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REDUCTION IN BOX COMPRESSION STRENGTH AFTER SHIPMENT
THROUGH THE OVERNIGHT SMALL PARCEL
DISTRIBUTION ENVIRONMENT

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REDUCTION IN BOX COMPRESSION STRENGTH AFTER SHIPMENT THROUGH THE OVERNIGHT SMALL PARCEL DISTRIBUTION ENVIRONMENT

by

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ABSTRACT

REDUCTION IN BOX COMPRESSION STRENGTH AFTER SHIPMENT THROUGH THE OVERNIGHT SMALL PARCEL DISTRIBUTION ENVIRONMENT

By

Henrique Gnani Braun

The purpose of this study was to determine the reduction in compression strength of corrugated containers when shipped through the overnight parcel distribution system. The study measured the top-to-bottom compression strength and corresponding deflection of empty boxes before and after shipment. All boxes (three different sizes) were conditioned at 72 °F and 50% Relative Humidity for at least 24 hours before testing. Three different package weights were shipped. The packages were also tested using the International Safe Transit Association (ISTA), Preshipment Project 1A test procedure.

The data collected showed the packages tested using the ISTA test lose approximately 55% of the compression strength. This is also true for actual shipments in the overnight parcel delivery system for the lighter weight packages (30 lbs.). However the heavier packages showed a much larger reduction in compression strength by as much as 74% in actual shipments and the ISTA test does not truly represent these conditions.

This thesis is dedicated to my parents, Walter and Luzia Braun for their love and belief in me. Also to my loving wife, Isabela, for all her patient and support throughout my research.

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1.0 INTRODUCTION

In the United States, a number of forms of commercial transportation is used to move packaged goods. The word "carrier" identifies both the general type, such as truck or rail, and the private company used to transport goods. In addition to truck and rail, air cargo is used for many perishable or timely shipments, and a number of specialized services have been established to handle relatively small shipments. Facilitating product handling is the second most important function of distribution packaging after protecting the product. Time is of the essence when it comes to moving products, and handling requires time. Eliminating handling events saves time and simultaneously creates a kinder and gentler environment for packaged products.

Unitizing products for the distribution environment results in a winning situation for reducing damage for both the shipper and customer. It facilitates internal handling and storage, speeds up trailer loading and unloading, shortens the processing of manifests and bills of lading, subjects products to reduced handling hazards, and overall provides cost savings.

There are reasons however why everyone is not unitizing their packages for shipment. The first is that unitizing does cost money and may require additional space in containers and trailers. Another obvious reason is that you may not be sending sufficient packages to a single destination to form a unit load. This is the case of the Small Parcel Environment distribution system which deals with packages of different sizes and weights being shipped to different destinations. These often are direct delivery of individual packages to both residential and business customers. The next sections describe the operations involved with moving individual packages by Federal Express, the carrier used in this study.

1.1 Federal Express Company.

Federal Express (FedEx) is one of the major privately owned U.S. companies offering a one class service for door to door shipment of small parcel packages. This company is the world's largest express transportation company, providing fast and reliable services for packages, important documents, and freight. FedEx delivers more than two million items to customers in over 210 countries each business day. FedEx employs more than 110,000 people worldwide, and operates 471 aircraft and over 35,000 vehicles in its integrated logistical system.

Federal Express first started its business in 1973 from Memphis, TN. Federal Express has grown since then and has specialized only in air delivery systems. In 1989, with the acquisition of Tiger International Co. and the integration of Flying Tigers Co. into its system, Federal Express became the worlds largest full service all-cargo international airline. Federal Express now provides overnight air deliveries to virtually every address in the U.S. through its next day "Priority" and "Standard" services [1]. The "Priority" service provides door-to-door delivery by

10:30 a.m. the next business day to thousands of U.S. cities. The "Standard" service is an option for those shipments that can wait until the afternoon for delivery by 3:00 p.m. the next business day. Both services operate shipments for packages that weigh up to 150 lbs., and measure up to 119 inches in length and up to 165 inches in length and girth combined. Federal Express handles an average daily package volume of 1.7 million parcels in its combined air delivery services.

1.2 Next Day Air Delivery System.

Federal Express "Priority" services use the "Hub-and-Spoke" system to deliver packages. The local operating centers all around the U.S. serve as the "spokes". Each operating center provides pickup and delivery service within an individual territory. The all-cargo aircraft connect these local operating centers with the central Air-Hub. The "Hub" is a single central sorting facility. The aircraft called "Feeders" take a consignment of packages from the local operating centers to the Central Air-Hub for sorting every night. These packages are sorted at the Air-Hub in a matter of approximately three hours. After sorting the packages, the aircraft departs with a load of packages to be delivered the next morning at the destination operating center. Federal Express operates 1400 local service centers worldwide. While the concept of picking up and delivering documents and packages is simple, systems that make it operate efficiently and reliably are innovative, complicated, and expensive [2].

During the distribution of packaged goods, damage during handling and sorting is commonly observed. Once the packaged product is shipped through a distribution system such as Federal Express, it is subjected to a series of hazards such as drops, impacts, crushing forces, vibration, climatic, and pressure changes, before it reaches the customer. The factors that contribute to the damage of a product during handling and distribution are numerous: the physical environment, the climatic or atmospheric environment, and the human environment. Within each of these there are potential hazards which must be considered when designing a package for the product.

1.3 Corrugated Shipping Containers.

The paper corrugated fiberboard box is the most commonly used package by the U.S. manufacturer to contain and transport their products to the final consumer. According to the Association of Independent Corrugated Converters, 95% of packaged products are shipped in corrugated containers. Performance requirements for corrugated boxes have for the most part been dictated by the U.S. railroad and motor carrier industries.

In the case of the truck and rail carriers, the individual companies, working through committees of their associations, have developed descriptions of services, and the conditions (including packaging specifications) and rates under which they are performed. These documents, known as freight classifications, are filed as tariffs with the Interstate Commerce Commission, giving them, when applicable, the force of law for interstate shipments.

The two major sets of Classifications - the National Motor Freight Classification issued by the truck lines through the National Classification Committee of the National Motor Freight Traffic Association and published by the American Trucking Associations, and the Uniform Freight Classification (issued by the railroads through the National Railroad Freight Committee of the Western Railroad Association) contain the necessary corrugated packaging information.

Uniform Freight Classification, Rule 41, [3] and National Motor Freight Classification, Item 222, [4] require that single-wall corrugated fiberboard boxes have a bursting strength ranging from 125 psi (875 kPa) to 350 psi (2450 kPa) with a combined weight of facings ranging from 52 lb (23.6 kg) to 180 lb (81.7 kg) to allow for product weight of 20 lb (9.0 kg) to 120 lb (54.4 kg). An individual company uses these tariffs to develop corrugated boxes depending on their distribution and warehouse conditions and the characteristics of their products. What may be an ideal choice of corrugated board combination for one company may not be relevant for another. For instance if one is shipping small and heavy parts in a LTL (less than truck load) environment, it may be necessary to choose a corrugated board with a high bursting strength and puncture resistance. Similarly lighter and larger items to be stacked may require a board with high edge crush strength [5].

1.4 Box Compression Strength.

Box compression strength is not a requirement in either of the Uniform Freight Classification, Rule 41, or National Motor Freight Classification, Item 222.

The compression strength of a corrugated container is a good measure of the performance of a package during stacking. Packages undergo compression during shipment and warehouse stacking. A package must be designed to be able to withstand the abuse it will experience, especially the bottom box in a stack on the back of a truck or in storage under adverse climate conditions for a long period of time. The compression strength of a package is defined to be the force required to compress it to failure. Failure does not necessarily mean that both the box and product inside are completely damaged. Failure is often a specific amount of damage (usually deflection) often pre-determined that is found to be unacceptable. This can be either damage to the box, or damage to both the product and box.

1.5 Compression Strength Testing.

The compression strength of a package is determined using a compression tester. Compression is accomplished by placing the specimen between a fixed base and a moving platen. A load cell measures the force exerted by the platen as it compresses the package and is displayed on a scale. Most compression testers measure force and deflection simultaneously and graph the relationship automatically using a strip chart recorder.

A typical force versus deflection curve for a corrugated box is shown in Figure 1. A compression tester is used to determine the package compression strength, which is useful in estimating stacking performance. It however does not truly simulate the actual environment for a number of reasons. One reason is that most compression testers are of the fixed platen type. This means that the platen remains horizontal and parallel to the base during compression. If the corners of the box have different heights, then the platen will contact the box first at the highest corner. This corner then takes the bulk of the load until the platen contacts the next highest corner, and so on. If the platen contracts all four corners before the box fails, then the compression strength so obtained represents a reasonable estimate of the actual dead load it could support from other boxes on top of it. If the box fails before the platen contacts all four corners, then the estimate is unreasonable since all four corners will come into play in a real stack. It is usually the case however that the box fails after all four corners have been contacted.

Another reason why compression testing using a machine falls short of reproducing actual conditions is that it cannot maintain the equivalent of a dead load for any length of time. Simply stopping the machine travel (fixing the separation between the platen and the base) does not accomplish this. What usually happens in this case is that the load (as measured by the load cell) falls off over time.

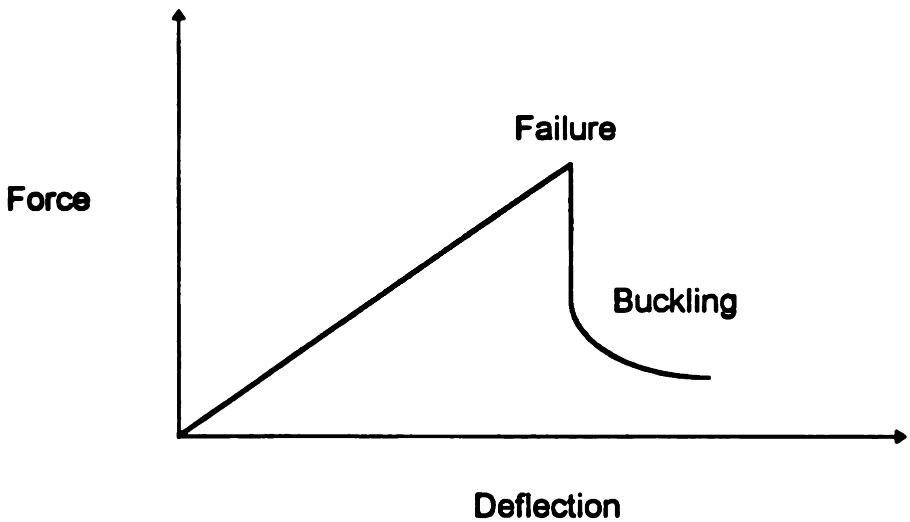


Figure 1. Compression Force vs. Deflection.

This phenomenon known as relaxation, is the tendency for an object under fixed compression to internally deform to relieve the load on it. Also most box compression strength tests use a slow rate of load application (usually 0.5 in./min. or less) to avoid dynamic loading of the corrugated. Higher loading rates would result in higher dynamic compression values which will not truly represent box performance under static conditions.

The primary standard used for compression testing of shipping containers is ASTM D-642, Compression Test for Shipping Containers. This standard recommends the use of either a fixed or floating platen compression tester and requires in the procedure that a 50 lb. "preload" be applied to a single-wall box "to ensure definite contact between the specimen and platen" before any deformation is recorded. The test consists of compressing the box to failure and recording the compression strength (lbs) and the associated deflection (inches) measured from the pre-loaded configuration. The Performance Testing of Shipping Containers (ASTM D-4169) recommends the amount of load a shipping container must be tested for to account for static and dynamic compression forces.

An important capability of a compression tester which allows for extended use of the results is its ability to accurately measure the compression and corresponding deformation at failure. This information helps to estimate the compression strength for the whole package from the individual compression strengths for the box and a product. It may also be used to make design alterations in the height of the box (headspace) to achieve maximum combined compression strength from the box and the contents.

The most important external influences which affect the strength of a box are humidity, storage time, and stacking pattern. An increase in humidity weakens the box because the paper corrugated board readily absorbs moisture (which tends to reduce rigidity). The box also weakens with time, a phenomenon also known as creep or fatigue. The final factor which affects strength is the stacking pattern. A stack of identical boxes aligned perfectly in a vertical column can be stacked much higher than if the boxes are somewhat staggered. Whenever the compression load on a box is not supported by its strongest members, the corners and sidewalls, the strength of the box is compromised. A stack of different sized boxes has the same effect as staggering identical boxes: the compression strength is reduced because the corners and walls are not aligned. The actual compression strength of a box taking into account all of these conditions may be mathematically described as;

$$TBCS = LTCS \times T \times H \times SP$$

where,	TBCS	=	True Box Compression Strength
	LTCS	=	Lab Test Compression Strength
	T	=	Storage Time Factor
	H	=	Humidity Factor
	SP	=	Stacking Pattern Factor

The Society of Plastics Industry conducted a five year study on "The Stacking Performance of Plastic Bottles in Corrugated Boxes". This study provides data on the various factors that effect the performance of corrugated boxes. According to ASTM D-642, the compression test should be performed at standard conditions of 73°F and 50% Relative Humidity. The effect of humidity, fatigue, and stacking pattern that would affect the compression strength is shown in Table 1. The effect of the same three factors on the deformation of the box at failure is negligible [6].

Many studies have been undertaken to develop empirical relationships that will predict the compression strength of corrugated boxes [7]. Most relate the compression strength of the box to the material properties of the corrugated fiberboard used to fabricate the box. Peterson and Fox (1980), reported a theory to demonstrate how boxes fail in compression. The compression failure morphology of the liners was studied, to develop an understanding of what may be done to increase compression strength. Failure was consistently seen in the regions of the panel subjected to compressive loads as a result of the critical combination of stresses acting there at a much lower level than would be required to cause a box failure due to tension. After a physical examination of linerboard cross sections, that had failed under compressive loads, it was revealed that on occasion the board delaminated as if it were made of many layers and that the bonds between the layers ruptured when loaded. Other samples were seen to have fibers buckle or delaminate and then buckle.

Table 1. Fatigue, Humidity and Stacking Pattern factors of corrugated

Box Fatigue Factors		Box Humidity Factors		Stacking Pattern Factor	
Duration of Load	T	Relative Humidity	H	Alignment	SP
Short Term	100%	Dry	125%	Perfect	1
10 days	65%	25%	110%	Offset	0.5
30 days	60%	50%	100%		
100 days	55%	75%	80%		
1 year	50%	85%	60%		
		90%	50%		

It was concluded that inter-fiber bond strength and fiber stiffness are the most important variables related to linerboard compressive strength.

Hanlon [8] advises that a good rule of thumb for long-term storage is to use one-fourth of the compression strength of a corrugated box as a safe design load when predicting stacking strength. A more accurate method would be to calculate the fatigue factor for the length of time in storage along with a factor for humidity. There should also be consideration given to the dynamic loading that occurs during normal distribution and product handling. Adams [9] found that the compression strength of corrugated boxes increased after exposure to vibration in a stack. He attributes this to the evening (uniform height) of corners during vibration which allows each corner to offer equal strength. He reported an approximate 8% increase in top-to-bottom compressive strength due to vibration. Singh [10] investigated the effect of mechanical shocks on the compressive strength of corrugated containers. The results show that as much as 75% of the original compressive strength can be lost after multiple handling. Langlois [11] compared the compression strengths of corrugated fiberboard boxes using a fixed and a floating platen on the compression tester. The floating platen showed an average compression value that was 3.6% lower than the fixed platen. However this difference is not significant because of larger variations that exist in the box performance.

Singh [12] investigated the change in compression strength of corrugated containers as a function of package gross weight at given drop heights expected during handling. The mean overall box compression strength decreased as the gross weights and drop heights increased. Voss [13] measured the dynamics of the small parcel environment in the UPS ground shipping environment. The effect of weight and size was also studied. The study used packages of different sizes and weights that were instrumented with drop height recorders. The results showed that the size of the package had no significant effect on drop heights. Weight did not have a significant effect on the medium and large size packages. However small size lighter weight packages experienced higher drop heights. This was attributed to more automated handling for the larger and heavier packages in the UPS sorting environment.

There has been a significant increase in the amount of single parcel distribution systems in the last decade. This has resulted in companies such as Federal Express, United Parcel Service, Roadways Express, Emery, USPS Priority Mail, etc. These companies provide pickup and delivery of individual parcels to both domestic and international locations. These packages undergo a different type of compression loading, since they are often placed with other packages that vary both is size and weight. Existing lab simulation methods do not account for all these variations of load distribution and compression loading. As a result this study was initiated by the Consortium of Distribution Packaging to determine the loss in compression strength of single wall corrugated boxes as a result of domestic next day air parcel delivery system. Federal Express was selected as the carrier.

The following were the objectives of this study :

To determine the reduction in compression strength of corrugated containers when shipped in the overnight parcel distribution system.

To compare these actual measured values to those determined from lab simulated test methods recommended by the International Safe Transit Association.

2.0 EXPERIMENTAL DESIGN

Three different package sizes were tested in this study. All the boxes used in this study were regular slotted containers (RSC) type made from single-wall C-flute corrugated board (Figure 2). The material and size specifications of the boxes tested are shown in Tables 2 and 3. All corrugated containers were obtained from Stone Container Corporation. Three package weights were tested and shipped in this study. These were: 30 lbs., 50 lbs., and 80 lbs.

2.1 Conditioning of Test Samples.

The boxes were received knocked-down from Stone Container. All the boxes were conditioned at 72°F at 50% Relative Humidity for at least 24 hours before testing in accordance with ASTM D-4332. After conditioning, boxes were sealed both top and bottom as required in ASTM D-642 using a plastic tape (3M Scotch Brand Tape - core series 2-3300 plastic sealing tape).

2.2 Testing Procedure.

Using ASTM D-642, ten boxes of each type were tested for compression strength and corresponding deflection. The average peak force for these ten boxes was used as the **control** box compression strength.

Three package weights (30 lbs, 50 lbs, and 80 lbs) were used for the shipping, and performing the ISTA tests.

Figure 2. Three Different Box Sizes Used.

Table 2. Boxes Specifications (English units)

Size (inches)		Burst Strength (psi)	Minimum Combined Weight of Facings (lb)	Size Limit (inches)	Gross Weight Limit (lb)
SMALL	12.5 x 9.5 x 5.75	175	75	60	40
MEDIUM	12.5 x 12.5 x 12.5	275	138	90	90
LARGE	21.25 x 19 x 13.25	275	138	90	90

Table 3. Boxes Specifications (Metric units)

Size (cm)		Burst Strength (Kg/m2)	Minimum Combined Weight of Facings (Kg)	Size Limit (cm)	Gross Weight Limit (Kg)
SMALL	31.75 x 24.13 x 14.61	12.3	366.4	152.4	18.16
MEDIUM	31.75 x 31.75 x 31.75	19.4	674.1	228.6	40.86
LARGE	58.98 x 48.26 x 33.66	19.4	674.1	228.6	40.98

The boxes were filled with sand bags and cushions (Polyurethane and Expanded Polyethylene - DOW Ethafoam) to achieve the desired weight. Fifteen sample boxes of each type were shipped from School of Packaging, Michigan State University, East Lansing, MI to Clorox Technical Center, Pleasanton, CA. The boxes were emptied out and the residual compression strength measured in California. The dummy weights were repackaged in new boxes and return shipped to School of Packaging, East Lansing. The residual strength of these boxes was measured. All shipments were done using Federal Express next day air delivery system.

FedEx uses the "Hub and Spoke" system to deliver its packages. Packages were picked up by a courier from the School of Packaging, Michigan State University and loaded in small delivery vehicle referred to as a "Package Car". The packages were taken to respective operating centers of FedEx in the Lansing area where they were consolidated with all other packages also meant for next day delivery. The consignment of packages were put into air transport containers which were then transported by truck to the regional air facility. The air transport containers were then loaded into the cargo aircraft which serves as the "Feeder". The aircraft was then flown to the national Air-Hub with packages and documents headed for various domestic and international locations. These air hubs serve as the central sorting facilities for packages from all over the United States.

The Federal Express air-hub is located in Memphis, TN, where the arriving aircraft are unloaded. The air containers are unloaded and transferred on rollers to the central sort area. There the employees remove the packages from the containers, scan them, and send them on belts to a central sort area, where scanners track and check package destination and size. Packages speed through the hub on a several miles long network of belts and chutes. Diverters, activated by information in the bar code labels discharge packages down chutes and on to proper sort belts. The packages are then collected by their destination and any special handling requirement that may be required depending on the contents.

After sorting, the packages are consolidated together with all the other packages bound for the same destination or service area. These are then loaded into containers and onto another "Feeder" aircraft to be delivered to the destination operating center. The packages, after sorting at the local operating facility, are loaded into "Package Car" to be delivered to the final destination. The test packages were then return shipped to Lansing, going through a similar process.

In addition ten boxes of each type and weight were tested for vibration and drops in accordance with the ISTA Project 1A test method.

2.3 Cushion and Weight Placement for Test Packages.

Each box type was measured and a 0.5 inch polyurethane foam was cut to fit the interior of the box faces (Figures 3, 4 and 5). A pattern was chosen so that

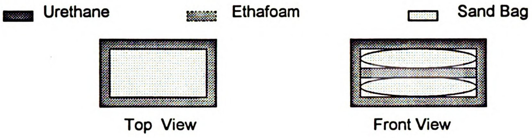


Figure 3. Cushion and Weight Placement (Small Box: 30 lbs.)

Figure 4. Cushion and Weight Placement (Medium Box: 50 lbs.)

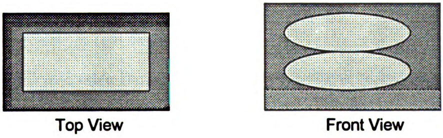


Figure 5. Cushion and Weight Placement (Large Box: 80 lbs.)

a full face cushion would be present on all lateral sides and between the sand bags used as dummy weights. This was considered important so as to keep the distribution hazards effects as uniform as possible on all corrugated sides. Sand bags were used to obtain necessary weights for all three sizes of test boxes. The polyurethane was cut to provide a tight fit so that the weight would not move within the cushion fixture. The large boxes had an additional layer of a 2 inch thick expanded polyethylene cushion (Dow Ethafoam) pad on the bottom in order to support the heavy weight of 80 lbs. All the weights were evenly balanced in all the test packages.

2.4 Compression Strength Test.

All samples were compression tested using a Lansmont Corporation Compression Tester (Model No. 76-5K) with a fixed platen as shown in Figure 6. This machine had digital readout of force with a +/- 1% linearity. This machine is in accordance with ASTM D-642 and TAPPI T-804 test methods. The compression test was performed at a platen speed of 0.5 inches per minute.

2.5 The ISTA Project 1A Test Method.

The ISTA Preshipment Test Procedures provide a means for a manufacturer to pre-determine the probability of the safe survival of its packaged products at their destination through the utilization of tests developed to simulate the shocks and

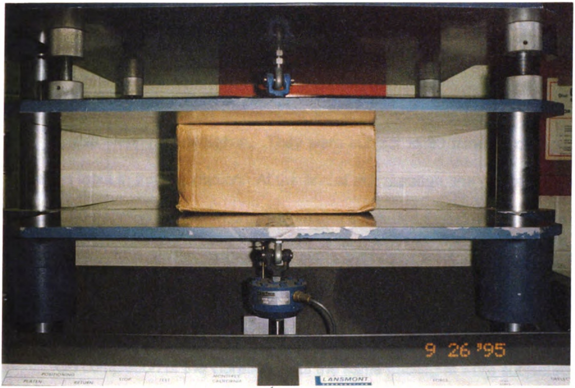


Figure 6. Compression Tester With Fixed Platen.

Stresses normally encountered during handling and transportation. Project 1A is intended for packages weighing less than 100 pounds (45.5 kgs.). The basic requirements of this procedure consist of performing vibration and drop tests. The compression tests are optional. The vibration tests on the packages were performed using a Lansmont electro-hydraulic vertical vibration table. The test was conducted using the Composite Truck/Air Power Density Spectrum with an overall Grms of 1.15 G (Figure 7). The packages were placed on the table representing their normal shipping orientation. They were subject to 30 minutes of random vibration input in this orientation. At the end of this duration, the packages were rotated 180 degrees (top down orientation) and continued to test for an additional 10 minutes. In a similar fashion, the same packages were tested on all the remaining four side faces for 10 minutes each.

On completion of the vibration tests the same packages were subjected to a drop sequence. The drop heights were selected based on the individual package weights as recommended in the ISTA test protocol. Generally lighter boxes are dropped from higher drop heights. The drop heights used were as follows:

- Small boxes (30 lbs.), 24 inches
- Medium boxes (50lbs.), 18 inches
- Large boxes (80 lbs.), 12 inches

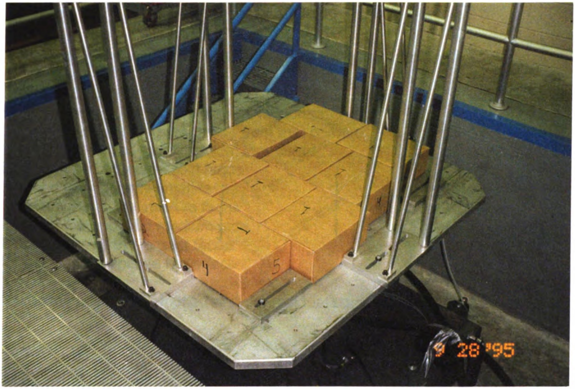


Figure 7. Electro-Hydraulic Vertical Vibration Table

The box surfaces were identified as follows:

- top as one
- right side as two
- bottom as three
- left side as four
- near end as five
- far end as six

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

1. the 2-3-5 corner.
2. the shortest edge radiating from that corner.
3. the next longest edge radiating from that corner.
4. the longest edge radiating from that corner.
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 boxes were then emptied and the residual compression strength measured.

3.0 DATA AND RESULTS

One hundred fifty corrugated fiberboard boxes were tested to determine the reduction in compression strength of shipping containers after being submitted through the Federal Express next day air delivery system. The data collected is listed in Tables presented in the Appendix section. The average compression strength and corresponding deflection are listed in Table 4 (English Units) and Table 5 (Metric Units). The average percent reduction in corrugated containers for the different sizes is listed in Table 6.

3.1 Small Size Boxes.

Table 4 shows the average compression strength values for the small size boxes for the various tests performed. The individual values for each package tested are listed in the Appendix (Table A1 to A4). Ten samples were compression tested as a control. The mean compression strength value for the control boxes was found to be 597 lbs.. The compressive strength reduced by as much as 56% for the boxes tested using the ISTA Project 1A method. A similar result was achieved for the compressive reduction of boxes shipped through the Federal Express delivery system. The reduction in compression strength from East Lansing to Pleasanton was 54% and from Pleasanton to East Lansing was 60%. The results show that for this size and weight of packages the ISTA shows similar reduction

Table 4. Average Load and Deflection (English Units)

	Size of Box		
Test Condition	Small Load(lbs) Deflection(in)	Medium Load(lbs) Deflection(in)	Large Load(lbs) Deflection(in)
Control	597 (0.31)	941 (0.39)	1073 (0.37)
THE ISTA Simulated	262 (0.29)	443 (0.29)	530 (0.38)
E. Lansing to Pleasanton	275 (0.47)	328 (0.34)	282 (0.65)
Pleasanton to E. Lansing	239 (0.34)	335 (0.41)	302 (0.50)

Table 5. Average Load and Deflection (Metric Units)

	Size of Box		
Test Condition	Small Load(Kg) Deflection(cm)	Medium Load(Kg) Deflection(cm)	Large Load(Kg) Deflection(cm)
Control	271 (0.79)	427 (0.99)	487 (0.94)
THE ISTA Simulated	119 (0.74)	201 (0.74)	241 (0.97)
E. Lansing to Pleasanton	125 (1.19)	149 (0.86)	124 (1.65)
Pleasanton to E. Lansing	108 (0.86)	152 (1.04)	137 (1.27)

in compression strength as those found in actual shipments.

3.2 Medium Size Boxes.

Table 4 also shows the average compression strength values for this size and weight package for the various tests performed. The individual values for each sample are listed in the Appendix (Tables A5 to A8). Ten samples were compression tested as a control. The mean compression strength value for the control boxes was found to be 941 lbs.. The compression strength reduced by as much as 53% for the boxes tested by the ISTA Project 1A method. The reduction in compression strength from East Lansing to Pleasanton was 65% and from Pleasanton to East Lansing was 64%. The values for the actual trip through the Federal Express delivery system were approximately 10% higher than the values using the ISTA test.

3.3 Large Size Boxes.

Table 4 shows the average compression strength values for this size and weight box for the various tests performed. The individual values for each sample are also listed in the Appendix (Tables A9 to A12). Ten samples were compression tested as a control. The mean compression strength value for the control boxes was 1073 lbs.. The compression strength reduced as much as 51% for the boxes tested using the ISTA Project 1A method. The reduction in compression strength from East Lansing to Pleasanton was 74% and from Pleasanton to East Lansing was 72%. A higher result was achieved for the compressive reduction of boxes shipped through the Federal Express delivery system.

3.4 General Observations.

Table 6 shows the average percent reduction of all the various boxes tested. It provides a summary of the compression strength reduction data. Figures 8, 9, and 10 show the percent reduction values for the three size and weight packages tested under different conditions.

In general all individual packaged products undergo shock and vibration inputs that are different from those of other packaged products. The differences may be due the presence of many variables such as: location in the transportation vehicle, vehicle operator differences, drops during handling, routing, climatic exposure, etc. This is the reason why a large variation of compression strength values after shipments is seen. Another important factor is that during actual shipments packages may be submitted to either manual or mechanized handling which is usually a function of the size and weight of the package. These factors have a direct impact on the reduction of compression strength of the packages. Manual handling includes many operations such as lifting, transferring, marking, sorting and placement. These operations are generally performed at a work station and careful design of the package and the work station itself can reduce fatigue and

Table 6. Percent Reduction in Compression Strength

Test Condition	Size of Box		
	Small	Medium	Large
THE ISTA Simulated	56	53	51
E. Lansing to Pleasanton	54	65	74
Pleasanton to E. Lansing	60	64	72

Figure 8. Average Load (Small Boxes)

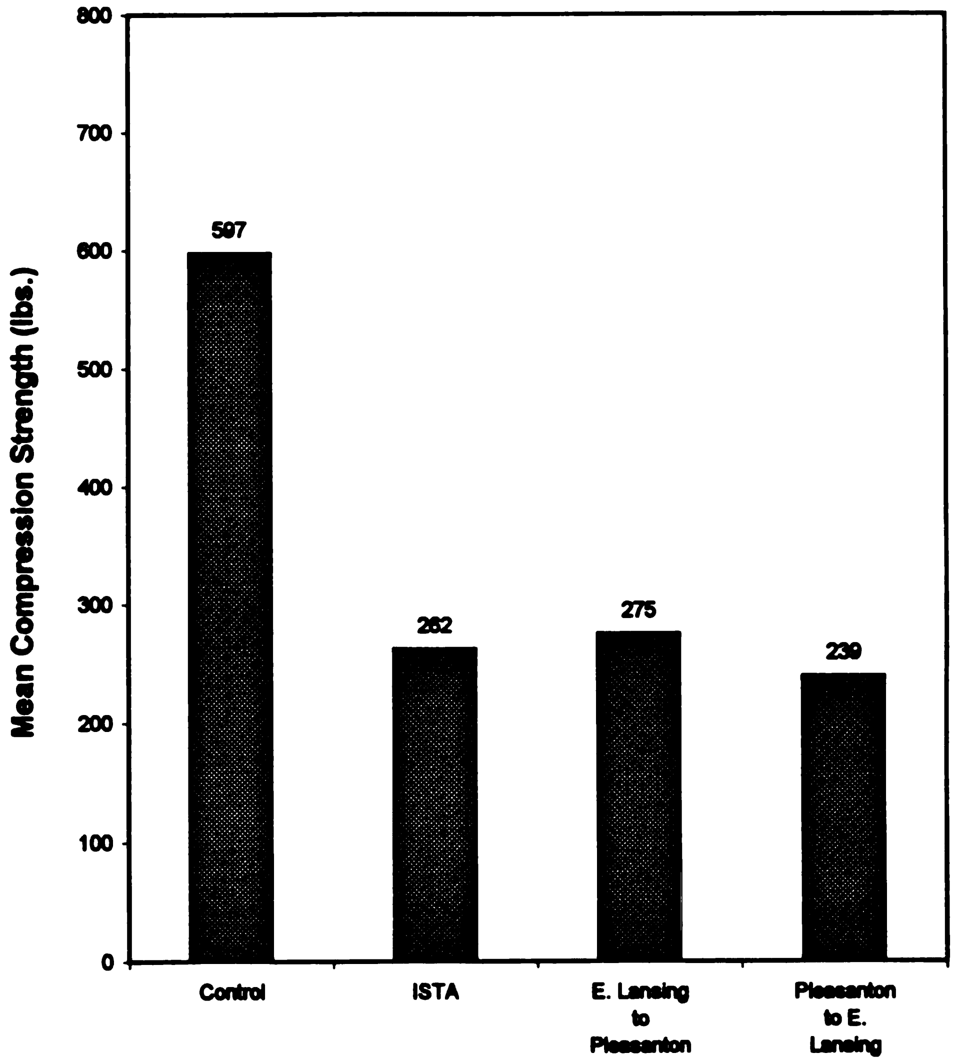


Figure 9. Average Load (Medium Boxes)

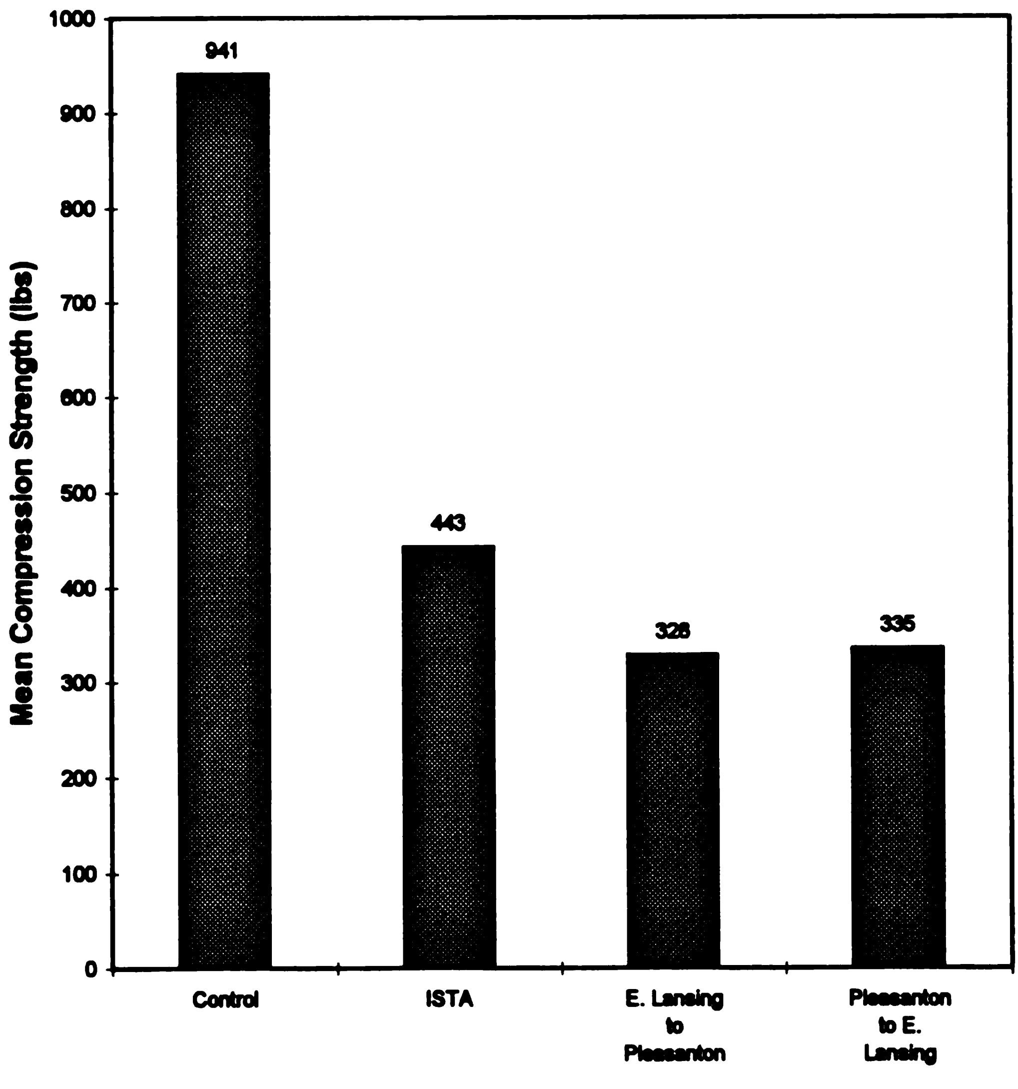
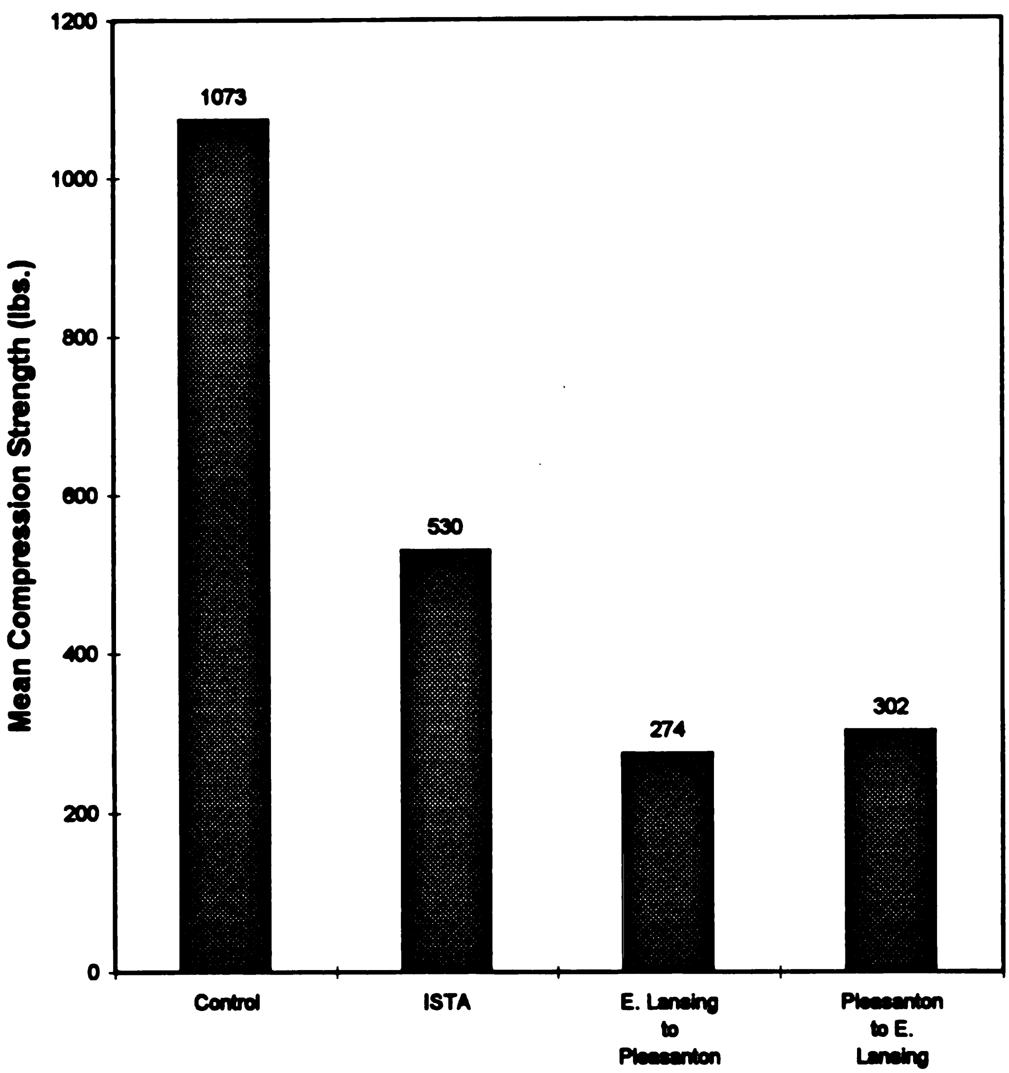


Figure 10. Average Load (Large Boxes)



increase the ease of handling, both factors lowering the potential for injury either to the operator or damage to the package. The various pictorial markings such as "THIS SIDE UP", "DO NOT DROP", "FRAGILE", ETC. often do not play a critical role in the small parcel environment where most of the packages undergo automated sorting and transfer. Package style, shape, and strength are generally very important in ensuring packages survive these special environments.

Automated package sorting and processing covers a whole array of operations including the conveying, metering, and recognition of packages. Conveying devices include belts, rollers, slides, carrier chains, and elevators. Metering equipment can include bar and corner stops, gates, traffic cops, accumulators, friction wires, and pushers. Whenever automatic equipment is used, especially involving high speed operations, the demand on the packaging system increases. Impact forces resulting from sudden stops and starts and the chafing action from sliding and transfer operations places heavy demands on the flap closure and corners of the box. Once the flaps become loose and corners become damaged, additional handling rapidly aggravates the situation (Amcor, 1992).

The overnight parcel distribution system submit packages to both manual and automated handling. The roughness of each individual package handling system varies. The data collected from this study shows that generally the ISTA simulated packages loose approximately 55% of the compression strength. This is also true for actual shipments using the overnight parcel delivery system for the smaller size and lighter weight packages (30 lbs.). However the heavier packages showed a much larger reduction in compression strength to as much as 74%.

Figure 11 shows the three package sizes used in this study in good condition prior to any testing or shipping. Figure 12 shows a small size package received after an overnight shipment. All of these boxes showed deformed edges, but maintained the contents integrity and did not open during shipment. Figure 13 shows a medium size package received after an overnight shipment. Similar to the small size packages, these boxes also showed deformed edges, but maintained the contents integrity and did not open during shipment. Figure 14 to 17 are examples of the large size packages received after shipment. Figures 14 and 15 show the condition of a package exposed to frictional forces caused by the belt or conveying system, when the package was obstructed from travelling freely. Figures 16 and 17 are examples of packages that got severely damaged and exposed the contents due to torn sides and edges.

As discussed earlier, the ISTA test on the large and heavy size boxes did not truly represent the same level of compression strength reduction and physical damage as found in real shipments. This is also evident in Figure 18 where the column on the left is a stack of boxes tested using the ISTA test protocol and the stack on the right is stacked boxes from real shipments. It is evident that the boxes on the right were exposed to a higher degree of dynamic compression and caused higher deformation and bulging. This is also attributed to the lack of a stacked vibration test in the ISTA protocol.

Figure 11. Three Package Sizes Tested

Figure 12. Small Size Package after Overnight Shipment Tested

Figure 13. Medium Size Package after Overnight Shipment Tested

Figure 14. Large Size Package after Overnight Shipment Tested

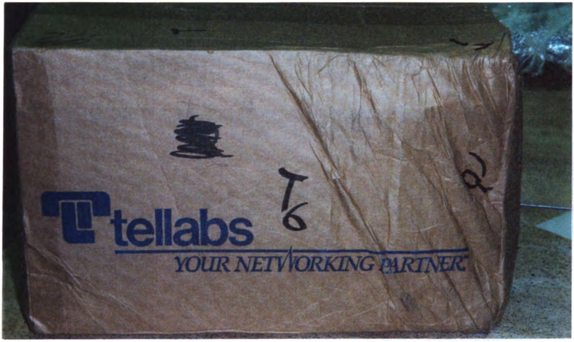


Figure 15. Large Size Package after Overnight Shipment Tested

Figure 16. Large Size Package after Overnight Shipment Tested

Figure 17. Large Size Package after Overnight Shipment Tested

Figure 18. Comparison of ISTA Tested and Actually Shipped Packages

4.0 CONCLUSIONS

Following are the conclusions of this study:

1. The percent reduction in compression strength increased as the package size and weight of boxes increased when shipped through the overnight parcel delivery system. The average amount of percent reduction measured in the large size boxes was found to be 74%.

2. The ISTA Project 1A method test results, showed an average reduction of approximately 55% for all sizes and weights.

3. The ISTA Project 1A results showed good correlation only for the small size packages. For the larger size boxes they showed compression strength reduction much lower than actual shipments.

5.0 RECOMMENDATIONS

1. Environmental considerations: All testing was performed at standard conditions of temperature and relative humidity. The effect of increased temperature and humidity were not investigated which could further lower compression strength values.

2. Box style variation: All testing was performed on regular slotted containers (RSC). More corrugated box sizes and styles need to be tested to see if these trends are still valid.

4. Determine the reduction of compression strength of boxes through other routes especially in the southern part of the country where higher temperature and humidity could further decrease compression performance.

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APPENDIX

Table A1 - Compression and Deflection Data of Control Small Boxes.

Small Boxes : 12.5" x 9.5" x 5.75"; 30 lbs.

Sample ID	Peak Force (lb)	Deflection (in)	Date
1	522	0.29	9/22/95
2	595	0.28	9/22/95
3	601	0.30	9/22/95
4	616	0.28	9/22/95
5	616	0.26	9/22/95
6	566	0.33	9/22/95
7	628	0.32	9/22/95
8	613	0.39	9/22/95
9	597	0.37	9/22/95
10	613	0.24	9/22/95
Average	596.7	0.31	
Std. Deviation	31.3	0.05	
Min	522.0	0.24	
Max	628.0	0.39	

Table A2 - Compression and Deflection Data of Small Boxes shipped from East Lansing, MI to Pleasanton, CA.

Small Boxes : 12.5" x 9.5" x 5.75"; 30 lbs.

Sample ID	Peak force (lb)	Deflection (in)	Testing Date	Shipment Date
1	186.8	0.31	9/14/95	9/12/95
2	150.2	0.33	9/14/95	9/12/95
3	321.8	0.55	9/19/95	9/12/95
4	434.8	0.56	9/19/95	9/13/95
5	305.5	0.33	9/19/95	9/13/95
6	215.1	0.54	9/19/95	9/13/95
7	347.0	0.47	9/22/95	9/18/95
8	388.5	0.42	9/22/95	9/18/95
9	240.5	0.39	9/22/95	9/19/95
10	297.6	0.73	9/22/95	9/19/95
11	219.0	0.53	9/22/95	9/19/95
12	278.6	0.44	9/22/95	9/20/95
13	218.8	0.59	10/3/95	9/25/95
14	206.8	0.45	10/3/95	9/25/95
15	308.0	0.36	10/3/95	9/26/95
Average	274.6	0.47		
Std. Deviation	79.0	0.12		
Min	150.2	0.31		
Max	434.8	0.73		

Table A3 - Compression and Deflection Data of Small Boxes shipped from Pleasanton, CA to East Lansing, MI .

Small Boxes : 12.5" x 9.5" x 5.75"; 30 lbs.

Sample ID	Peak force (lb)	Deflection (in)	Testing Date	Shipment Date
1	198	0.25	9/19/95	9/18/95
2	213	0.33	9/19/95	9/18/95
3	228	0.31	9/21/95	9/20/95
4	277	0.40	9/21/95	9/20/95
5	280	0.49	9/21/95	9/20/95
6	218	0.32	9/21/95	9/20/95
7	256	0.41	9/26/95	9/25/95
8	84	0.22	9/26/95	9/25/95
9	145	0.37	9/26/95	9/25/95
10	334	0.31	9/28/95	9/27/95
11	298	0.21	9/28/95	9/27/95
12	291	0.30	9/28/95	9/27/95
13	240	0.45	10/5/95	10/4/95
14	184	0.36	10/5/95	10/4/95
15	344	0.29	10/5/95	10/4/95
Average	239.3	0.33		
Std. Deviation	69.9	0.08		
Min	84.0	0.21		
Max	344.0	0.49		

Table A4 - Compression and Deflection Data of Small Boxes tested for ISTA.

Small Boxes : 12.5" x 9.5" x 5.75"; 30 lbs.

Sample ID	Peak Force (lb)	Deflection (in)	Date
1	297	0.19	9/29/95
2	259	0.25	9/29/95
3	287	0.33	9/29/95
4	298	0.36	9/29/95
5	200	0.35	9/29/95
6	268	0.38	9/29/95
7	268	0.28	9/29/95
8	272	0.20	9/29/95
9	268	0.24	9/29/95
10	200	0.28	9/29/95
Average	261.7	0.29	
Std. Deviation	35.0	0.07	
Min	200.0	0.19	
Max	298.0	0.38	

Table A5 - Compression and Deflection Data of Control Medium Boxes.

Medium Boxes : 12.5" x 12.5" x 12.5", 50 lbs.

Sample ID	Peak Force (lb)	Deflection (in)	Date
1	1106	0.45	9/22/95
2	977	0.35	9/22/95
3	1003	0.40	9/22/95
4	868	0.44	9/22/95
5	924	0.33	9/22/95
6	836	0.34	9/22/95
7	1006	0.37	9/22/95
8	915	0.35	9/22/95
9	888	0.52	9/22/95
10	885	0.34	9/22/95
Average	940.8	0.39	
Std. Deviation	81.5	0.06	
Min	836.0	0.33	
Max	1106.0	0.52	

Table A6 - Compression and Deflection Data of Medium Boxes shipped from East Lansing, MI to Pleasanton, CA.

Medium Boxes : 12.5" x 12.5" x 12.5"; 50 lbs.

Sample ID	Peak force (lb)	Deflection (in)	Testing Date	Shipment Date
1	456.7	0.35	9/14/95	9/12/95
2	302.4	0.23	9/14/95	9/12/95
3	390.5	0.80	9/19/95	9/13/95
4	429.8	0.41	9/19/95	9/13/95
5	0.0	0.00	9/19/95	9/13/95
6	405.1	0.28	9/22/95	9/19/95
7	331.7	0.42	9/22/95	9/19/95
8	343.0	0.66	9/22/95	9/19/95
9	451.4	0.43	9/22/95	9/20/95
10	518.0	0.41	9/22/95	9/18/95
11	0.0	0.00	9/22/95	9/18/95
12	0.0	0.00	9/22/95	9/18/95
13	316.0	0.36	10/3/95	9/25/95
14	617.3	0.35	10/3/95	9/25/95
15	361.9	0.33	10/3/95	9/26/95
Average	328.3	0.34		
Std. Deviation	188.4	0.22		
Min	0.0	0.00		
Max	617.3	0.80		

Table A7 - Compression and Deflection Data of Medium Boxes shipped from Pleasanton, CA to East Lansing, MI.

Medium Boxes : 12.5" x 12.5" x 12.5"; 50 lbs.

Sample ID	Peak force (lb)	Deflection (in)	Testing Date	Shipment Date
1	444	0.47	9/19/95	9/18/95
2	383	0.43	9/19/95	9/18/95
3	292	0.29	9/21/95	9/20/95
4	331	0.45	9/21/95	9/20/95
5	331	0.61	9/21/95	9/20/95
6	530	0.34	9/26/95	9/25/95
7	239	0.60	9/26/95	9/25/95
8	147	0.54	9/26/95	9/25/95
9	412	0.34	9/26/95	9/25/95
10	336	0.31	9/28/95	9/27/95
11	124	0.21	9/28/95	9/27/95
12	298	0.34	9/28/95	9/27/95
13	354	0.33	10/5/95	10/4/95
14	381	0.41	10/5/95	10/4/95
15	415	0.47	10/5/95	10/4/95
Average	334.5	0.41		
Std. Deviation	106.7	0.12		
Min	124.0	0.21		
Max	530.0	0.61		

Table A8 - Compression and Deflection Data of Medium Boxes tested for ISTA.

Medium Boxes : 12.5" x 12.5" x 12.5", 50 lbs.

Sample ID	Peak Force (lb)	Deflection (in)	Date
1	500	0.38	10/2/95
2	624	0.33	10/2/95
3	371	0.26	10/2/95
4	122	0.11	10/2/95
5	353	0.20	10/2/95
6	491	0.33	10/2/95
7	463	0.26	10/2/95
8	459	0.36	10/2/95
9	460	0.33	10/2/95
10	586	0.35	10/2/95
Average	442.9	0.29	
Std. Deviation	139.9	0.08	
Min	122.0	0.11	
Max	624.0	0.38	

Table A9 - Compression and Deflection Data of Control Large Boxes.

Large Boxes : 21.25" x 19" x 13.25", 80 lbs.

Sample ID	Peak Force (lb)	Deflection (in)	Date
1	1112	0.31	9/22/95
2	1038	0.38	9/22/95
3	1042	0.36	9/22/95
4	1123	0.33	9/22/95
5	1076	0.34	9/22/95
6	950	0.36	9/22/95
7	1027	0.43	9/22/95
8	1091	0.38	9/22/95
9	1121	0.33	9/22/95
10	1153	0.43	9/22/95
Average	1073.3	0.37	
Std. Deviation	60.1	0.04	
Min	950.0	0.31	
Max	1153.0	0.43	

Table A10 - Compression and Deflection Data of Large Boxes shipped from East Lansing, MI to Pleasanton, CA.

Large Boxes : 21.25" x 19" x 13.25"; 80 lbs.

Sample ID	Peak force (lb)	Deflection (in)	Testing Date	Shipment Date
1	506.6	0.26	10/18/95	10/10/95
2	160.6	0.55	10/18/95	10/10/95
3	218.7	0.79	10/18/95	10/10/95
4	153.0	0.59	10/18/95	10/10/95
5	407.3	0.68	10/18/95	10/10/95
6	179.1	0.60	10/18/95	10/10/95
7	218.4	0.80	11/16/95	10/15/95
8	422.5	0.38	11/16/95	10/15/95
9	345.6	0.80	11/16/95	10/15/95
10	359.3	0.81	11/16/95	10/15/95
11	181.7	0.58	11/16/95	10/15/95
12	142.3	0.80	11/16/95	10/15/95
13	290.6	0.75	12/1/95	11/16/95
14	256.8	0.75	12/1/95	11/16/95
15	386.5	0.61	12/1/95	11/16/95
Average	281.9	0.65		
Std. Deviation	115.6	0.17		
Min	142.3	0.26		
Max	506.6	0.81		

Table A11- Compression and Deflection Data of Large Boxes shipped from Pleasanton, CA to East Lansing, MI .

Large Boxes : 21.25" x 19" x 13.25", 80 lbs.

Sample ID	Peak force (lb)	Deflection (in)	Testing Date	Shipment Date
1	234	0.52	10/9/95	10/6/95
2	300	0.70	10/9/95	10/6/95
3	434	0.36	10/9/95	10/6/95
4	313	0.71	10/9/95	10/6/95
5	206	0.79	10/9/95	10/6/95
6	368	0.60	10/9/95	10/6/95
7	0	0	11/21/95	11/20/95
8	0	0	11/21/95	11/20/95
9	410	0.55	11/21/95	11/20/95
10	421	0.61	11/21/95	11/20/95
11	485	0.69	11/21/95	11/20/95
12	448	0.51	11/21/95	11/20/95
13				
14				
15				
Average	301.6	0.50		
Std. Deviation	164.8	0.26		
Min	0.0	0.00		
Max	485.0	0.79		