Influence of pallet pattern on top-to-bottom compression performance of unitized loads

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ABSTRACT: Environmental scaling factors estimate a corrugated container's ability to withstand various conditions it will encounter during the storage and distribution process. In this project, we examined the compressive resistance of unitized loads using differing pallet stacking patterns. To simulate real-world failure scenarios in our laboratory tests, we used two different nominal board grades of single-wall C-flute regular slotted containers loaded with a plywood panel and bagged salt to direct the failure location to the bottom of the stack. Our results showed that the columnar aligned pattern provided the greatest compressive resistance and the interlocked stacking arrangement yielded the lowest of the patterns evaluated. Based on the study results, we calculated box compression retention multipliers for each pattern and compared them to scaling factors published by the Fibre Box Association.

Application: This work highlights how the pallet pattern used for stacking corrugated containers affects the overall compression strength of the unit load. This paper provides environmental scaling factors based on different pallet patterns used for unitizing loads.

A unit load system is the predominant means of moving packaged goods through the supply chain [1]. Traditionally, the unit load system is comprised of three fundamental factors: pallet, package, and stabilizer [2]. The package component most commonly used in conjunction with the unit load system is the corrugated container. The corrugated container must be designed and tested to fundamentally understand if it can withstand the distribution channel through which it will pass. A common test used to evaluate corrugated containers is the compression test. Compression testing of corrugated containers can help establish metrics for determining how successful a package and subsequent unit load will be for traversing the supply chain. To successfully design a system, the packaging industry relies on a series of environmental scaling factors used to relate single box compression test (BCT) values to the expected performance of a unit load system in the field [3]. These environmental strength reduction factors, used as multipliers, were compiled for time under load, the humidity of the storage/distribution environment, stacking pattern, palletization, and other unitizing influences.

A variety of stacking patterns are available to select when constructing a unit load system. The pattern is often selected by what the system is looking to overcome. Columnar aligned stacking configuration provides the greatest top-to-bottom compression strength because it aligns all the corners of the packages. Although providing the greatest resistance for vertical top-to-bottom compression, the arrangement can be unstable in certain circumstances, depending on the geometric dimensions of the stacked containers. Interlocked patterns are comparably more stable than columnar aligned for the same containers, but there is a noted reduction in stacking strength due to the corners, which offer the greatest support to the container, not being in alignment [3]. The hybrid stacking pattern is a combination of columnar and interlocked. This stacking pattern looks to blend the sought-after characteristics of both columnar and interlocked.

Many of the environmental factors used to predict the performance of stacked containers are based on research data performed in the 1960s and 1970s [4,5]. Although more recent research has been performed, the scaling factors have not been updated. Singh et al. [6] reported that perfectly aligned stacks of corrugated containers reported 6%–15% reduction in compression strength compared to the individual box compression test. The most prevalent comparison of stacked containers in the literature reviewed was between columnar aligned and interlocked patterns. Previous research reports [3-5,7,8] showed a 35%–60% loss for corrugated containers stacked in an interlocked pallet pattern. Singh et al. [6] noted offsetting and misaligning two adjacent panels of a stack of containers could reduce compression strength by almost 60%. A study conducted by Rha [9] reported a reduction in compression strength based on the percentage of contact area, showing that the reduction for diagonally misaligned containers could be as high as 51%. The majority of the studies reviewed used empty containers that were single stacked (between 2 and 3 containers high), which would not necessarily represent the typical stack height of a unit load. Additionally, by using a single stack of containers, the interactions between surrounding packages would not be observed, which could influence the stacking behavior.

Laboratory testing is designed to provide an assessment to accurately depict field measured responses. Most of the testing research related to box compression has used empty containers to evaluate stacked containers and their performance against these environmental factors. Frank et al. [10] performed research indicating that by using loaded containers, the failure locations of laboratory-based testing more closely match that of field failures occurring at or near the bottom of the unit stack. Their study showed that the failure mechanism and location of empty stacked containers occurs in the middle of the stack, not at the bottom, as observed in field failures [10]. As a result, their work indicates that to accurately assess corrugated containers' unit load testing, the containers must be loaded with proper weight (distributed evenly) and tested using a complete pallet load configuration.

This technical brief presents the results of a small study exploring the impact of stacking patterns on effective box compression strength. With conditioning according to TAPPI Standard Test Method T 402 "Standard conditioning and testing atmospheres for paper, board, pulp handsheets, and related products" and using loaded boxes to properly simulate real-world situations, we tested column stacked, interlocked, and hybrid patterns. The results provide important validation and revision of the commonly used scaling factors in the industry.

	32 ECT (n=20)	44 ECT (n=20)
Nominal combination, lb/msf	35-23-35	56-23-56
Caliper, mils	154 ± 2	167 ± 3
Length, in.	19.5	19.5
Width, in.	13	13
Depth, in.	12	12
Loaded container weight, lb	44.6 ± .2	44.8 ± .3

I. Physical properties of the boxes used in this study (ECT = edge crush test).

1. Corrugated container with internal weight.

MATERIALS AND METHODS

Two nominal corrugated board grade materials were selected for this project: 32 and 44 edge crush test (ECT). For both board grades, the single-wall C-flute regular slotted containers (RSC) had outside dimensions of 19.5 in. x 13 in. x 12 in. Upon receipt of the converted containers, they were randomized and sorted based on their nominal ECT values, either 32 or 44 ECT. During the samples' randomization, we recorded the board's caliper using a digital caliper, taking measurements along the major flap (**Table I**).

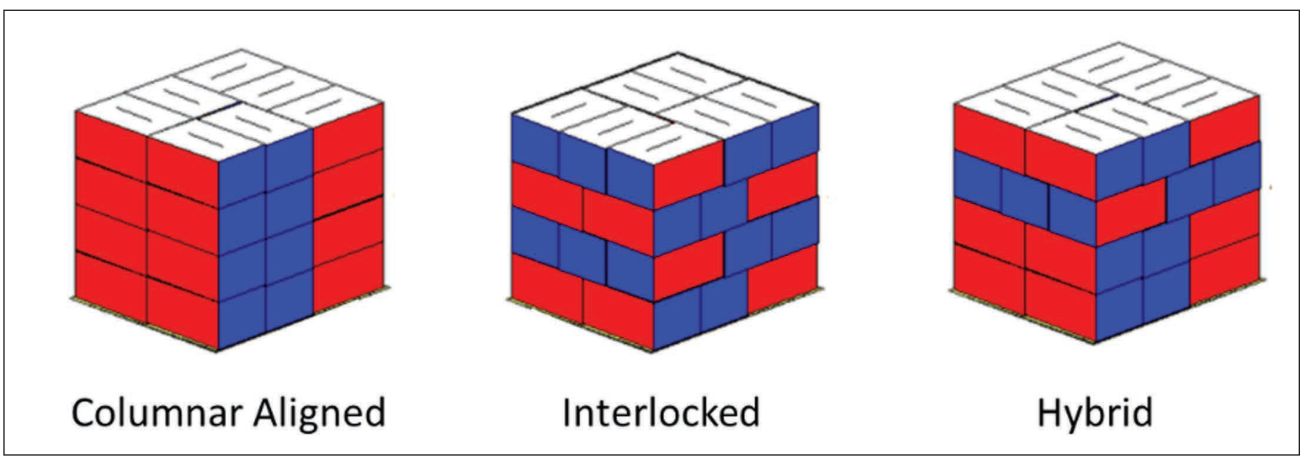
We closed all boxes in this project using hot melt glue to join the minor and major flaps of the container. Before performing any compression testing, the containers were subjected to pre-conditioning and conditioning cycles following TAPPI T 402. The chamber was programmed to perform a 2-step conditioning cycle: Step 1 — Pre-conditioning at 30°C and 25% relative humidity (RH) for 48 h, and Step 2 — Conditioning at 23°C and 50% RH for 48 h.

To obtain the BCT of the individual container, we performed ten compression tests on each of the two nominal ECT board grades, as defined by TAPPI T 804 "Compression test of fiberboard shipping containers." The boxes used for BCT were tested empty. A Lansmont Compression Tester Model 122-15K (Lansmont Corp.; Monterey, CA USA) was used to execute the single box compression tests. We recorded the peak force and deflection at the peak for each of the samples, as well as the force vs. deflection curves.

2. Example unit load compression test noting the consistent orientation.

For the boxes used to construct the unit loads of the pallet patterns, we placed a plywood panel (18.75 in. x 12.5 in. x 0.5 in.) in the bottom of the container and placed weight — a water softener salt bag — onto the wood panel before closing it. We referred to it as a "loaded box" (**Fig. 1**). The addition of the plywood panel aids in distributing the payload without creating unequal pressure points to the box below [10]. The simulated weight was loaded into the container such that it would not influence the sidewalls. Table I shows the average total container weight for the 32 and 44 ECT containers. After completing the conditioning cycle, the samples were stacked to represent the pallet pattern being evaluated, and a compression test was performed on the unit load. For each unit load test, 28 of the loaded boxes were assembled into one of the pallet patterns used for the study. We stacked the loaded containers directly onto the steel base of the compression tester to eliminate the variability of pallet-surface interaction. To maintain consistent orientation and repeatability, we stacked the containers identically based on the location of the box manufacturer's certificate (BMC) for all unit load tests (**Fig. 2**). The peak force and deflection at the peak were recorded for each of the samples, as well as the force vs. deflection curves. Five replicates of each pallet pattern and ECT board grade were tested. To evaluate the influence of stacking patterns, the corrugated boxes were arranged into one of three pallet pattern types for this study: columnar aligned, interlocked, and hybrid. **Figure 3** illustrates the patterns constructed for this project.

A Cole-Parmer Symmetry MB halogen-heated moisture balance (Antylia Scientific; Vernon Hills, IL, USA) tested the moisture content of the samples. The moisture contents were obtained before the start of each test and were averaged across the samples for a particular pallet pattern configuration. The moisture content for the 32 ECT boxes averaged 7.0% and the 44 ECT



3. Pallet patterns for the experiment.

		Measured (without salt weight)				Actual (with salt weight)			
		32 ECT (n=5)		44 ECT (n=5)		32 ECT (n=5)		44 ECT (n=5)	
		Force, lb	Deflection, in.	Force, lb	Deflection, in.	Force, lb	Deflection, in.	Force, lb	Deflection, in.
Columnar aligned	Mean	2972	0.76	3979	0.94	3909	0.76	4920	0.94
	CV, %	4	7	8	15	3	7	6	15
Interlocked	Mean	1330	0.79	1912	0.92	2266	0.79	2853	0.92
	CV, %	9	15	4	13	5	15	3	13
Hybrid	Mean	1518	0.75	2202	1.02	2454	0.75	3142	1.02
	CV, %	10	16	12	20	6	16	8	20

II. Pallet pattern testing results (ECT = edge crush test; CV = coefficient of variation)

Pallet Pattern	Force, lb		Percent Loss, %		Best Case	Worst Case
	32 ECT	44 ECT	32 ECT	44 ECT		
Single layer (7 boxes)	4462	6143	-	-	-	-
Columnar aligned	3909	4920	12	20	0.88	0.80
Hybrid	2454	3142	45	49	0.55	0.51
Interlocked	2266	2853	49	54	0.51	0.46

III. Pallet pattern loss as compared to single box compression (ECT = edge crush test).

boxes averaged 6.7%, independent of unit load configuration. Although the moisture contents were lower than expected at equilibrium, due to their consistency across all groups tested for this study, it is not likely to have affected the final comparisons.

RESULTS AND DISCUSSION

Single box compression test

The average compression strength of the 32 ECT single wall container was 637 lb (coefficient of variaton [CV] = 4%), with a corresponding peak deflection of 0.38 in. (CV = 7%). The average compression strength of the 44 ECT single wall container was 878 lb (CV = 4%), with a corresponding peak deflection of 0.50 in. (CV = 16%). All samples compressed had a convex failure mode.

Unit load compression test

Table II displays the individual and averaged results for the vertical top-to-bottom compression testing performed using the columnar aligned stacking pattern. The peak force data shown in Table II was adjusted to include the total weight of the containers loaded with salt above the bottom layer of the stack [10]. The initial failure location for all columnar aligned and interlocked patterns tested was the bottom layer. The initial failure location for all hybrid patterns tested was the second layer from the bottom. The visible failure mode of the boxes was convex, although it is likely a mixture of convex and concave failures could be observed inside the stacked configurations.

The results showed that the columnar aligned stacking pattern provided the greatest resistance in compression, followed by hybrid and then interlocked. These results are in agreement with previous studies noting that columnar aligned unit loads provide higher compressive resistance than other stacking configurations [4-7,10]. The interlocked pallet pattern provided the least compressive resistance for both the 32 and 44 ECT board grades.

Discussion of pallet pattern test results

Corrugated containers support most of the load at their corners, which act as a column, transferring the load from the top surface of the box to the surface below [11]. In a columnar alignment, the corners of the corrugated containers are aligned allowing for the greatest transfer of the load through the stack, which results in the greatest compressive resistance of all the stacking patterns [11]. Although offering the greatest resistance to compression, some amount of compressive loss is observed due to the stacked nature of the containers. Previous research has indicated a loss for columnar aligned containers can be between 10%–12% based on the compressive resistance of

Pallet Pattern	Compression Loss	Multiplier
Columnar aligned	12%–20%	0.84
Hybrid	45%–49%	0.53
Interlocked	49%–54%	0.49

IV. Single multiplier for designers by using the mean compression loss as reported from study data.

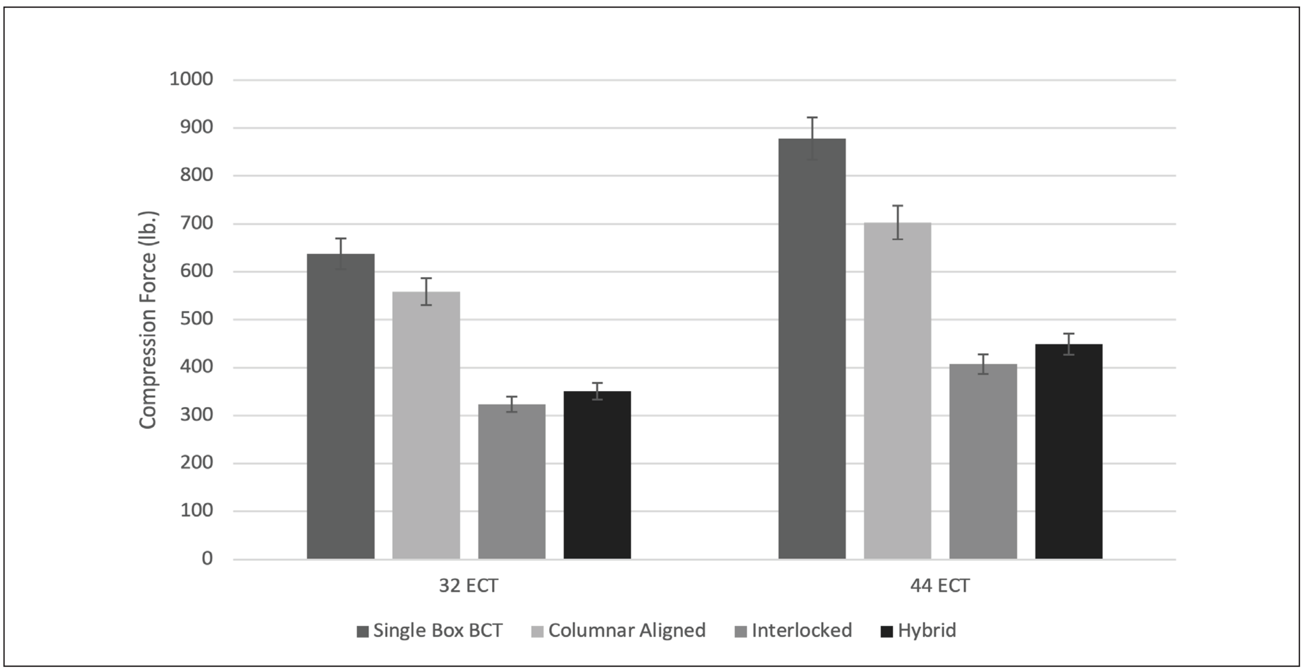
the individual container test [3,10]. Results from this project produced average individual BCT of 637.4 lb and 877.6 lb for the 32 and 44 ECT containers, respectively. Based on the individual BCT and the adjusted peak forces reported for columnar aligned containers, the BCT reduction of column stacking the containers for this study was between 12%–20%, extending beyond previously published research [5,6].

Interlocking the stacks of containers for shipping has been shown to increase the stability of the load [12]. However, the interlocked pattern misaligns corners, reducing the effective compression strength of the stacked containers, and this reduction will be dependent on the container geometry [13]. For this project, the interlocked pattern had the greatest percent loss, or reduction, of the three patterns evaluated. The *Fibre Box Handbook*, along with other research reports [3-5,7,8] showed a 35%–60% loss for corrugated containers stacked in an interlocked pallet pattern. The average percent loss from this study was 49%–54%, which is in alignment with the currently published range provided by the *Fibre Box Handbook* [3].

Hybrid patterns are designed to retain some of the compressive resistance of columnar stacking, while also being stable due to the interlocked nature of the top layers. Currently, no published research exists using a hybrid stacking pattern, so we are unable to determine a correlation with the project findings from this experiment and other research studies. The percent loss observed from this study was 45% and 49% for 32 and 44 ECT, respectively. However, only one hybrid pattern was evaluated, so further exploration and testing of the hybrid stacking pattern is recommended, using a varying number of pallet layers and well as different geometric size containers. The research results we produced do show the hybrid pattern is viable and does provide more compressive resistance as compared to the interlocked pattern, while also demonstrating increased stability of the stacked containers.

Environmental factors for pallet patterns

Table III displays the pallet pattern and the corresponding environmental factor loss as computed using the single BCT. Based on the results of this study, **Table IV** provides a single multiplier for each pattern using the mean compression loss data as reported in this study. **Figure 4** displays the overall mean adjusted compressive force for the pallet patterns compared to the single BCT results from the "Single box compression test" section of this technical brief.



4. Mean compressive force on individual boxes in a unit compared to single box compression (BCT = box compression test; ECT = edge crush test).

The columnar aligned unit load had the highest compressive strength of the four pallet patterns evaluated, reporting adjusted peak forces of 3909 lb and 4920 lb for the 32 and 44 ECT containers, respectively. The interlocked pattern had adjusted peak forces of 2266 lb for the 32 ECT and 2853 lb for the 44 ECT containers. Compared to the single BCT, a percent loss of 49% and 54% was observed for the 32 and 44 ECT containers, respectively. The hybrid stacking configuration reported adjusted peak forces of 2454 lb for the 32 ECT and 3142 lb for the 44 ECT containers. This resulted in a percent loss of 45% and 49% for the 32 and 44 ECT containers, respectively, compared to the single BCT.

The results created from this project may be used to update the environmental factors provided by the Fibre Box Handbook related to “Pallet Pattern”. The *Fibre Box Handbook* provides multipliers that can be used to estimate the impact of pallet pattern configuration using the compression strength of an empty box. For columnar aligned, a multiplier of 0.84 (0.88–0.80) was calculated based on the mean compression loss observed from this study. This value is outside the range currently provided by the *Fibre Box Handbook*. Results from this study are in line with the suggested interlocked pattern multipliers and provide a new option for hybrid stacking. For the interlocked pattern, this research reported a multiplier of 0.49 (0.51–0.46), which is in the range of 0.40–0.60 currently used by the *Fibre Box Handbook*. Currently, the *Fibre Box Handbook* does not include a multiplier specifically related to the

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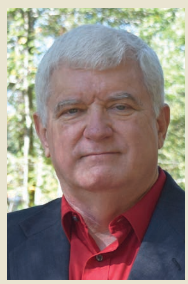

Rogers

Johnson

We worked on this project under the direction and support of the Fibre Box Association (FBA) and the FBA Technical Committee. This research project differs from previously reported findings, as our approach used loaded containers assembled into complete unit loads that were representative of those used for transport so that we could accurately simulate real-world situations during laboratory evaluations.

The most challenging part of this research was ensuring the pallet patterns were consistent throughout all testing. To overcome this, we devised and developed stacking fixtures to aid in the proper alignment for all tests.

By working on this research project, we discovered how the compressive resistance of unit loads can vary greatly by the pallet stacking pattern. The most interesting findings of the project were related to the hybrid stacking pattern. The hybrid pattern blends both the columnar and interlocked patterns, and as a result, we anticipated a greater compressive resistance than reported. Ultimately though, the compressive resistance was much closer to the interlocked pattern than the columnar aligned one.

For producers of corrugated packaging, the research here will allow them to accurately determine how the compression strength of stacked corrugated containers is affected by the pallet stacking pattern. As for next steps, we are continuing to evaluate unit load stacking factors such as overhang and misalignment and how those affect compression performance of unit loads.

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hybrid pallet pattern. Therefore, based on the results of this study, a multiplier of 0.53 (0.55–0.51) is proposed based on the mean compression loss. However, further exploration of the hybrid pattern is recommended.

CONCLUSIONS

Understanding the influence of pallet patterns is critical to designing a unit load that will successfully travel throughout the supply chain to the end-user. Pallet patterns are often selected based on the geometric limitations of the pallet (cube efficiency) or to increase the inherent stability of the load. Our research reveals that the stacking configuration has a tremendous effect on the overall compression strength of the load. The pallet pattern, therefore, should also be a significant consideration when designing unit load systems. Being able to predict the compressive strength of the load accurately will allow designers to determine which pallet stacking pattern is best suitable for their particular application. **TJ**

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