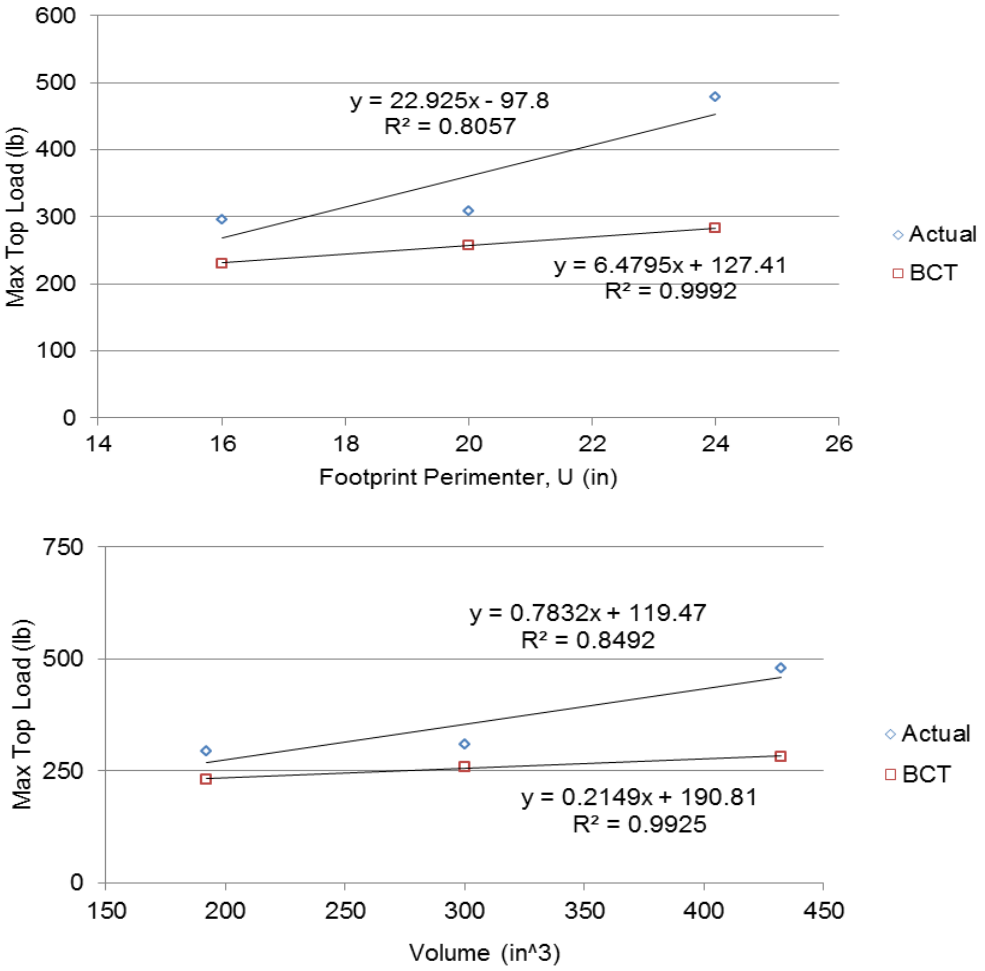

Figure 6: *Effect of Footprint Perimeter and Volume – Boxes with Same Height*

Using the trend line equations from Figure 5, the box strengths from the experiment were 21% and 66% greater those predicted from the McKee formula (BCT) for Volume = 27 in^3 (3”x3”x3” box size) and Volume = 343 in^3 (7”x7”x7” box size), respectively. Similarly, the trend line equations from Figure 6 yielded 16% and 61% greater BCT for Volume = 192 in^3 (4”x4”x12” box size) and Volume = 432 in^3 (6”x6”x12” box size), respectively.

3.3. Effect of Height

Three box sizes were used in this experiment. Each box size had the same footprint of 5”x5” but varied in height of 5”, 12”, and 48”. Ten boxes of each size were crushed, and the data was summarized in Table 6. Results were plotted in Figure 7. Using the trend line equations from Figure 7, the box strengths from experiment were 33% over and 51% under those obtained from the McKee formula (BCT) for Height = 5 in (5”x5”x5” box size) and Height = 48 in (5”x5”x48” box size), respectively.

Table 6: *Effect of Height*

No.	Box Compression Strength (lb)		
	5"x5"x5"	5"x5"x12"	5"x5"x48"
1	326	317	139
2	394	286	120
3	352	313	139
4	331	316	118
5	342	327	106
6	332	305	137
7	327	289	132
8	350	301	128
9	342	308	141
10	311	325	117
Avg (lb)	***341***	***309***	***128***
SD (lb)	*22*	*14*	*12*
SD (% of Avg)	*6.57*	*4.48*	*9.32*
BCT (lb)	***258***	***258***	***258***
Height (in)	***5***	***12***	***48***

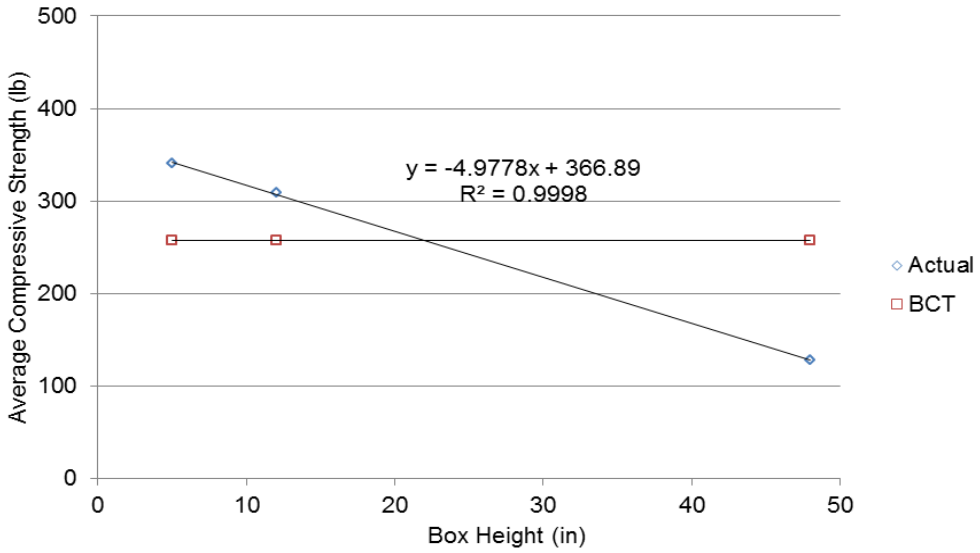

Figure 7: *Effect of Height*

3.4. Box Compression Strength

Further analysis of data is summarized in Table 7 and Figure 8.

Table 7: *Box Strengths*

	3"X3"X3"	5"X5"X5"	4"X4"X12"	5"X5"X12	7"X7"X7"	6"X6"X12"	5"X5"X48"
Actual Strength (lb)	*252*	*341*	*295*	*309*	*513*	*478*	*128*
McKee Strength, BCT (lb)	*200*	*258*	*231*	*258*	*305*	*282*	*258*
% Diff from BCT	*25.96*	*32.12*	*27.90*	*19.71*	***68.07***	*69.36*	***-50.48***
Volume (in^3)	*27*	*125*	*192*	*300*	*343*	*432*	*1200*
Strength/in of Volume (lb/in^3)	*9.32*	*2.73*	*1.54*	*1.03*	*1.50*	*1.11*	*0.11*

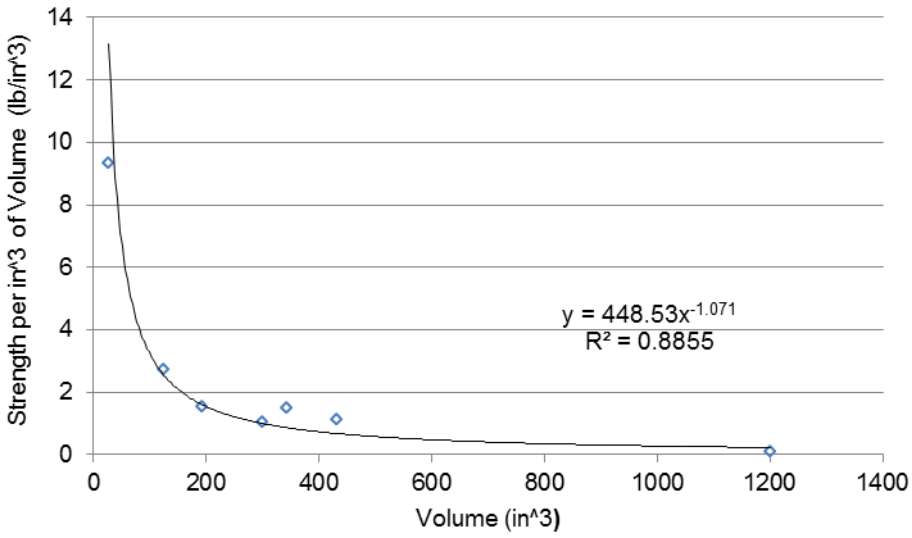

Figure 8: *Box Strength per Unit Volume*

4. Conclusion

The experimental data, obtained from seventy RSC single-wall boxes in seven sizes, showed that the box compression strengths (BCT) predicted by the McKee formula were off anywhere from 50.48% overestimate for the 5”x5”x48” box size to 69.36% underestimate for the 6”x6”x12” box size (Table 7). As the box volume increases, its compression strength per unit volume decreases rapidly as can be seen in Figure 8.

Only seven box sizes were included in this study. This represents only a small fraction of corrugated boxes commonly used. The results of this study must be used with caution. More data would be needed to improve these results. For example, it is well known that a buckling curve is not linear unlike the trend line shown in Figure 7. However, the goal of this study was to verify the accuracy of the McKee formula. Results from this study, using various angles of examination, indicate that the McKee formula could be off significantly.

Acknowledgement

Part of the data was presented at the 2014 HPC Fall Meeting (November 2014). Use with permission from Christian Brothers University.

References

[1] Wikipedia, 2014: *Edge Crush Test*. http://en.wikipedia.org/wiki/Edge_crush_test.

[2] TAPPI, 2008: *TAPPI T839: Edgewise Compressive Strength of Corrugated Fiberboard Using the Clamp Method (Short Column Test).*