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LOSS OF COMPRESSION STRENGTH IN CORRUGATED BOXES
DURING OVERNIGHT SHIPMENT IN UPS

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LOSS OF COMPRESSION STRENGTH IN CORRUGATED BOXES DURING OVERNIGHT SHIPMENTS IN UPS

By

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ABSTRACT

LOSS OF COMPRESSION STRENGTH IN CORRUGATED BOXES DURING OVERNIGHT SHIPMENT IN UPS

By

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The purpose of this study was to determine the loss of compression strength in corrugated shipping containers after being shipped through the UPS Next Day Air delivery service (Overnight shipment). Three different sizes of boxes were tested. The weights of the filled boxes were 13, 30, and 38 lb. The boxes contained apparel products (clothes, shoes, and cosmetics) that were provided by QVC. These products were not load supporting. The packages were shipped between East Lansing, MI, Sunnyvale, CA, and Duluth, GA. In addition, the packages were tested using the ISTA test protocol (Procedure 1A) and the loss of compression strength was determined.

The data for the packages shipped through the UPS overnight delivery system showed an average reduction in compression strength of 27.3%. The packages that were tested in accordance with the ISTA Procedure 1A showed an average reduction in compression strength of 32.4%. Results obtained from field-shipped boxes, however, were highly variable due to the unique shipping environment that individual packages were exposed to.

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1. INTRODUCTION

The purpose of good packaging is to contain, convey, and protect a product so that it reaches the customer in good condition. During distribution, packages undergo a series of loading conditions. The lack of sufficient protection often results in damage to the package, the product, or both. Many studies have shown that damage levels are reduced when packages are shipped in a unitized configuration as opposed to individual parcels. However, this distribution system may not be practical for every product.

Over the past decade, there has been a great increase in the number of individual packages shipped. In the past, most companies shipped palletized loads of packages from manufacturing plants to distribution centers. These distribution centers were strategically located in various regions of the country. Packages were then shipped to retail stores in mixed quantities based on customer demand.

Consumers traditionally bought most of their products by going to a retail store and selecting items. Today, however, many products, including clothing, food, jewelry, cosmetics, electronic items, and computers, are ordered directly from catalogs, TV, or the web, and are shipped from the manufacturing plant directly to the customer's residential or business address. In most of these types of shipments, time is critical either for customer satisfaction for special, rare, and replacement items or for the short shelf life of products like flowers, exotic fruits, and medications.

As the demand for individual package delivery increases, it is important to understand the shipping and handling environment that these packages are exposed to. Since corrugated fiberboard boxes are widely used as shipping containers for many kinds of products, knowledge of box compression strength is important for estimating the degree of protection boxes can provide to the product. Currently, there are many carriers in the United States that deliver individual packages. Each carrier requires packages to meet some minimum level of performance, using either the American Society for Testing and Materials (ASTM) or the International Safe Transit Association (ISTA) laboratory tests. These tests are performed on both the packaging materials and the final packaged product. A manufacturer may test the burst strength or edgewise compression strength of the corrugated board alone and may also perform compression, vibration, and drop tests on the packaged product.

1.1. The United Parcel Service Company

One of the largest packages carriers today is the United Parcel Service (UPS). It is a private company that ships and delivers approximately 11.7 million packages and documents every day. It uses both a ground delivery and an express air delivery distribution network for its customers. The company was established in 1907 as the American Messenger Company in Seattle, Washington. It then merged with other competitors, and expanded its services to other cities in the country during the 1920s and 1930s. The company then expanded to deliver packages by air, continued to extend its distribution network, and finally became known as the United Parcel Service (UPS).

The economic crisis in 1929 and World War II caused a shortage of many resources and many retail stores encouraged their customers to carry packages home instead of having them delivered. In the early 1950's, UPS decided to expand its delivery services from major retail stores to all addresses (private and commercial), which made it a direct competitor to the US Postal Service. As the demand for faster service increased, a two-day delivery service, UPS Blue Label Air, was available for delivery in every state by 1953. An overnight delivery service, UPS Next Day Air, was available in all 48 states and Puerto Rico by 1985. The company continuously expands its services. Most recently, it has been expanding its international air package and document delivery services to Europe, Asia, and South America [1].

1.2. UPS Next Day Air

Every UPS delivery system consists of transferring packages between two facilities: the operating center and the hub. Currently the company has over 1,500 facilities strategically located across the country to keep the packages moving smoothly from point to point. This shipping operation model is known as the "Hub and Spoke" system, which is illustrated in Figure 1.1.

The UPS Next Day Air or overnight delivery service is the fastest service offered by the UPS. This service starts with a package pickup, then moves packages to the Hub, provides shipping to destination using the Feeder Network, and ultimate delivery to the customer. The difference between air delivery service and conventional ground service is that after a package is picked up by a UPS driver in the afternoon, it is sorted separately from ground service packages at a local facility. Then it is sent to the nearest air hub and transferred to the destination air hub during that same night. When a package reaches its delivering terminal (hub or operating center), it is sorted and loaded on the package car for delivery to the final destination the next morning (Figure 1.2.). The delivery time depends on the flight schedule between the local (original) air hub and the destination air hub [2].

In the UPS delivery service, each package is considered to be a single shipment. The maximum acceptable weight is 150 pounds, and packages cannot exceed 108 inches in length, or 130 inches in combined length and girth [3]. Individual packages that are to be delivered by UPS are recommended to pass ISTA pre-shipment performance tests [4].

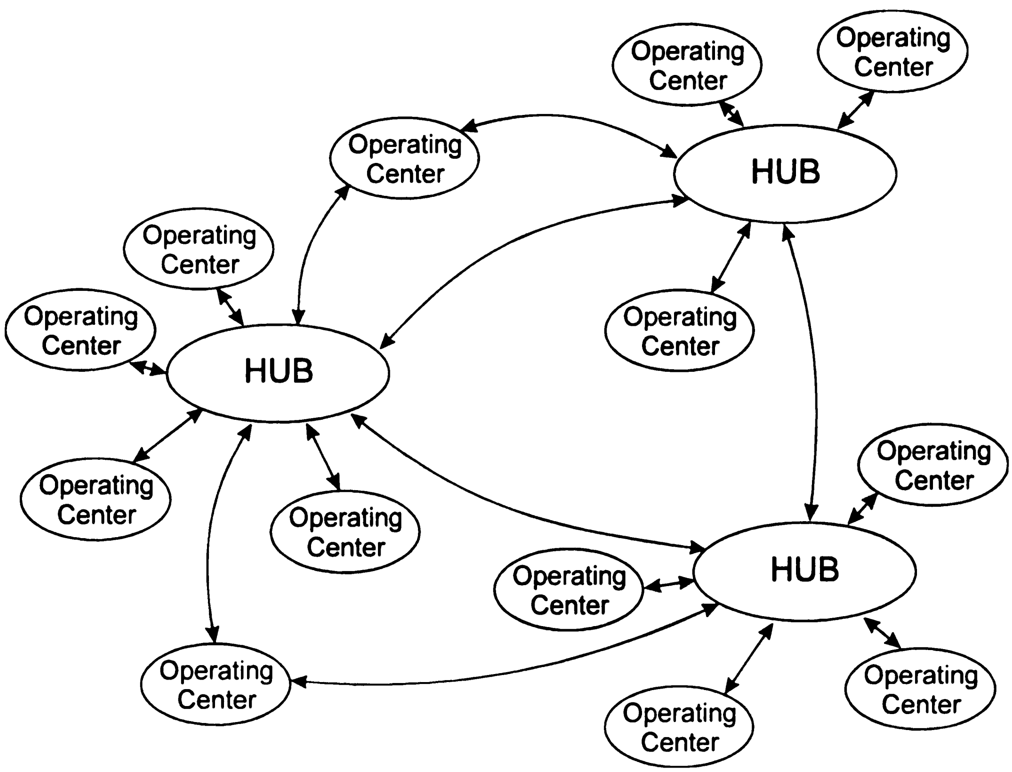

Figure 1.1. Basic operation of the UPS "Hub and Spoke" system

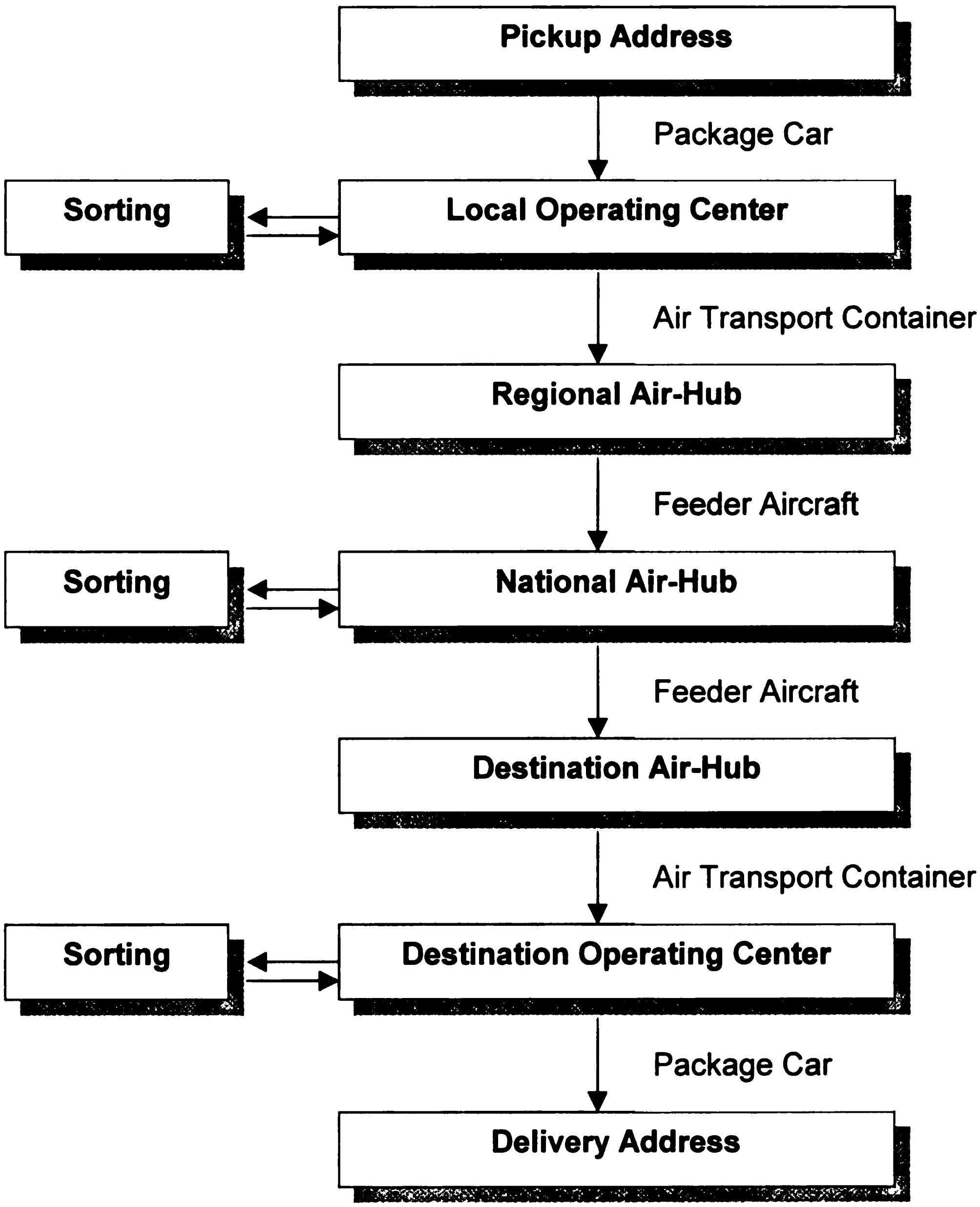

Figure 1.2. UPS Next Day Air service model

1.3. Small Parcel Delivery Environment

In the UPS small parcel delivery system, most packages are unique in their size, shape, and weight. Usually they are all critical shipments. Each package has a chance to experience the most severe conditions due to mixed load distribution and less than truck-load environment (LTL). The current automated and high-speed delivery system makes it possible for a package to travel in a random orientation and encounter dynamic loads on any surface [5].

It is estimated that when a package is delivered by the UPS air service, it will have experienced at least six handlings at pickup point, local terminal, local operating center/hub, destination operating center/hub, delivering terminal, and delivery point [2]. These activities produce a series of dynamic loads on the packaged product, lead to a loss in performance of the shipping container, and may cause damage to the packaged product.

Unlike other common distribution environments, the small parcel delivery environment rarely exposed packages to a long-term warehouse stacking load. Packages are likely to be moved from place to place in very short time periods.

1.4. Corrugated Fiberboard Shipping Container

In the United States, the materials used for the package shipping industry (by sales) are based on paperboard (39%), metal (24%), plastic (19%), paper (7%), glass (7%), and others (4%). Almost 75% (by weight) of the paperboard-based packaging consists of corrugated shipping containers [6].

Generally, freight cost is directly related to the packaging cube (volume) and weight utilization in a trailer. Corrugated fiberboard often provides a lighter weight and larger volume container with reasonable strength, resulting in lower overall shipping costs. Hence, corrugated fiberboard boxes are often preferred shipping containers. Most corrugated fiberboard boxes are shipped in knocked-down or flat condition before they are erected and packed. They provide good space utilization, stacking ability, and flexibility in design. The only drawback of corrugated materials is that paper is hygroscopic, which makes it sensitive to humidity present in the shipping and storage environment. An increase or decrease in humidity of the environment changes the moisture content of paper and thus affects the mechanical properties of paperboard based containers, such as compression strength, burst resistance, and puncture resistance.

Corrugated shipping containers used for most packages in the US must be produced from materials that meet certain performance classifications. Currently there are two classifications, the Uniform Freight Classification, Rule 41, issued by the National Railroad Freight Committee of the Western Railroad Association; and the National Motor Freight Classification, Item 222, issued by the National Classification Committee of the National Motor Freight Traffic Association [7].

Rule 41 and Item 222 both specify the minimum requirements for a shipping container. A carrier can refuse to carry the freight, increase the freight cost, and/or deny a claim for damage, if a container does not comply with these specification. A manufacturer of corrugated boxes that meet the specification can print a legible box certificate on the outside surface of the box to notify its specification (Section 10 in Rule 41 and Item 222-1).

1.5. Compression Strength and Compression Testing

Compression strength (stacking strength) is the ability of a container to resist compressive load. A compression test is usually done by placing a sample container between a pair of platens (one fixed - one moving). The compression strength of the test container is read on a load cell attached to one of the platens. Together with the load, the deflection of the box is also measured. This deflection, however, is not a true box panel deflection. It is a measure of the distance that a platen will travel until it reaches the maximum load in the test. Figure 1.3. shows the relationship between theoretical and observed load and deflection in a compression test for corrugated containers. The observed load-deflection curve of a corrugated container shows a buckling phenomenon. During a compression test of a corrugated box, buckling, or the deformation of the side panels, allows the box to relieve the compressive load and reduces the load reading value below the theoretical value until it reaches the maximum load.

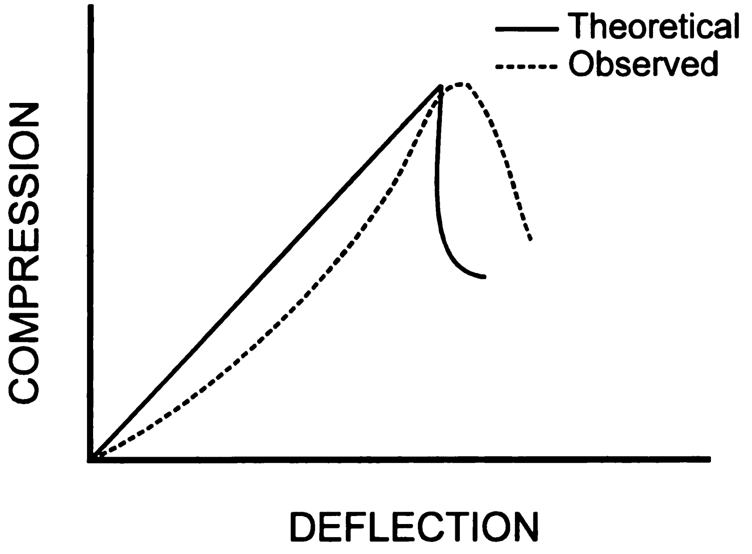

Figure 1.3. Relationship between compression load and deflection during compression testing

Packaging professionals agree that stacking or compression strength is a better predictor of a box performance in distribution environment because most products do not bear any load. The container then has to support the majority of loads. Therefore, it is important to know the compression strength of a container to predict package performance.

The current Rule 41 and Item 222 do not take compression strength into account. However, the alternative rules revised in 1991 allow manufacturers to use either edgewise compression test (ECT) or burst strength test. In part, this revision was based on the relationship between the ECT value and compression strength as presented in McKee's formula [8], which allows indirect estimation of compression strength.

Many studies indicate that the compression strength of a box does not depend solely on the material properties. It also depends on the geometry of the box (length, width, height, and their ratios), dynamic loading conditions during handling and transportation (vibration, impact, and compression), and environmental conditions (humidity and temperature).

With respect to the geometry of boxes, Mirasol [9] reported that compression strength of a box was affected by different length to width ratio (L:W). A square box (L:W = 1.0) provides lower box compression strength than a rectangular box (L:W = 1.25 and 1.5). However, an adverse effect occurs if the ratio exceeds 1.75. The load that a box supports on the perimeter is not uniform. Most of the load actually transfers through the corners or in the area immediately adjacent to the corners. Generally, an increase in perimeter will increase compression strength. Carlson [10] reported that given the same perimeter, compression strength decreases as the height of the box increases.

The inside flaps of a regular slotted container (RSC) box contribute to the end-to-end and side-to-side compression strength. The compression strengths in these directions are important in certain cases, such as when the vehicle carrying the packages comes to an abrupt stop, the package is moved by a clamp truck, or the package is stacked on its side or end. A square shape (length = width) box has inner flaps that meet at the center (no flap gap and thus full support). A rectangular shape (length > width) box has a flap gap (partial support) which will affect the end-to-end compression strength.

The dynamic loading conditions that occur during handling and transportation can affect the compression strength in many respects. Nada [11] and Godshall [12] showed that vibration adversely affected the compressive strength of a stack of corrugated boxes, especially for the lower containers in the stack. However, Adams [13] found an increase in compression strength of corrugated boxes after exposure to vibration in a stack. Singh [14] showed that the compression strength of corrugated boxes could decrease by up to 75% after experiencing mechanical shocks. Singh [15] also investigated the effect of package gross weight and drop height on corrugated container strength, and showed that compression strength decreased sharply as gross weight and drop height increased.

Voss [16] studied the relationship between the size and weight of a package and the expected drop heights that occurred in UPS ground shipments. The study showed that smaller and lighter containers had higher probabilities of being exposed to higher drop heights. The package weight did not have a significant effect on the drop heights for medium and large size packages weigh over 40 lbs. Braun [17] showed a higher percent reduction in box compression strength of large size corrugated containers after FedEx overnight shipment as compared to lab simulated test packages.

As the demand for single package delivery increases, a container must have sufficient compression strength to protect the product from compressive forces that occur during handling, storage, and shipping. Therefore, the measurement of compression strength in static tests (ASTM D-642) alone is not enough to predict the ability of a package to withstand actual small parcel shipping requirements.

Table 1.1. shows the factors [18] that are currently used to estimate the box compression performance based on lab test. The estimated actual compression strength (Actual CS) is calculated by multiplying the laboratory test compression strength (Lab Test CS) with related factors as shown in the following equation:

$$\text{Actual CS} = (\text{Lab Test CS}) \times F \times H \times SP$$

Where F, H, and SP are the fatigue, humidity and stacking pattern factor respectively. To obtain a better evaluation of a corrugated shipping container, a test plan recommended in ASTM D-4169 or ISTA Procedure takes various environmental factors into account to evaluate the actual packaged product performance. The test procedures are intended to simulate shipping environments that packages will be exposed to during distribution. These methods allow packaging engineers to evaluate what will happen to a package and product after being exposed to climatic, drop, vibration, and compression conditions.

Table 1.1. Fatigue, relative humidity, and stacking pattern factor used to estimate the actual compression strength of corrugated containers.

Fatigue factor		Humidity factor		Stacking pattern factor	
Duration of Load	F	Relative Humidity	H	Alignment	SP
Short Term	100%	Dry	125%	Perfect	100%
10 days	65%	25%	110%	Offset	50%
30 days	60%	50%	100%		
100 days	55%	75%	80%		
1 year	50%	85%	60%		
		90%	50%		

1.6. Objectives of This Study

1. To determine the loss of compression strength of corrugated containers after being shipped by the UPS Next Day Air service.
2. To compare the percent reduction in compression strength of actually shipped boxes to those tested in the lab as recommended by the International Safe Transit Association.

2. EXPERIMENTAL DESIGN

Three different package sizes were used in this study (A, B, and C, Figure 2.1.). All corrugated containers (boxes) used in this study were regular slotted containers (RSC) and were made from single-wall, 200 psi, C-flute corrugated board. The size and material specifications of these boxes are shown in Table 2.1. All boxes were obtained in knocked-down flat condition from QVC Inc. These boxes were tested for their original compression strength and used as controls in three labs (Michigan, California, and Georgia). Boxes were tested for their residual compression strength after being shipped through the UPS overnight service (field data) and after testing by ISTA Procedure 1A (laboratory data). The reduction in compression strength were determined.

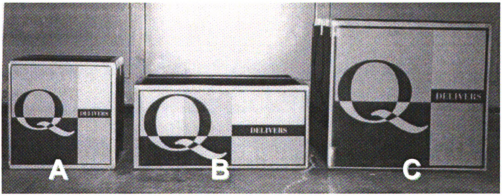

Figure 2.1. Packages used in this study

Table 2.1. Box specifications

Box Identification	Box A	Box B	Box C
Identification Code (QVC code)	Q6 Auto	Q11/275	Q34
Dimension (inch)	14 × 14 × 14	$23^7/_8 \times 17^7/_8 \times 11$	22 × 20 × 20
Bursting Strength Test (psi)	200	N/A	200
Edge Crush Test (lb/inch)	N/A	44	N/A
Minimum Combined Weight of Facings (lb)	84	N/A	84
Size Limit (inch)	75	95	75
Gross Weight Limit (lb)	65	95	65

2.1. Test Conditions

All boxes were conditioned at 73°F and 50 % relative humidity for at least 24 hours in accordance with ASTM D-4332. After conditioning, the top and bottom flaps were closed and sealed using a two-inch wide plastic tape as required in ASTM D-642.

2.2. Test Procedure

Twenty boxes of each size were tested for compression strength and deflection using ASTM D-642 at the School of Packaging, East Lansing, MI. The average compression strength of these boxes was used as the control compression strength of boxes shipped from Michigan.

Ten boxes of each size were also tested for the same purpose at the two Lansmont Corporation test labs in Sunnyvale, CA and Duluth, GA (control compression strength of boxes shipped from California and Georgia).

Ten boxes of each size were filled with products for shipping to the assigned destinations and for performing the ISTA tests. The average package gross weight was 13, 30, and 38 lbs for boxes A, B, and C respectively. The boxes were filled with apparel products, consisting of a mixture of clothes, shoes, and cosmetic products that are generally marketed by QVC through their television merchandising.

The first set of ten boxes of each size was shipped by UPS Next Day Air delivery service from Michigan to California. The boxes were emptied, resealed, and tested for residual compression strength at their destination. The second set of ten boxes of each size was filled with the same products, sealed, and shipped by the same carrier from California back to Michigan, where they were emptied, resealed, and tested for residual compression strength. The same procedure was repeated on the third and fourth set of boxes that were shipped between Michigan and Georgia.

The fifth set was filled and sealed in the same manner as the previous packages. This set, however, was tested with the procedure recommended in ISTA Procedure 1A. After the test, the boxes were emptied, resealed, and compression tested for their residual compression strength.

2.3. Compression Strength Test

Boxes were tested using the fixed platen test method in accordance with ASTM D-642 and the Technical Association of Pulp and Paper Industry (TAPPI) T-804. The test was performed at a platen speed of 0.5 in per minute. A 50 lb pre-load for zero deflection setting was used in all tests.

Three Lansmont Corporation Compression Testers were used to perform the test at each of the three laboratories. The Compression Tester Model No. 76-5K was used at the School of Packaging, East Lansing, MI (Figure 2.2.). The Touch-Test Compression Test Data Acquisition System 152-30TTC was used at Sunnyvale, CA and Duluth, GA (Figure 2.3.). All three machines had a digital readout of force with a +/- 1% linearity.

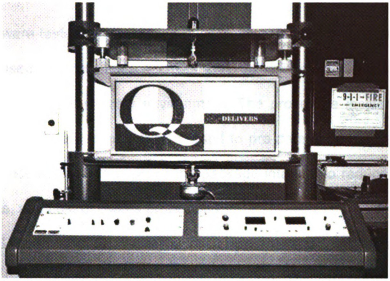

Figure 2.2. Compression tester model no. 76-5K

Figure 2.3. TouchTest Compression Test Data Acquisition System 152-30TTC

2.4. The ISTA Procedure 1A

Boxes were tested according to the ISTA preshipment test procedures, which are currently used by companies such as QVC to validate packages for shipment through the small parcel delivery environment. The procedure includes a vibration and a drop test. The test results can be used to pre-determine safe shipment of a packaged product and also to improve the package integrity to reduce product loss, damage claims, and cost of claims processing.

The ISTA Procedure 1A is a pre-shipment test procedure for testing packaged products weighing under 100 lbs (45.4 kg). The procedure starts with a vibration test using either a mechanical vibrator (Method A) or a hydraulic vibrator (Method B), followed by a drop test.

In the vibration test sequence, the vibration system (Figure 2.5.) complied with ASTM D-4728 requirements to control frequency and acceleration or displacement amplitude independently. The vibration spectrum used in the test is presented in Table 2.2. The boxes were subjected to the following vibration program:

- bottom down orientation for 30 minutes
- top down orientation for 10 minutes
- each two remaining orientations for 10 minutes.

The total duration of the vibration test was 60 minutes and the overall G rms. was 1.15 G. Figure 2.4. shows the orientations of a sample box and test duration used in the vibration sequence.

Table 2.2. Truck/air breakpoints for the vibration spectrum

Frequency (Hz)	PSD Level (G^2/Hz)
1.0	0.0001
4.0	0.01
100.0	0.01
200.0	0.001

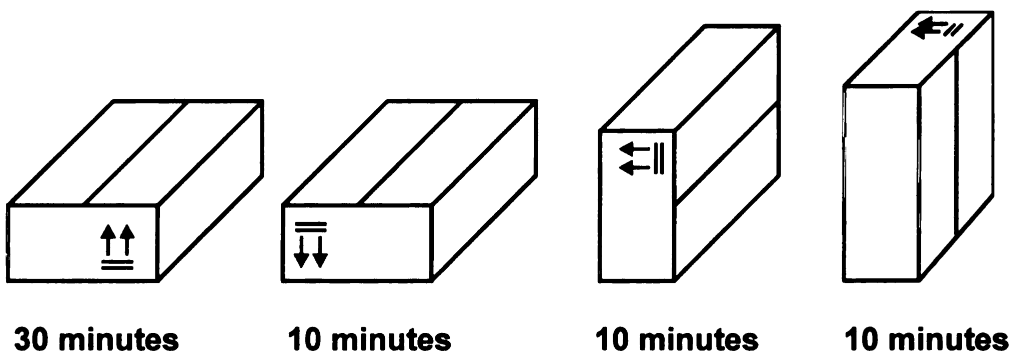

Figure 2.4. Box orientation and test duration used in vibration sequence

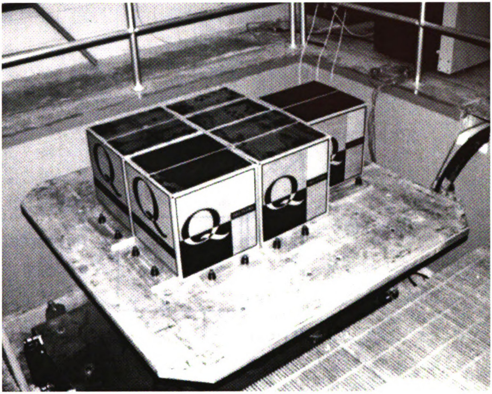

Figure 2.5. Vibration tester

In the drop test sequence, box surfaces were identified as illustrated in Figure 2.6. and then were subjected to the Precision Drop Tester system (Figure 2.7.), which complied with ASTM D-5276.

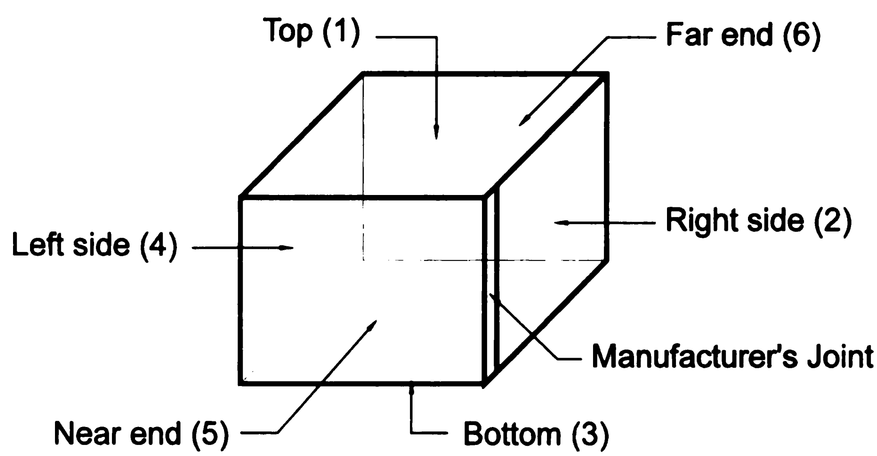

Figure 2.6. Box surface identification

The boxes were subjected to ten drops using the following sequence:

1. the 2-3-5 corner
2. the shortest edge radiating from the corner tested
3. the next longest edge from the corner tested
4. the longest edge radiating from the corner tested
5. flat on one of the smallest faces
6. flat on the opposite small face
7. flat on one of the medium faces
8. flat on the opposite medium face
9. flat on one of the largest faces
10. flat on the opposite large face.

The drop heights used in this study were based on data recommended in the ISTA Procedure 1A (Table 2.3.).

Table 2.3. Drop heights suggested by ISTA Procedure 1A.

Packaged-product weight (lb)	Free fall drop height (inch)
1 thru 20.99	30
21 thru 40.99	24
41 thru 60.99	18
61 thru 100.00	12

After the drop test, the boxes were emptied, resealed, and the residual compression strength was measured.

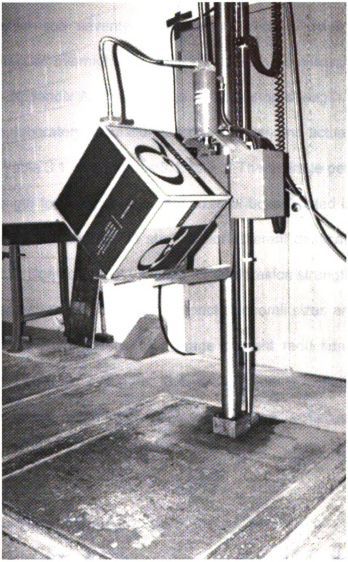

Figure 2.7. The Precision Drop Tester

3. RESULTS

Two hundred and seventy corrugated fiberboard boxes were tested to determine the effect of overnight shipment by UPS on compression strength. The data are listed in Appendix A. The average compression strength and deflection of the control boxes, laboratory simulation shipment boxes, and actual shipment boxes are presented in Table 3.1. and Figures 3.1. to 3.3. The average percent reduction in compression strength for the three different sizes of boxes tested is shown in Table 3.2. Percent change in compression strength for different destinations is shown in Tables 3.3. and 3.4. Coefficients of variation for compresion strength data are shown in Table 3.5. The percent reduction with respect to overall sizes and shipments are shown in Table 3.6. Comparisons of average percent reduction in compression strength are also illustrated in Figures 3.4. to 3.7. The reduction in compression strength with respect to each type of package tested is discussed in the next sections.

3.1. Box A (Gross Weight 13 lb)

Table 3.1. shows the average compression strength for Box A in the various shipment and lab tests performed. Individual compression strength and deflection values for each package tested are listed in Appendix A. Twenty box samples tested in Michigan as a control showed an average compression strength of 705.4 lb. The average compression strength of boxes subjected to the ISTA Procedure 1A was 467.0 lb. The percent reduction in compression strength compared to the control was 33.8%.

Control boxes tested in California and Georgia showed average compression strengths of 720.8 and 727.3 lb respectively. The average residual compression strength after shipment from Michigan to California was 654.5 lb and from Michigan to Georgia was 402.4 lb. The average residual compression strength after shipment from California to Michigan was 483.0 lb and from Georgia to Michigan was 585.0 lb. The reduction in compression strength for the shipments to California was 7.2% and on return was 33.0% (Table 3.2.). The reduction in compression strength for the shipments to Georgia was 42.9% and on return was 19.6%. Overall, the average reduction for packages shipped between Michigan and California was 20.1% and for those shipped between Michigan and Georgia was 31.2%.

3.2. Box B (Gross Weight 30 lb)

The average compression strength values for Box B are presented in Table 3.1. Box compression strength and deflection values for individual packages are listed in Appendix A. The average compression strength of control boxes tested in Michigan was 1175.8 lb. The average compression strength for boxes subjected to the ISTA Procedure 1A was 927.0 lb. The percent reduction in compression strength of lab tested boxes compared to the control was 21.2%.

Control boxes tested in California and Georgia showed average compression strengths of 1180.0 and 1155.5 lb respectively. The average residual compression strength tested after shipment from Michigan to California was 1130.4 lb and from Michigan to Georgia was 1168.3 lb. The average residual compression strength tested after shipment from California to Michigan was 1243.0 lb and from Georgia to Michigan was 963.0 lb. The reduction in compression strength for the shipments to

California was 3.9%. However, the return shipments from California showed an increase in compression strength by 5.3%. The reduction in compression strength for shipments to Georgia was 0.7% and for return shipments was 16.7% (Table 3.2.). Overall, the packages shipped between Michigan and California showed an average gain in compression strength of 0.7% and those shipped between Michigan and Georgia showed a reduction of 8.7%.

3.3. Box C (Gross Weight 38 lb)

The average compression strength values for Box C are presented in Table 3.1. The individual compression strength and deflection values are given in Appendix A. The average compression strength for boxes tested by the ISTA Procedure 1A was 428.0 lb. The percent reduction in compression strength of lab tested boxes compared to the control was 42.3%.

Control boxes tested in California and Georgia showed average compression strengths of 750.7 lb and 742.0 lb respectively. The average residual compression strength after shipment from Michigan to California was 380.9 lb and from Michigan to Georgia was 378.3 lb. The average residual compression strength after shipment from California to Michigan was 333.0 lb and from Georgia to Michigan was 334.0 lb. The reduction in compression strength for the shipments to California was 48.7% and on return was 55.6% (Table 3.2.). Similarly the reduction in compression strength for the shipments to Georgia was 49.0% and on return was 56.0%. Overall, the average reduction in compression strength was 52.2% for the California shipments and was 52.5% for the Georgia shipments (Table 3.3.).

Table 3.1. Average (± 95 % CL) compression strength and deflection

Shipment	Average Compression Strength, lb (Deflection, inch)		
	Box A	Box B	Box C
Control in Michigan	705.4 ± 21.6 (0.32 ± 0.01)	1175.8 ± 30.0 (0.40 ± 0.02)	742.0 ± 21.4 (0.34 ± 0.02)
Control in California	720.8 ± 58.3 (0.34 ± 0.01)	1180.0 ± 37.5 (0.47 ± 0.04)	750.7± 28.7 (0.38 ± 0.01)
Control in Georgia	727.3 ± 22.7 (0.37 ± 0.02)	1155.5 ± 39.4 (0.45 ± 0.02)	758.6 ± 40.8 (0.40 ± 0.03)
Michigan to California	654.5 ± 53.7 (0.29 ± 0.02)	1130.4 ± 57.1 (0.35 ± 0.02)	380.9 ± 59.7 (0.32 ± 0.05)
California to Michigan	483.0 ± 80.5 (0.32 ± 0.04)	1243.0 ± 107.7 (0.39 ± 0.05)	333.0 ± 108.6 (0.46 ± 0.14)
Michigan to Georgia	402.4 ± 76.9 (0.27 ± 0.04)	1168.3 ± 84.3 (0.38 ± 0.04)	378.3 ± 57.1 (0.48 ± 0.20)
Georgia to Michigan	585.0 ± 76.5 (0.32 ± 0.05)	963.0 ± 96.0 (0.44 ± 0.04)	334.0 ± 84.5 (0.40 ± 0.14)
ISTA	467.0 ± 71.4 (0.26 ± 0.03)	927.0 ± 79.2 (0.41 ± 0.05)	428.0 ± 29.7 (0.45 ± 0.06)

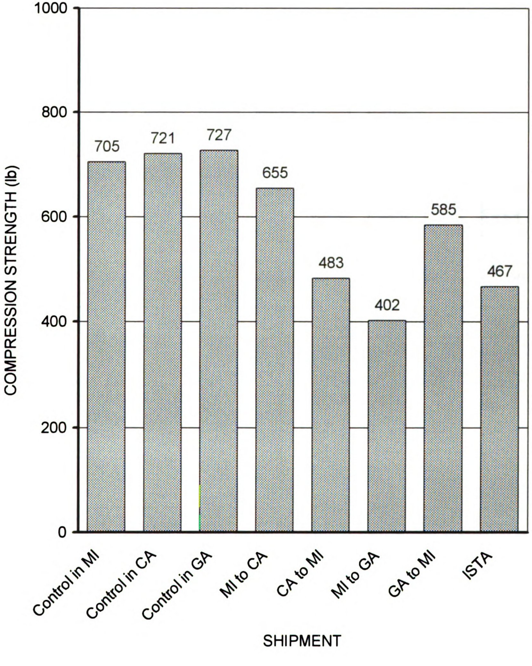

Figure 3.1. Average compression strength of Box A

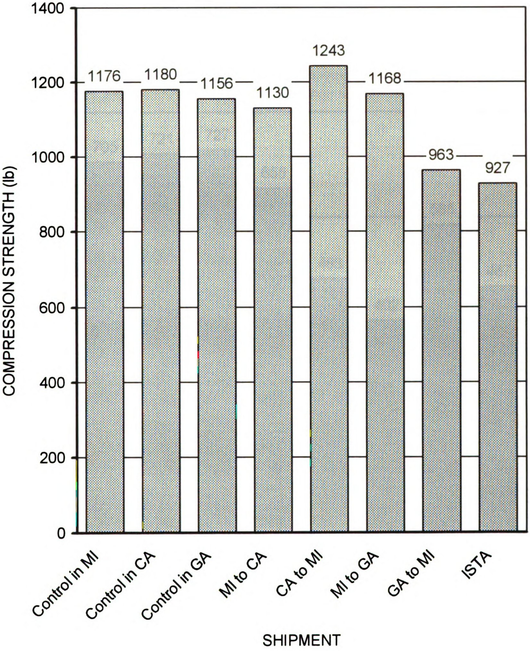

Figure 3.2. Average compression strength of Box B

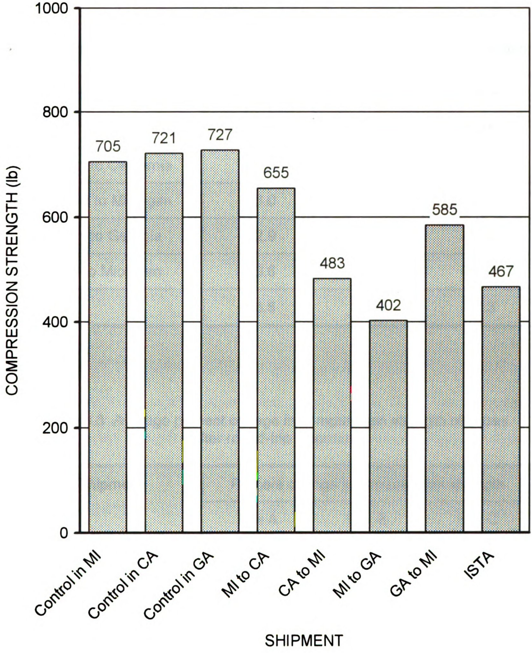

Figure 3.3. Average compression strength of Box C

Table 3.2. Percent change in compression strength of boxes after one-way shipment

Shipment	Percent change in compression strength		
	Box A	Box B	Box C
Michigan to California	-7.2	-3.9	-48.7
California to Michigan	-33.0	+5.3	-55.6
Michigan to Georgia	-42.9	-0.7	-49.0
Georgia to Michigan	-19.6	-16.7	-56.0
ISTA	-33.8	-21.2	-42.3

Table 3.3. Average percent change in compression strength of boxes after round-trip shipment

Shipment	Percent change in compression strength		
	Box A	Box B	Box C
Michigan and California	-20.1	+0.7	-52.2
Michigan and Georgia	-31.2	-8.7	-52.5
ISTA	-33.8	-21.2	-42.3

3.4. Overall Observations

The average reduction in compression strength of Box A was 25.7% for field shipments and 33.8% for ISTA tested samples (Table 3.4.). The reduction in compression strengths of field shipments varied between 7.2 and 42.9% (Table 3.2.). Although the average percent reduction of boxes from field shipments was lower than that of lab-tested boxes, some samples in field shipments showed a significantly higher percent reduction in compression strength (Table 3.5.). This reflects the large variability that exists when packages are shipped and handled by UPS. If a small package was placed under a large heavy package, it would undergo substantially higher dynamic loads during shipment and therefore show higher reductions in compression strength.

For Box B, the average reduction in compression strength was 4.0% for field shipments and 21.2% for lab-tested packages (Table 3.4.). The compression strengths in actual shipments varied from an increase in compression strength of 5.3% to a reduction of 16.7% (Table 3.2.). Several explanations for the observed increase are possible. First, boxes that were shipped from California may have been exposed to a dry environment. Second, control boxes that were tested in Georgia may have had the flutes partially crushed when they were shipped to Georgia in the knocked-down mode. A third possibility is that the shape of this particular style of package is more flat (larger top area, low height) compared to Boxes A and C; thus this type of box is more likely to be placed on its side to give better cube utilization in a trailer. This orientation would greatly reduce the top-to-bottom dynamic load and amount of damage caused to these boxes during shipment as compared to Boxes A and C. Therefore Box B is more likely to maintain its original strength.

For Box C, the average reduction in compression strength was 52.3% for field shipments and 42.3% for ISTA lab tested samples (Table 3.4.). The reduction in compression strength in actual shipments varied between 48.7% and 56.0% (Table 3.2.). All boxes tested after field shipment had a higher percent reduction in compression strength compared to the lab-tested samples. This is probably attributable to the fact that this package had the largest footprint as compared to Boxes A or B. These packages would most likely be placed on the bottom of the trailer bed, supporting other packages above it. They would be exposed to higher dynamic loads, resulting in greater reduction of vertical compression strength.

In conclusion, most of the Box A samples (relatively small boxes) are likely to be positioned in the middle or top layers in a trailer and therefore would be exposed to a lesser degree of damage. Box B, due to its flat configuration, is likely to be shipped on its side and therefore would be exposed to lesser damage in the vertical direction. Box C is likely to be placed at the bottom, below other packages, which causes greater damage. Almost all packages showed good seal integrity, with tape closures staying intact. Only one box was actually torn during field shipment. The overall reduction in compression strength of all boxes in field shipments was 27.2 % and of those in laboratory simulations was 32.4% (Table 3.6.). The safety factors calculated from the overall reduction in field shipment and laboratory simulation were 3.7 and 3.1 respectively.

The variation in this study was analyzed using the coefficients of variation and analysis of variance (ANOVA). Table 3.5. shows the coefficients of variation for compression strength observed in each set of shipments. Results from control samples, (except Box A tested in California), showed a coefficient of variation of 4.4

to 7.5%. These results indicate either consistency of samples, good precision of the test instruments, or both. Results from shipped boxes (except Box B shipped from Michigan to California) and boxes after testing with ISTA, showed a coefficient of variation close to 10.0% and up to 45.6%. The high variation in this group indicated that individual packages may have been exposed to different dynamic loading during distribution, resulting in different residual compression strength. Other sources of variation may be due to the following processes: opening the box, removing the product, and resealing the box. The compression strengths of the control boxes of identical size measured at the three labs (Michigan, California, and Georgia) did not show significant differences at the 95% confidence level.

Table 3.7. shows the worst cases (the highest percent reduction in compression strength) that occurred in each set of shipments. If packages are designed to meet only the minimum recommended protection level, some packages and/or products may not survive the worst shipping enviroments. Therefore, knowing only the average percent reduction in compression strength may not be enough to guarantee protection for all packaged products; indeed, in practice, higher safety factors are usually applied to packages containing valuable products.

Table 3.4. Average percent reduction in compression strength of field-tested and laboratory-tested boxes

Shipment	Percent reduction in compression strength		
	Box A	Box B	Box C
Field Data	25.7	4.0	52.3
Laboratory Data (ISTA)	33.8	21.2	42.3

Table 3.5. Coefficients of variation of compression strength

Shipment	Coefficients of variation, %		
	Box A	Box B	Box C
Control in Michigan	6.5	5.5	6.2
Control in California	11.3	4.4	5.4
Control in Georgia	4.4	4.8	7.5
Michigan to California	11.5	7.1	21.9
California to Michigan	23.3	12.1	45.6
Michigan to Georgia	26.7	10.1	21.1
Georgia to Michigan	18.3	13.9	35.4
ISTA	21.4	12.0	9.7

Table 3.6. Overall percent reduction in compression strength of field-tested and laboratory-tested boxes

Shipment	Percent reduction in compression strength
Field Data	27.3
Laboratory Data (ISTA)	32.4

Table 3.7. Observed worst case of percent reduction in compression strength

Shipment	Percent reduction in compression strength		
	Box A	Box B	Box C
Michigan to California	22.3	15.3	62.3
California to Michigan	56.6	17.5	100.0
Michigan to Georgia	63.0	21.4	69.6
Georgia to Michigan	48.4	41.6	85.5
ISTA	51.6	31.7	53.6

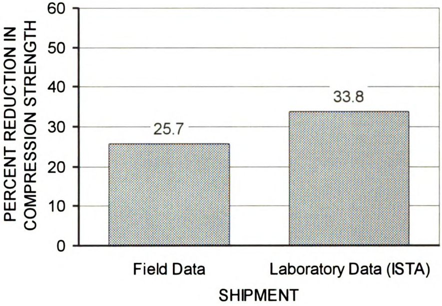

Figure 3.4. Percent reduction in compression strength of Box A

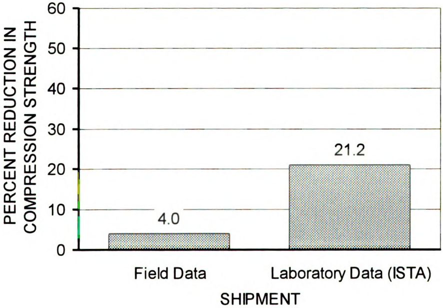

Figure 3.5. Percent reduction in compression strength of Box B

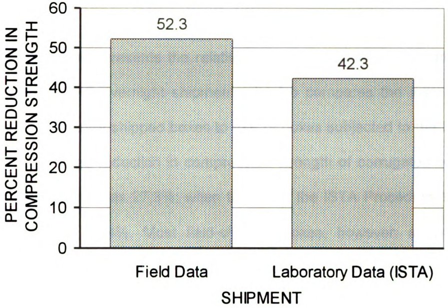

Figure 3.6. Percent reduction in compression strength of Box C

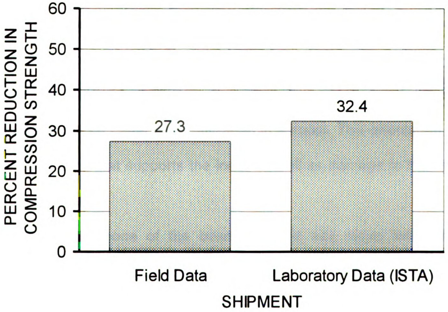

Figure 3.7. Overall percent reduction in compression strength of field-tested and laboratory-tested boxes

4. CONCLUSIONS

This study presents the relative loss in compression strength of corrugated boxes after UPS overnight shipment. It also compares the loss in compression strength of actually shipped boxes to that of boxes subjected to the ISTA Procedure 1A. The average reduction in compression strength of corrugated boxes after UPS overnight service was 27.3%; when tested by the ISTA Procedure 1A, the average reduction was 32.4%. Most field-shipped boxes, however, showed inconsistent results caused by the unique shipping environment encountered by individual boxes. The safety factors calculated from the study were 3.7 (field shipped) and 3.1 (ISTA tested), which are close to the minimum value of 3.0 recommended in both ISTA Procedure 1A and ASTM D-4169. To protect the packaged product from all possible damage, a safety factor greater than 3.0 should be recommended.

The shape of a box can play an important role in the loss of box compression strength. Flat boxes with relatively low height are more likely to be positioned and stacked on their sides. They are commonly used as void fillers among other packages to obtain better cube utilization in a trailer. This orientation greatly reduces the surface area that supports the load, as well as damage to the strength of a box in vertical direction.

Generally, none of the boxes showed any major form of damage after shipment. Only one box had a tear in its side. In this case the plastic sealing tape also had come undone. The plastic tape used for all other boxes was intact and the contents were maintained in the package.

5. RECOMMENDATIONS

This study used three sizes of boxes that contained apparel products. Since this type of product does not support any load, the corrugated boxes had to provide the majority of the support. Some possible additional research is listed below:

- Test alternate types of internal support members to provide additional strength to the boxes along their perimeter;
- Evaluate flat boxes of equal volume but different shapes to determine relative reduction in compression strength;
- Compare data collected from ISTA Procedure 1A to the newly developed ISTA Procedure 3C in order to determine their relative value in simulating field shipment;
- Document the relative humidity boxes are exposed to during shipment and assess its effect on compression strength.

APPENDIX

Table A1

Compression strength and deflection of control boxes
tested at MSU, East Lansing, MI

Box #	Box A		Box B		Box C	
	Load (lb)	Deflection (inch)	Load (lb)	Deflection (inch)	Load (lb)	Deflection (inch)
1	744	0.39	1182	0.42	751	0.37
2	779	0.33	1312	0.43	795	0.32
3	716	0.29	1220	0.43	800	0.43
4	659	0.28	1100	0.39	671	0.42
5	754	0.32	1201	0.40	759	0.39
6	759	0.38	1192	0.35	745	0.35
7	697	0.32	1194	0.39	742	0.28
8	707	0.36	1092	0.32	651	0.32
9	647	0.28	1173	0.39	789	0.32
10	722	0.32	1309	0.42	780	0.28
11	738	0.33	1209	0.39	722	0.35
12	638	0.32	1159	0.38	675	0.26
13	730	0.27	1118	0.44	744	0.34
14	638	0.31	1110	0.38	735	0.35
15	621	0.31	1207	0.38	818	0.33
16	694	0.31	1177	0.51	766	0.38
17	760	0.32	1151	0.44	733	0.31
18	730	0.27	1082	0.45	729	0.26
19	689	0.30	1109	0.42	754	0.34
20	685	0.30	1218	0.33	675	0.30
$\overline{X}$	705	0.32	1176	0.40	742	0.34
SD	46.1	0.03	64.1	0.04	45.7	0.05
Max.	779	0.39	1312	0.51	818	0.43
Min.	621	0.27	1082	0.32	651	0.26

Table A2

Compression strength and deflection of control boxes
tested at Lansmont Corp., Sunnyvale, CA

Box #	Box A		Box B		Box C	
	Load (lb)	Deflection (inch)	Load (lb)	Deflection (inch)	Load (lb)	Deflection (inch)
1	792.2	0.34	1256.4	0.48	745.1	0.38
2	688.0	0.37	1221.0	0.39	738.3	0.40
3	799.4	0.33	1242.8	0.40	759.0	0.42
4	791.5	0.35	1166.0	0.50	819.5	0.35
5	763.7	0.35	1098.5	0.47	730.8	0.39
6	805.0	0.33	1135.3	0.49	665.7	0.38
7	715.0	0.34	1161.8	0.44	775.2	0.35
8	586.7	0.35	1191.5	0.48	741.4	0.35
9	624.5	0.33	1204.9	0.56	746.1	0.40
10	641.7	0.30	1121.5	0.51	786.1	0.38
$\overline{X}$	720.8	0.34	1180.0	0.47	750.7	0.38
SD	81.5	0.02	52.5	0.05	40.2	0.02
Max.	805.0	0.37	1256.4	0.56	819.5	0.42
Min.	586.7	0.30	1098.5	0.39	665.7	0.35

Table A3

Compression strength and deflection of control boxes tested at Lansmont Corp., Duluth, GA

Box #	Box A		Box B		Box C	
	Load (lb)	Deflection (inch)	Load (lb)	Deflection (inch)	Load (lb)	Deflection (inch)
1	703.7	0.38	1250.4	0.48	694.1	0.31
2	747.4	0.40	1082.6	0.46	699.6	0.42
3	746.8	0.32	1172.7	0.44	756.4	0.41
4	753.5	0.37	1171.7	0.48	740.4	0.41
5	710.0	0.37	1148.9	0.40	733.5	0.38
6	766.6	0.34	1216.3	0.45	790.9	0.42
7	751.1	0.39	1188.1	0.49	869.6	0.44
8	710.5	0.34	1100.2	0.44	733.9	0.41
9	722.1	0.39	1131.3	0.46	836.4	0.44
10	661.3	0.35	1092.4	0.44	731.6	0.38
$\overline{X}$	727.3	0.37	1155.5	0.45	758.6	0.40
SD	31.8	0.03	55.1	0.03	57.1	0.04
Max.	766.6	0.40	1250.4	0.49	869.6	0.44
Min.	661.3	0.32	1082.6	0.40	694.1	0.31

Table A4

Compression strength and deflection of shipped boxes
from MSU, East Lansing, MI to Lansmont Corp., Sunnyvale, CA

Box #	Box A		Box B		Box C	
	Load (lb)	Deflection (inch)	Load (lb)	Deflection (inch)	Load (lb)	Deflection (inch)
1	608.6	0.26	1171.9	0.39	361.4	0.35
2	723.7	0.31	1130.0	0.35	327.1	0.29
3	694.4	0.25	1254.5	0.37	501.0	0.28
4	707.6	0.26	1141.4	0.31	306.2	0.29
5	554.4	0.26	996.2	0.33	421.1	0.24
6	722.4	0.29	1165.8	0.33	390.0	0.28
7	694.4	0.29	1059.9	0.35	536.8	0.30
8	548.1	0.29	1222.5	0.33	328.0	0.47
9	722.5	0.30	1117.0	0.38	356.9	0.38
10	569.1	0.35	1045.1	0.36	280.1	0.32
$\overline{X}$	654.5	0.29	1130.4	0.35	380.9	0.32
SD	75.1	0.03	79.9	0.03	83.5	0.07
Max.	723.7	0.35	1254.5	0.39	536.8	0.47
Min.	548.1	0.25	996.2	0.31	280.1	0.24

Table A5

Compression strength and deflection of shipped boxes
from Lansmont Corp., Sunnyvale, CA to MSU, East Lansing, MI

Box #	Box A		Box B		Box C	
	Load (lb)	Deflection (inch)	Load (lb)	Deflection (inch)	Load (lb)	Deflection (inch)
1	544	0.32	1192	0.54	368	0.40
2	548	0.36	1536	0.39	515	0.32
3	560	0.37	1151	0.28	336	0.38
4	562	0.37	970	0.40	354	0.21
5	351	0.30	1223	0.37	209	0.91
6	313	0.27	1250	0.42	359	0.40
7	595	0.38	1415	0.39	436	0.42
8	480	0.28	1224	0.35	248	0.60
9	562	0.30	1201	0.36	501	0.53
10	313	0.22	1270	0.43	0	torn
$\overline{X}$	483	0.32	1243	0.39	333	0.46
SD	112.6	0.05	150.7	0.07	151.9	0.20
Max.	595	0.38	1536	0.54	515	0.91
Min.	313	0.22	970	0.28	0	0.21

Table A6

Compression strength and deflection of shipped boxes
from MSU, East Lansing, MI to Lansmont Corp., Duluth, GA

Box #	Box A		Box B		Box C	
	Load (lb)	Deflection (inch)	Load (lb)	Deflection (inch)	Load (lb)	Deflection (inch)
1	266.6	0.16	1189.7	0.33	413.5	0.43
2	553.5	0.35	1317.7	0.41	225.7	0.24
3	445.1	0.27	1263.8	0.39	427.9	0.40
4	261.1	0.34	1068.3	0.32	414.5	0.33
5	287.4	0.21	1272.7	0.38	466.1	0.33
6	349.7	0.28	924.3	0.42	453.3	0.40
7	460.9	0.28	1097.5	0.45	388.0	1.20
8	516.1	0.23	1114.0	0.33	347.9	0.67
9	494.7	0.25	1218.8	0.43	257.8	0.39
10	389.0	0.30	1215.9	0.32	387.8	0.45
$\overline{X}$	402.4	0.27	1168.3	0.38	378.3	0.48
SD	107.6	0.06	117.9	0.05	79.8	0.28
Max.	553.5	0.35	1317.7	0.45	466.1	1.20
Min.	261.1	0.16	924.3	0.32	225.7	0.24

Table A7

Compression strength and deflection of shipped boxes
from Lansmont Corp., Duluth, GA to MSU, East Lansing, MI

Box #	Box A		Box B		Box C	
	Load (lb)	Deflection (inch)	Load (lb)	Deflection (inch)	Load (lb)	Deflection (inch)
1	607	0.30	970	0.42	407	0.68
2	375	0.18	939	0.32	110	0.22
3	638	0.28	956	0.38	375	0.45
4	738	0.32	869	0.50	445	0.35
5	650	0.42	1174	0.45	427	0.41
6	598	0.31	675	0.46	251	0.23
7	638	0.39	954	0.39	263	0.17
8	427	0.23	991	0.52	306	0.42
9	595	0.39	1118	0.46	251	0.80
10	588	0.33	982	0.45	501	0.31
$\overline{X}$	585	0.32	963	0.44	334	0.40
SD	107.0	0.07	134.3	0.06	118.2	0.20
Max.	738	0.42	1174	0.52	501	0.80
Min.	375	0.18	675	0.32	110	0.17

Table A8

Compression strength and deflection of boxes subjected to the ISTA Procedure 1A at MSU, East Lansing, MI

Box #	Box A		Box B		Box C	
	Load (lb)	Deflection (inch)	Load (lb)	Deflection (inch)	Load (lb)	Deflection (inch)
1	548	0.30	897	0.36	425	0.37
2	460	0.34	836	0.36	344	0.41
3	341	0.22	1186	0.50	403	0.62
4	474	0.25	945	0.39	475	0.43
5	392	0.24	803	0.38	419	0.32
6	400	0.22	873	0.39	492	0.42
7	410	0.27	933	0.43	397	0.41
8	444	0.26	854	0.38	436	0.60
9	504	0.22	913	0.38	448	0.44
10	695	0.31	1027	0.57	436	0.49
$\overline{X}$	467	0.26	927	0.41	428	0.45
SD	99.9	0.04	110.8	0.07	41.6	0.09
Max.	695	0.34	1186	0.57	492	0.62
Min.	341	0.22	803	0.36	344	0.32

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