PLACE IN RETURN BOX to remove this checkout from your record.
TO AVOID FINES return on or before date due.
MAY BE RECALLED with earlier due date if requested.

DATE DUE	DATE DUE	DATE DUE
C5 02 2004		
DEC 1 8 2005 0 1 0 6	1 0	

DEVELOPMENT OF CORRUGATED FIBERBOARD PERFORMANCE SPECIFICATION FOR BOXES CONTAINING "FLOWABLE" PRODUCTS

By

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ABSTRACT

DEVELOPMENT OF CORRUGATED FIBERBOARD PERFORMANCE SPECIFICATION FOR BOXES CONTAINING "FLOWABLE" PRODUCTS

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This study investigated the corrugated fiberboard specification that are recommended in the Fibre Board Association Handbook as part of Item 222 of the National Motor Freight Classification for shipping flowable items such as fasteners, nuts, bolts and printed paper using single parcel shipping environment (UPS, FedEx, USPS). Three different box sizes were selected to hold two types of flowable products: Box A – 9.5" x 9.5" x 7.5" containing 55 lbs of steel nuts, Box B – 7.5" x 7.5" x 18" containing 35 lbs of clay-coated paper, and Box C – 18" x 12" x 12" containing 97 lbs of clay-coated paper. Boxes were fabricated from six different grades of corrugated fiberboard: 150 lb/sq.in. B-flute, 175 lb/sq.in. C-flute, 200 lb/sq.in. C-flute, 275 lb/sq.in. C-flute, 275 lb/sq.in. BC-flute, and 350 lb/sq.in. BC-flute. The performance of boards was evaluated by laboratory test using ISTA Project 3C Version Date: June, 1999, and the actual shipment using UPS 2nd Day Air delivery service between MI and CA. The study found that the Project 3C does not represent the damage levels found in field shipment. The existing specifications (Item 222) do not provide adequate containment of these types of products in these environments. This study recommends to double the requirements for bursting strength when such items need to be shipped in the single parcel environment and to limit the maximum package weight to 35 lb.

ACKNOWLEDGEMENTS

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A special thanks to Mr. Chad Thomson (the United Parcel Service) for providing us a delivery service during the actual shipment. Erik Knudsen (Agilent Technologies, Inc.) for colleting data and shipping the samples back during those actual shipments.

I would like to thank all friends in the School of Packaging, especially Jagjit (Jay) Singh, for the assistance and friendship during this course of study; and Michelle Ryan, for correcting my writing. Finally, I would like to thank my family, for the encouragement throughout the program.

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1. INTRODUCTION

Recent business practices such as Business-to-Customer (B2C), e-commerce, just in time, and maintaining minimum inventory, often cause companies to depend significantly on express delivery services such as next-day, two-day, 2-3 day, etc. These practices incorporate a shipping environment known as single parcel shipping. Many packages can easily be delivered in this shipping environment without any damage. Single parcel carriers such as the United Parcel Service (UPS), Federal Express (FedEx), and the United States Postal Service (USPS), however, found that corrugated boxes made from the board specification recommended in Item 222 [1] could cause significant problems when containing heavy flowable products such as fasteners, nuts, bolts, and printed paper.

As the number of packages shipped through the single parcel shipping environment increases, many unusual products such as flowable products have opportunities to be shipped in this environment as well. When a package containing one of these flowable products is damaged, the contents might spill out. The products and/or the damaged package may block or jam the sorting line and stop the automatic conveyer or sorting equipment of the parcel carrier. This problem may only require the operator to clean the line and restart the process. However, In the worst-case scenario, the products may fall into the critical path of the line or certain machine, requiring the operator to spend an extended period of time in fixing the problem. Since a substantial amount of packages are carried through these facilities, any time spent fixing the problem can result in a great financial loss to the carriers. Therefore, single parcel carriers are now looking forward to a performance specification of corrugated boxes containing flowable products.

1.1. Single Parcel Shipping Environment

In a single parcel shipping environment, carriers such as UPS and FedEx have adopted an automated, high-speed operation into their delivery systems. Although packages delivered in this environment rarely experience a long-term warehouse stacking load. The differences in size, shape, and weight of the packages that enter into this shipping environment lead to a mixed load distribution system and a less than truckload environment (LTL). Each package experiences the most severe condition from traveling in random orientation and encounters dynamic loads on any surface [2, 3]. These harsh conditions deteriorate the performance of packages and can cause failure of the packages to protect and hold their contents [4, 5, 6, 7, 8, 9]. Based on this observation, carriers recommend that a package to be delivered in this shipping environment pass a certain performance or pre-shipment test. Additionally, single parcel carriers also specify the package size, weight limitation, and a variety of products they will deliver in their guidelines. For example, UPS accepts packages that weigh up to 150 lbs and considers any package weighing more than 70 lb as a heavy package that required a special label (Figure 1.1.). If a package is heavier than a specified weight limit, a label must be attached to it. The label alerts the operator working with this package to pay more attention to safely and properly handling it [10].

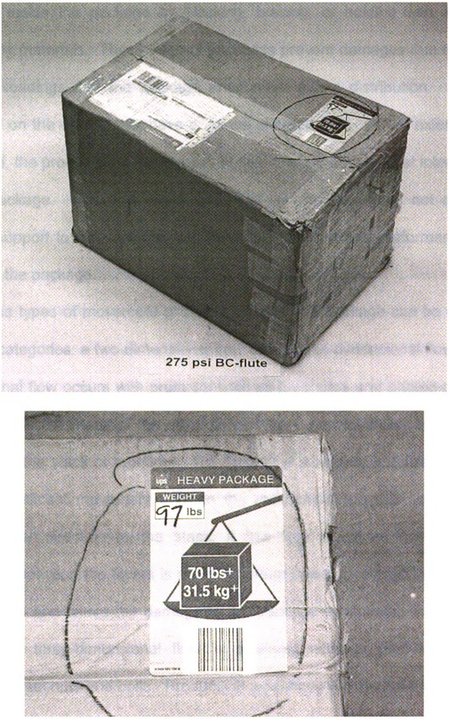


Figure 1.1. A package with heavy package label

1.2. Flowable Product

Manufacturers or shippers of products tend to limit the movement of products inside the package by blocking, bracing, or holding with inserts or cushioning materials. These internal packages prevent damages due to several dynamic loadings that the package encounters during distribution. Flowable products, on the other hand, have a unique characteristic. When external force is applied, the products act like a mass of fluid and will flow against internal walls of the package. This flow characteristic of the products does not contribute internal support to the package, and therefore, the package performance relies solely on the package.

The types of movement of flowable items in a package can be classified into two categories: a two-dimensional flow and a three-dimensional flow. A two-dimensional flow occurs with products such as brochures and printed-paper. In this case, the flat shape of the products causes it to move easily in the parallel direction of the stack of products. The force that is applied parallel to the layer causes significant movement. When the mechanical force is applied in the perpendicular direction to the stack, it has little effect on the movement. Movement between the layers is more important because it could move against the package and cause the damage to the package eventually. In the second category, a three-dimensional flow is observed with on products such as fasteners, steel nuts and bolts. Products in a package are always surrounded by voids. These voids make it possible for the products to move. When any external dynamic load such as impact, compression, or vibration is applied to the package, products move against each other and package, and must adjust their position to reconcile the load.

Several studies indicate that a package delivered in a single parcel shipping environment experienced a number of dynamic loadings such as multiple impacts from drops, tosses, and kicked [11, 12, 13]. These impacts could cause flowable items to move abruptly against themselves and the package. Stress develops in the package system and stress concentration develops on the edge and corner of the corrugated box. If this stress exceeds the tolerable limit of the corrugated board (board performance), it will cause damages such as cracks or tears on corrugated box and tape. Figure 1.2. shows major damages found on corrugated boxes containing flowable products; edge and corner of box tear out, tape tears and breaks. In addition, flowable items such as fasteners, steel nuts and bolts, have sharp edges and corners that can puncture the corrugated board weaken it. Damages from punctures also lead to tearing on the face of box. Some forms of packaging such as woven polypropylene bags or burlap bags may be able to contain flowable products better than corrugated boxes. However, those package types (bags) that do not have a specific shape are not preferred by single parcel carriers (UPS, FedEx) since they cannot hold a flat label with the bar code on the top. These carriers prefer boxes with flat bar code labels on top to allow for high-speed automatic sortation. Moreover, the unstable shape and heavy bag makes itself more difficult to handle. These problems are considering by single parcel carriers whether the corrugated shipping containers that comply with current freight rules will provide sufficient performance to use with flowable products.

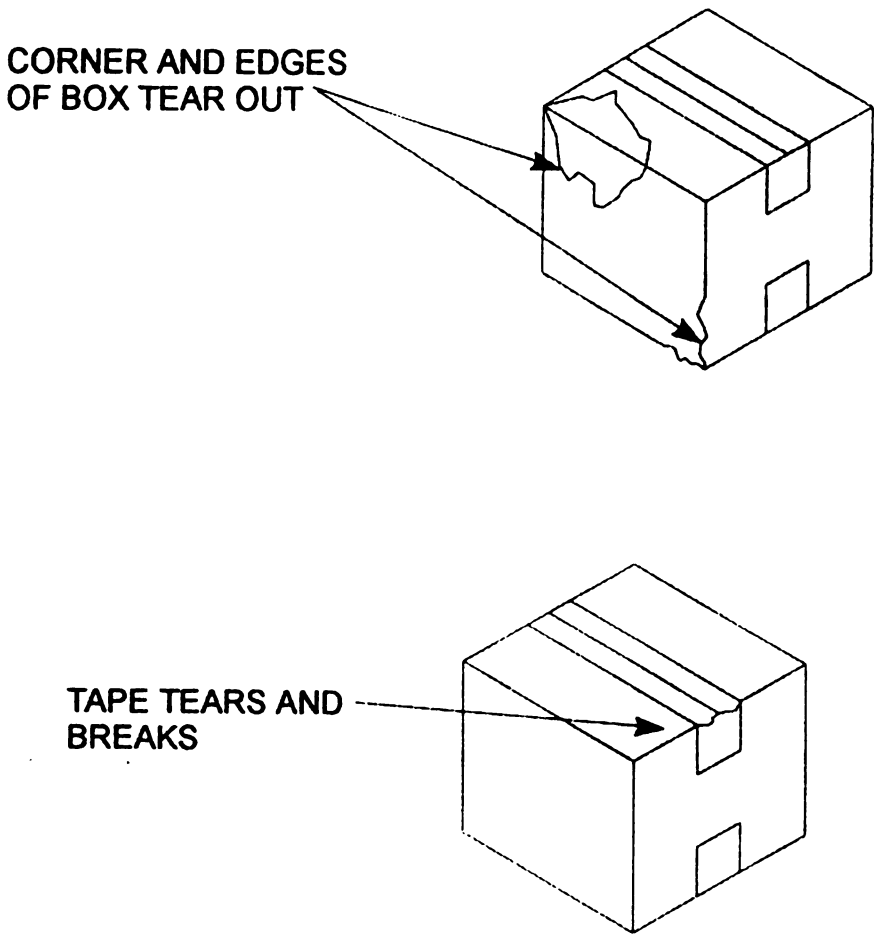


Figure 1.2. Damages found on corrugate box containing flowable product

1.3. Corrugated Board Performance Specifications

Corrugated boxes are widely used as shipping containers because they have several advantages over other type of containers. For instance, they are lightweight at a larger volume and provide reasonable strength. Corrugated boxes can be made from a wide range of board qualities to fit different applications. They save freight space during transportation of empty boxes because they are generally shipped in knocked-down form. A corrugated fiberboard can be made from two to several sheets of papers. For example, a single-face corrugated fiberboard is made from a flat sheet of paper (liner) glued with another sheet of corrugated paper (medium). A double-face or single-wall corrugated fiberboard (SW) is made from two flat sheets glued on both sides of corrugated medium. A double-wall corrugated fiberboard (DW) is made from three sheets of liners and two sheets of corrugated mediums. Corrugated fiberboards are also designated as A, B, C, and E by their flute size, which is defined by flute height and the number of flutes per unit length. Table 1.1. shows specifications of each flute [14].

Table 1.1 Specifications of corrugated fiberboard flutes

Flute	Flute Height, inch	Number of flutes per foot	Take-Up Factor
A	0.167	36	1.53
B	0.089	51	1.33
C	0.130	42	1.43
E	0.036	96	1.20

Flute size contributes to several strength properties of corrugated fiberboard. For example, A-flute provides excellent cushioning properties and compression strength while B-flute provides better flat crush strength. Since A-flute requires more corrugated medium (high take-up factor), it is now difficult to find sources of A-flute. C-flute is widely used for corrugated shipping containers because it compromises the overall properties between A-flute and B-flute. E-flute is an alternative to the folding carton board for retail boxes because it provides an excellent choice for high quality post printing and has better strength. Although other flute sizes are available, they have very limited applications. Corrugated boxes used as shipping containers must be made from materials that meet certain performance specifications. In the US, carriers generally establish some restrictions to limit their liabilities that may occur from loss or damage of their shipments. The most common restrictions are National Motor Freight Classification (NMFC) Item 222, issued by the National Classification Committee of the National Motor Freight Traffic Association; and Uniform Freight Classification (UFC) Rule 41, issued by the National Railroad Freight Committee of the Western Railroad Association. For a single parcel shipment, Item 222 has been adopted to specify the minimum board performance required for boxes that will be transported by these carriers. Table 1.2. shows the minimum board specification required for corrugated shipping boxes [1]. Carriers 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 specifications.

To get a proper corrugated shipping box from the table in Item 222, shippers need to know their product's weight and dimensions of the box they intend to ship. Next, they have to compare their estimated gross weight of package with the weight in the first column (Maximum Weight of Box and Contents) and choose the row that has a value equal to or greater than their product's weight. They then have to calculate the outside dimensions of their box (the summation of the box length, width, and depth or height) and compare it with the value in the second column (Maximum Outside Dimensions) of the same row. If the outside dimension of the box does not exceed the value in the table, users can choose the corrugated board that provides either bursting test value (TABLE A) or edge crush test value (TABLE B) from the same row for their shipping box. On the contrary, if the outside dimension of box is greater than the value in the Maximum Outside Dimensions of the same row, shippers have to choose the board from the next row that has Maximum Outside Dimensions values equal to or greater than the outside dimensions of their box.

Even after shippers choose the corrugated board that complies with the freight rule for their shipping box, they are not certain that the package will be shipped to their customer safely. To increase their confidence, several shippers perform additional performance tests (pre-shipment tests) such as an integrity test or simulation test with their package.

Table 1.2. Minimum board specification required by Item 222

		TABLE A		TABLE B
Maximum Weight of Box and Contents (lb)	Maximum Outside Dimensions, Length, Width and Depth Added (in)	Minimum Bursting Test, Single-wall, Double-wall ($lb/in.^2$)	Minimum Combined Weight of Facing(s) ($lb/1000 ft.^2$)	Minimum Edge Crush Test (ECT) (lb/in. width)
SINGLE-WALL CORRUGATED FIBREBOARD BOXES				
20	40	125	52	23
35	50	150	66	26
50	60	175	75	29
65	75	200	84	32
80	85	250	111	40
95	95	275	138	44
120	105	350	180	55
DOUBLE-WALL CORRUGATED FIBREBOARD BOXES				
80	85	200	92	42
100	95	275	110	48
120	105	350	126	51
140	110	400	180	61
160	115	500	222	71
180	120	600	270	82

1.4. The ISTA Project 3C

Currently there are several simulation tests available for shippers to evaluate their packages performance before the actual shipment. The International Safe Transit Association (ISTA) and the American Society for Testing and Materials (ASTM) are two well-known organizations for their simulation test procedures: the ISTA test series and ASTM D 4169. These tests intend to provide logical procedures for shippers to evaluate their packages prior to the actual shipment. For example, ISTA organizes its test protocols into 5 series, from common interest in Integrity Test in the 1 Series to the most intensive investigation in the Focused Simulation Test in the 5 Series.

In 1999, ISTA released test Project 3C to be used as a performance test of individual packages that weigh less than 150 lbs (68.3 kg) and are delivered in a single parcel shipping environment such as FedEx, UPS, and USPS. This project is categorized in the 3 Series or the General Simulation Test. The test protocol was designed to generate the general damage-producing forces and conditions of transport environments. The project was revised with minor changes in 2000. After intensive use and reviews by several parties, this test project was adopted as Test Procedure 3C by the end of year 2000. There is a minor change in the package orientation used during the third sequence in vibration test [15, 16]. The test project consists of five required test elements and one optional test element.

- Atmospheric preconditioning (required)
- Atmospheric condition (optional)

- Shock or drop test (required)
- Compression test (required)
- Random vibration test (required)
- Shock or drop test (required)

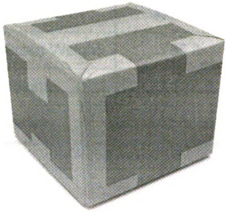
1.5. Objectives of This Study

1. To investigate the effects of "flowable" products on corrugated board box performance in single parcel shipping environment.
2. To verify the reliability of using general simulation (ISTA Project 3C) with the actual single parcel shipment for the products.
3. To establish the corrugated board performance specification for a box containing flowable products.

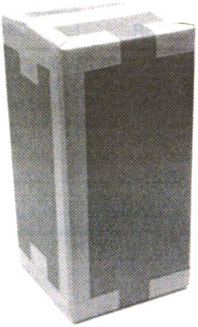
2. EXPERIMENTAL DESIGN

Six commercial corrugated boards, 150 lb/sq.in. single-wall B-flute, 175 lb/sq.in. single-wall C-flute, 200 lb/sq.in. single-wall C-flute, 275 lb/sq.in. single-wall C-flute, 275 lb/sq.in. double-wall BC-flute, and 350 lb/sq.in. double-wall BC-flute, were used in this study. Boxes made from these boards were prepared in three different sizes (Box A, B, and C, Figures 2.1.). The dimension of Box A is based on the current commercial size of a box containing 55 lbs (25 kg) of steel nuts. The dimensions of Box B and Box C are based on the package weight and the maximum utilization of standard 8 ft by 4 ft corrugated board. The dimensions and content configurations of these boxes are shown in Table 2.1. After being filled with designated products, the boxes were closed with reinforce paper tape and then pre-conditioned. They were then subjected to the laboratory simulation test recommended in ISTA Project 3C.

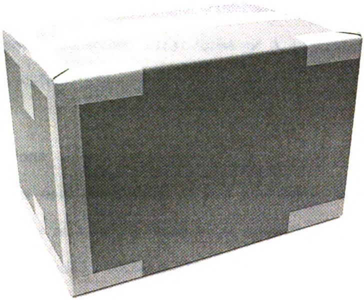
In addition to the lab simulation test, selected samples were sent through an actual shipment. Packages were shipped between the School of Packaging, East Lansing, MI and Agilent Technologies, Inc., Santa Rosa, CA by UPS 2nd Day Air delivery service. The boards used in this study were determined for their two performance specifications: burst test and edge crush test. Results from the laboratory simulation test and the actual shipment were compared for correlation, and the performance specifications of corrugated board were evaluated. A study of the presence of flaps gap and the effect of different kinds of tape used for closing the box were added to explain these certain damages.



Box A



Box B



Box C

Figure 2.1. Packages used in this study

Table 2.1 Boxes dimensions, contents, and configurations

	Box A	Box B	Box C
Box Style	RSC	CSSC	RSC
Dimension	9.5" x 9.5" x 7.5"	7.5" x 7.5" x 18"	18" x 12" x 12"
Content	steel nuts	clay-coated paper	clay-coated paper
Gross Weight	55 lb	35 lb	97 lb
Volume	0.4 cu.ft.	0.6 cu.ft.	1.5 cu.ft.
Density	140 lb/cu.ft	60 lb/cu.ft.	64 lb/cu.ft.

2.1. Samples Preparation

Six different commercial boards were cut using a sample cutting table, ArtiosKongsberg PremiumLine™ 1930 (Figure 2.2.) and fabricated into three different boxes. Samples were filled with products, closed and sealed with six pieces (H-sealed) of reinforced paper tapes or a closure method 2C5 in accordance with ASTM D1974.

2.2. Test Conditions

All samples were pre-conditioned at a temperature of 73°F and 50% relative humidity for at least 12 hours in accordance with the atmospheric conditioning recommended in ASTM D-4332.

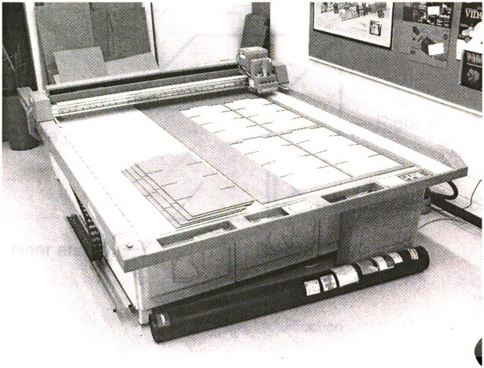


Figure 2.2. The ArtiosKongsberg PremiumLine^{TM} 1930 sample cutting table

2.3. The ISTA Project 3C

The test project requires three specimens to complete the test of each sample. Details of the tests performed on each specimen are noted in the following test procedures. After subjected to pre-conditioning, the faces, edges, and corners of each box were identified (Figure 2.3.).

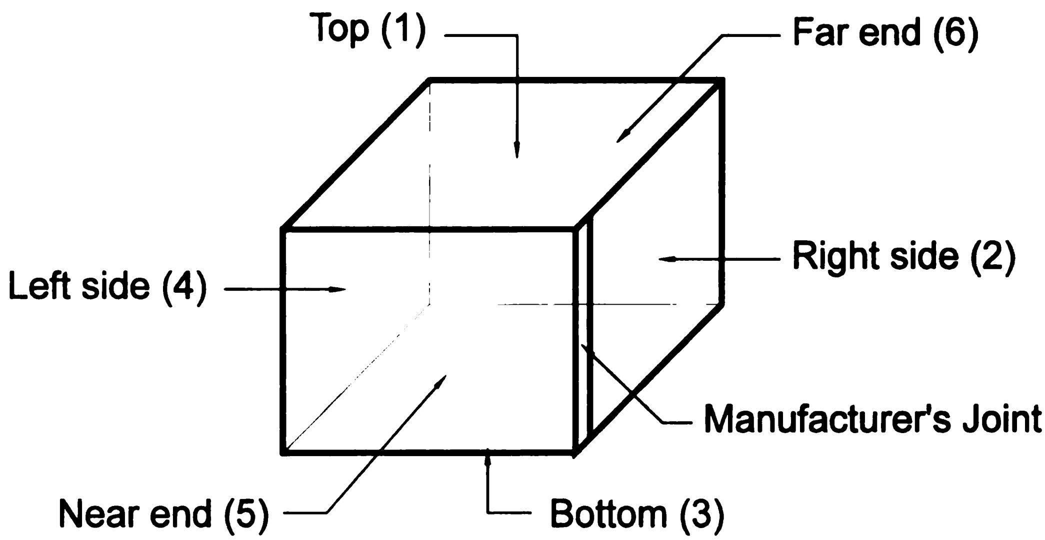


Figure 2.3. Box identification

2.3.1. Drop test (first set)

After identification of the faces, edges, and corners, samples were subjected to drop tests (the first set). Drop heights are varied by the package weight (Table 2.2.). In this study, both Box A and Box B were tested at 15 inches of drop height. Box C was tested at 12 inches of drop height. Samples were subjected to additional hazards for drop numbers six and seven. At drop number six, the specimen was tested at double height (30 inches for Box A and Box B, and 24 inches for Box C). The specimen was tested on a hazard block (Figure 2.4.) for drop number seven, at the same drop height as tested in drop numbers 1 to 5. Each specimen was subjected to different drop orientations as shown in Table 2.3. Figure 2.5. shows the Precision Drop Tester that was used to perform this test. After the test, samples were inspected for their damages.

Table 2.2. Drop height recommended in ISTA Project 3C

Package Weight	Drop Height
Less than 50 (< 22.7 kg)	15 in. (381 mm)
50 – 100 lb (22.7 – 45.4 kg)	12 in. (305 mm)
More than 100 – 150 lb (> 45.4 – 68 kg)	9 in. (229 mm)

Table 2.3. Drop orientations for each specimen in drop test (first set) recommended in ISTA Project 3C

Drop Number	Specimen no. 1	Specimen no. 2	Specimen no. 3
1	face 3	face 4	face 6
2	face 3	face 4	face 6
3	face 3	face 4	face 6
4	corner 3-4-6	corner 2-3-6	corner 1-4-6
5	edge 3-6	edge 4-5	edge 1-6
6	face 3 at double height	face 4 at double height	face 6 at double height
7	face 3 on hazard	face 4 on hazard	face 6 on hazard

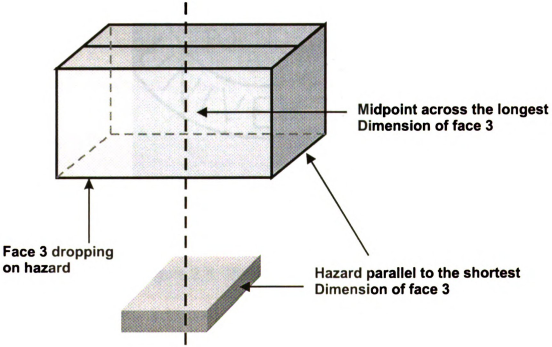


Figure 2.4. Drop on hazard recommended in ISTA Project 3C

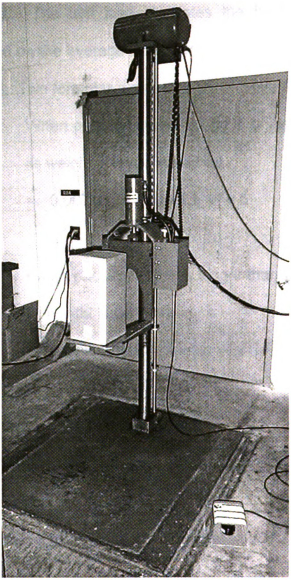


Figure 2.5. The Precision Drop Tester

2.3.2. Compression Test

After the drop test (first set), each specimen was subjected a to compression test with a predetermined load (test load) which was released after it reached this load. The test load simulates the load that occurs during shipment. It is based on the average freight density of 12 lb/cu.ft and the height of a trailer (108 inch). Two formulas were used to calculate the test load.

Formula One: When package's size is 2 cu.ft. or less or its weight is less than 30 lbs.

$$TL = 0.007 \times (54 - H) \times L \times W \times 5$$

Formula Two: When package's size is bigger than 2 cu.ft. or its weight is 30 lbs or more

$$TL = 0.007 \times (108 - H) \times L \times W \times 5$$

Where:

TL	=	Calculated Test Load (lbf)
H	=	Height of shipping unit (inches)
L	=	Length of shipping unit (inches)
W	=	Width of shipping unit (inches)

and

Average freight density	=	0.007 lb/cu.in
Height stacked above shipping unit	=	54 or 108 inches
Compensation factor	=	5

The test loads used for Box A, B, and C were 305 lbf, 195 lbf, and 690 lbf, respectively. After the compression test, the samples were inspected and damages were recorded.

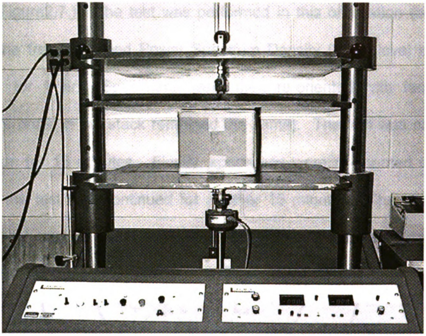


Figure 2.6. Compression Tester

2.3.3. Random Vibration Test

Specimens were placed with their bottom face (face 3) down on the vibration table. Specimen no. 1, 2, and 3 were placed in the bottom, middle, and top of stack respectively. Retaining guide rails were attached in order to maintain the test orientation of the specimens and to allow free movement in the vertical direction (Figure2.7.). The test was performed in this orientation (bottom face down) at the frequency and Power Spectrum Density (PSD) level specified in Table 2.4. for 1 hr. Specimens were then re-oriented with face 4 down (specimen's order in the stack remained the same). The test was continued in this direction for 15 minutes. Finally, specimens were re-oriented with face 3 down and the test was continued for another 15 minutes. The total vibration period for each sample was 1.5 hrs. After the time elapsed, each specimen was inspected for damages.

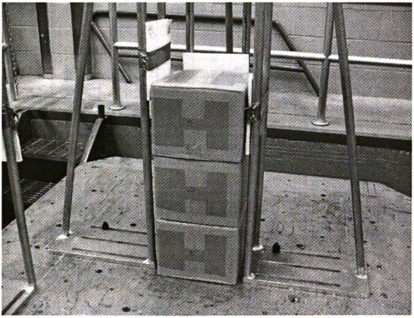


Figure 2.7. Samples on vibration table

Table 2.4. Frequency and PSD level for random vibration test

Frequency (Hz)	PSD Level (g^2/Hz)
2	0.00036
4	0.036
5	0.036
7	0.0016
11	0.013224
15	0.008004
21	0.008004
50	0.00032
100	0.00032

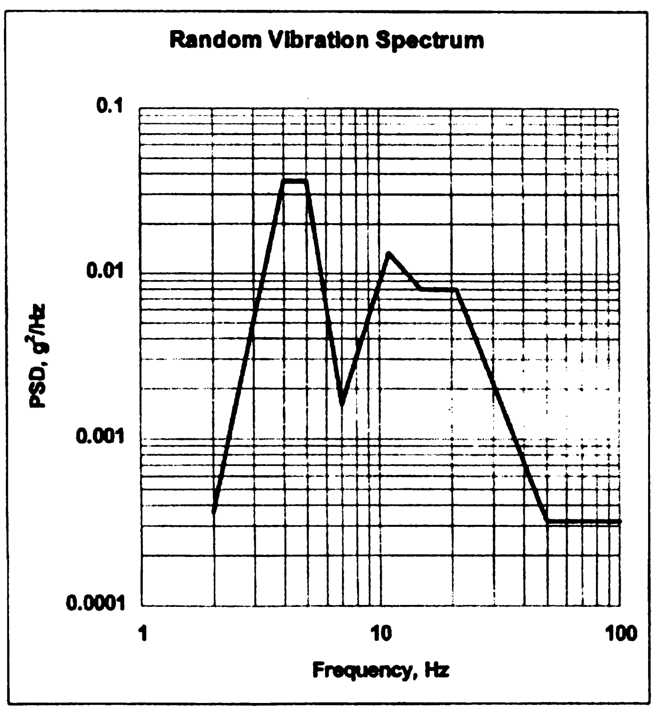


Figure 2.8. Random vibration spectrum recommend in the ISTA Project 3C

2.3.4. Drop Test (second set)

Next, specimens were tested with the second set of drop tests at the same drop heights as previously used (15 inches. for Box A and Box B, 12 inches for Box C). The last drop test (drop number 15) was performed at double the drop height (30 inches. for Box A and Box B, 24 inches for Box C). Table 2.5. shows the drop orientations for each specimen in the second set of drop tests.

Table 2.5. Drop orientations for each specimen in drop test (second set) recommended in ISTA Project 3C

Drop number*	Specimen no. 1	Specimen no. 2	Specimen no. 3
8	face 3	face 4	face 6
9	face 3	face 4	face 6
10	face 3	face 4	face 6
11	corner 2-3-5	corner 3-4-6	corner 1-2-5
12	edge 2-3	edge 3-5	edge 3-4
13	edge 2-5	edge 4-5	edge 4-6
14	face 1	face 2	face 5
15	face 1 at double height	face 2 at double height	face 5 at double height

* Drop number continues from drop test in the first set (seven drop)

2.4. Actual Shipment

Two sets of Box A, Configuration No.1 and 2., made from six commercial corrugated boards, were shipped by UPS 2nd Day Air delivery service from the School of Packaging, East Lansing, MI to Agilent Technologies Inc., Santa Rosa, CA. Boxes were inspected for damage at their destination. They were then emptied and the contents were put into new boxes, closed, and sealed with reinforced paper tape. These boxes were shipped back to the School of Packaging using the same service. They were inspected for their damages.

For Box B and Box C, only boxes made from double-wall corrugated board (275 lb/sq.in and 350 lb/sq.in BC-flute) were shipped to the same destinations using the same service as Box A. Boxes were inspected for damages at their destinations.

2.5. Material Tests (Mullen Burst Test and Edge Crush Test)

Corrugated board samples were conditioned at a temperature of 73°F and 50% relative humidity for at least 24 hr before testing. The Mullen test or burst test was performed on the Mullen Tester in accordance with Technical Association of Pulp and Paper (TAPPI), Official Test Method T-810, Bursting Strength of Corrugated and Solid Fiberboard. The edge crush test was performed on TMI Series 400 Tester in accordance with TAPPI, Official Test Method T-811, Edgewise Compressive Strength of Corrugated Fiberboard (Short Column Test).

2.6. Diagonal Compression Test

Two sets of Box A made from six boards used in this study were fabricated. Boxes were sealed with reinforced paper tape in the first set, and plastic tape in the second set. They were then compression tested in diagonal direction with the manufacturing joint (edge 2-5) set on the lower platen of the compression tester (Figure 2.9.). During the test, the box was supported on its side panels (face 2 and face 5) to maintain the diagonal direction. The supports were carefully removed when the upper platen of the compression tester touched the upper edge (edge 4-6). The deflection and load were monitored and used to analyze the damage that appeared on the previous simulation tests and actual shipment.

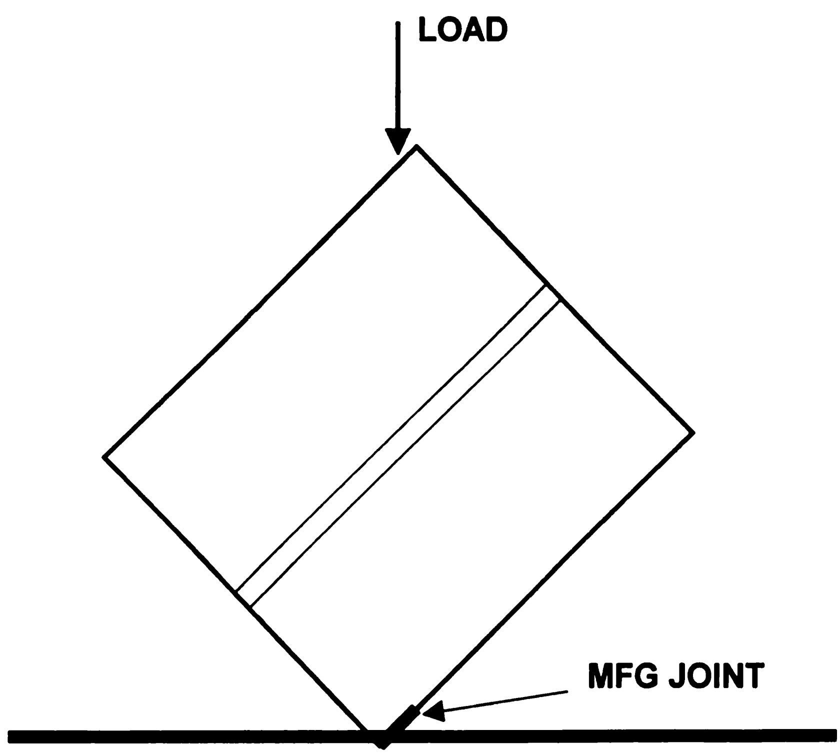


Figure 2.9. Diagonal Compression Test

3. RESULTS

Three different sizes of boxes fabricated from six commercial corrugated boards were tested using the ISTA Project 3C. Results are shown in Tables 3.1. and 3.2. Additional set of these boxes were shipped in the single parcel environment using UPS 2nd Day Air delivery service. Results are shown in Tables 3.3. and 3.4. The damage levels found in packages tested using the ISTA Project 3C and actual shipments were compared. A set of corrugated boxes reinforced with three strands of sesame tapes were also tested with the ISTA Project 3C. This modified corrugated structure was stated to have a better performance by the manufacturer (Willamette Industries, Inc., St. Paul, MN). Results are shown in Table 3.1. The corrugated boards used in this study were also tested for their material specifications (Mullen Burst Test and Edge Crush Test). Results are shown in Table 3.5. In addition, diagonal compression tests on empty boxes were also performed. The recommended modification for material specifications of corrugated boxes containing flowable products are discussed.

3.1. Results from the ISTA Project 3C

3.1.1. Box A

At the start of this study, three different internal package configurations of Box A were studied. These were: Box A with double plastic bags (Configuration No.1), Box A with internally reinforced plastic corrugated board (Configuration

No.2), and Box A with four canvas bags containing the product (Configuration No.3). All package configurations showed failure before completion of the entire sequence of tests recommended in ISTA Project 3C. Boxes were ripped open at the tape or torn on the edge before they reached the end of first set of drop tests. Most boxes failed during the edge drops (drop number 4 and 5). The details of damage observed are listed in Tables A1, A2, and A3 (Appendix A). Examples of damages found on Box A are also presented in Figure 3.1.

The subsequent tests were performed with some modification in the test procedure. At the end of each test sequence, instead of terminating the test when any damage occurred, the box was repaired with plastic tapes and the test sequence continued. This modification simulates the action when a carrier finds damage to a box during actual shipments and attempts to fix or repair it while it continues in the shipment. The additional tests were performed on Box A Configuration No. 1 with a specially strand reinforced. Details of the damages are listed in Table A4 (Appendix A). Examples of damages found on Box A and the special box are shown in Figure 3.2. Table 3.1. shows the summary of results on Box A after being tested with the ISTA Project 3C.

3.1.2. Box B

Two sets of Box B (containing clay-coated paper) were tested. In the first set, the test was terminated when any significant damage was discovered. Most boxes could not endure the entire test. Only boxes made form 350 lb/sq.in double-wall BC-flute board passed the entire test. The second set of tests was performed with some modifications during the test cycle (repair the damaged box with plastic tape at the end of each test sequence). Tests were also limited to samples made form double-wall corrugated board (275 lb/sq.in and 350 lb/sq.in BC-flute board). Table 3.2. shows the results of Box B after being tested with the ISTA Project 3C. Only boxes made form 350 lb/sq.in double-wall BC-flute were able to withstand the complete ISTA test. The details of damage found are listed in Tables A5 and A6 (Appendix A). Examples of damages found on Box B after these tests are shown in Figure 3.3.

3.1.3. Box C

Due to the high weight of this sample, the tests were limited to boxes made from double-wall corrugated board (275 lb/sq.in and 350 lb/sq.in BC-flute board). Tests were also performed with some modification (reseal the damage box with plastic tape at the end of each test sequence). All samples did not withstand the complete test project (Table 3.2.). The details of damage found are listed in Table A7 (Appendix A). Examples of damages found on Box C after the tests are shown in Figure 3.4.

Table 3.1. Results from Box A after testing with the ISTA Project 3C

Board Specification	Configuration No.			
	1*	2*	3*	1**
150 lb/sq.in SW B-flute	Fail	Fail	Fail	Fail
175 lb/sq.in SW C-flute	Fail	Fail	Fail	Fail
200 lb/sq.in SW C-flute	Fail	Fail	Fail	Fail
275 lb/sq.in SW C-flute	Fail	Fail	Fail	Fail
275 lb/sq.in DW BC-flute	Fail	Fail	Fail	Fail
350 lb/sq.in DW BC-flute	Fail	Fail	Fail	Fail
32 lb/in ECT SW C-flute	N/A	N/A	N/A	Fail

* Test was terminated when damage found on specimen.

** Box was repaired when damage found and the test was continued.

Table 3.2. Results from Box B and Box C after testing with the ISTA Project 3C

Board Specification	Box B		Box C**
	First Set*	Second Set**	
150 lb/sq.in SW B-flute	Fail	N/A	N/A
175 lb/sq.in SW C-flute	Fail	N/A	N/A
200 lb/sq.in SW C-flute	Fail	N/A	N/A
275 lb/sq.in SW C-flute	Fail	N/A	N/A
275 lb/sq.in DW BC-flute	Fail	Fail	Fail
350 lb/sq.in DW BC-flute	Pass	Pass	Fail

* Test was terminated when damage found on specimen.

** Box was repaired when damage found and the test was continued.

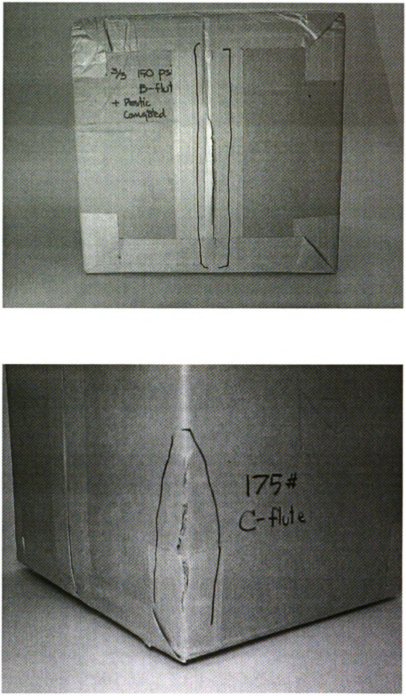


Figure 3.1. Examples of damages on Box A after testing with the ISTA Project 3C (Test was terminated when damage was found on box)

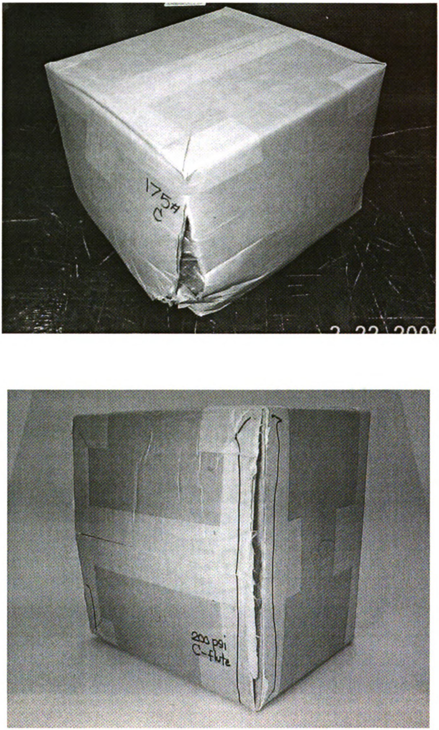


Figure 3.1. Examples of damages on Box A after tested with the ISTA Project 3C (Test was terminated when damage was found on box)

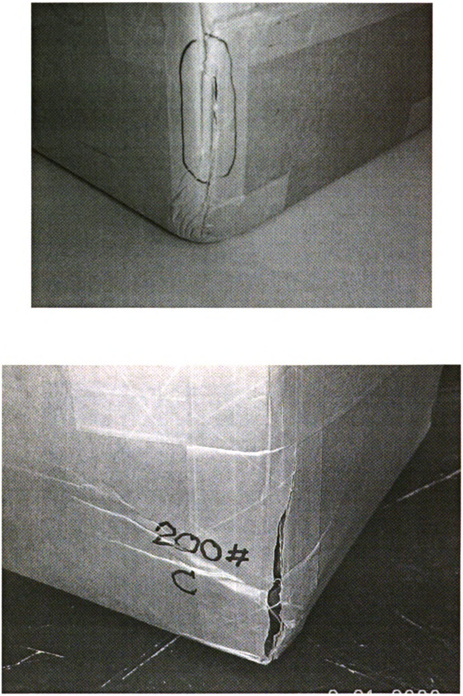
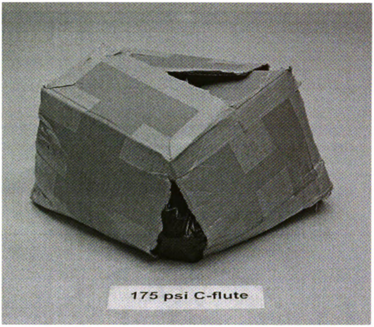


Figure 3.1. Examples of damages on Box A after tested with the ISTA Project 3C
(Test was terminated when damage was found on specimen)



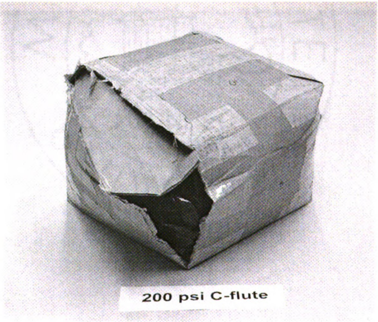
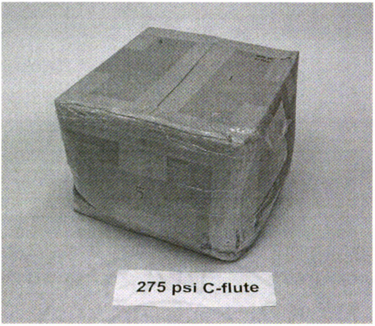


Figure 3.2. Examples of damages on Box A after being tested with the ISTA Project 3C (Box was repaired when damage was found and test was continued)



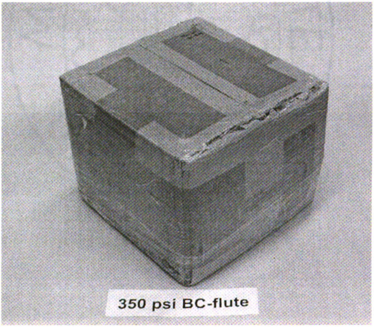


Figure 3.2. Examples of damages on Box A after being tested with the ISTA Project 3C (Box was repaired when damage was found and test was continued)

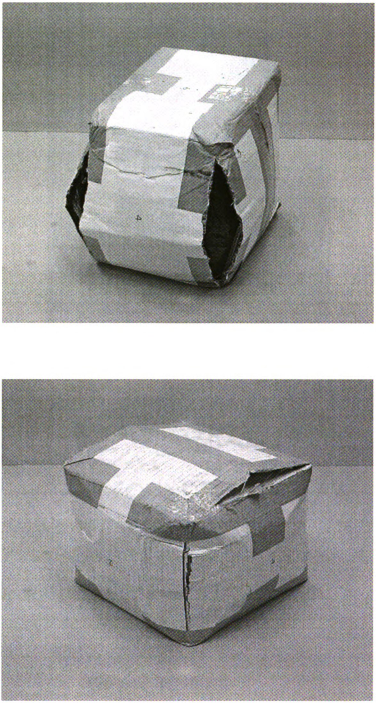
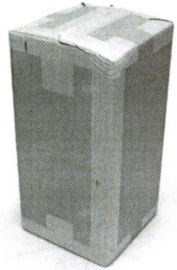


Figure 3.2. Examples of damages on Box A after being tested with the ISTA Project 3C (Box was repaired when damage was found and test was continued)



275 psi BC-flute

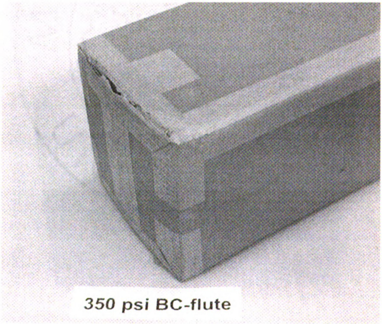
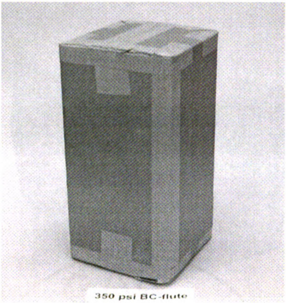


Figure 3.3. Examples of damages on Box B after testing with the ISTA Project 3C



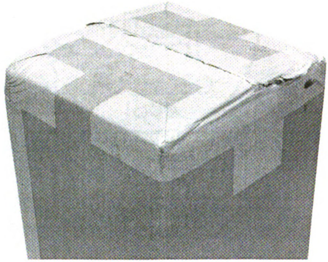
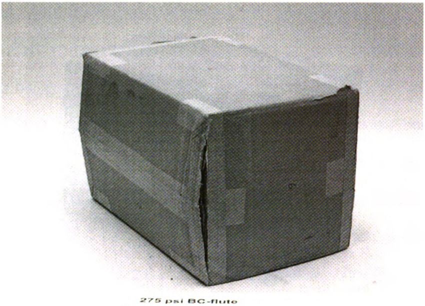


Figure 3.3. Examples of damages on Box B
after testing with the ISTA Project 3C



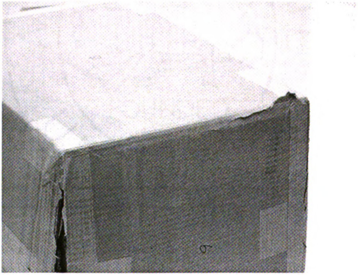
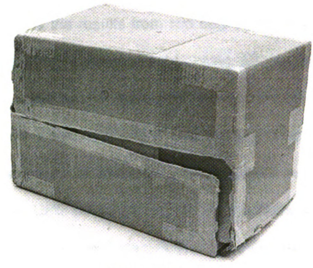


Figure 3.4. Examples of damages on Box C after testing with the ISTA Project 3C



350 psi BC-flute

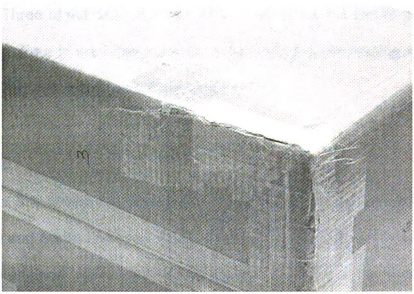


Figure 3.4. Examples of damages on Box C
after testing with the ISTA Project 3C

3.2. Results from Actual Shipments

3.2.1. Box A

Table 3.3. shows the results from two sets of Box A (Configuration No. 1 and 2) after being shipped between East Lansing, MI and Santa Rosa, CA. All boxes were in bad conditions at their destinations. Most boxes had their tape torn apart, flaps were open, and edges and corners of box were cracked and torn. They were covered with additional plastic tape all over the packages that had been applied by UPS personnel at the various hubs where the packages were sorted. Details of damages are listed in Tables A8, A9, A10, and A11 (Appendix A).

Figure 3.5. shows examples of damages on Box A after they arrived at their destinations. During these shipments, several boxes were seriously damaged. Three of the original boxes were replaced by the carrier during transit (Figure 3.6.). Four of the boxes opened during shipping and sorting and lost their contents. They did not arrive at their destinations.

3.2.2. Box B

Table 3.4. shows the results of Box B after being shipped between East Lansing, MI and Santa Rosa, CA. Only boxes made from double-wall corrugated board were shipped. About half of the samples had minor damages including short tear on tape and minor punctures on side and end panels. The details of the damage are list in Tables A12 and A13 (Appendix A). Figure 3.7. shows examples of damages on Box B after actual shipments.

3.2.3. Box C

Table 3.4. shows results of Box C after being shipped between East Lansing, MI and Santa Rosa, CA. Only boxes made from double-wall corrugated board were shipped. All boxes were seriously damaged. Most boxes had tapes on top and bottom flaps torn apart and the flaps came open. Also the edges and corners of the boxes were torn. Again most boxes were covered with additional plastic tape applied all over the packages by UPS package handlers. Details of the damage are listed in Tables A14 and A15 (Appendix A.)

Figure 3.8. shows examples of damages on Box C at their destination. Although the contents of these damaged boxes were exposed, they retained the entire contents during all shipments.

Table 3.3. Results from Box A after being shipped between MI and CA

Board Specification	Configuration No. 1 (MI to CA)	1 (CA to MI)	2 (MI to CA)	2 (CA to MI)
150 lb/sq.in SW B-flute	Fail	Fail[1]	Fail[2]	Fail
175 lb/sq.in SW C-flute	Fail[1]	Fail	Fail	Fail
200 lb/sq.in SW C-flute	Fail	Fail	Fail	Fail
275 lb/sq.in SW C-flute	Fail	Fail[1]	Fail	Fail
275 lb/sq.in DW BC-flute	Fail	Fail	Fail	Fail
350 lb/sq.in DW BC-flute	Fail	Fail	Fail[2]	N/A

[1] Some boxes were replaced by the carrier.

[2] Some boxes lost their contents and did not reach their destination.

Table 3.4. Results from Box B and Box C after being shipped between MI and CA

Board Specification	Box B MI to CA	Box B CA to MI	Box C MI to CA	Box C CA to MI
275 lb/sq.in DW BC-flute	Fail[1]	Pass[2]	Fail	Fail
350 lb/sq.in DW BC-flute	Pass	Pass[2]	Fail	Fail

[1] All boxes showed tape failure.

[2] One of the boxes failed at the tape.

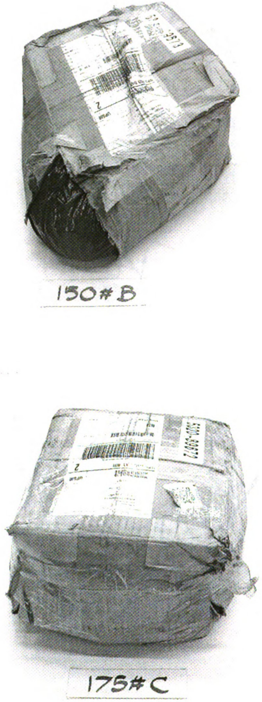


Figure 3.5. Examples of damages on Box A after shipment

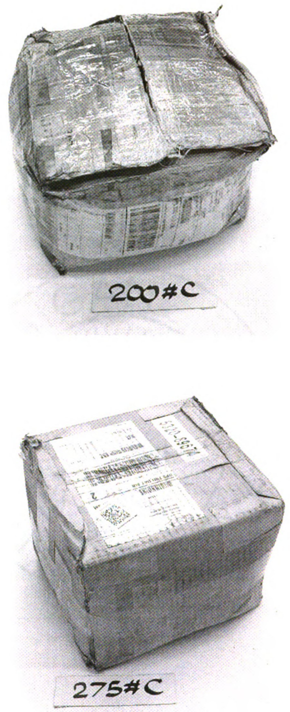


Figure 3.5. Examples of damages on Box A after shipment

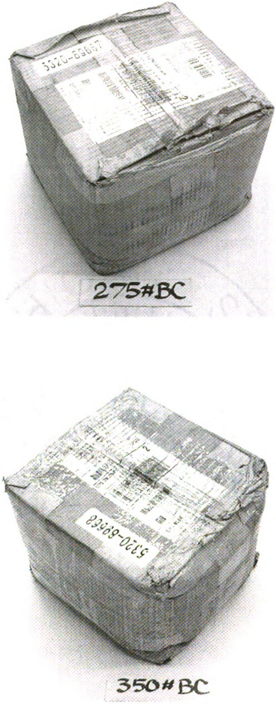


Figure 3.5. Examples of damages on Box A after shipment

Figure 3.6. Box A (left) and replacement box (right)

275 psi BC-flute

350 psi BC-flute

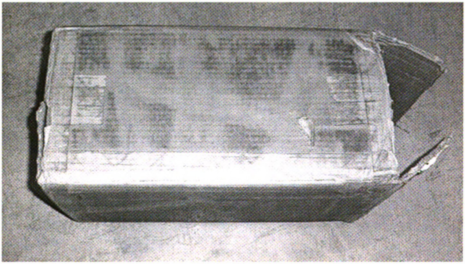
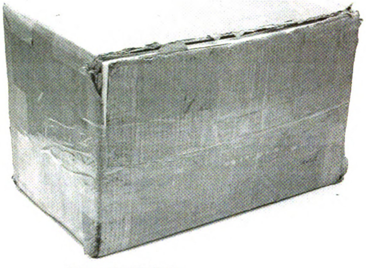


Figure 3.7. Examples of damage on Box B after shipment



275 psi BC-flute

275 psi BC-flute

Figure 3.8. Examples of damage on Box C after shipment

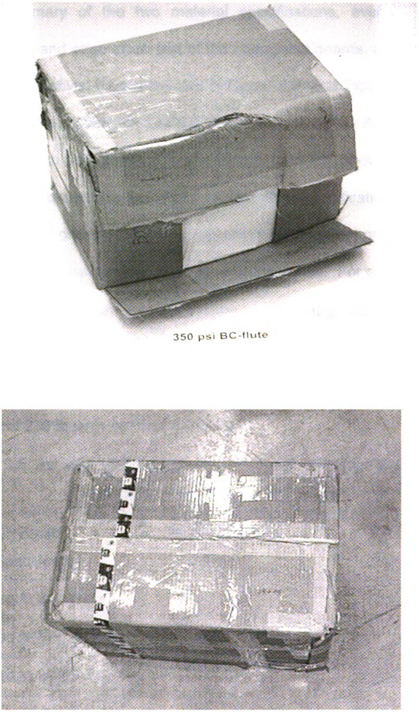


Figure 3.8. Examples of damage on Box C after shipment

3.3. Material Tests (Mullen Burst Test and Edge Crush Test)

The summary of the two material specifications, average values of bursting strength and edge crush test of the corrugated boards, are presented in Table 3.5. and graphical data presented in Figure 3.9. and Figure 3.10. Details of the tests data are provided in Table A16 and A17 (Appendix A). Results of the tests compared with the values recommended in Item 222 show no relationship or equivalence between the two board performance specifications. Moreover, the board grade recommended by the manufacturer does not guarantee that all board samples have the bursting strength value as stated. For example, the 200 lb/sq.in single-wall board used in this study had an average burst test of 251.1± 11.7 lb/sq.in and an average ECT of 27.3 ± 0.7 lb/in, whereas Item 222 recommends the board with a burst test of 200 lb/sq.in or ECT of 32 lb/in. and bursting test of 250 lb/sq.in or ECT of 40 lb/in.

Table 3.5. Average (±95% CL) bursting strength and edge crush test of corrugated boards used in this study

Board Specification	Bursting Strength lb/sq.in	ECT lb/in
150 lb/sq.in SW B-flute	171.1 ± 8.6	37.8 ± 1.2
175 lb/sq.in SW C-flute	235.9 ± 11.8	26.4 ± 0.7
200 lb/sq.in SW C-flute	251.1 ± 11.7	27.3 ± 0.7
275 lb/sq.in SW C-flute	343.3 ± 13.8	50.9 ± 1.2
275 lb/sq.in DW BC-flute	251.9 ± 9.6	56.6 ± 0.6
350 lb/sq.in DW BC-flute	340.5 ± 16.4	62.5 ± 1.5

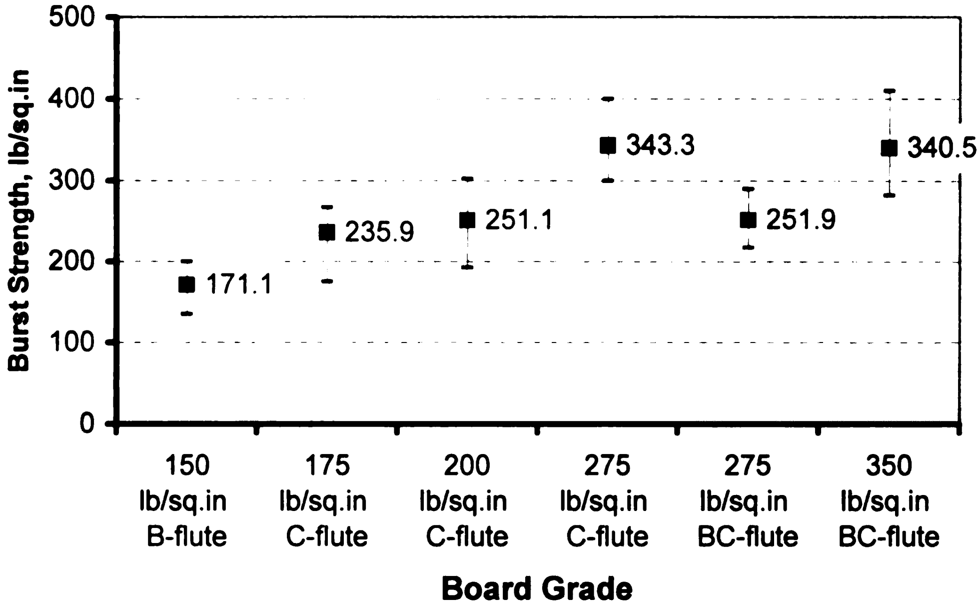


Figure 3.9. Burst strength of corrugated boards used in this study

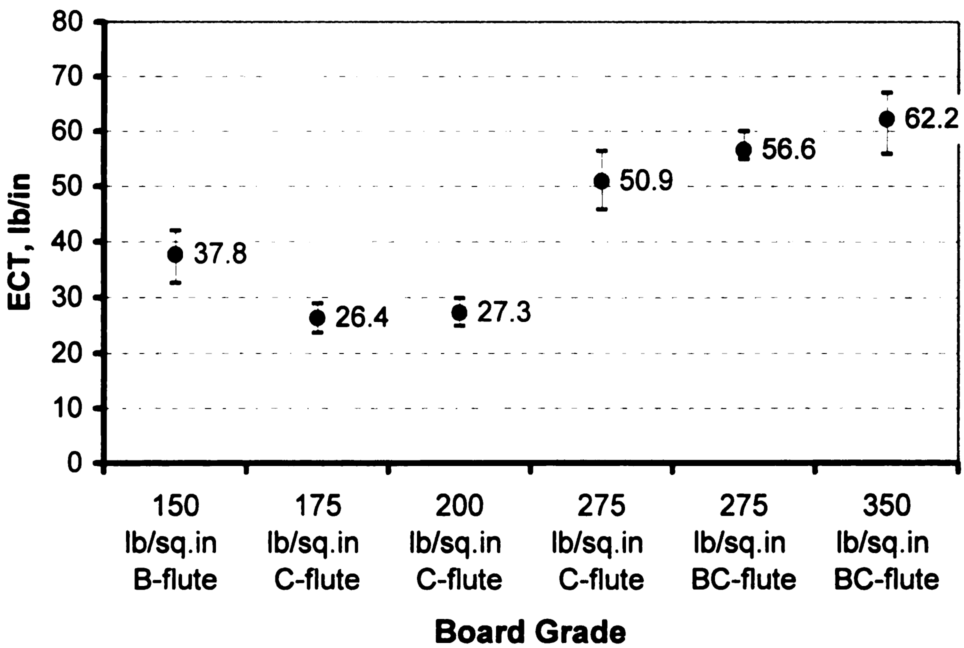


Figure 3.10. Edge crush test of corrugated boards used in this study

3.4. Results from Diagonal Compression Test

Figure 3.11. shows the load-deflection plot of the compression test. At the early stage of the test, the box does not produce a significant resisting load until the deflection reaches between 1 - 1.5 inches. The details of the test plots are shown in Appendix B. Table 3.6. shows the results from Box A after diagonal compression test. Boxes sealed with reinforced paper tape tend to have higher diagonal compression strength than boxes sealed with plastic tape. During this test, the plastic tapes on boxes made form double-wall board got delaminated from the corrugated board. All boxes showed a high deflection value.

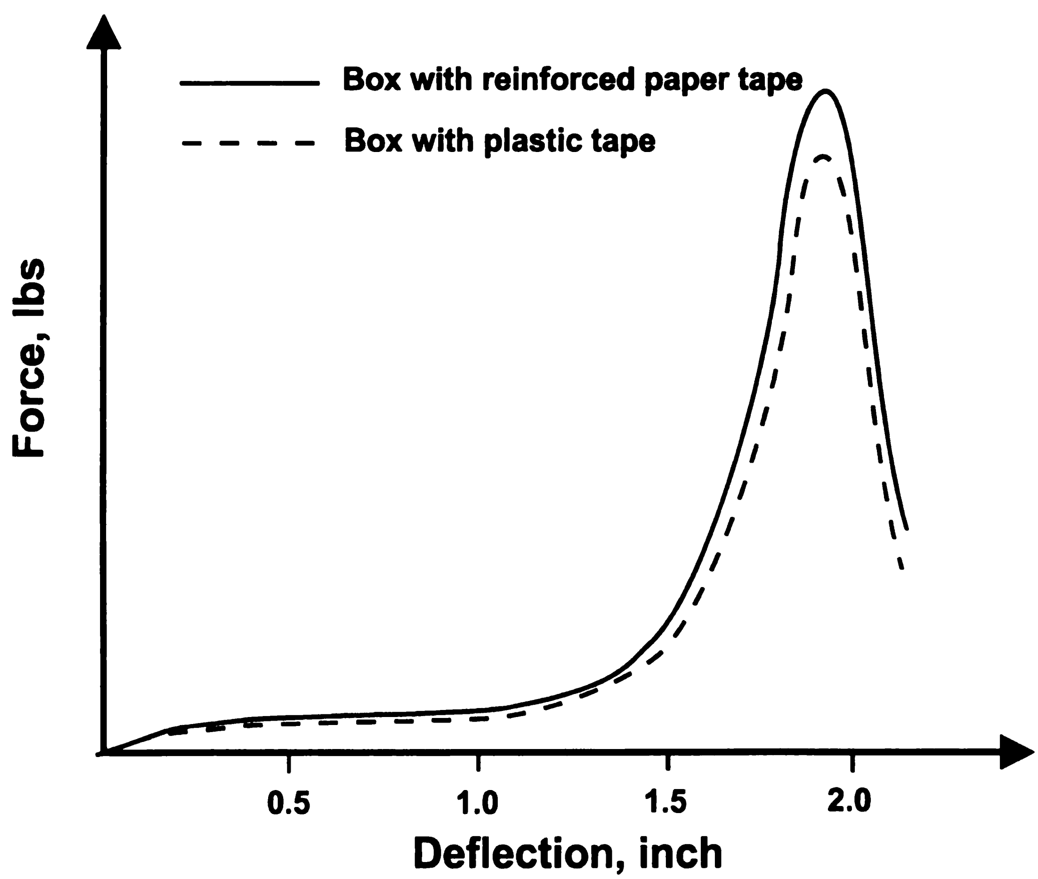


Figure 3.11. Load-deflection plot of diagonal compression test

Table 3.6. Peak force and deflection of Box A after diagonal compression test

Board Specification	Tape Type	Peak force lb	Deflection in
150 lb/sq.in SW B-flute	Paper[1]	134.9	1.61
	Plastic	113.2	1.67
175 lb/sq.in SW C-flute	Paper[1]	251.0	3.92
	Plastic	194.3	2.28
200 lb/sq.in SW C-flute	Paper[1]	230.6	2.72
	Plastic	138.1	1.86
275 lb/sq.in SW C-flute	Paper[1]	350.3	2.09
	Plastic	247.8	2.07
275 lb/sq.in DW BC-flute	Paper[1]	354.4	2.08
	Plastic	302.6	3.06
350 lb/sq.in DW BC-flute	Paper[1]	232.3	1.43
	Plastic	284.9	1.77

[1] Reinforced paper tape

4. CONCLUSIONS

There were three significant findings from this study. First, boxes closed using reinforced paper tape provide a better performance than those using hand-applied pressure sensitive plastic tapes. During this study, plastic tapes (manually applied) tended to come loose when the force was applied on a vertical edge. This was observed during the diagonal compression test. Figure 4.1. shows the effect of flap gap when the vertical edges of box are under load. The long (outer) flaps are forced to move closer and touch each other eventually. Before the long flaps touch each other, the resisting load is contributed from the sealing tape and after contact from parts of the short flaps. For this reason, the load at the beginning state of diagonal compression test is relatively small. However it significantly increases when the long flaps touch (reach take up height). This situation also explains the damage that appears on the tape. According to Mc Kee's study, the perimeter of corrugated box (2L+2W) is a key factor in compression strength formula [17]. Based on this fact, boxes with flap gap could lose half of its short flaps length (4 x W/2) to support the load.

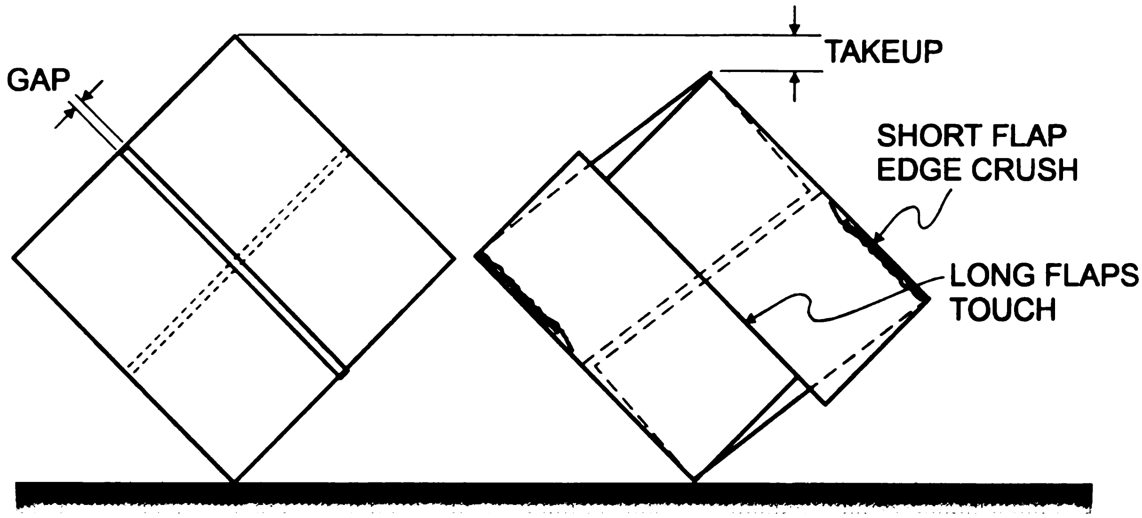


Figure 4.1. Effect of flap gap on corrugated box strength

Next, corrugated boxes that were designed using the board specifications described in Item 222 did not provide adequate protection for the flowable products to be shipped in single parcel shipments. The failure level on most samples was extremely high. Failures ranged from tape failure (tape tears along the edges) to container "blow-out" (box tears on edges and corners). In the case of a container blowout, the entire contents of the package were lost during shipment. In addition the carrier had to re-tape a majority of the boxes and sometimes repack in order to deliver the remainder of contents.

Finally, the test method ISTA Project 3C does not adequately simulate the kind of damage that occurred on packages containing heavy flowable products. The failure modes and levels are not representative of actual shipments. A large degree of bulging and eventual blowout as occurred in actual shipment does not occur during the lab tests (ISTA Project 3C). Figure 4.2. shows conditions of boxes under vibration test. The sample box at the top of stack never experiences any load. It is recommended that a dynamic compression test with an additional dead load on top of the stacked packages be used instead of the three-high stack vibration test for these types of products.

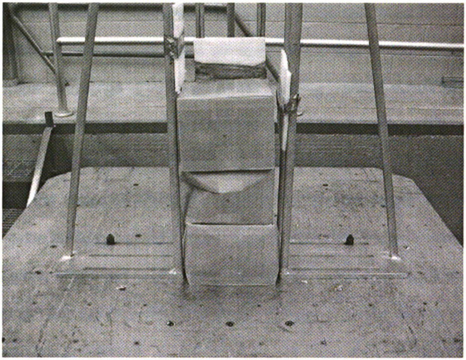


Figure 4.2. Condition of boxes in the stack after vibration test

Based on the results that only Box B made from 350 lb/sq.in double-wall board could tolerate both laboratory simulation test and actual shipment, therefore, a new set of guidelines using twice the specified burst strength and ECT from table in Item 222 should be allowed to shippers, to select board material for boxes containing flowable products for single parcel shipments. It is also recommended to limit the maximum package weight of these types of packages to 35 lb [18], since ergonomically they are difficult to handle due to a high weight density.

Virtually all of the major strength properties of corrugated board are utilized when boxes containing flowable products are shipped through the single parcel environment. Mullen burst strength determines the ability of the board to resist sidewall blowouts from internal pressure. Edge crush test limits not only top-to-bottom compression strength, but resistance to distortion during edge and corner drops. An edge drop onto one of the four vertical edges of the box crushes not only the edge that hits, but the edges of the inner (short) flaps, which bear against the sidewalls to keep the opening square. Flat crush test determines the extent to which the board thins out due to the weight of the product inside pushing against it. The tear strength of the liners limits resistance to tears along the edges of the box. Specifying corrugated board using only burst strength and basis weights of liners as in Table A of Item 222, or using only edge crush as in Table B, is therefore not likely to cover all the necessary requirements.

No grade of corrugated board tested in this study, from 150 lb/sq.in single-wall B-flute to 350 lb/sq.in double-wall BC-flute, was found to be adequate for real shipments involving 55 lb boxes containing steel nuts. Only the two double-wall boxes were found to be adequate for the 35 lb boxes containing clay-coated paper. Part of the reason for these findings is weight, and part is the nature of the flowable product itself. Not all flowable products are alike. The clay-coated paper tends to flow or shift only when the box is dropped on its edges and corners, not on its faces. A face drop causes the paper to land either horizontally or on its side. In either case, there is no tendency for the stack of papers to shift and so it behaves for the most part like a rigid object. In ISTA Project 3C, there are two sequences of drops. The first set of seven drops consists of four face drops, one edge drop, one corner drop, and one "hazard" drop on a face. The second set of eight drops consists of five faces, two edges, and one corner. Altogether, there are only 6 out of 15 drops that would cause the stack of paper to shift. Therefore, the stack of paper acts like a rigid product more than half of the time and acts like flowable product less than half of the time. Even though the damage found in the ISTA tests did not correlate with that from real shipments, this same sort of behavior is expected to take place in real shipments.

Steel nuts behave in a totally different way as compared to sheeted paper. They tend to shift no matter what the drop orientation because they act as much like a fluid as a solid. They also have peaks which press against the corrugated board and create stress concentrations in the inside liner. Probably the most damaging behavior, however, is the wedging effect. The effect was observed in controlled compression/vibration tests and it free body diagram is shown in Figure 4.3., using 1-inch diameter spheres in stead of steel nuts for illustration purposes.

When a 1 lb (0.45 kg) force, P, applied to a single out-of-line sphere in an effort to wedge it into a row of aligned spheres, it creates tremendous side forces, F, depending on the amount of misalignment, h. Table 4.1. shows theoretical relationship between the amount of misalignment and this force when a 1 lb of wedged force is applied.

In the real box of steel nuts, the force tending to wedge a nut in between a group of others is not 1 lb, but whatever the weight of everything on top of it is, including other packages on top of the box itself. Once it wedges its way in, it pushed the walls of the box apart with relative ease and opens up gaps in other groups, with nearby nut attempting to wedge into these. And the process goes on. Given the size of the numbers in Table 4.1., it is doubtful whether any board can withstand this for long.

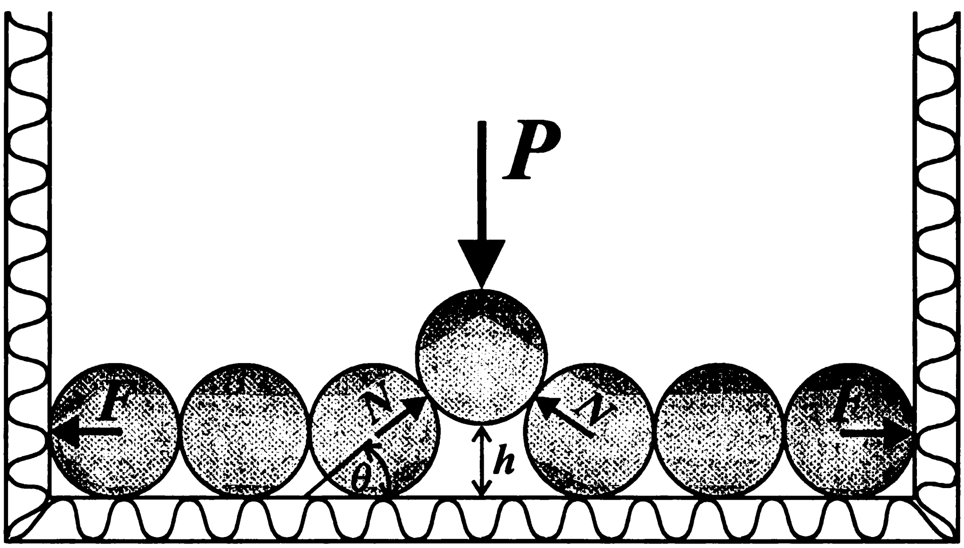


Figure 4.3. Free body diagram of spheres under load

$$N = \frac{P}{2\sin\theta}$$

$$F = N\cos\theta$$

$$F = \frac{P}{2\tan\theta}$$

$$Sin\theta = \frac{h}{2R}$$

$$F = P\left[\frac{\sqrt{D^2 - h^2}}{2h}\right]$$

Where: $D = 2R$ diameter of sphere

Table 4.1. Magnification of a 1 lb wedge force, P

Amount of misalignment, h (inch)	Side force, F (lb)
0.50	1
0.25	2
0.10	5
0.01	50

5. RECOMMENDATIONS

Because of the number of strength properties of corrugated board involved at the same time (bursting strength, ECT, FCT, tear resistance), specifying corrugated board on the basis of Mullen alone or ECT alone as in Item 222 cannot guarantee that the other properties not specified are adequate. Proposing modifications to the numbers in Item 222 to cover flowable products while still adhering to these same specification criteria therefore cannot ensure performance. On the other hand, Item 222 has been a widely accepted set of guidelines for years and so some effort to do this will be made. At the very least,

1. The board should be double-wall. The burst strength and ECT will be high, but the FCT of the board and tear strength of the liners will only be as high as those at the single-wall boards they are constructed from.
2. If the product is flowable in three dimensions, like the steel nuts, instead of two, like the clay-coated paper, use a containment bag so that if a blowout occurs, the product is not immediately lost. It is recommended that a black plastic bag be used to contain the flowable items inside the box, since it calls attention to the problem because of the color contrast.
3. Use reinforced paper tape instead of plastic tape and consider applying three additional bands around the box as shown in Figure 5.1.

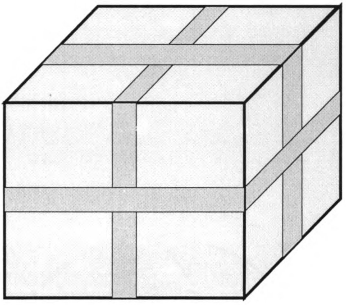


Figure 5.1. Additional tape bands around box with flowable items

APPENDICES

APPENDIX A

Table A1

Damage found on Box A with double plastic bags after subjected to the ISTA Project 3C tested at East Lansing, MI

Sample		Damage
Board Specification	Specimen no.	
150 lb/sq.in SW B-flute	1	Box tears on edge 4-6 at drop no. 5
	2	Tape tears on edge 3-5 at drop no. 5
	3	Box tears on edge 1-2 at drop no. 6
175 lb/sq.in SW C-flute	1	Box tears on edge 4-6 at drop no. 6
	2	Tape tears on edge 3-5 at drop no. 6
	3	Box tears on edge 4-6 at drop no. 5
200 lb/sq.in SW C-flute	1	Box tears on edge 2-6 at drop no. 6
	2	Tape tears on edge 3-5 at drop no. 5
	3	Box tears on face 2, punctures on face 6 at drop no. 6
275 lb/sq.in SW C-flute	1	Box tears on edge 4-6 at drop no. 6
	2	Tape tears on edge 3-5 at drop no. 5
	3	Box tears on edges 1-3 and 1-4 at drop no. 6
275 lb/sq.in DW BC-flute	1	All tape and box intact
	2	Tape tears on edges 3-5 and 3-6 at drop no. 6
	3	Tape tears on edge 1-6
350 lb/sq.in DW BC-flute	1	All tape and box intact
	2	Tape tears on edges 1-5 and 3-5 at drop no.7
	3	Tape tears on edge 1-6 at drop no.4

Table A2

Damage found on Box A with plastic corrugated board reinforced internally after subjected to the ISTA Project 3C tested at East Lansing, MI

Sample		Damage
Board Specification	Specimen no.	
150 lb/sq.in SW B-flute	1	Tape tears on face 3 at drop no. 5
	2	Box tears on edge 3-6 at drop no. 6
	3	Tape tears on face 1 at drop no. 5
175 lb/sq.in SW C-flute	1	Tape tears on edges 3-5 and 3-6 (<1")
	2	Tape tears on edge 3-5 at drop no. 6
	3	Tape tears on face 1 at drop no. 5
200 lb/sq.in SW C-flute	1	All tape and box intact
	2	Tape tears on edges 3-6 and 3-5 at drop no. 6
	3	Tape tears on face 1 at drop no. 5
275 lb/sq.in SW C-flute	1	Tape tears on face 3 at drop no. 5
	2	Tape tears on edge 1-5 at drop no. 5
	3	Tape tears on face 1 at drop no. 5
275 lb/sq.in DW BC-flute	1	Tape tears on face 3 at drop no. 4
	2	Tape tears on edge 1-5 at drop no. 6
	3	Tape tears on face 1 at drop no. 5
350 lb/sq.in DW BC-flute	1	Tape tears on face 3 at drop no. 5
	2	Tape tears on edge 3-6 at drop no. 4
	3	Tape tears on face 3 at drop no. 6

Table A3

Damage found on Box A with four canvas bags after subjected to the ISTA Project 3C tested at East Lansing, MI

Sample		Damage
Board Specification	Specimen no.	
150 lb/sq.in SW B-flute	1	Box tears on face 4 at drop no. 4
	2	Tape tears on edge 3-5 at drop no. 4
	3	Box tears on edge 1-2 at drop no. 3
175 lb/sq.in SW C-flute	1	All tape and box intact
	2	Punctures on face 4
	3	Box tears on edge 2-3 at drop no. 6
200 lb/sq.in SW C-flute	1	Box tears on edge 2-6 at drop no. 3
	2	Punctures on face 4
	3	Punctures on face 6
275 lb/sq.in SW C-flute	1	Tape tears on edges 1-5, 1-6, 3-5, and 3-6 after vibration on face 4 for 6 minutes
	2	Tape tears on edge 1-5 after vibration on face 4 for 6 minutes
	3	All tape and box intact
275 lb/sq.in DW BC-flute	1	All tape and box intact
	2	Tape tears on edge 3-6 at drop no. 4
	3	Tape tears on edge 1-6 at drop no. 4
350 lb/sq.in DW BC-flute	1	Tape tears on face 3 at drop no. 6
	2	Tape tears on edge 3-6 at drop no. 4
	3	Tape tears on edge 1-6 at drop no. 4

Table A4

Damage found on Box A with double plastic bags after subjected to the modified ISTA Project 3C tested at East Lansing, MI

Sample		Damage
Board Specification	Specimen no.	
150 lb/sq.in SW B-flute	1	Box tears on all vertical edges 2-5, 2-6, 4-5, and 4-6 at drop no. 6, content spill out from bottom flaps at drop no. 14
	2	Tape tears on both top and bottom flaps, Punctures on face 4
	3	Box tears on edges 1-2, 1-4 and 2-3, tape tears on both top and bottom flaps, punctures on face 4
175 lb/sq.in SW C-flute	1	Box tears on edges 4-6, 2-6, and 4-5, content spilled out from top flaps at drop no.13
	2	Tape tears on whole edge 1-5, box tears on face 4 and content spill out at drop no. 11
	3	Top flaps opened at drop no 7 and were resealed, no further damage found.
200 lb/sq.in SW C-flute	1	Box tears on edges 2-6, 4-6, and 4-5, box blow out and content spill out at drop no.13
	2	Tape tears on both top and bottom flaps, content spill out from bottom flaps at drop no.13
	3	Tape tears on both top and bottom flaps, box tears on entire edge 1-4 at drop no.15

Table A4 (cont'd.)

Damage found on Box A with double plastic bags after subjected to the modified ISTA Project 3C tested at East Lansing, MI

Sample		Damage
Board Specification	Specimen no.	
275 lb/sq.in SW C-flute	1	Box tears on whole edges 4-6, 2-6, 4-5
	2	Bottom flaps opened
	3	Tape tears on both top and bottom flaps, bottom flaps opened
275 lb/sq.in DW BC-flute	1	Box tears on edges 4-6 and 4-5, tape tears on both top and bottom flaps
	2	Bottom flaps opened, tape tears on whole edge 1-5
	3	Tape tears on both top and bottom flaps
350 lb/sq.in DW BC-flute	1	Tape tears on bottom flaps and edge 2-5
	2	Tape tears on both top and bottom flaps
	3	Tape tears on both top and bottom flaps
32 lb/in ECT SW C-flute reinforced w/ sesame tapes	1	Box tears on edge 4-6 at drop no. 6, edge 2-5 at drop no. 8, and edges 2-6 and 4-5 at drop no. 12, tape tears on edge 3-5 and 3-6, content spill out.
	2	Tape tears on edges 3-5 and 3-6 at drop no. 6, edge 1-5 at drop no. 10, and bottom flaps open at drop no. 13.
	3	Tape tears on bottom flaps at drop no. 5, top flaps at drop no. 6, box tears on edges 1-4 and 3-4 at drop no. 15.

Table A5

Damage found on Box B after subjected to
the ISTA Project 3C tested at East Lansing, MI

Sample		Damage
Board Specification	Specimen no.	
150 lb/sq.in SW B-flute	1	Box tears on edge 3-4 at drop no. 6
	2	Box tears on edge 1-4 at drop no. 5
	3	Box tears on edge 3-6 at drop no. 6
175 lb/sq.in SW C-flute	1	Box tears on edge 2-6 at drop no. 6
	2	Tape tears on edge 3-5 at drop no. 5
	3	Box tears on edge 4-6 at drop no. 4
200 lb/sq.in SW C-flute	1	Tape tears on edge 2-5 at drop no. 6
	2	Tape tears on edge 3-5 at drop no. 5
	3	Tape tears on edge 3-6 at drop no. 6
275 lb/sq.in SW C-flute	1	Tape tears on edge 2-5 at drop no. 12
	2	Tape tears on edges 1-5 and 3-5 at drop no.13
	3	Tape tears on edges 1-6 and 3-6 at drop no.13
275 lb/sq.in DW BC-flute	1	Box tears on edge 4-6 at drop no. 6
	2	All tape and box intact
	3	Tape tears less than 1"
350 lb/sq.in DW BC-flute	1	Box tears on edge 3-6 at drop no. 12
	2	Tape tears on edge 3-5 at drop no. 13
	3	Tape tears on edge 1-6 at drop no. 15

Table A6

Damage found on Box B after subjected to the ISTA Project 3C tested at East Lansing, MI

Sample		Damage
Board Specification	Specimen no.	
275 lb/sq.in DW BC-flute	1	Tape tears on edges 3-5, 1-5, and 3-6
	2	Tape tears on edge 3-5
	3	Tape tears on edges 3-6, 1-6, 1-5, and 3-5, tape tears on bottom flaps.
350 lb/sq.in DW C-flute	1	Box tears on edge 2-6, tape tears on bottom flaps
	2	Tape tears on edge 3-5
	3	Tape tears on both top and bottom flaps, both top and bottom flaps open at drop no. 13

Table A7

Damage found on Box C after subjected to the ISTA Project 3C tested at East Lansing, MI

Sample		Damage
Board Specification	Specimen no.	
275 lb/sq.in DW C-flute	1	Box tears on edges 1-2 and 2-3, tape tears on edges 1-5, 3-5, and 2-5
	2	Tape tears on bottom flaps (face 3), edges 3-5, 1-5, and 2-5 (whole edge), box tears on edges 1-2, and 3-4 at drop no. 13
	3	Box tears on edges 3-6, 1-4, 2-6, tape tears on edges 3-5 (whole edge), 3-6, and 1-6
350 lb/sq.in DW BC-flute	1	Tape tears on face 3, edges 3-5 (whole edge), 2-5 (whole edge),
	2	Box tears on edge 3-4, tape tears on edges 2-5 (whole edge), 1-5, and 3-5
	3	Box tears on edge 3-5 (whole edge), 3-6, and 1-4, tape tears on edges 2-5 (whole edge), 3-6 (whole edge), and 3-5

Table A8

Damage found on Box A with double plastic bags
after being shipped from East Lansing, MI to Santa Rosa, CA

Sample		Damage
Board Specification	Specimen no.	
150 lb/sq.in SW B-flute	1	Box tears on vertical edges, side panels bulge, and box was resealed with plastic tape.
	2	Box tears on vertical edges, top flaps open and box was resealed with plastic tape.
175 lb/sq.in SW C-flute	1	Box tears on vertical edges, side panels bulge, and box was resealed with plastic tape.
	2	Box was replaced with carrier's box.
200 lb/sq.in SW C-flute	1	Box tears on vertical edges and box was sealed with plastic tape.
	2	Box tears on vertical edges, side panels bulge, and box was resealed with plastic tape.
275 lb/sq.in SW C-flute	1	Box tears on vertical edges and box was resealed with plastic tape.
	2	Tape tears on top and bottom flaps, side panels bulge, and box was resealed with plastic tape.
275 lb/sq.in DW BC-flute	1	Box tears on one vertical edge, and box was resealed with plastic tape.
	2	Box tears on vertical edges, side panels bulge, and box was resealed with plastic tape.
350 lb/sq.in DW BC-flute	1	Box tears on one vertical edge, and box was resealed with plastic tape.
	2	Tape tears on top edge.

Table A9

Damage found on Box A with double plastic bags
after being shipped from Santa Rosa, CA to East Lansing, MI

Sample		Damage
Board Specification	Specimen no.	
150 lb/sq.in SW B-flute	1	Box tears on vertical edges.
	2	Box has been replaced with carrier's box.
175 lb/sq.in SW C-flute	1	Box tears on vertical edges.
	2	Box tears on vertical edges, and bottom flaps open.
200 lb/sq.in SW C-flute	1	Box tears on vertical edges, and bottom flaps open.
	2	Box tears on vertical, and horizontal edges, and bottom flaps open.
275 lb/sq.in SW C-flute	1	Box tears on vertical edges.
	2	Box has been replace with carrier's box.
275 lb/sq.in DW BC-flute	1	Tape tears on one edge.
	2	Box tears on one vertical edge, and tape tears on bottom flaps.
350 lb/sq.in DW BC-flute	1	Box tears on vertical edges.
	2	Box tears on vertical edges.

Table A10

Damage found on Box A with plastic corrugated board reinforced internally after being shipped from East Lansing, MI to Santa Rosa, CA

Sample		Damage
Board Specification	Specimen no.	
150 lb/sq.in SW B-flute	1	Tape tears on bottom flaps box was resealed with plastic tapes.
	2	Box was damage and content lost.
175 lb/sq.in SW C-flute	1	Box tears on bottom edges and was resealed with plastic tapes.
	2	Box tears on bottom edges and was resealed with plastic tapes all over the package.
200 lb/sq.in SW C-flute	1	Box and tape tear on bottom edges, box was resealed with plastic tapes.
	2	Box and tape tear on bottom edges, flaps opened, box was resealed with plastic tapes.
275 lb/sq.in SW C-flute	1	Puncture on side panel.
	2	Box tears on bottom edge and was resealed with plastic tape.
275 lb/sq.in DW BC-flute	1	Tape tears on bottom flaps and edges.
	2	Tape tears on bottom flaps and box was resealed with plastic tapes.
350 lb/sq.in DW BC-flute	1	Box was damage and content lost.
	2	Box was damage and content lost.

Table A11

Damage found on Box A with plastic corrugated board reinforced internally after being shipped from Santa Rosa, CA to East Lansing, MI

Sample		Damage
Board Specification	Specimen no.	
150 lb/sq.in SW B-flute	1	Tape tears on edges 3-6, 3-6 and face 3
	2	N/A
175 lb/sq.in SW C-flute	1	Box tears on edge 3-4, tape tears on edges 3-5 and 3-6, on faces 1 and 3
	2	Box tears on edge 2-3, tape tears on edge 3-5 and face 3.
200 lb/sq.in SW C-flute	1	Tape tears on edges 3-5 and 3-6, and on face 3
	2	Box was damaged and the content lost.
275 lb/sq.in SW C-flute	1	Tape tears on edges 3-5 and 3-6
	2	Tape tears on edges 3-5 and 3-6, and on face 3
275 lb/sq.in DW BC-flute	1	Tape tears on face 3
	2	Tape tears on edges 3-5 and 3-6, and faces 1 and 3, flaps were reseal with plastic tape.
350 lb/sq.in DW BC-flute	1	N/A
	2	N/A

Table A12

Damage found on Box B after being shipped from East Lansing, MI to Santa Rosa, CA

Sample		Damage
Board Specification	Specimen no.	
275 lb/sq.in DW BC-flute	1	Tape on opening flaps ripped open.
	2	Tape on opening flaps ripped open.
	3	Tape on opening flaps ripped open.
350 lb/sq.in DW BC-flute	1	Tape and box intact.
	2	Tape and box intact.
	3	Tape and box intact.

Table A13

Damage found on Box B after being shipped from Santa Rosa, CA to East Lansing, MI

Sample		Damage
Board Specification	Specimen no.	
275 lb/sq.in DW BC-flute	1	Three small punctures on face 2 near bottom edge, all tape intact.
	2	Three small punctures on face 2, one small puncture on face 1, tape tears on edge 1-6 (0.25").
	3	One small puncture on face 2, one small puncture on face 5, tape tears on edges 1-5 and 1-6.
350 lb/sq.in DW BC-flute	1	One puncture on face 5, tape tears on edge 3-5 (0.5").
	2	One puncture on edge 3-6, all tape intact.
	3	Tape tears on edges 1-5 and 3-5, little dent on box.

Table A14

Damage found on Box C after being shipped from East Lansing, MI to Santa Rosa, CA

Sample		Damage
Board Specification	Specimen no.	
275 lb/sq.in DW BC-flute	1	Box tears on vertical edge, tape tears on edges and box was resealed with plastic tapes.
	2	Box tears on vertical and bottom edges, tape tears on edges and box was resealed with plastic tapes.
	3	Box tears on vertical and bottom edges, tape tears on edges and box was resealed with plastic tapes.
350 lb/sq.in DW BC-flute	1	Box tears on vertical and bottom edges, tape tears on edges and box was resealed with plastic tapes all over the package.
	2	Box tears on vertical edges, tape tears on edges and box was resealed with plastic tapes.
	3	Box tears on vertical and bottom edges, tape tears on edges and box was resealed with plastic tapes all over the package .

Table A15

Damage found on Box C after being shipped from Santa Rosa, CA to East Lansing, MI

Sample		Damage
Board Specification	Specimen no.	
275 lb/sq.in DW BC-flute	1	Box tears on edges 3-4, 3-6, and 2-6 tape tears on edges 2-5, 1-5, and 1-6, puncture on face 5, box was resealed with plastic tape.
	2	Box tears on edges 2-5 and 3-4, all tapes at bottom-opening flaps were torn off and resealed with plastic tape.
	3	Box tears on edge 4-5, tape tears on edges 2-5, 1-5, and 3-5, top-opening flaps opened, box was resealed with plastic tape.
350 lb/sq.in DW BC-flute	1	Box tears on edge 3-4, tape tears on edges 2-5, 1-6, 3-5, and 1-5, box was resealed with plastic tape.
	2	Tape tears on edges 2-5, 1-5, 1-6, 3-5, and 3-6, and box was resealed with plastic tape.
	3	Box tears on edge 2-3, tape tears on edges 2-5, 1-5, 1-6, 3-5, and 3-6, bottom-opening flaps opened, and was resealed with plastic tape.

Table A16

Burst test (lb/sq.in) of corrugated boards tested at East Lansing, MI

Specimen no.		150 lb/sq.in SW B-flute	175 lb/sq.in SW C-flute	200 lb/sq.in SW C-flute	275 lb/sq.in SW C-flute	275 lb/sq.in DW BC-flute	350 lb/sq.in DW BC-flute
Measure from inside to Outside	1	200.0	252.5	285.0	327.5	290.0	327.5
	2	187.5	220.0	225.0	330.0	267.5	310.0
	3	185.0	262.5	285.0	300.0	247.5	397.5
	4	180.0	235.0	237.5	320.0	260.0	375.0
	5	182.5	260.0	235.0	330.0	275.0	385.0
	6	175.0	247.5	302.5	317.5	217.5	410.0
	7	177.5	265.0	237.5	305.0	290.0	375.0
	8	175.0	260.0	257.5	300.0	265.0	350.0
	9	185.0	215.0	265.0	330.0	257.5	307.5
	10	142.5	215.0	255.0	362.5	275.0	345.0
Measure from outside to Inside	11	155.0	245.0	267.5	347.5	237.5	282.5
	12	157.5	260.0	232.5	360.0	230.0	350.0
	13	145.0	232.5	192.5	335.0	257.5	342.5
	14	162.5	220.0	235.0	400.0	227.5	337.5
	15	152.5	237.5	240.0	330.0	240.0	357.5
	16	175.0	175.0	242.5	375.0	242.5	325.0
	17	182.5	232.5	237.5	370.0	232.5	295.0
	18	200.0	190.0	262.5	390.0	240.0	305.0
	19	167.5	267.5	275.0	360.0	247.5	307.5
	20	135.0	225.0	252.5	375.0	237.5	325.0
Average		171.1	235.9	251.1	343.3	251.9	340.5
Std dev.		18.4	25.3	25.0	29.5	20.5	35.1
Maximum		200.0	267.5	302.5	400.0	290.0	410.0
Minimum		135.0	175.0	192.5	300.0	217.5	282.5

Table A17

Edge crush test (lb/in) of corrugated boards tested at East Lansing, MI

Specimen no.	150 lb/sq.in SW B-flute	175 lb/sq.in SW C-flute	200 lb/sq.in SW C-flute	275 lb/sq.in SW C-flute	275 lb/sq.in DW BC-flute	350 lb/sq.in DW BC-flute
1	36.4	25.4	24.9	45.9	55.8	67.1
2	36.9	27.7	27.7	45.8	57.9	61.6
3	41.1	25.7	28.7	53.6	55.6	63.4
4	39.8	28.5	27.1	51.7	56.5	59.4
5	36.8	25.0	29.0	49.9	56.5	66.5
6	35.4	23.8	26.3	54.5	58.1	63.9
7	38.8	26.9	28.0	49.2	57.5	67.0
8	37.6	26.4	27.3	56.4	56.2	64.3
9	42.0	25.2	28.9	49.6	54.9	59.2
10	39.3	25.5	26.2	50.8	56.7	60.8
11	37.6	25.8	29.2	49.9	60.0	63.9
12	39.5	26.3	27.6	52.8	56.3	55.9
13	37.3	26.2	26.7	51.7	55.9	61.7
14	32.6	26.5	29.9	51.5	55.6	61.4
15	40.5	27.5	25.2	51.3	56.7	63.7
16	36.2	25.9	26.2	52.5	56.0	61.3
17	36.8	28.6	27.0	50.0	57.6	59.7
18	39.6	29.0	28.7	51.1	58.0	57.9
19	32.9	27.9	26.1	50.9	55.7	66.6
20	38.9	23.7	26.0	50.4	55.9	64.3
Average	37.8	26.4	27.3	50.9	56.6	62.5
Std. dev	2.5	1.5	1.4	2.5	1.2	3.1
Max	42.0	29.0	29.9	56.4	60.0	67.1
Min	32.6	23.7	24.9	45.8	54.9	55.9

APPENDIX B

Chart B1

Diagonal compression test on Box A (150 lb/sq.in SW B-flute)
close with reinforced paper tape

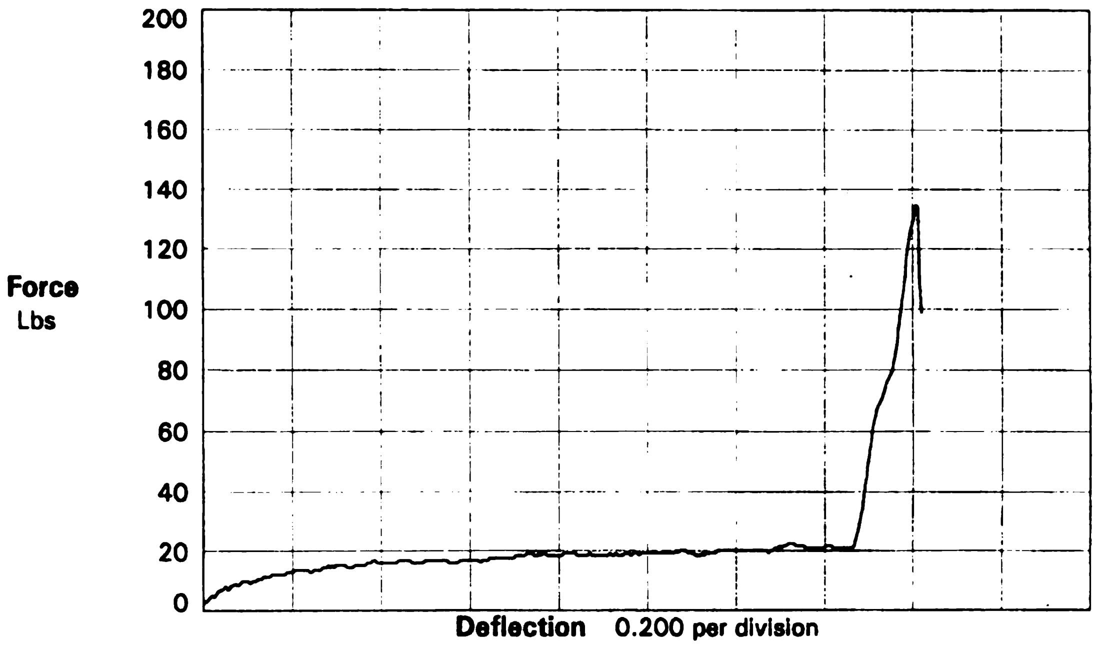


Chart B2

Diagonal compression test on Box A (150 lb/sq.in SW B-flute)

close with plastic tape

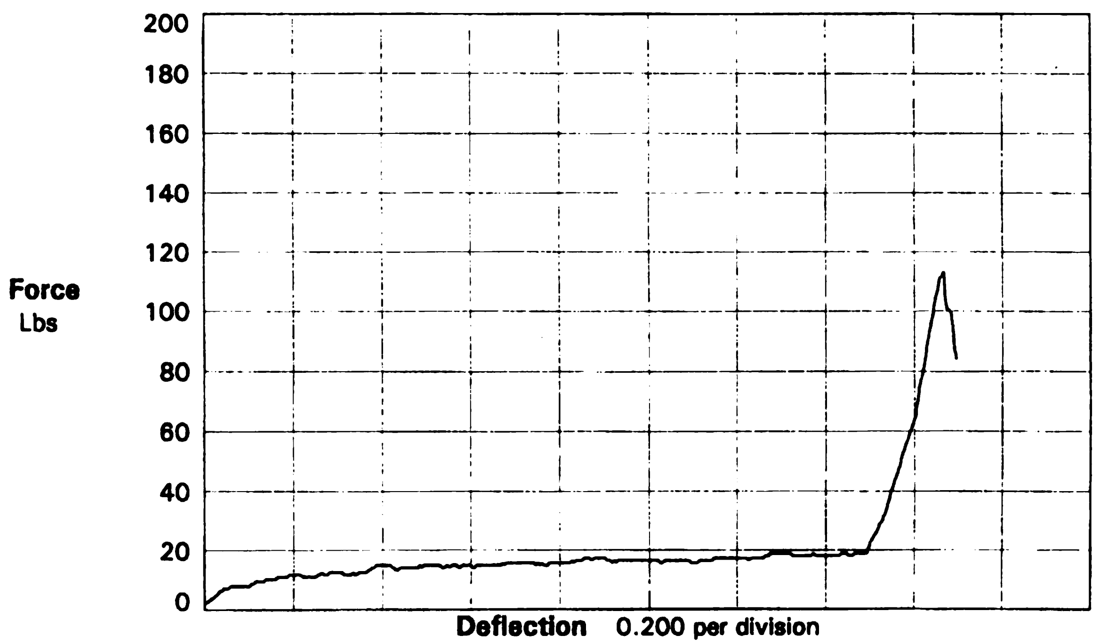


Chart B3

Diagonal compression test on Box A (175 lb/sq.in SW C-flute)
close with reinforced paper tape

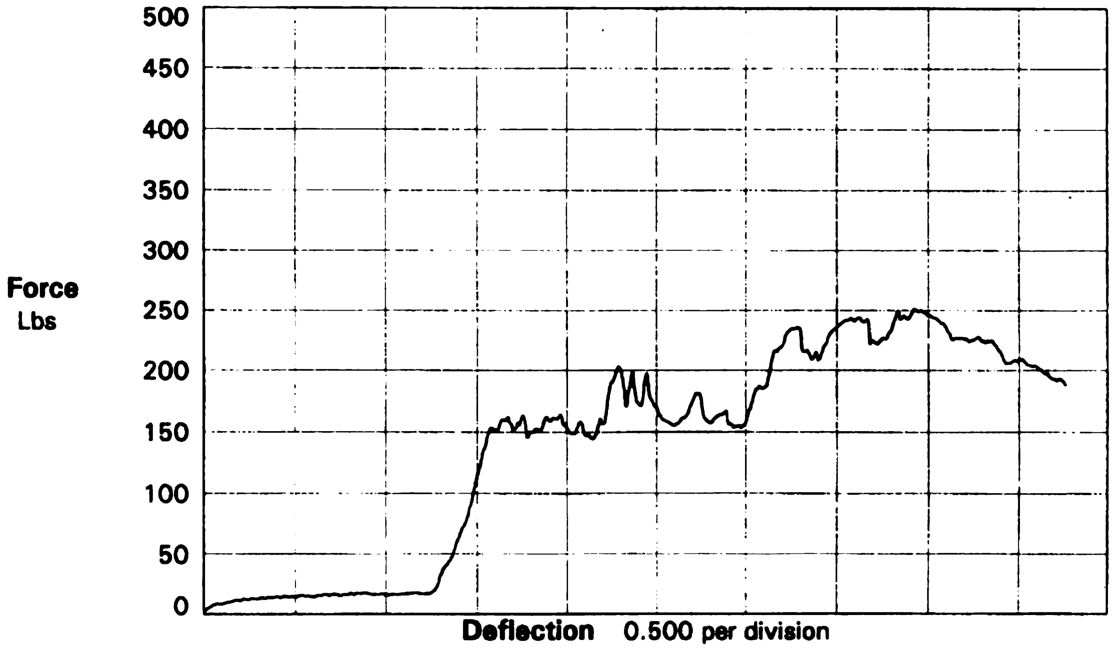


Chart B4

Diagonal compression test on Box A (175 lb/sq.in SW C-flute)
close with plastic tape

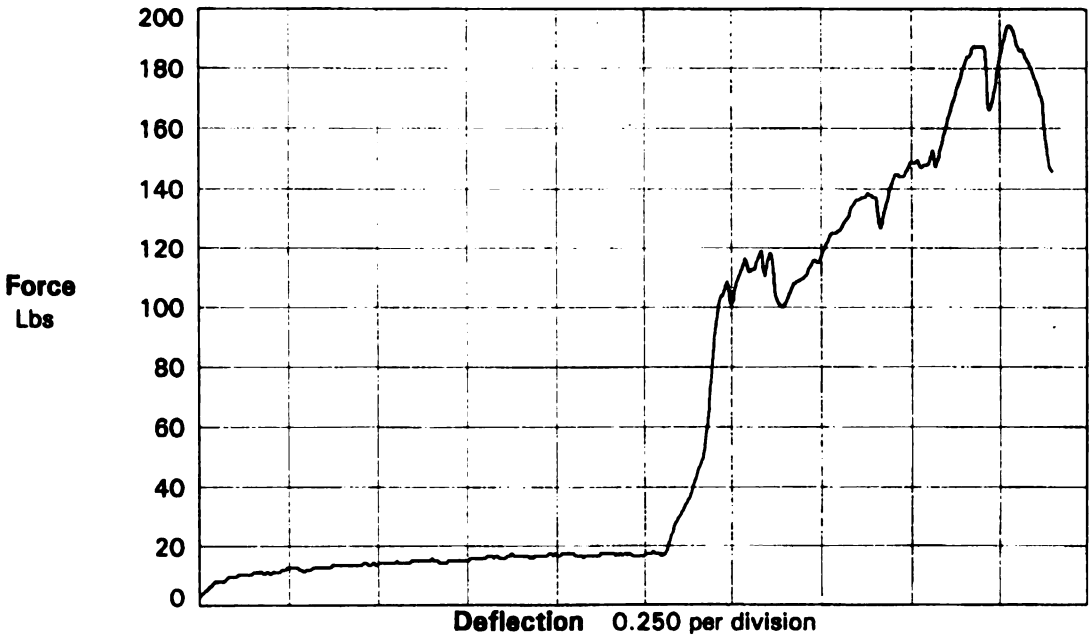


Chart B5

Diagonal compression test on Box A (200 lb/sq.in SW C-flute)
close with reinforced paper tape

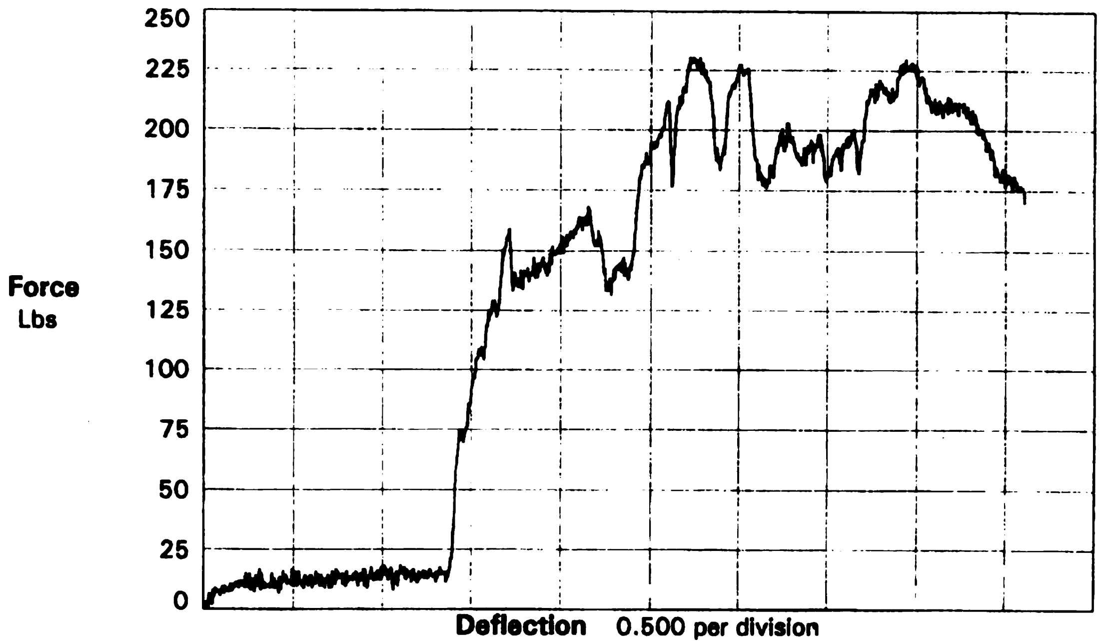


Chart B6

Diagonal compression test on Box A (200 lb/sq.in SW C-flute) close with plastic tape

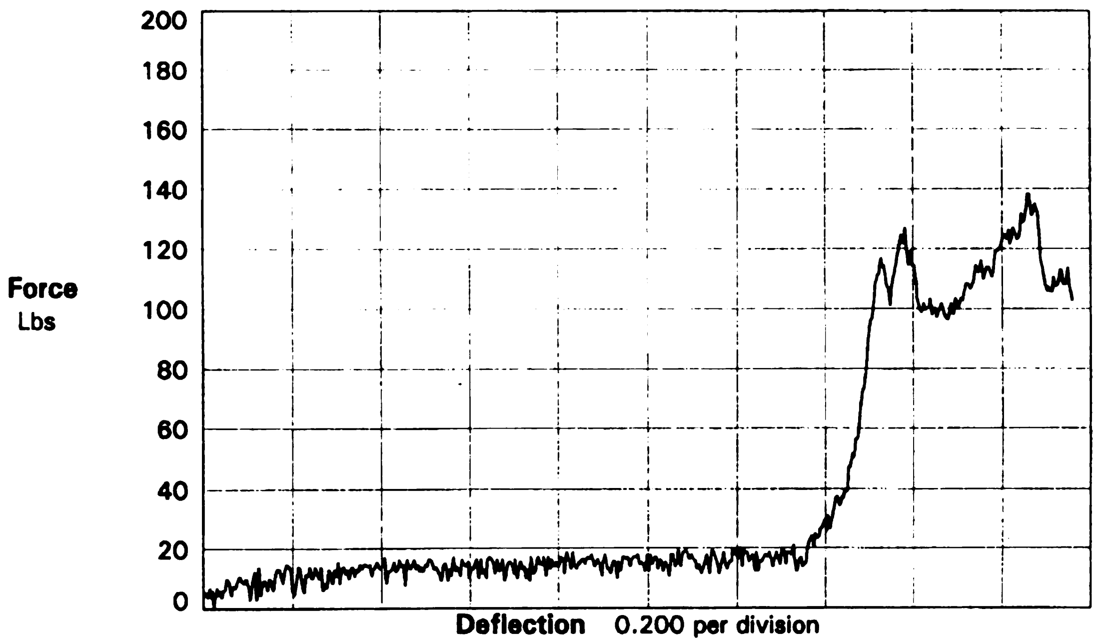


Chart B7

Diagonal compression test on Box A (275 lb/sq.in SW C-flute)
close with reinforced paper tape

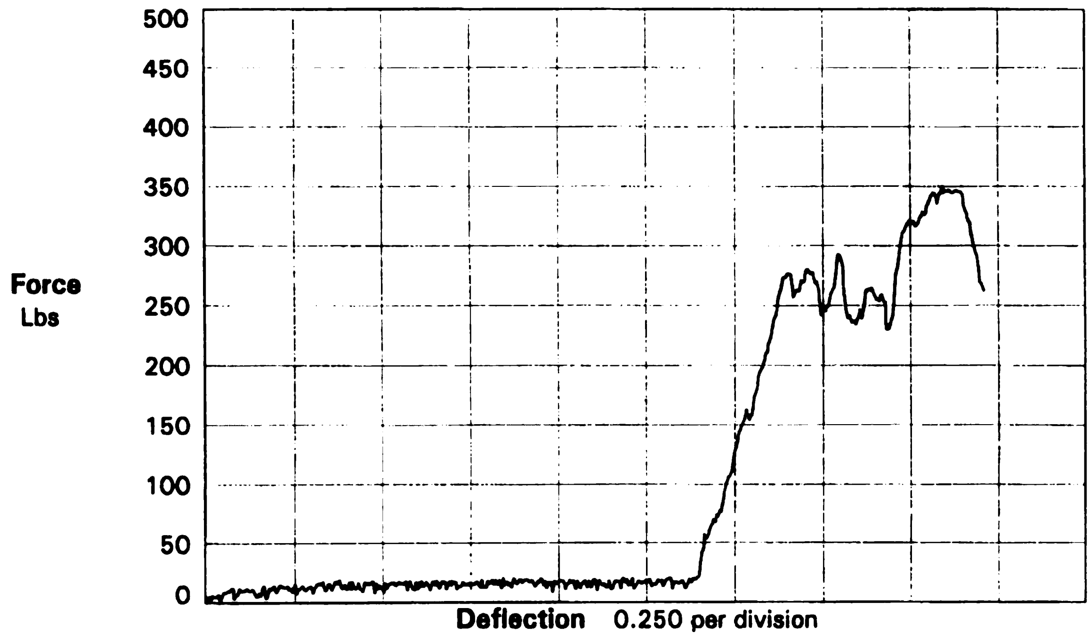


Chart B8

Diagonal compression test on Box A (275 lb/sq.in SW C-flute)

close with plastic tape

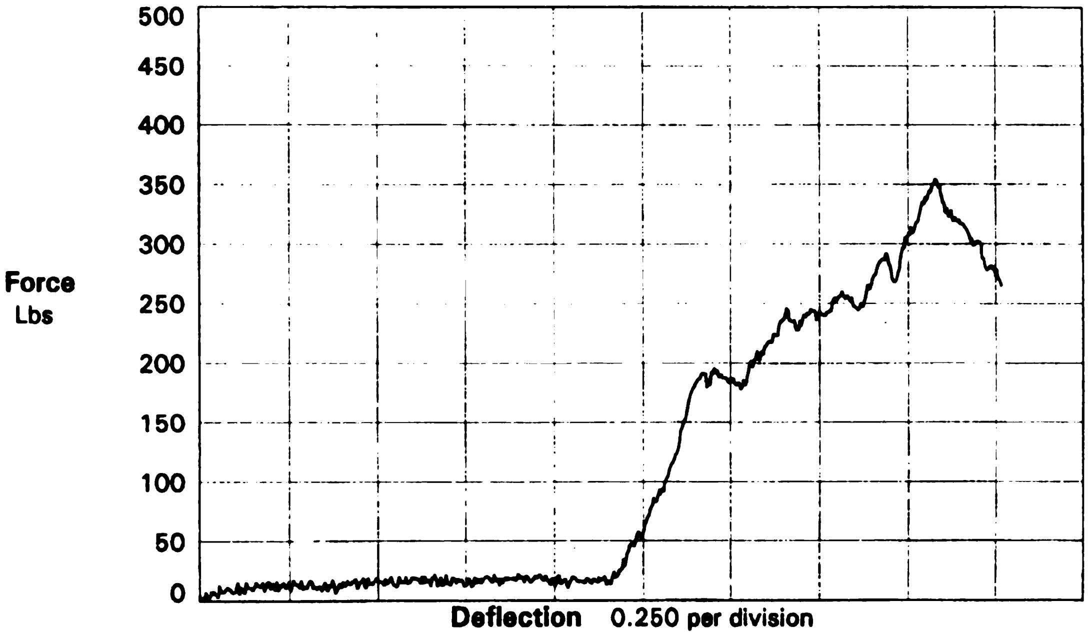


Chart B9

Diagonal compression test on Box A (275 lb/sq.in DW C-flute)
close with reinforced paper tape

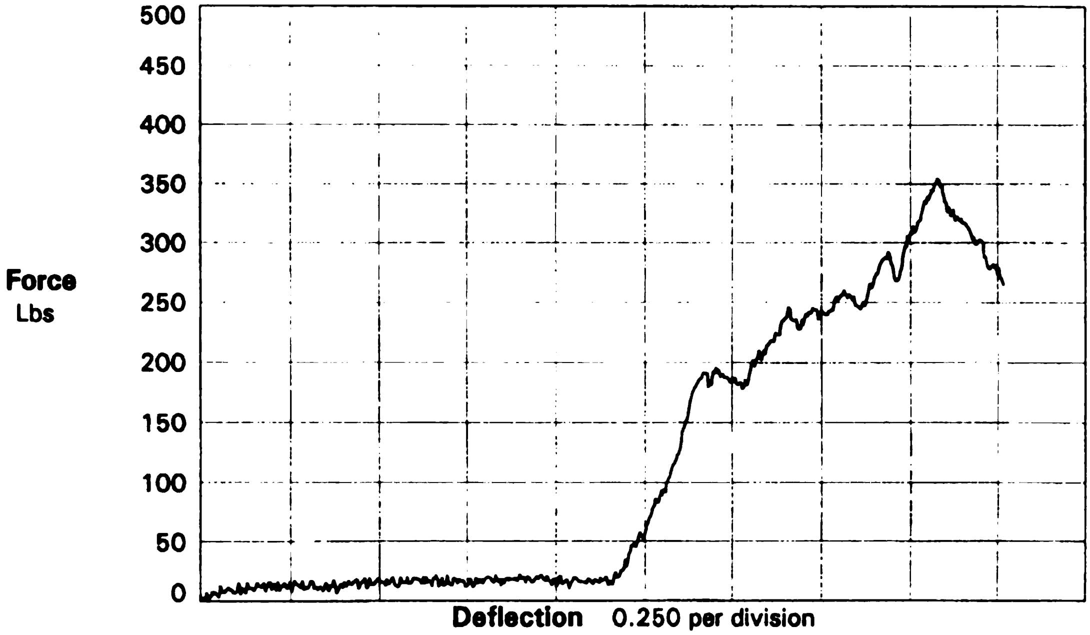


Chart B10

Diagonal compression test on Box A (275 lb/sq.in DW C-flute)
close with plastic tape

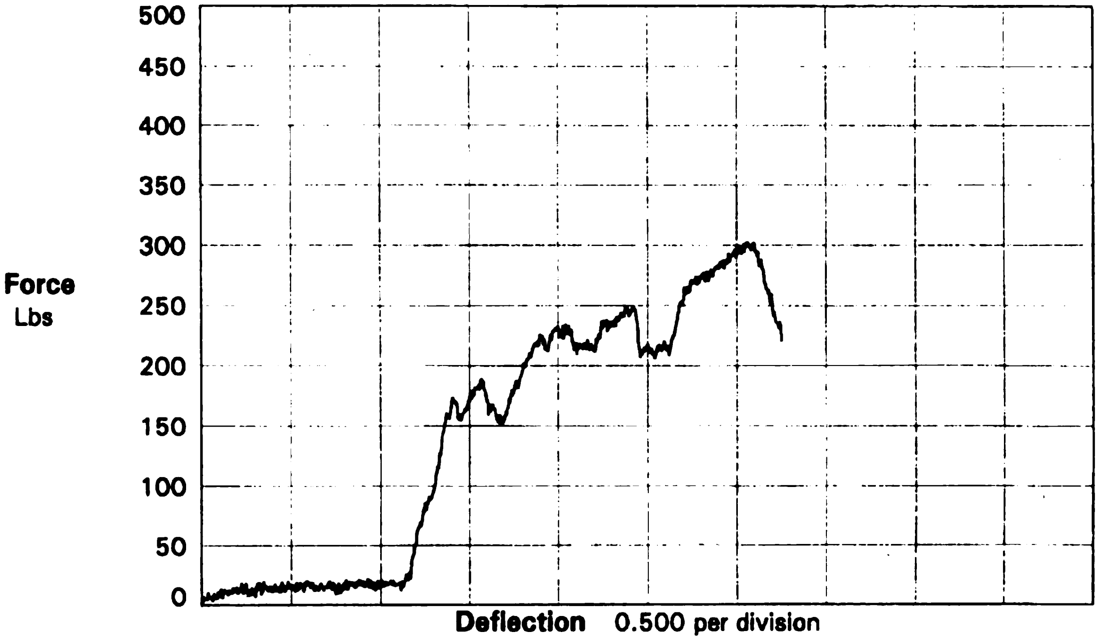


Chart B11

Diagonal compression test on Box A (350 lb/sq.in DW C-flute) close with reinforced paper tape

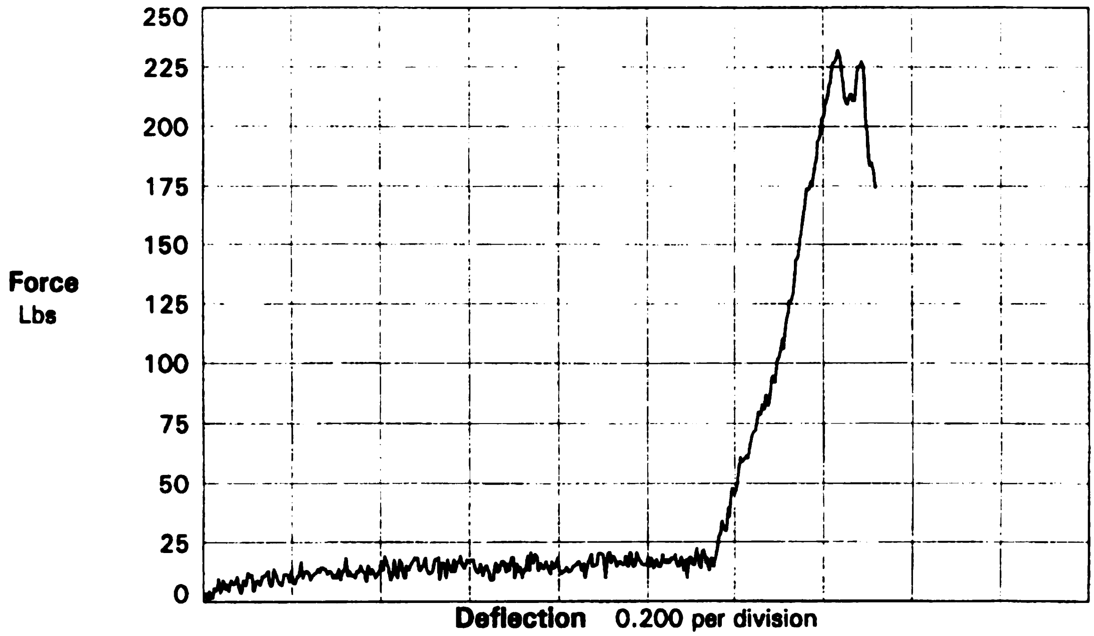
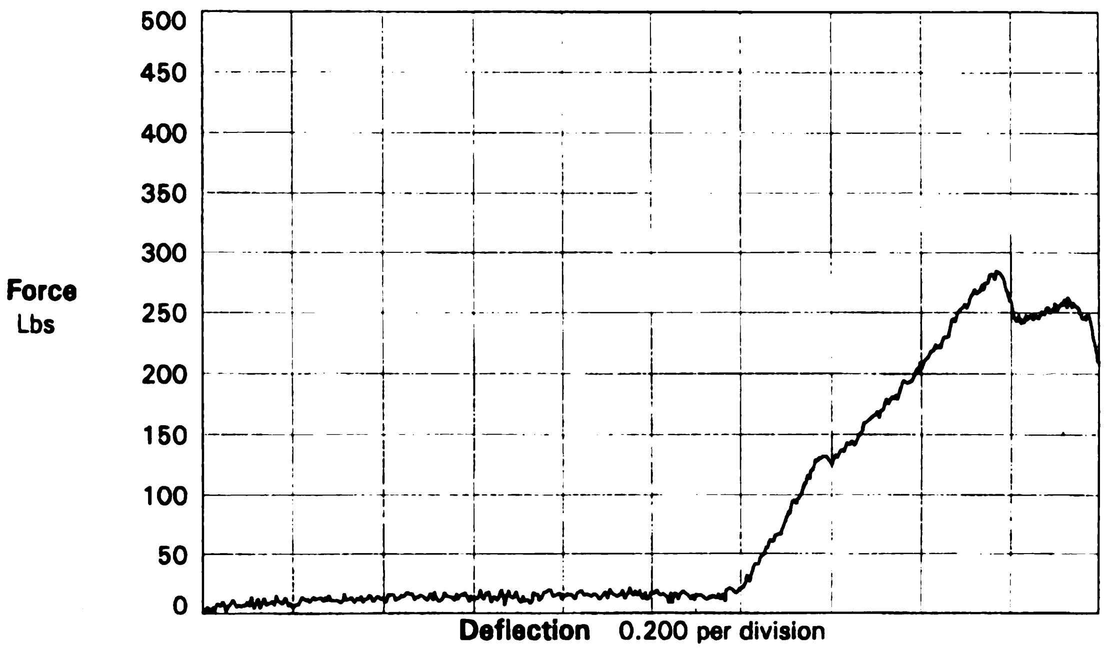


Chart B12

Diagonal compression test on Box A (350 lb/sq.in DW C-flute)

close with plastic tape



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