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Research Article

Optimum Corner Offset for Cubical Corrugated Boxes

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Abstract Several C-flute single-wall regular slotted cubical corrugated boxes with dimensions from 12X12X12 to 22X22X22 were modified at the four corners with corner offsets from 1 inch to 8 inches to form diagonal (or “two-angle”) corners. They were conditioned at the standard test condition of 73 $^{\circ}F$ and 50% RH. The optimum corner offset varied from 22% of box dimension to 26% with an average of 24%. The maximum compression strength increased from the regular corner configuration from 23% to 62%, with an average of 44%. In addition, an average of 14% saving on material at optimum corner offset.

Keywords *Box Design; Corrugated Box; Diagonal Box Corner*

1. Introduction

About 2/3 (or 67%) of compression strength of a typical regular slotted container (RSC) comes from the four vertical corners [1]. In a previous study [2], regular box corners were pushed inward to form a three-angle configuration instead of the normal one-angle configuration. This resulted in a significant increase in compression strength. However, the three-angle configuration is not practical. A two-angle (diagonal) corner [3, 4] is more common and more practical, as shown in Figure 1. Figure 2 shows various box corner configurations mentioned in this article. A preliminary study of two-angle corner (or diagonal corner) configuration for 16X12X12 boxes [5] showed that the compression strength increased up to a corner offset, then dropped as shown in Figure 3. The objective of this study was to determine an optimum corner offset for C-flute single-wall cubical corrugated boxes.

Figure 1: *Examples of Two-Angle Corner (or Diagonal Corner) Boxes*

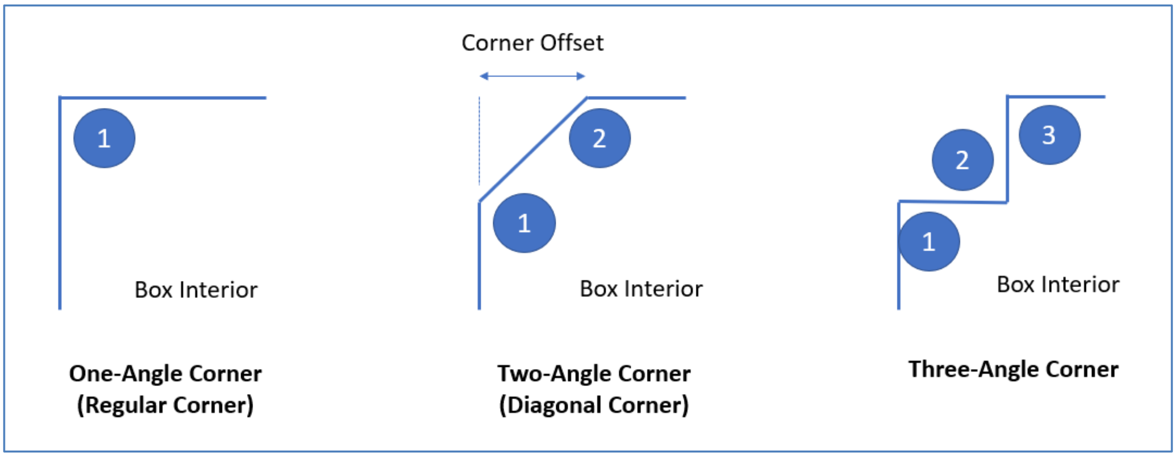

Figure 2: *Various Box Corner Configurations*

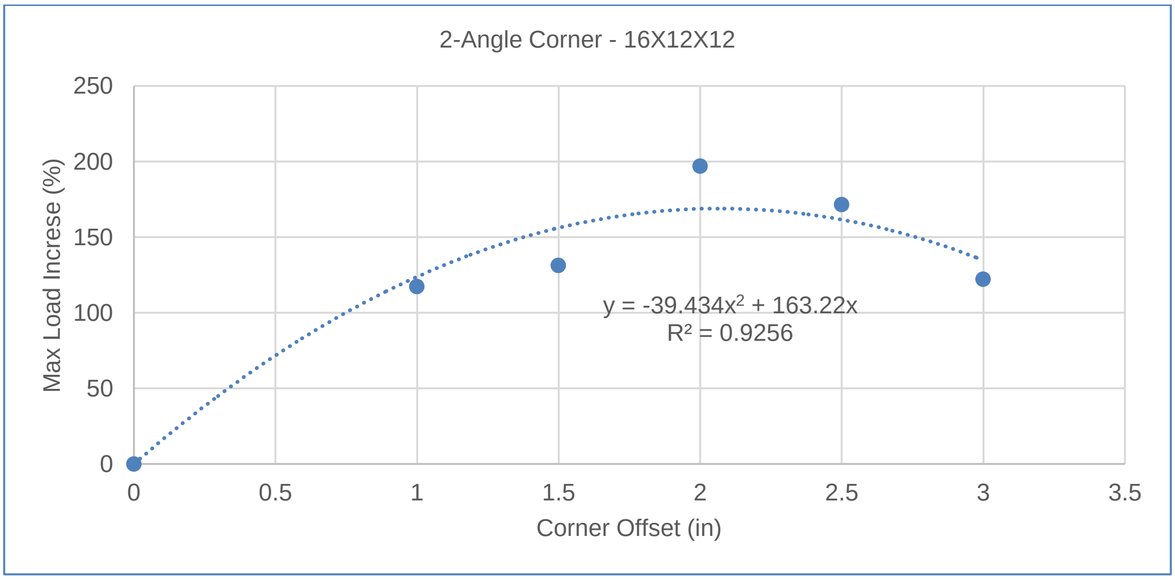

Figure 3: *Box Compression Strength vs Corner Offset: 16X12X12 Box [5]*

2. Materials and Methods

C-flute single-wall cubical corrugated boxes were used in this study. Cubical boxes were selected to simplify box dimension representation to one single number instead of three. The following box sizes were used in this study: 12X12X12, 14X14X14, 16X16X16, 18X18X18, 20X20X20, and 22X22X22 with corner offsets from 1 inch to 8 inches. Average Edge Crush Test (ECT) and Mullen Burst Test of these boxes were 24 lb/in and 203 psi, respectively.

These boxes were acquired from the same vendor to ensure consistency, even though it was not guaranteed. Top and bottom flaps were removed. The glue joint was slit open. Boxes were then reconfigured. Paper and binder clips were used to hold corner angels as shown in Figure 4. It should be noted that paper clips were placed on the exterior side of the box, thus they did not show up in Figure 4. The same was done to the regular corner boxes to maintain consistency. Three boxes were compressed for each box size with a corner offset after conditioning in an environmental chamber at 73^{o}F and 50% RH for at least 12 hours. Their average maximum compression strength was used to represent the case.

Due to its size, the 24X24X24 boxes were conditioned in the laboratory ambient temperature and humidity, which were not exactly 73^{o}F and 50% RH. A humidity adjustment factor equation from a previous study [6] was used to make an appropriate adjustment to its compression strength. The laboratory ambient temperature was very close to 73^{o}F, thus no adjustment was necessary.

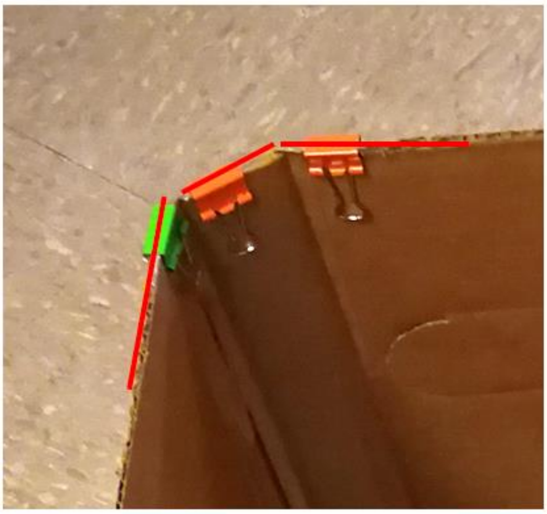

Figure 4: *Reconfigured Two-Angle (Diagonal) Corner*

3. Data & Results

Compression test results are summarized in Table 1 and plotted in Figure 5. The optimum corner offset for each case was found by setting the derivative of its trendline equation to zero. The peak increase in compression strength was then determined at this optimum offset. Table 2 summarizes optimum corner offsets and their corresponding peak compression strength increases. Optimum offsets were plotted against box dimensions in Figure 6, while peak strength at optimum offsets plotted against box dimension in Figure 7. A diagonal or two-angle corner also resulted in material saving as shown in Table 3.

Table 1: *Box Compression Strength*

Box Size	Corner Offset (in)	Pmax 1 (lb)	Pmax 2 (lb)	Pmax 3 (lb)	*Pmax avg (lb)*	*% Increase from Regular Corner*
12X12X12	0	458	436	414	*436*	*0*
	1	447	542	470	*486*	*12*
	2	459	545	593	*532*	*22*
	3	572	574	450	*532*	*22*
	4	489	523	571	*528*	*21*
	5	455	502	456	*471*	*8*
14X14X14	0	468	432	455	*452*	*0*
	1	543	543	573	*553*	*22*
	2	632	644	525	*600*	*33*
	3	665	631	606	*634*	*40*
	4	736	611	626	*658*	*46*
	5	596	603	604	*601*	*33*
	6	590	560	546	*565*	*25*
16X16X16	0	602	632	673	*636*	*0*
	1	704	783	726	*738*	*16*
	2	706	781	963	*817*	*28*
	3	766	875	1075	*905*	*42*
	4	831	929	1089	*950*	*49*
	5	928	961	838	*909*	*43*
	6	762	892	807	*820*	*29*
18X18X18	0	422	432	425	*426*	*0*
	1	559	475	498	*511*	*20*
	2	636	616	647	*633*	*48*
	3	638	671	698	*669*	*57*
	4	679	703	735	*706*	*66*
	5	645	634	716	*665*	*56*
	6	631	650	600	*627*	*47*
20X20X20	0	446	481	417	*448*	*0*
	1	496	476	508	*493*	*10*
	2	595	585	495	*558*	*25*
	3	620	757	625	*667*	*49*
	4	667	682	722	*690*	*54*
	5	717	569	672	*653*	*46*
	6	723	730	711	*721*	*61*
	7	628	703	630	*654*	*46*
	8	701	595	544	*613*	*37*
22X22X22	0	834	717	705	*752*	*0*
	2	718	912	966	*865*	*15*
	3	980	931	956	*956*	*27*
	4	1093	1089	1084	*1089*	*45*
	5	1230	1016	1072	*1106*	*47*
	6	917	1004	1114	*1012*	*35*
	7	1005	1040	989	*1011*	*34*
	8	971	930	1001	967	*29*

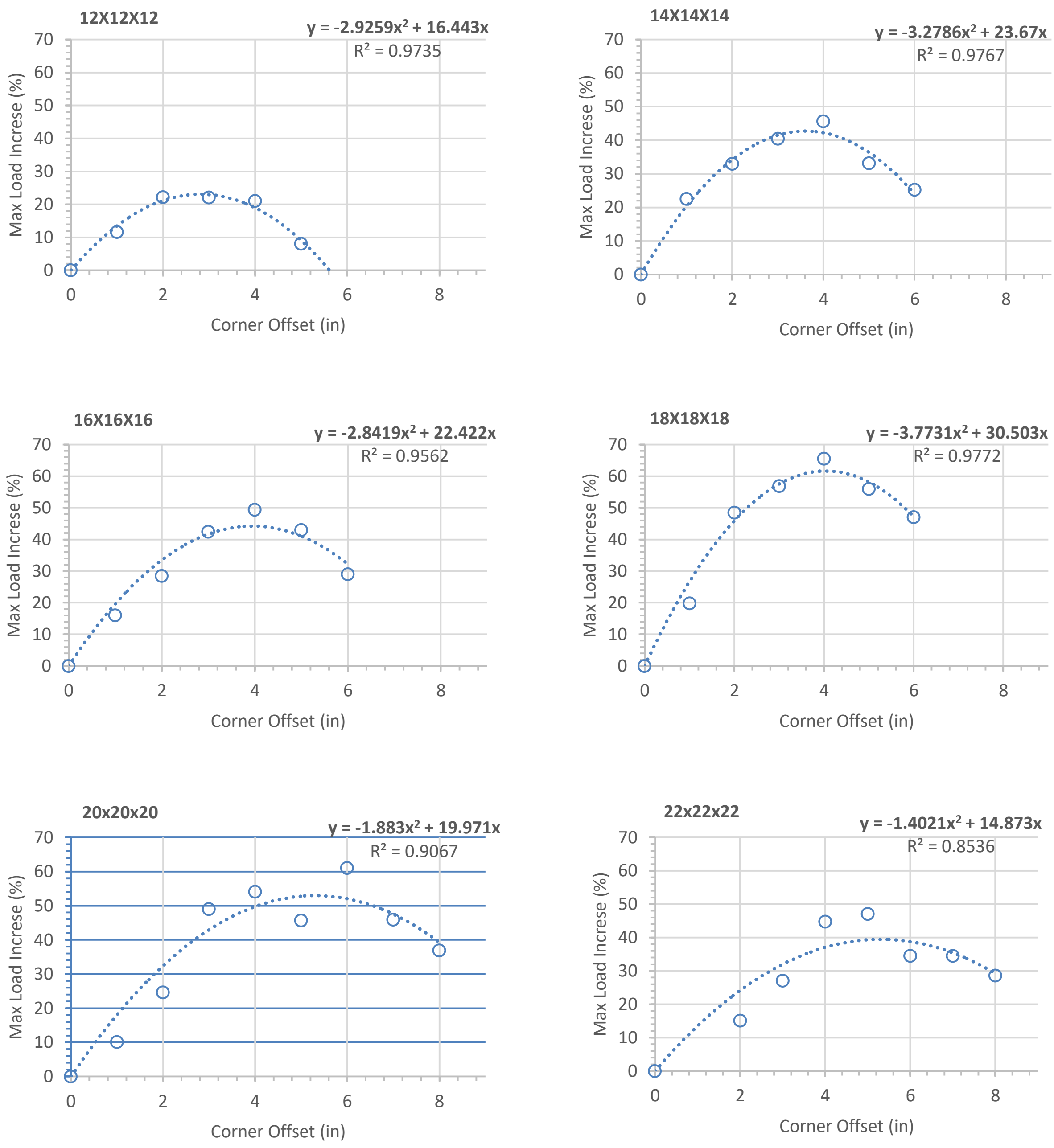

Figure 5: *Effect of Corner Offset to Box Compression Strength*

***Table 2:** Optimum Corner Offsets & Corresponding Peak Compression Strength Increases*

Box Size (in)	Trendline Equation	Optimum Offset (in) from ($\frac{dy}{dx} = 0$)	Strength Increase at Optimum Offset (%)	Offset/Size Ratio
12	$y = -2.9259x^2 + 16.443x$	2.81	23.10	0.23
14	$y = -3.2786x^2 + 23.67x$	3.61	42.72	0.26
16	$y = -2.8419x^2 + 22.422x$	3.96	44.23	0.25
18	$y = -3.7731x^2 + 30.503x$	4.04	61.65	0.22
20	$y = -1.883x^2 + 19.971x$	5.30	52.95	0.26
22	$y = -1.4021x^2 + 14.873x$	5.30	39.44	0.24
		AVG =	***44.02***	***0.24***

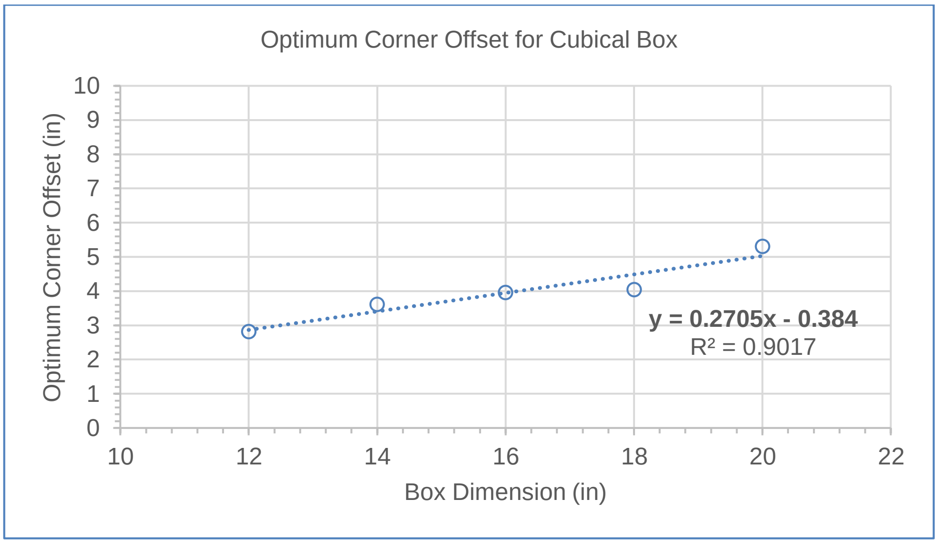

***Figure 6:** Optimum Corner Offset Equation*

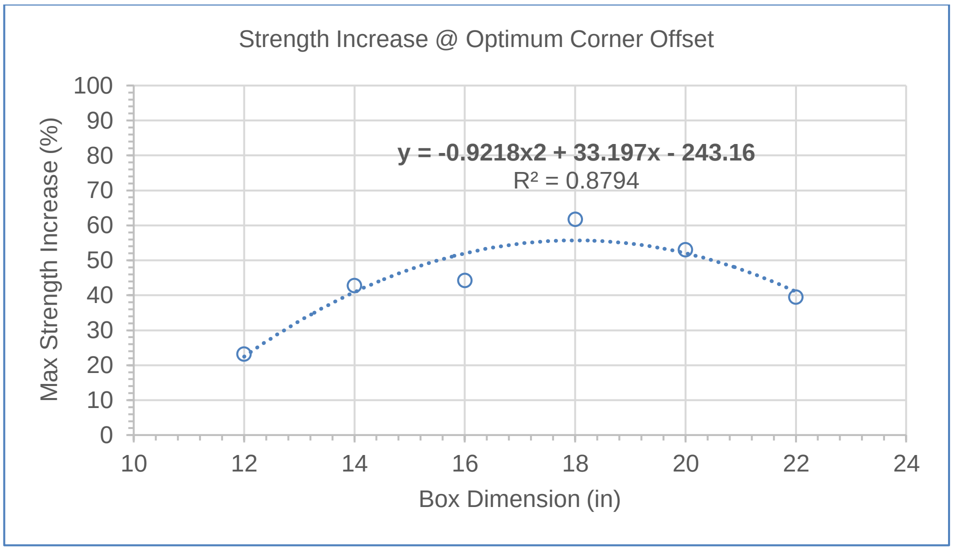

***Figure 7:** Peak Strength Increase Equation*

Table 3: *Saving of Diagonal (Two-Angle) Corner Configuration*

Box Size	Side Length (in)	Corner Offset (in)	Total Wall Length (in)	Saving (%)
12X12X12	12	0	48.00	0
	12	2	43.31	10
	12	*2.81*	*41.42*	*14*
	12	4	38.63	20
	12	6	33.94	29
	12	8	29.25	39
14X14X14	14	0	56.00	0
	14	2	51.31	8
	14	*3.61*	*47.54*	*15*
	14	4	46.63	17
	14	6	41.94	25
	14	8	37.25	33
16X16X16	16	0	64.00	0
	16	2	59.31	7
	16	*3.96*	*54.72*	*14*
	16	4	54.63	15
	16	6	49.94	22
	16	8	45.25	29
18X18X18	18	0	72.00	0
	18	2	67.31	7
	18	4	62.63	13
	18	*4.04*	*62.53*	*13*
	18	6	57.94	20
	18	8	53.25	26
20X20X20	20	0	80.00	0
	20	2	75.31	6
	20	4	70.63	12
	20	*5.30*	*67.58*	*16*
	20	6	65.94	18
	20	8	61.25	23
22X22X22	22	0	88.00	0
	22	2	83.31	5
	22	4	78.63	11
	22	*5.30*	*75.58*	*14*
	22	6	73.94	16
	22	8	69.25	21

4. Discussion & Conclusion

The goal of this study was to determine the optimum corner offset, i.e., an offset that yielded the highest compression strength. The optimum corner offset can be found from the following equation (Figure 6):

$$y = 0.2705x - 0.384 \qquad \text{…. Eqn. (1)}$$

where y = optimum corner offset (inches) and x = box size or dimension (inches).

Table 2 shows the ratio of Corner Offset over Box Size has a range of 0.23 to 0.26 with an average value of 0.24. Thus, a rough estimate of optimum corner offset is about 25% or ¼ of the box dimension. This is a significant corner offset since the total offset of a side wall is 50% of the wall length, i.e., offsets at both ends of a side wall. However, this is not uncommon and is similar to the octagonal box shown on the right in Figure 1.

To test if Equation 1 above would be applicable to non-cubical boxes, the derivative of trendline equation for 16X12X12 box shown in Figure 3 was set to zero. This resulted in the optimum corner offset of 2.06 inches. Depending of which side is used to represent box dimension in Equation 1, the error from Equation 1 is either 39% or 91% with an average error of 65%. Thus, Equation 1 is not applicable to non-cubical boxes. Determining optimum corner offset for non-cubical boxes would be a good future study.

Table 4: *Error of Applying Optimum Corner Offset to Non-Cubical Boxes*

Box	Actual Optimum Corner Offset (inches)	Box Dimension Used in Eqn. 1 (inches)	Optimum Corner Offset from Eqn.1 (inches)	Error (%)
16X12X12	2.06	Long Side = 16	3.94	91
		Short Side = 12	2.86	39
		Average = (16+12)/2 = 14	3.40	65

Strength increase at optimum corner offset can be determined from the trendline equation shown in Figure 7.

$$y = -0.9218x^2 + 33.197x - 243.16 \qquad \text{…. Eqn. (2)}$$

where y = % increase in compression strength from regular box corner configuration or 0-inch corner offset, and x = box dimension (inches). The strength-increase peaked at about 18” box dimension and dropped afterward. Since these were cubical boxes, box height increased with its base dimension. When the height increased, so did the wall slenderness ratio. This caused buckling failure. Modified corners did not help in taller boxes as much as they did for shorter boxes. This would also be a good future study.

Besides the increase in compression strength, diagonal (two-angle) corner configuration also uses less material as shown in Table 3. The larger the corner offset used, the more saving is obtained. However, the usable volume of the box is reduced as the material saving increases. Thus, a balance must be made on corner offset between practicality and strength. As mentioned in a previous work [5], the manufacturing cost for diagonal corner boxes might override the benefit of the compression strength gained and stacking misalignment could create some issues when flaps are used.

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Research Article

Effect of Drinking Water Bottle Arrangement to Multi-Pack Vertical Compression Strength under Semi-Confinement Condition

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Abstract Water bottles are sold in multi-pack of several bottles and shrink-wrapped for handling purposes. When lateral pressure is applied to a multi-pack of bottles, the pack can carry more vertical stacking strength during warehousing and transportation. In this study a rubber exercise band was used to apply lateral pressure to a pack of four 16.9-oz drinking water bottles. Under this semi-confinement condition, the pack stacking strength increased up to 19% for non-interlocking bottle arrangement. However, the lateral pressure decreased the stacking strength for interlocking bottle arrangement due to the non-uniform load-carrying distribution of the four bottles. Failure occurred in the neck and shoulder areas of these bottles. Thus, adding vertical ribs or some patterns in the neck and shoulder areas would increase their compression strength.
Keywords *Water Bottles; Semi-Confinement; Bottle Arrangement*

1. Introduction

Bottled water is usually sold in multi-pack of bottles wrapped together with shrink film [1] for ease of handling. Thinner bottles have been used in recent years to minimize the environmental impact. However, thinner bottles reduce the multi-pack stacking strength during warehousing and transportation.

Confined compression strength is vertical load carrying capacity under lateral confinement. The increase of vertical load carrying capacity due to lateral confinement was well documented in concrete [2] and soil [3]. In a previous study [4], a rubber exercise band was used to apply lateral pressure to a pack of four 16.9-oz drinking water bottles. This created a semi-confinement condition for the bottles. A stiffness curve of the rubber band was developed by stretching the rubber band from 0” to 10” using a luggage scale as shown in Figures 1 and 2. The vertical compression strength of the pack increased up to some point and then decreased due to the deviation of the bottle wall from its vertical plane as the tension force in the rubber band increased (Figure 3).

The purpose of the work described in this article was to study the effect of an interlocking bottle arrangement on the vertical compression strength comparing to the non-interlocking arrangement in the previous study. Figure 4 shows a non-interlocking bottle arrangement versus interlocking arrangement.

Figure 1: *Exercise Band Stiffness Determination* [4]

Displacement (in)	Force (lb)
0.00	0.00
0.50	1.50
1.00	2.50
1.50	4.00
2.00	4.50
2.50	5.50
3.00	6.00
3.50	6.90
4.00	7.70
4.50	8.40
5.00	9.00
5.50	9.30
6.00	9.70
6.50	9.90
7.00	10.80
7.50	11.00
8.00	11.80
8.50	12.30
9.00	12.80
9.50	13.30
10.00	13.90

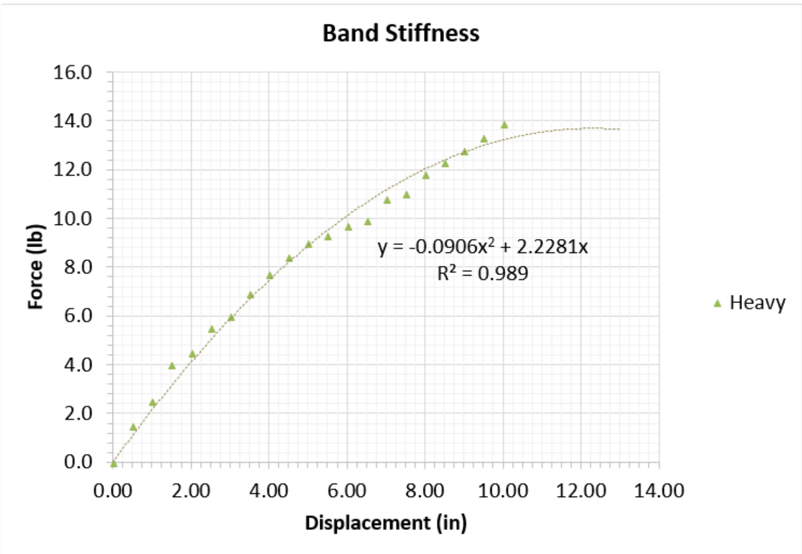

Figure 2: *Exercise Band Stiffness Curve and Equation* [4]

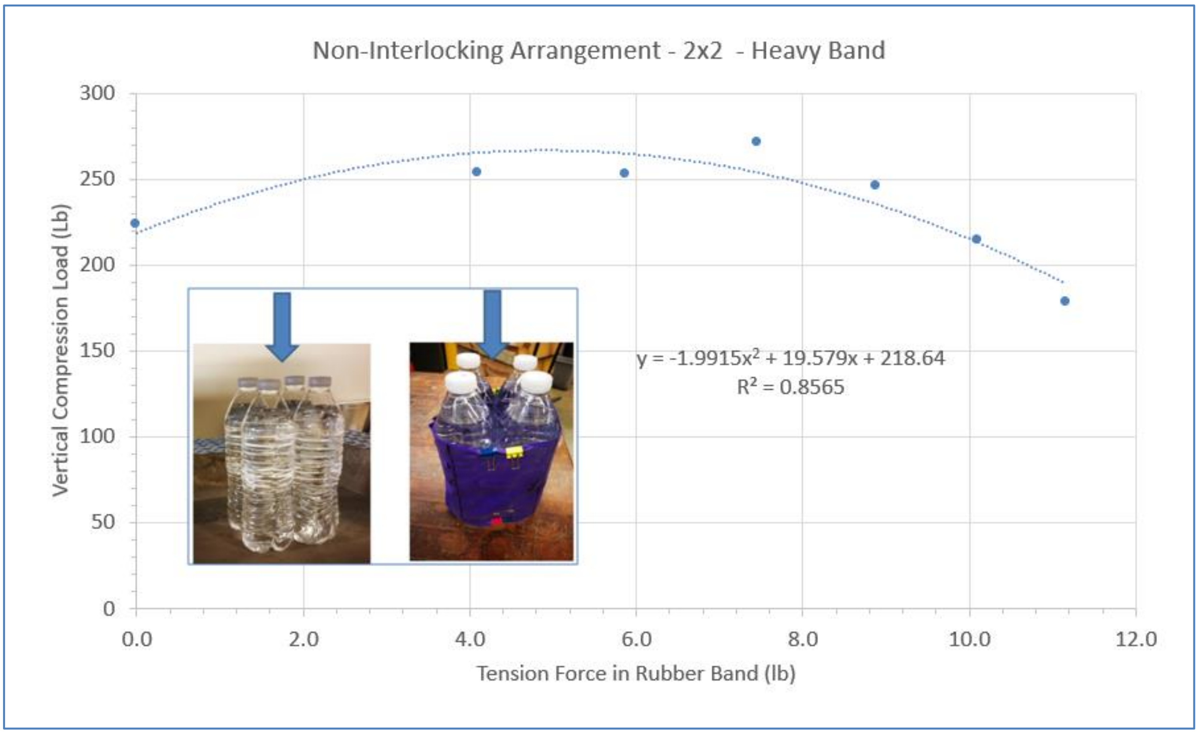

Figure 3: *Effect of Lateral Pressure on Vertical Compression Strength*

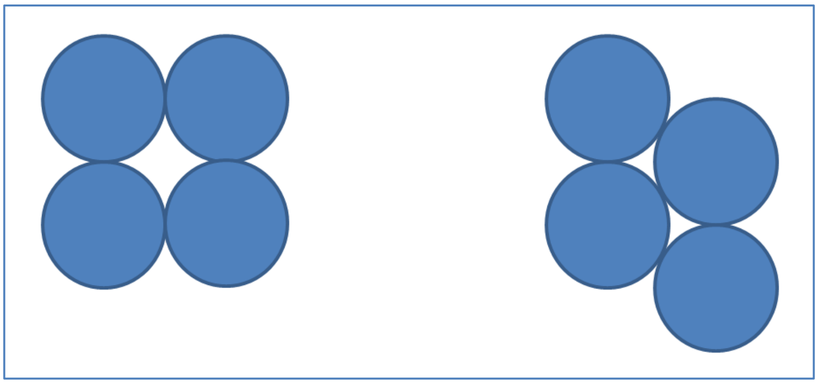

Figure 4: *Non-Interlocking Arrangement (Left) vs Interlocking Arrangement (Right)*

2. Materials and Methods

Water bottles of the same brand and size used in the previous study [4] were used in this study to maintain consistency for comparison. The same rubber band used in the previous study was also used. A non-linear stiffness curve for the rubber band was developed in the previous study which resulted in the equation shown below:

$$y = -0.0906x^2 + 2.2281x$$

where x is the rubber band stretch (in) and y is the tension force in the rubber band (lb).

The rubber band was stretched from 2 inches to 7 inches with a 1-inch increment. The above equation was used to determine the tension force in the rubber band at a specific stretch. Three sets of bottles with the same stretch were crushed by a compression table and an average maximum load was used to represent the case.

3. Data & Results

Data and results are summarized in Table 1. For comparison, data for the non-interlocking arrangement from the previous work [4] is presented in Table 2. The results of the two cases are compared in Figure 5. Trend line equations were obtained using Excel's 2^{nd} order least squared curve fitting routine. Failures around bottle's neck and shoulder were consistent among bottles tested in this study. Failure lines were traced with black ink for visibility in Figure 6.

The peak stacking strength of the non-interlocking trend line equation shown in Figure 5 was found to be 266.76 lb at 4.92 lb of tension force in the rubber band by taking $\frac{dy}{dx} = 0$. This was about 19% increase from zero-tension case. However, the lateral pressure reduced the stacking strength in the interlocking bottle arrangement.

Table 1: *Data & Results for Interlocking Arrangement Case*

Interlocking Arrangement - 2x2 Square					
Stretch (in)	Tension Force in Band (lb)	Pmax 1 (lb)	Pmax 2 (lb)	Pmax 3 (lb)	Pmax avg (lb)
0	0.0	223	239	225	229
2	4.1	260	181	280	240
3	5.9	198	151	258	202
4	7.5	216	163	195	191
5	8.9	182	164	245	197
6	10.1	213	170	190	191
7	11.2	134	169	133	145

Table 2: *Data & Results for Non-interlocking Arrangement Case* [4]

Non-Interlocking Arrangement - 2x2 Square					
Stretch (in)	Tension Force in Band (lb)	Pmax 1 (lb)	Pmax 2 (lb)	Pmax 3 (lb)	Pmax avg (lb)
0	0.0	241	214	216	224
2	4.1	236	279	246	254
3	5.9	243	256	260	253
4	7.5	266	273	275	271
5	8.9	283	235	220	246
6	10.1	212	212	220	215
7	11.2	200	175	160	178

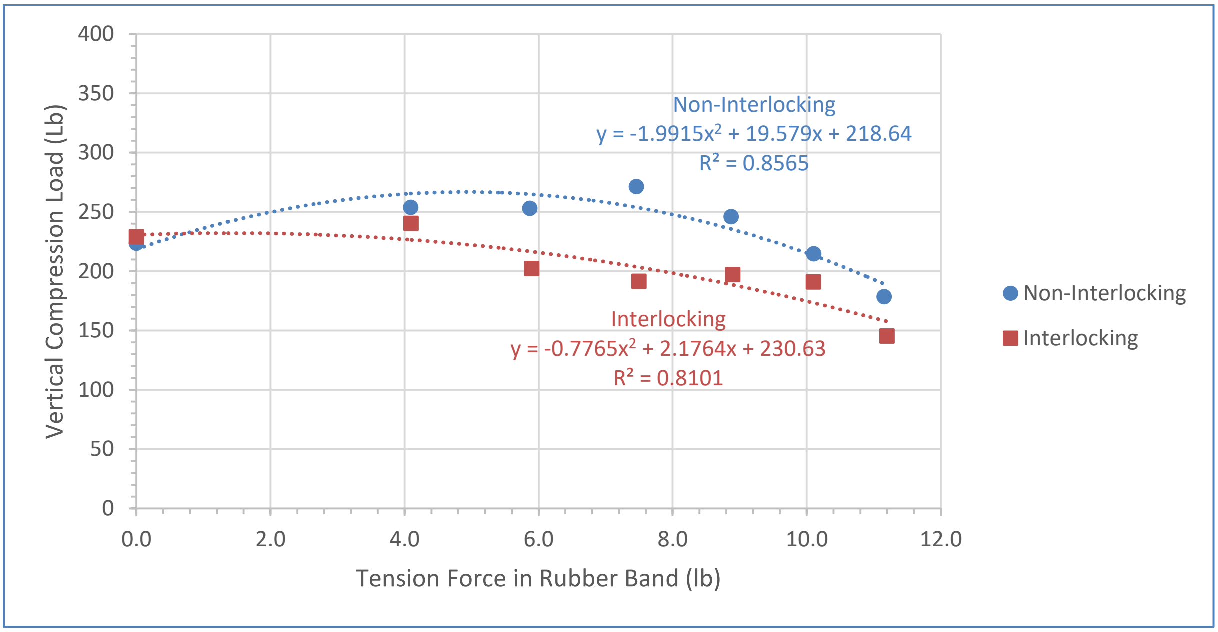

Figure 5: *Comparison of Non-Interlocking and Interlocking Bottle Arrangements*

Figure 6: *Failure on Neck and Shoulder of Bottle*

4. Discussion & Conclusion

The following observations can be made from Figure 5.

- The rise and fall of vertical compression strength of the two different arrangements follow a similar pattern with lower strength on the interlocking arrangement.
- At 0 tension force in rubber band, i.e., no rubber band, the vertical compression strengths of the two bottle arrangements are comparable.

Explanations of the above observations can be drawn from Figures 7 to 9 below. When the rubber band was tightened up, it squeezed the bottles together. Figure 7 shows lateral support provided by adjacent bottles to the lower-left bottle (which is the same as the upper-right bottle) and to the upper-left bottle (which is the same as the lower-right bottle). All bottles in the non-interlocking arrangement received the same lateral support from two adjacent bottles, thus they had a similar load carrying capacity. However, bottles in the interlocking arrangement did not receive the same lateral support. The lower-left bottle (also the upper-right bottle) received support from three adjacent bottles, while the upper-left bottle (and the lower-right bottle) received support from only two adjacent bottles. Thus, load distribution among the four bottles in interlocking arrangement was not uniform. In addition, the angle that supported the upper-left bottle from the two lateral forces from adjacent bottles in the interlocking arrangement was smaller than that of the non-interlocking arrangement. This made the upper-left bottle in the interlocking arrangement weaker than the same bottle in the non-interlocking arrangement.

Figure 8 shows resultant force from rubber band tension forces on the upper-left bottle for both arrangements. The interlocking arrangement had a larger resultant force, which caused the vertical misalignment of the upper-left bottle wall first. Due to having less angle support and more force from the rubber band made the upper-left bottle (also the bottom-right bottle) weaker than the remaining two for the interlocking arrangement

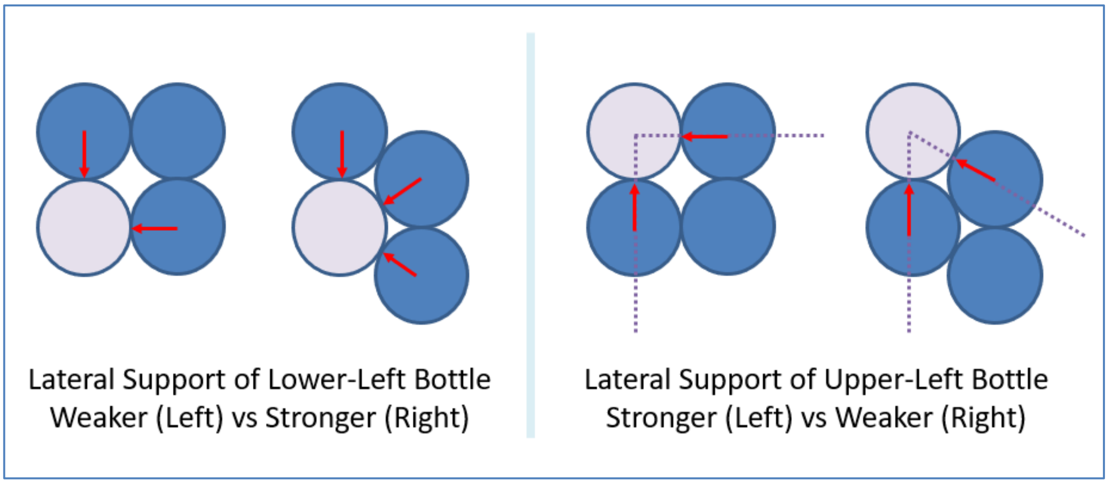

Figure 7: *Lateral Support from Adjacent Bottles*

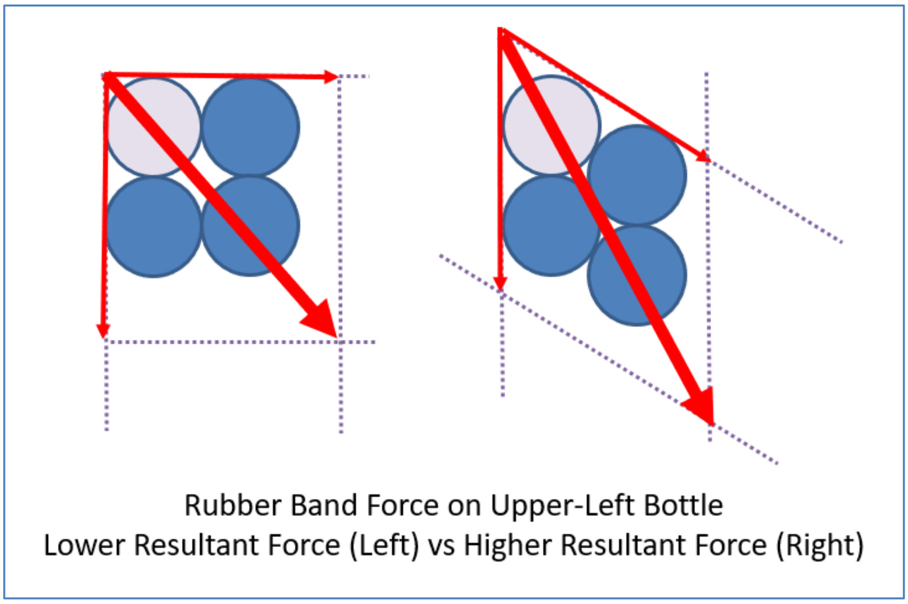

Figure 8: *Lateral Force from the Rubber Band*

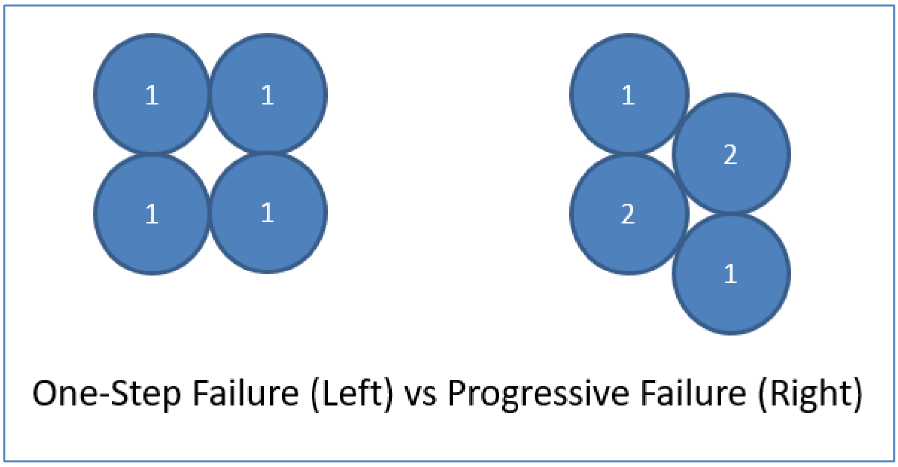

Figure 9: *Single-Step and Progressive Failures*

Figure 9 shows a single-step failure for the non-interlocking arrangement. Since all four bottles had the same load-carrying capacity, they failed at about the same time. However, in the interlocking arrangement, the upper-left and lower-right bottles (labelled "1") were weaker and failed first. Then the remaining two bottles (labelled "2") were overloaded and failed. This created a progressive failure. This explains why the interlocking curve was lower than the non-interlocking curve shown in Figure 5.

When there was no force in rubber band, the four bottles in both arrangements were not pushed against one another. Thus, each bottle behaved independently with very little lateral support from adjacent bottles. This explains the comparable compression strengths of both arrangements.

Failures, as shown in Figure 6, were around the neck and shoulder areas of these bottles. Thus, adding vertical ribs or other patterns in these areas, such as those shown in Figure 10, would strengthen the vertical compression strength.

Reference [5]

Reference [6]

Figure 10: *Samples of Patterns in the Neck & Shoulder Areas*

In conclusion, the non-interlocking arrangement gives a higher vertical load-carrying capacity than the interlocking arrangement. Interlocking arrangement is not recommended since it reduces the stacking strength of the pack. In addition, adding vertical ribs or some pattern in the neck and shoulder areas would increase the bottle's stacking strength.

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