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Analysis of compression strength of corrugated shipping containers with different designed hand holes

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ANALYSIS OF COMPRESSION STRENGTH OF CORRUGATED SHIPPING CONTAINERS WITH DIFFERENT DESIGNED HAND HOLES

By

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ABSTRACT

Analysis of compression strength of corrugated shipping containers with different designed hand holes

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The purpose of this study was to examine the compression strength of the corrugated shipping containers having the conventional purpose hand holes and the arc top hand holes. Generally, the arc top hand hole has stronger tear strength than the conventional purpose hand hole, but the arc top hand hole has a larger opening area than the conventional purpose hand hole, and the larger opening area needs more space of a dispersion of compression stress to increase compression resistance. However, when a hand hole has enough space to distribute compression stress, the only one variable is the width of the opening area in shipping containers if the containers have the same dimensions.

In this study, two designs of the hand hole have the same width of opening area and are located to have enough space to distribute compression stress. As a result, the resistance forces of containers are the same in each different environment.

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1.0 Introduction

Packaging is a means of ensuring safe delivery of a product to the ultimate user in a sound condition, at a minimum overall cost (Corrugated Board Packaging, 1993). Jay Singh, Eric Olsen, S.P. Singh, J. Manley, and F. Wallace explain in "The effect of ventilation and hand holes on loss of compression strength in corrugated boxes" why studying corrugated shipping containers is important (Journal of Applied Packaging Research 2.4, 2008). Corrugated fiberboard is an efficient and economical material for making shipping containers that are widely used for distribution, transportation and storage of products. Corrugated fiberboard is used to package about 90% of all products for retail distribution in the United States.

Corrugated shipping containers are designed to protect the product from hazards of the distribution, transportation and storage environment so that the product can be shipped to consumers without damage. This meets the manufacturer's condition.

In addition, some of corrugated shipping containers have hand holes because they increase performance of manual transportation function. The first concern in the process to make hand holes is the strength of hand holes to hold the weight of contents. Therefore, designers make an effort to develop new shapes to increase tear strength. However, the hand holes also affect the compression strength of corrugated containers during storage and distribution.

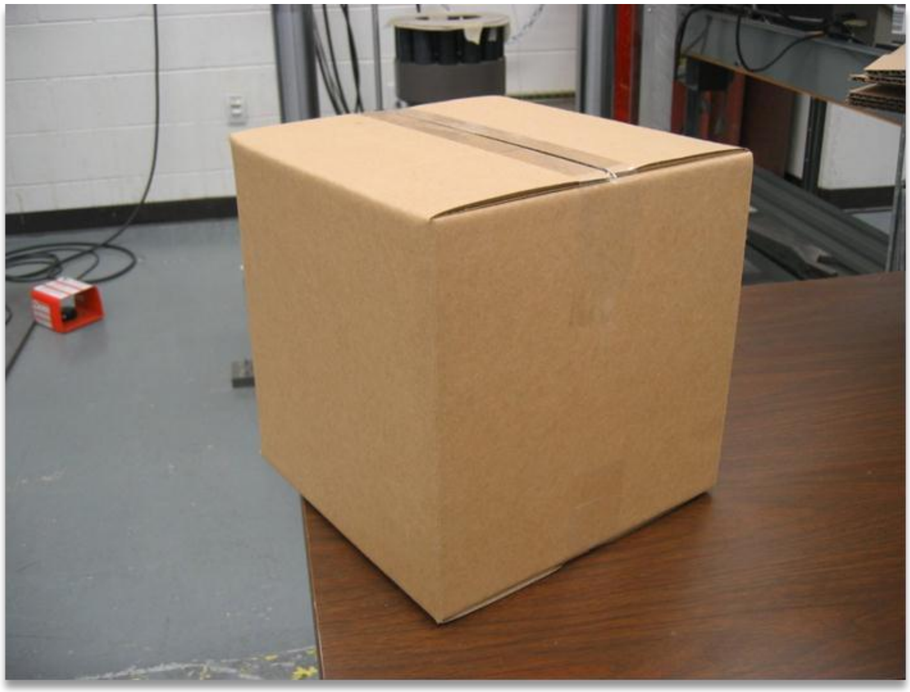
ASTM 6804, which is the “Standard Guide for Hand Hole Design in Corrugated Boxes,” provides a guide for designing hand holes with increasing tear strength.

This thesis project evaluates the compression strength of corrugated boxes with two different common holes which are introduced in ASTM 6804, named “Conventional purpose hand hole” (Figure B-5) and “Arc-top hand hole” (Figure B-7). The arc-top hand hole offers greater tear out resistance following ASTM 6804. However, the arc-top hand hole needs more opening area than the conventional purpose hand hole. It is generally considered that the compression strength of corrugated shipping containers with the arc-top hand hole is less than that which occurs with the conventional purpose hand hole. This study verifies the compression strength of corrugated shipping containers with the arc-top hand hole and the conventional purpose hand hole.

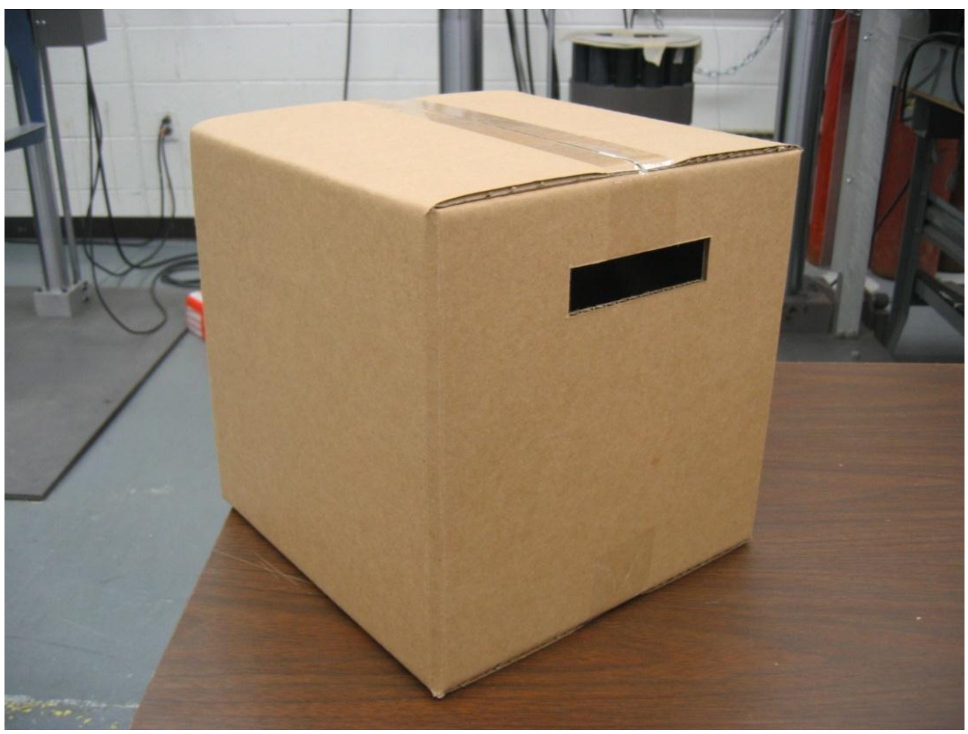
The compression strength was tested in three different humidity and temperature environments to consider multiple environments.

1.1 Problem statement

A pre-test showed that the hand holes decreased the compression strength of the corrugated shipping container. The peak force compression strength of the corrugated shipping container without hand holes was 822.4 lbs (Figure 1) and the peak force of compression strength of the corrugated box with hand holes sized 1”x4” was 511.9 lbs (Figure 2) – specimens were made by ‘C’ flute corrugated board and RSC (Regular Slotted Container, p.14) style corrugated shipping containers. The inside dimensions were 10”x10”x10” and the samples were placed in ambient room conditions (temperature was 68.4°F and humidity was 62%)for 72 hours before the test.



(Figure 1) 10″x10″x10″ 'C' flute RSC corrugated box sample.

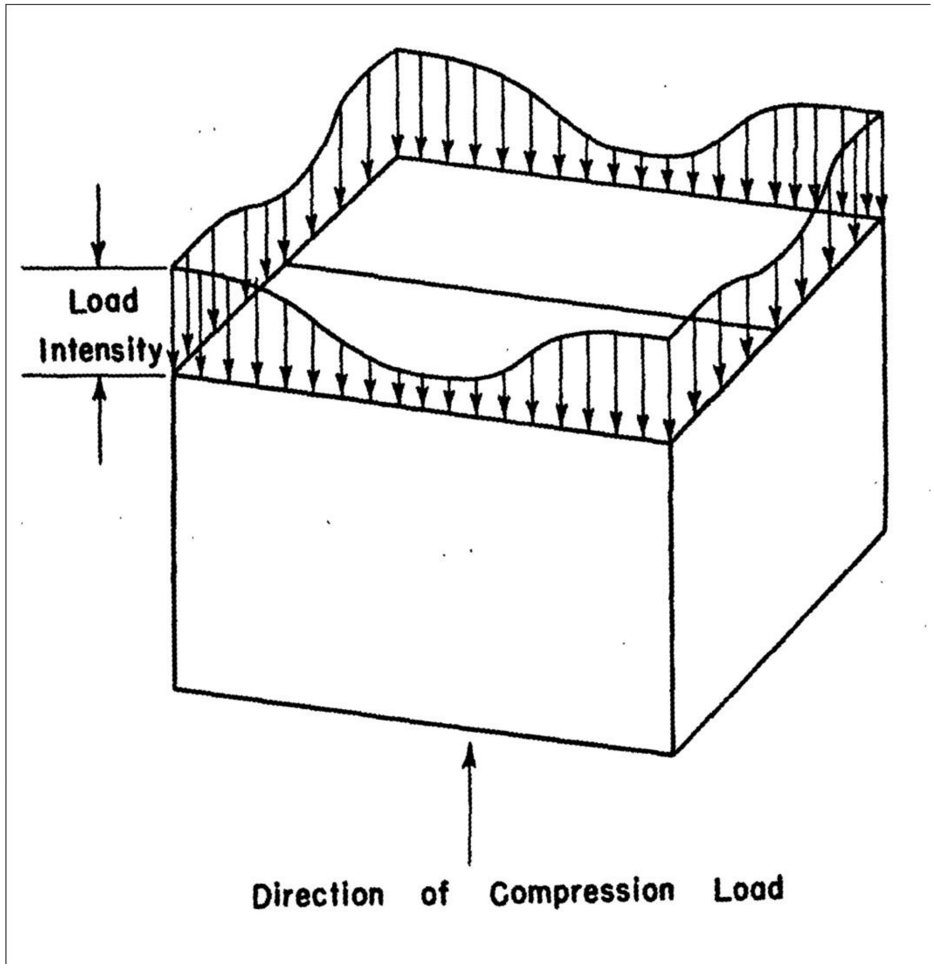


(Figure 2) 10″x10″x10″ 'C' flute RSC corrugated box sample with 1″x4″ own designed hand hole.

The compression strength of the RSC style corrugated shipping container is calculated using the McKee formula and it shows the relationship of compression strength and the dimension of the box, which is the perimeter of the corrugated shipping container.

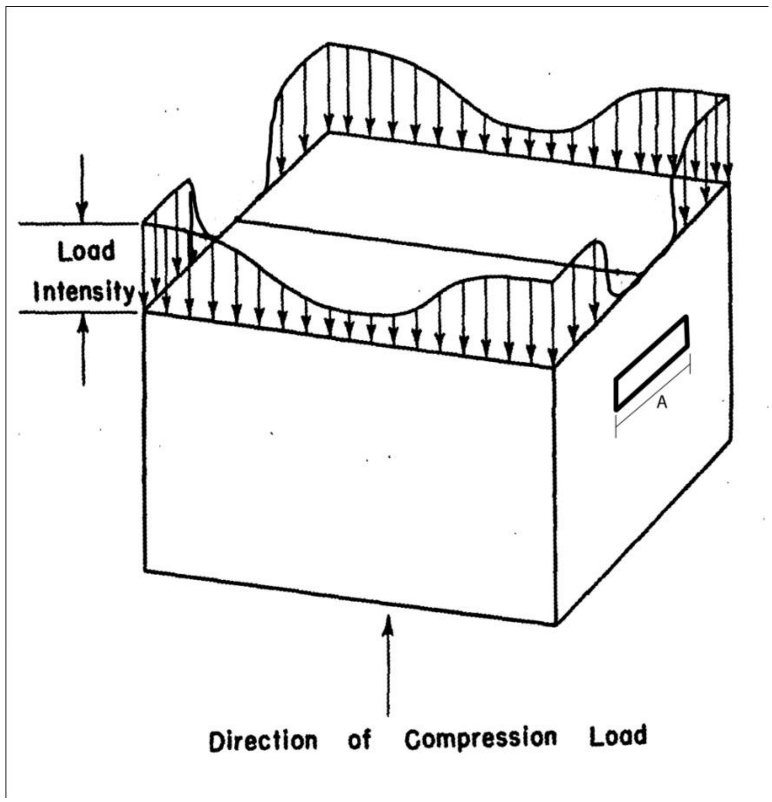
However, the McKee formula does not show the relationship between the opening areas, such as hand holes or vent holes[1], and the compression strength because the compression load intensity is not the same on all points of the perimeter, so a location of hand holes also has an effect on compression strength (Figure 3).

[1] Hole for the ventilation to keep fresh environment in a shipping container.



(Figure 3) Load of compression strength.

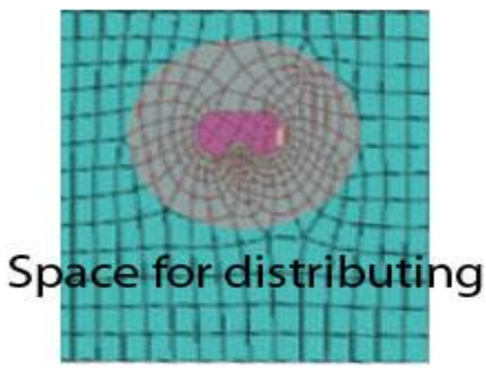
However, it is possible to apply the McKee formula to compare the compression strength of boxes with hand holes having enough space for dispersion. In determining the compression strength of the RSC (Regular Slotted Container) style corrugated container, the perimeter of the shipping container is the only variable in the McKee Formula when the same materials are used. The compression strength of the RSC style shipping containers with hand holes can be estimated by subtracting the width of the hand holes from the perimeter of the container if the hand holes are located in the same position (Figure 4).



(Figure 4) Load of compression strength with hand hole.

If boxes have holes with the same area but differently designed shape and location, the compression strength will be different. One study tested compression strength with different vent hole designs using a simulation program. The result of the test also showed different compression strength.

However, a problem with this test was that it was not concerned about strength dispersion space. Figure 5 shows the compression stress around the hand holes. If the hole does not have enough space horizontally and vertically around it for distributing the compression stress, the compression strength is lower than that of other designs. If the hole has enough space, the width of the hole is the only variable that will affect compression strength.



(Figure 5) Minimum space of distributing compression strength.

1.2 Hypotheses

The height and shape of hand holes are not major factors affecting compression strength. The width of the hand hole subtracted from the perimeter of the shipping container is the major factor in reduction of compression strength.

Even though the arc-top hand hole needs a larger opening area compared with the conventional purpose hand hole, the compression strength of corrugated shipping containers are equal if the width of the hand holes are the same and have enough space for distributing compression strength.

1) Hand holes on the shipping container affect the compression strength of the corrugated shipping box.
2) The height of the hand hole does not affect the compression strength of the corrugated shipping box.
3) If the corrugated shipping boxes have different hand holes but the width of the hand holes are same, the compression strength will be the same.
4) It shows the same result under different conditions, temperature and humidity.

1.3 Assumptions

1) The materials used for the test have the same specification and pre-conditioning.
2) The test machines used for the test have the same performance.

3) The compression tester’s applied forces to the samples are the same for all configurations.
4) Each type of sample is to be put under three different conditions and tested at the end of 72 hours. All the tests are performed in the same conditions during each test.

2.0 Literature review

2.1 Introduction of Packaging

Packaging is a means of ensuring safe delivery of a product to the ultimate user in a sound condition, at a minimum overall cost (Corrugated Board Packaging, 1993). This basic meaning of packaging explains the function of all packaging. The basic function of all packaging is to identify the product and carry it safely through the distribution system to the final user (The Packaging User's hand book,1991).

Packaging provides an economical way of protecting products during distribution. If the packaging is also adapted to the distribution system and is considered an integral part of both internal and external distribution, it is possible to minimize distribution cost (Corrugated Board Packaging, 1993). As a result, all packaging has to be designed to protect products and to reduce materials and then tested to prove having enough performance.

2.2 Corrugated board

Corrugated fiberboard is the most common distribution container material. Corrugated board has a sandwich material structure. It comprises a central paper (called the corrugating medium, or, simply the 'medium') which has been formed, using heat, moisture and pressure, in a corrugated, i.e. fluted, shape on a corrugator and one or two flat papers (called liners) have been glued to the tips of the corrugations. The sandwich can be formed in several ways (Paper and Paperboard Packaging Technology, 2005).

2.2.1 Flute Standards and Corrugated Board Grades

Corrugated board is normally made in one of the nine flute sizes which are A, B, C, D, E, F, G, K and O. However, A, B, C and E flute are commonly used for industry and properties are below:

Flute	Flutes/Metre	Flutes/Foot	Thickness*	Take-up Factor
A	100 to 120	30 to 36	4.67 (0.184 in.)	1.54 in.
B	145 to 165	44 to 50	2.46 (0.097 in.)	1.32 in.
C	120 to 140	36 to 42	3.63 (0.142 in.)	1.42 in.
E	280 to 310	86 to 94	1.19 (0.047 in.)	1.27 in.

(Table 1) Standard flute configurations

*Not including facing

(Source : ASTM D 5639, Selection of Corrugated Fiberboard materials and Box Construction Based on Performance Requirements.)

2.3 Corrugated shipping containers

Corrugated shipping containers were used almost hundred years ago and these have become the most popular shipping containers in the world.

Shipping containers exist to serve the needs of logistical systems. For most of the 20th century, they have been designed to meet requirements published by the railroad and trucking associations for specific grades of corrugated fiberboard, based on bursting of edge-crush test (ECT) strength.

Integration of supply chains and advances in packaging technology has enlarged the focus to a more system-wide approach, beyond just transport and simple properties of corrugated fiberboard.

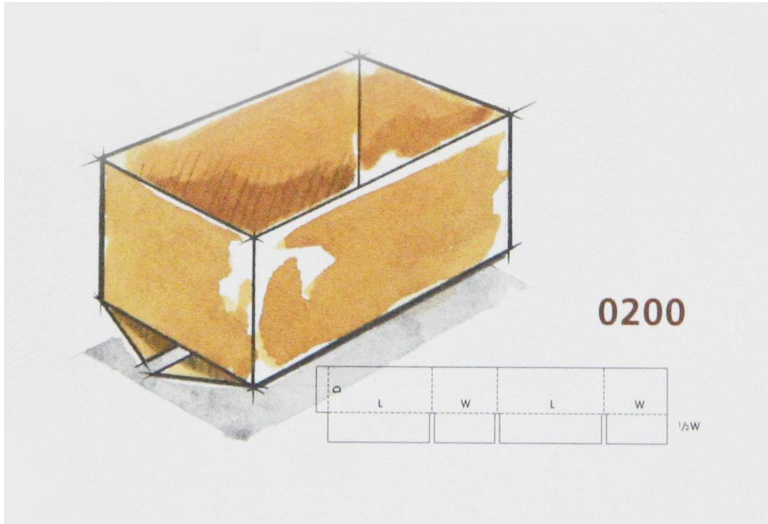
Since ECT and its relationship to compression and stacking strength plays a key role in corrugated fiberboard container performance (Cartons, crates and corrugated Board, 2005).

2.3.1 Styles of corrugated containers

There are a lot of corrugated boxes with different styles and some common style of boxes are introduced below:

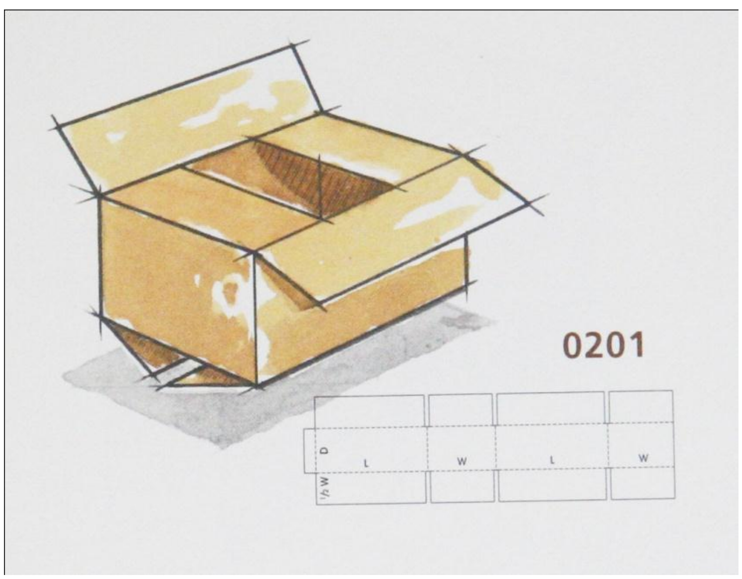
a. 0200 Half Slotted Container (HSC)

It is same as Regular Slotted Container (0201) without one set of flaps.



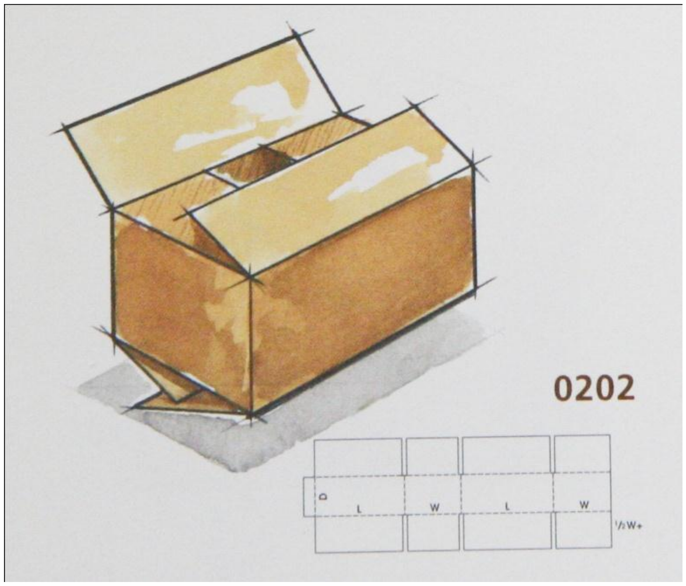
b. 0201 Regular Slotted Container (RSC)

All flaps have the same length, and the two outer flaps are one-half the container's width, so that they meet at the center of the box when folded.



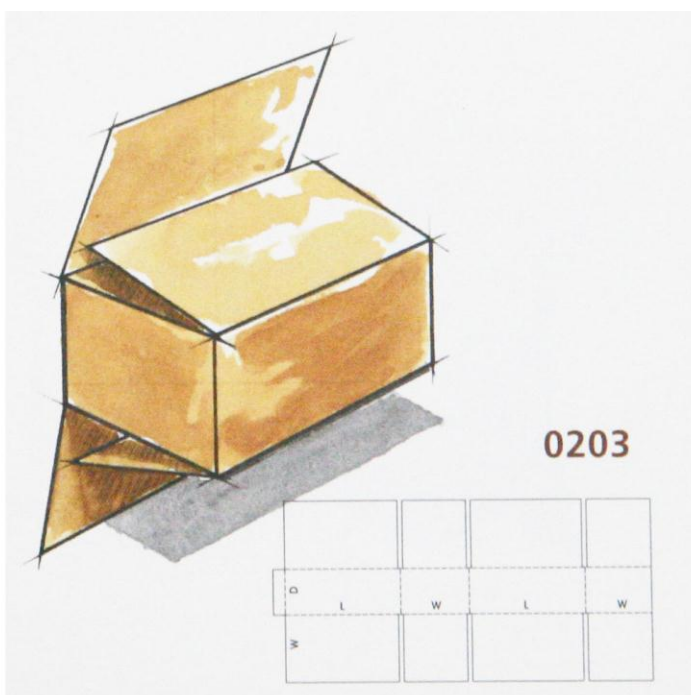
c. 0202 Overlap Slotted Container (OSC)

All flaps have the same length. The outer flaps overlap by one inch or more.



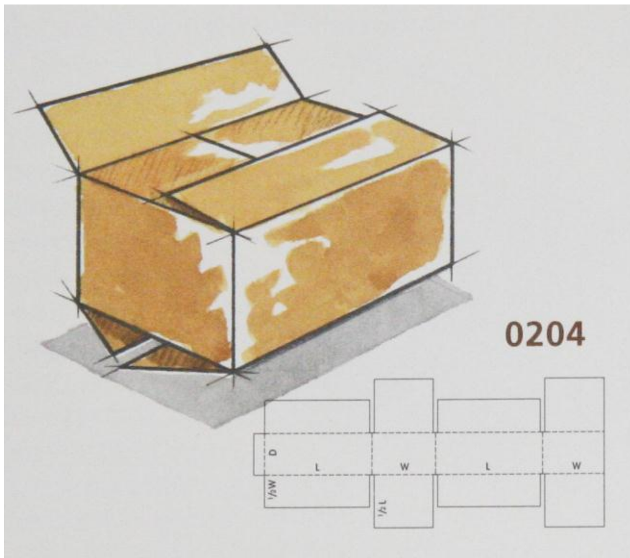
d. 0203 Full Overlap Slotted Container (FOL)

All flaps have the same length (the width of the box).



e. 0204 Center Special Slotted Container (CSSC)

Inner and outer flaps are cut to different lengths. Both pairs of flaps meet at the center of the box.



(Fibre Box handbook, 1999)

2.3.2 Compression Strength of corrugated containers

BusinessDictionary.com defines compression strength as Stacking strength of a fiberboard container measured as the maximum load that can be applied to it under specified conditions before it is crushed, and expressed in newtons or pounds per square inch. Printing directly onto the container face or surface reduces its compression strength by crushing the material and saturating the fibers with ink. Also the compression strength called compression resistance, compressive strength, or crush resistance.

2.4 Testing for Corrugated material

The compression strength of a corrugated board box is a direct measure of the stacking strength of corrugated board packages, but since the load-bearing properties of a box are often of decisive importance under modern transport conditions, it can also be said that the compression strength constitutes a general measure of the performance potential of a corrugated board package. The compression strength is measured according to some standardized test method which is, in general, designated the BCT, Box Compression Test, value (Testing Methods and Instruments for Corrugated Board, 1992).

2.4.1 BCT method

The BCT-method is only top to bottom load test, which is, as a rule, carried out on empty sealed corrugated board shipping containers. These are compressed between flat parallel plates in a compression tester at a constant compression rate (Figure B-8).

2.4.2 McKee's formula

McKee R. C. (1963) published what has become the industry's seminal article in box compression analysis, including detailed citations of the literature that preceded their analysis. Their work resulted in an equation to predict single-wall box compression strength P, called simply the "McKee equation,"

$$P = aP^b{}_m(\sqrt{D_x D_y})^{1-b} Z^{2b-1} \quad (1)$$

where P_m is the edge-crush value of the combined board, D_x and D_y are the flexural stiffness values for the combined board in each direction, and Z is the perimeter of the box to be modeled (Box Compression Analysis of World-Wide Data Spanning 46 Years, 2005).

According to the McKee equation, the compression strength BCT of a corrugated board box with the regular Slotted Box (RSC) design can be predicted from knowledge of:

1. The edgewise crush resistance of the corrugated board, the ECT-value in kN/m
2. The bending stiffness in the machine and cross-machine directions of the corrugated board, SB_{MD} and SB_{CD} , in Nm
3. The periphery of the box, Z in m.

In general, the so-called McKee formula says

$$BCT = k \times ECT^{b} \cdot S^{1-b} \cdot Z^{2b-1} \qquad (2)$$

The formula can, for corrugated board, be adapted to

$$BCT = k \times ECT^{0.75} \times SB^{0.25} \times Z^{0.5} \qquad (3)$$

where SB is the geometric mean stiffness given by $SB = \sqrt{SB_{MD} \cdot SB_{CD}}$

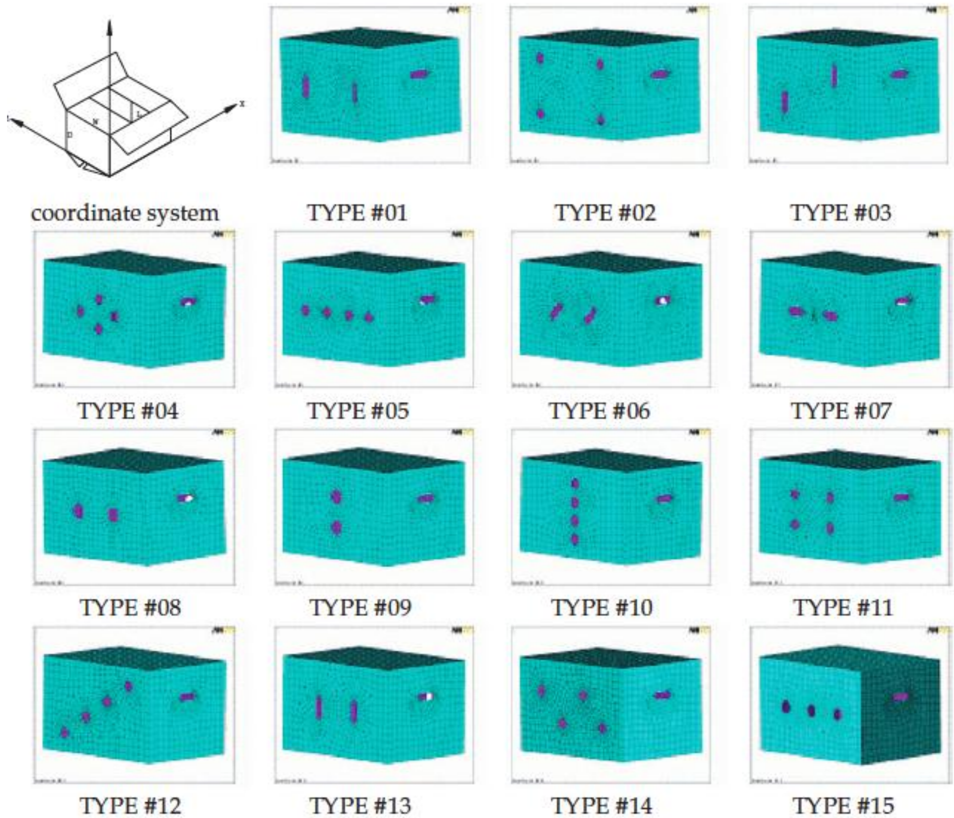
k represents constants chosen so that the product gives the BCT-strength in N (Testing Method and Instruments for Corrugated Board, 1988, p.11).

2.5 Holes in corrugated shipping containers

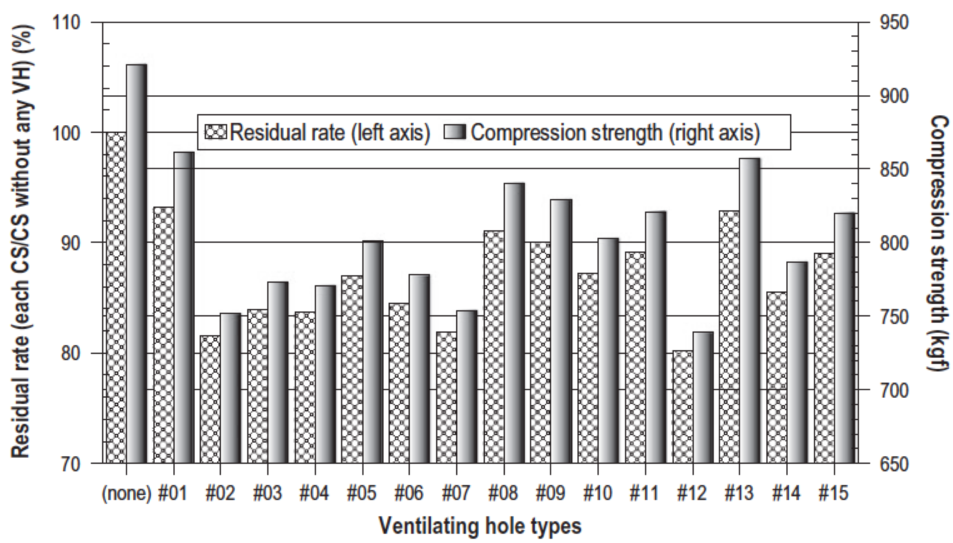
There are generally two kinds of holes on corrugated shipping container: vent holes and hand holes.

The vent hole exists for circulation of fresh air and keeps the temperature stable, and the hand hole makes a corrugated shipping container easy to carry. A recent trend in the physical distribution of fresh food produce requires a somewhat excessive multi-layer stacking of outer containers within a cold-chain distribution system. The outer containers with reasonable compression strength, despite having a couple of ventilating or hand hole structures, may be a primary concern in the development of those containers (Finite Element Analysis of Vent/Hand Hole Designs for Corrugated Fibreboard Boxes, 2007).

This study used two kinds hand hole for comparing compression strength. Two hand holes are of different design and different opening size but the same as sums of horizontal lengths in the opening areas.



(Figure 6) Models for various ventilation holes investigated



(Figure 7) Rate of compression strength of various ventilation hole types.

Above data showed that type #01, #02, #03, #08, #09, #11, #13 have the same width of the vent hole and #10 has the smallest width. #02, #03. #10 samples did not have enough space for distributing compression stress; therefore, these showed a lower compression strength than #01, #08, #09, #11, #13.

2.6 Distribution environments

The first step in designing an effective package system is to determine the severity of the shipping environment. Evaluation of the product's distribution method can determine which hazards the product will likely come across, as well as the level of intensity of those hazards. Then the package system can be designed accordingly.

Package handling, transportation, and storage can lead to a variety of hazards within the shipping environment, including, but not limited to, vertical drops, horizontal impacts, vehicle vibration, temperature extremes, and compression loads. The method of distribution greatly influences the presence and severity of these hazards, so understanding the shipping environment is essential to designing a package that will effectively protect its product.

There are four different ways of determining the environment through which a product is shipped:

- Observation

The most informative method of describing the distribution environment would be to actually follow a package as it travels through the shipping environment and watch what happens to it. Through the use of human observation, first-hand knowledge of the environment can be obtained. Cameras can provide documented evidence of the hazards that a package encounters. Of course, following a package through its complete travel route can be very time-consuming and expensive. The information acquired will only be relevant to the time the observation was made and will only provide a glimpse of that environment. In addition, the behavior of the handlers may be affected by the presence of the observers, as it is human nature to try to perform better while being watched.

Unless the observation can take place unnoticed, the results may not give a completely accurate description of the shipping environment. This method may work best for an initial assessment of the environment, which can later be correlated with supporting data gained from other types of measurement. It may also work well for simple and/or controlled environments that only utilize one or two different modes of distribution.

- Damage Claims

Some hazards in a distribution environment go unnoticed until they cause damage to products with insufficient protection. A review of damage reports, which can be obtained from carrier logs, customer complaints, or shipping department personnel, can provide a better understanding of the hazards encountered in a shipping environment. These reports can be used as documented evidence and can indicate how much money is lost due to damage in transit. It may be possible to characterize the type of damage, as well as the geographical location where the damage took place.

However, damage reports do not always contain specific information on the type or extent of damage that occurred. Sometimes damage is incorrectly blamed on insufficient packaging, when in fact the product itself was defective before shipping or the package was grossly mishandled during shipment. Faulty products are often incorrectly packaged for return, resulting in damage during shipping that is unrelated to, or compounds, the original problem. This often causes damage reports to be misleading. Furthermore, not all damage is reported, since sometimes losses are absorbed rather than claimed, making accurate information hard to obtain.

It can be costly to wait for damage to be reported before trying to determine its cause. This method is most effective when investigating damage that occurs to new products and when trying to improve existing package systems.

- Literature Search

Perhaps the most widely used approach is to research what others have done. There have been numerous studies performed and an examination of available data can provide a broad understanding of the issues surrounding the measurement of a distribution environment. Research also requires a smaller commitment of time and resources than actually performing the experiments. The difficulty with this approach is that the data can sometimes be outdated and sampling parameters can be unclear or unknown.

Conclusions drawn by studies are usually dependent on the author’s perspective and selective data may have been used. Also, the data may not be relevant to the shipping environment in question and some variables may not have been fully addressed. In general, however, this approach has provided the guidelines and rules of thumb used in today’s package design work.

- Direct Measurement

The best substitute for actual observation of the environment a package travels through is the use of a recording device to monitor the package and/or vehicle during shipment. The measurement device can record the events that happen throughout the trip without influencing the package’s treatment, since it is usually concealed inside the package. It can be calibrated in the lab before use to test for accuracy, and a correction factor can be established if necessary. Many devices can collect various types of measurements at the same time, thereby utilizing the full capacity of limited resources. Provided the same route is measured enough times using the same equipment and protocol, some sort of statistically valid information can be obtained to help describe that particular channel of distribution. Specific events will obviously vary from trip to trip but a general idea of what to expect will develop.

The disadvantages to this technique are that the equipment can be expensive, and the analysis of the data very time-consuming. The analysis is also subject to the limitations of the recording devices. The accuracy of the equipment determines how well the recorded event correlates to the actual event, and sometimes it can be difficult to compare data. Also, there may be such a great number of variables that only a rough estimate of the environment can be made. Although it is not ideal, for now direct measurement may be the best-suited approach for gaining information about a specific distribution channel (Four ways to define the environment distribution, Hewlett Packard Packaging department, 2004).

3.0 Design of experiment

3.1 Equipment

The equipment used for the project are a compression tester (Lansmont's model 152 compression test system), a sample cutting table (Data TECHnology model DT6646 counter cutter/sample maker), an environmental chamber (Bally environmental chamber assembly), and a computer based design system (Artios CAD). All equipment is located in Packaging Science Department of Rochester Institute of Technology.

3.1.1 Compression tester (Lansmont's model 152 series compression test system)

Lansmont's compression test system (Figure8 & 9) was used for this compression test. The specifications of the equipment are as follows:

Platen size (large): 60 in. square (152cm square)

Platen size (small): 30 in. square (76 cm square)

Maximum opening: 84 in. (213 cm)

Force capacity: 30,000 lbs (13,608 kg)

Force applicator: Hydraulic Cylinder

Cross-Head positioning: Electric Hoist @ 8 ft./min. (244 cm/min.)

Test speed :0.5 in./min. (1.27 cm/min)

Lansmont's Model 152 Compression Test System is specifically designed to efficiently and accurately evaluate the performance of individual packages, pallets, and unit loads under compressive forces (Http://www.Lansmont.com).

A condition for carrying out the BCT-test in an accurate and uniform way is that the compression tester meets the basic requirements specified in the test standard. These requirements are fixed so that different test conditions, which may influence the result, will be kept under control as much as possible. This is essential if the test results are to be comparable regardless of where the test has been carried out. Some of the requirements given in the standards concern the design of the compression plates. These shall be plane and rigid.

Another requirement is a fixed compression speed, specified to be 0.1 in./min. (10-

13mm/min.) (Testing Methods and Instruments for Corrugated Board, 1988)

(Figure 8) Compression strength tester

(Figure 9) Ending position of compression strength tester

3.1.2 Sample cutting table (Data TECHnology model DT6646 counter cutter/sample maker)

DT6646 counter cutter/sample maker (Figure 10) is a heavy-duty production counter cutter that turns into a high-speed sample maker with a quick tool head change. It is used for cutting sample containers that are designed by computer based design systems and the samples are used for verifying design, performance or small amounts of products. This machine is not a fast method to make a product, but it can produce a much more accurate product than producing by hand, and the cutting unit is manually located using control unit (Figure 11). The sample cutting table, used for this study, is model DT6646 made by Data TECHnology.

(Figure 10) Sample cutting table

(Figure 11) Control unit of sample cutting table

3.1.3 Environmental chamber (Bally environmental chamber assembly)

An environmental chamber (Figure 12) can control temperature and humidity. It can artificially make a common distribution environment or extreme distribution environment. This test used three conditions: room conditions, low temperature with humidity and high temperature with humidity because moisture can easily affect the compression strength of the corrugated board during distribution. The artificial environment is recorded during the test in data sheet in the control box (Figure 13).

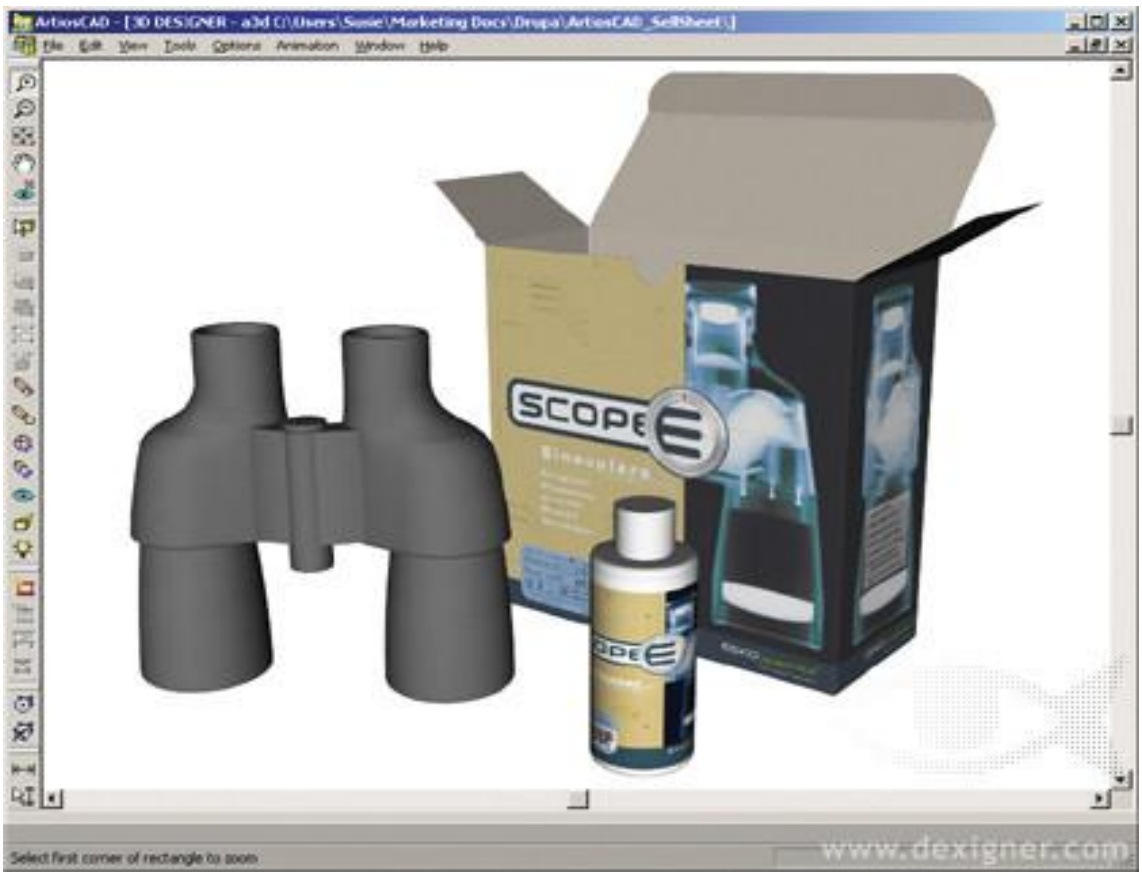
(Figure 12) Environmental chamber

(Figure 13) Control box of environmental chamber

3.1.4 Computer based design system (ArtiosCAD)

There are many computer based design system in engineering field such as AutoCAD, CADian and CivilVad. AutoCAD is a basic design program, ArchiCAD is used for architectural field materials. CADian is used for mechanical field, and CivilCAD is used for Civil Engineering.

Artios Corporation made ArtiosCAD specifically for the packaging science field. This program allows the designer to pick the material and common style of container, and easily modify the design. The designer can send the design to the cutting table machine to produce sample.



(Figure 14) Computer Aided Design system (Artios CAD)

3.2 Sample designs

The RSC style containers with two types of hand holes were used in the compression test. The specifications of the corrugated fiberboard are as follows:

Flute construction: C-Flute

Outer liner: Unbleached kraft

Inner liner: Unbleached kraft

Dimensions (outer): 10”X12”X10” (LXWXD)

- Conventional purpose hand hole (Figure B-6)

  Removed area: 3.29 sq inches

  Width of hand hole: 3.5 inches

- Arc-top hand hole (Figure B-8)

  Removed area: 5.41 sq inches

  Width of hand hole: 3.56 inches

3.3 Test method

The test used ‘C’ flute corrugated fiberboard to make samples under three different conditions which followed ISTA 2A as below 3.3.2. The test procedure followed ASTM D 642 which is the ‘Standard Method of

Determining Compressive Resistance of shipping Container components of Unit Loads'

3.3.1 Preconditioning

The ISTA 2A shows guidelines for preconditioning for testing. The packaged-product should be stored prior to climate conditioning at laboratory ambient temperature and humidity for six hours. All materials used for the study are stored under the same condition which is the laboratory condition ,67.2°F and 58% humidity, for a six hours, so all materials' conditions were the same.

3.3.2 Conditioning

To permit an adequate determination of a packaged product performance at anticipated atmospheric limits, and where it is known that the atmospheric extremes are detrimental to the product, ISTA:

-Requires the highest temperature and humidity limits of the product be used, but

-Recommends that both the highest and lowest atmospheric conditions be used.

Condition packaged-products according to one or more of the conditions listed in the table below:

Anticipated conditions	Time in Hours	Temperature in °F ± 4°F	Humidity in %
Extreme cold, uncontrolled RH	72	-20°F	Uncontrolled RH
Cold, humid	72	40°F	85% RH ± 5%
Controlled conditions	72	73°F	50% RH ± 5%
Hot, humid	72	100°F	85% RH ± 5%
Hot, humid then Extreme heat, moderate RH	72 then 6	100°F then 140°F	85% RH ± 5% then 30% RH ± 5%
Elevated temperature, uncontrolled RH	72	120°F	Uncontrolled RH
Extreme heat, dry	72	140°F	15% RH ± 5%
Severe cold, Uncontrolled RH	72	0°F	Uncontrolled RH

User defined high limit	72	Based upon known conditions	Known conditions
User defined low limit	72	Based upon known conditions	Known conditions
User defined cycle	72	Based upon known conditions	Known conditions

(Table 2) Environment condition <ISTA 2A>

- Remaining test requirements should be performed as soon as possible after removing the packaged-product from environmental conditioning apparatus.
- If more than one conditioning sequences are selected, a new and complete test should be performed following each sequence.

The test used empty corrugated shipping containers because the products in shipping containers can affect the compression strength.

The study used three conditions which are room condition -LAB condition-, high temperature and humid, and low temperature and humid.

Two types of samples were put into three different conditions' chambers for 72 hours, and then tested. Each sample was moved one by one from conditioning chamber to the compression tester to keep the conditions stable.

3.3.3 Test procedure

The compression strength test followed ASTM D642 (Standard Method of Determining Compressive Resistance of Shipping Container Components of Unit Loads, 2007).

Step 1) The corrugated board for the test was verified that it has all the same specifications and condition (pre-conditioning). All materials were in the Rochester Institute of Technology packaging science department LAB. Therefore, all materials were pre-tested using the ECT and stiffness test.

Step 2) 15 RSC style corrugated shipping containers with the conventional purpose hand hole and 15 RSC style corrugated shipping containers with the arc top hand hole were cut same day. The corrugated shipping containers were placed in Rochester Institute of Technology Packaging Department material lab to maintain the same conditions.

Step 3) To compare compression strength of corrugated shipping containers with the conventional purpose hand hole to those with the arc-top hand hole, four sets of five containers were prepared for the test. All samples were sealed using 2 inches wide transparent tape according to ASTM D642.

Step 4) Five samples were put into LAB condition for 72 hours. (67.2°F, 58%)

Step 5) The compression tester was set up with general parameters: pre-load is 50 lbs, fall back is 10% and displacement limit was turned off.

Step 6) The samples were brought one by one just before compression test to keep conditions stable.

Step 7) Each sample was tested and then all data were recorded.

Step 8) Same as Step 3

Step 9) Five samples were put into conditioning chamber cold and humid for 72 hours.(40°F, 85%)

Step 10) Same as Step 6 and 7

Step 11) Same as Step 3

Step 12) All samples were leave in conditioning chamber hot and humid for 72 hours.(100°F, 85%)

Step 13) Same as Step 6 and 7

4.0 Data and results

4.1 Data

200 RSC style corrugated shipping containers were produced with two kinds of hand holes in this study. The top to bottom compression strength of sample containers was recorded by a compression strength test machine.

The peak force and deflection at peak just before failure were collected during BCT test. Appendix A contains sample data for individual test.

4.2 Data analysis

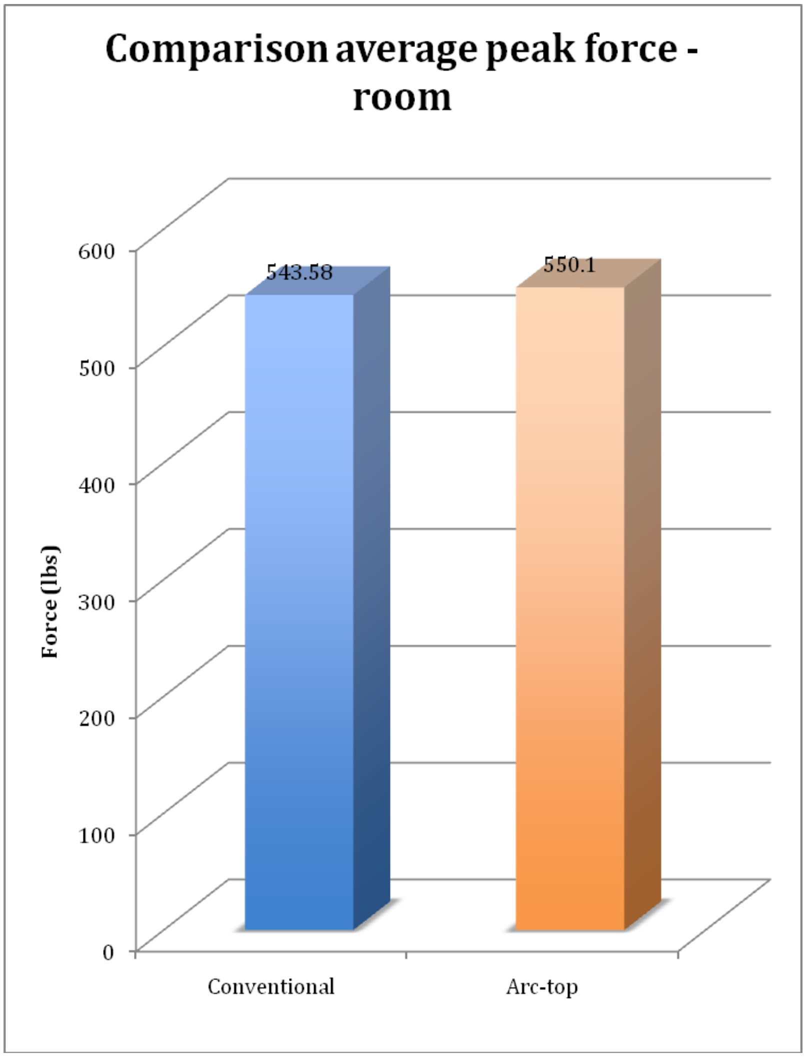
4.2.1 Room conditions

This study was the comparison of compression strength of the conventional hand hole with the arc-top hand hole. The results were from each of 5 samples set in room condition for 72 hours before test.

The average peak compression strength of the conventional hand hole was 543.58 lbs and the standard deviation was 24.04.

The average peak compression strength of the arc-top hand hole was 550.1 lbs and the standard deviation was 42.97 as shown graph 1.

Considering the error of each data, the average peak compression strengths of two designs can be regarded the same.



(Graph 1) Comparison compression strength under room temperature conditions.

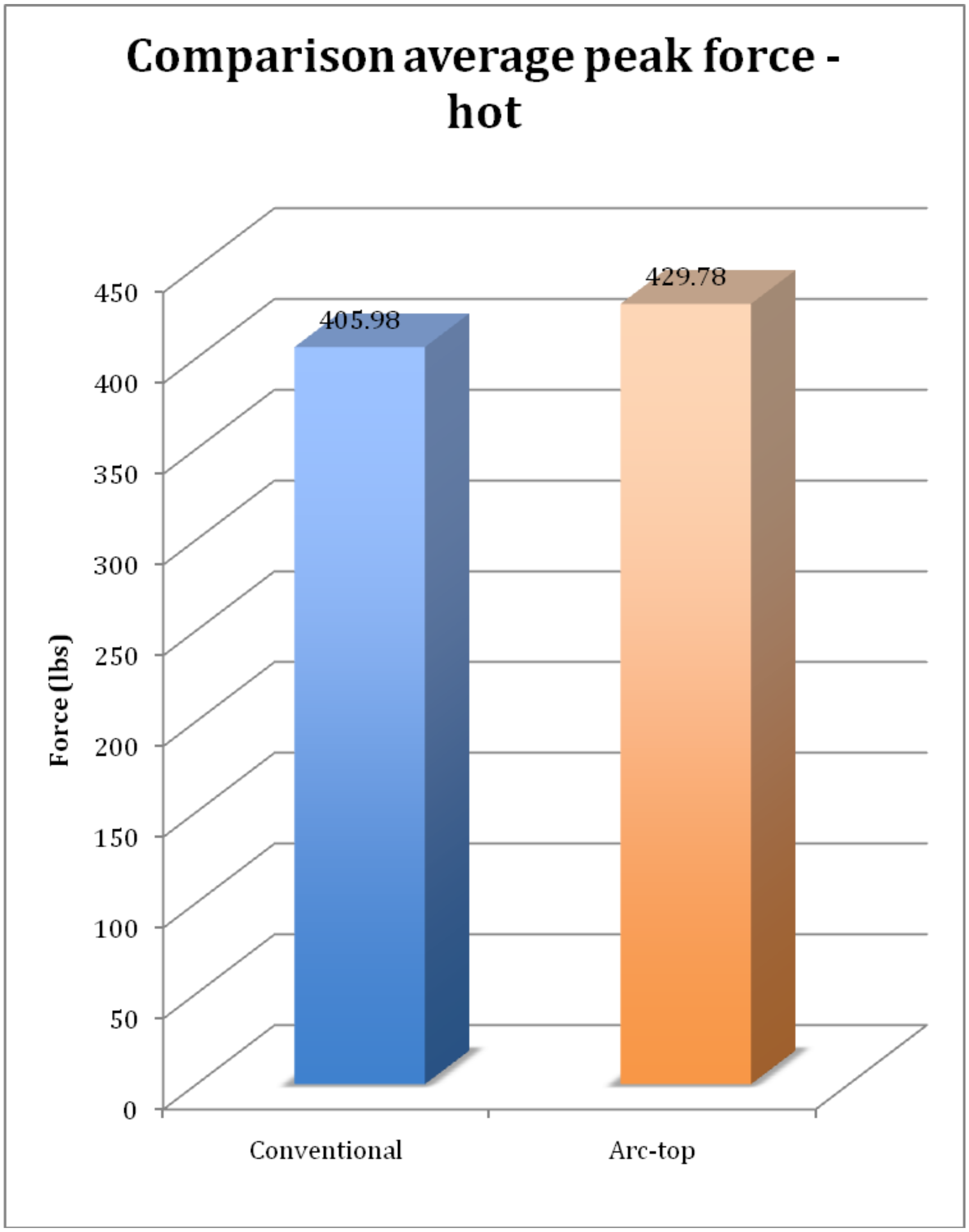
4.2.2 Hot and humid conditions

The study was comparison of compression strength of the conventional hand hole with the arc-top hand hole. The results were from each of 5 samples in hot (100°F) and humid (80%) condition for 72 hours before test.

The average peak compression strength of the conventional hand hole was 405.98 lbs and the standard deviation was 47.71.

The average peak compression strength of the arc-top hand hole was 429.78 lbs and standard deviation was 32.80 as shown graph 2.

Considering the error of each data, the average peak compression strengths of two designs can be regarded the same.



(Graph 2) Comparison compression strength under hot and humid conditions.

4.2.3 Cold and high humid conditions

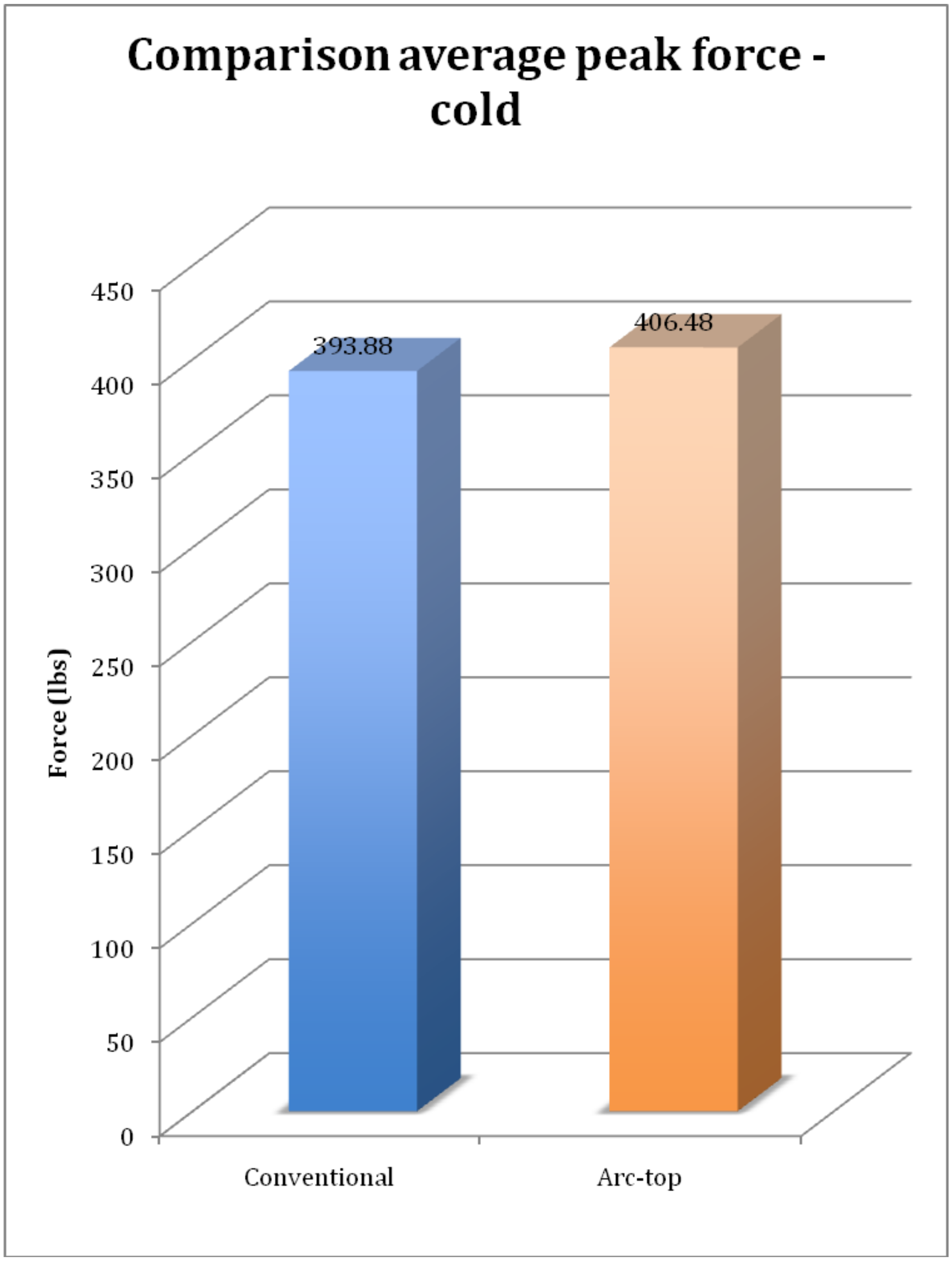
The study was comparison of compression strength of the conventional hand hole with the arc-top hand hole. The results were from each of

5 samples in cold (40°F)and humid (85%) condition for 72 hours.

The average peak compression strength of the conventional hand hole was 398.88 lbs and the standard deviation was 11.54.

The average peak compression strength of the arc-top hand hole was 406.48 lbs and the standard deviation was 8.79 as shown graph 3.

Considering the error of each data, the average peak compression strengths of two designs can be regarded the same.



(Graph 3) Comparison compression strength under cold and humid conditions.

5.0 Conclusion

The basic functions of Packaging are to contain, transport, inform and protect. All functions are vitally important for packaging so designers make an effort to increase the performance of packaging functions. This study specifically considers the compression strength of the corrugated shipping containers that have hand holes. Designers also make a new design of hand holes to make the container easy to carry, and to increase tear strength, as well as compression strength.

Two common styles of hand hole used in the study are the conventional purpose hand hole (Figure B-5) and the arc-top hand hole (Figure B-7), and which had almost same width, 3.5 inches. ASTM D 6804-02 Standard Guide for Hand Hole Design in Corrugated Boxes shows that the tear strength of the arc-top hand hole offers over four times as much strength conventional purpose hand hole.

However, the arc top hand hole has a larger opening area, 5.41 sq inches, than the conventional hand hole's opening area, 3.29 sq inches. A larger opening area generally has an negative effect on the compression strength of the container because the larger opening area needs a larger space for distributing compression strength. However, the dimension of the shipping containers are limited; therefore, the size of the hand hole needs to be considered according to the dimension of the containers.

When the hand hole is located with enough space around it for dispersion, the width of the hand hole is the only variable directly related with the compression strength of the corrugated shipping containers. The result of the study showed that the compression strengths of two different samples were the same in all different conditions, even though the arc-top hand hole’s opening area is 1.64 times larger than the conventional hand hole’s opening area. This study did not calculate the size of the appropriate space around the hand holes to distribute the compression strength, so it used a common design to give enough space for dispersion.

In conclusion, the compression strengths of corrugated shipping containers and corrugated fiber boards are not related with the size of the opening area. The compression strength is only related to the width of the opening area if the hole is located properly, and has enough space for distributing the compression strength.

As a result, resistance forces of containers are the same if the sums of the width of the hand holes are the same and the hand holes have enough space to distribute the compression stress, even though the designs of the hand holes are different.

6.0 Recommendations

There are many designs of hand holes for the corrugated shipping containers. This study used only two common styles the hand holes. In addition, two hand holes are located in the same position to allow for enough space to distribute a load stress and this study only compared two different designs of hand holes in three different conditions. Therefore, a future study is recommended to use more variety of designs of the hand holes to compare compression strength and opening area and to find the placement that will achieve optimum results.

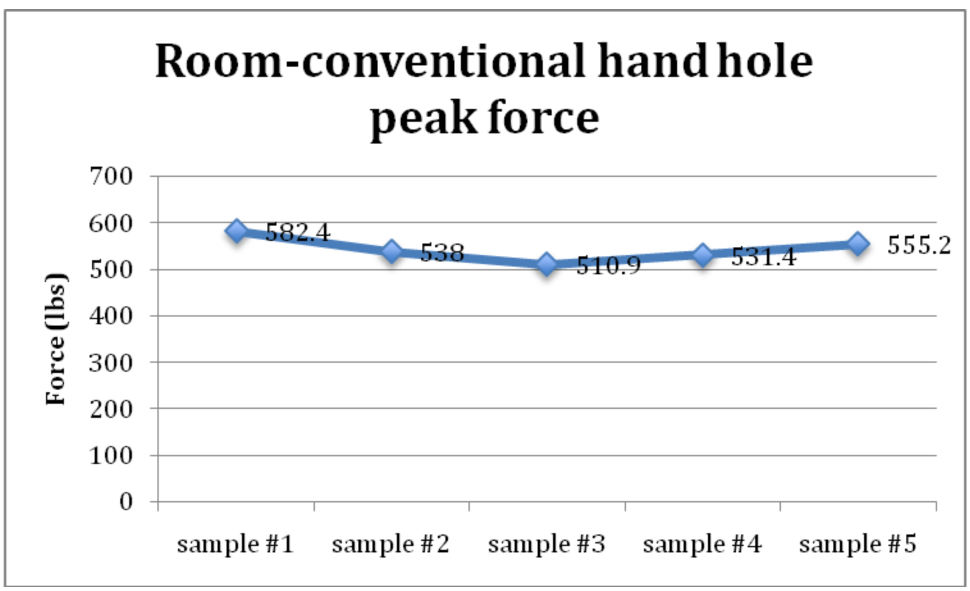
In addition, the corrugated board is moisture-sensitive material. A future study is also recommended to find the difference of each decrease ratio of the compression strength of the corrugated shipping container without hand holes under controlled condition and various extreme conditions and the compression strength of the corrugated shipping container with hand holes under controlled condition and various extreme conditions, such as high humid and low humid conditions. This will allow for comparisons between corrugated shipping containers with hand holes and those without.

7.0 Appendix A

(Table A- 1) BCT data of samples having the conventional hand hole under room conditions.

Normal-conventional hand hole		
	Peak force	Deflection
Sample #1	582.4 lbs	0.22 inches
Sample #2	538 lbs	0.22 inches
Sample #3	510.9 lbs	0.19 inches
Sample #4	531.4 lbs	0.2 inches
Sample #5	555.2 lbs	0.24 inches

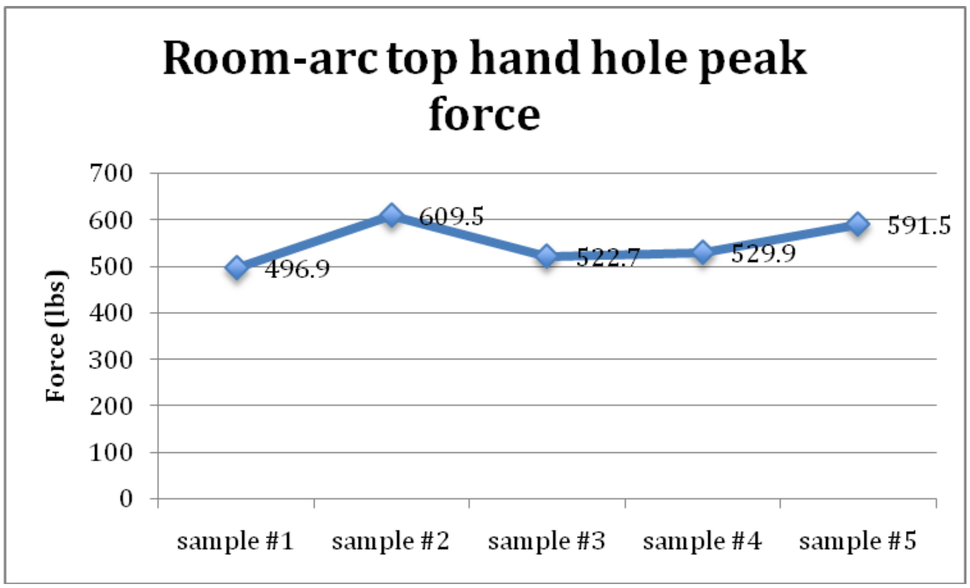
(Graph A- 1) Compression strength of samples having the conventional hand hole under room conditions.



(Table A- 2) BCT data of samples having the arc-top hand hole under room conditions.

Normal-arc top hand hole		
	Peak force	Deflection
Sample #1	496.9	0.22
Sample #2	609.5	0.29
Sample #3	522.7	0.18
Sample #4	529.9	0.18
Sample #5	591.5	0.3

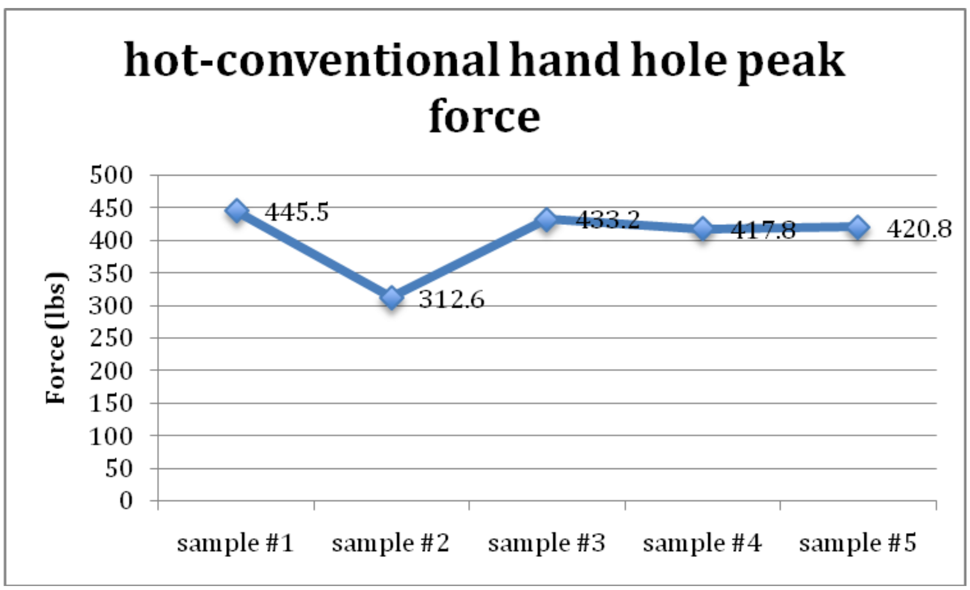
(Graph A- 2) Compression strength of samples having the arc-top hand hole under room conditions.



(Table A- 3) BCT data of samples having the conventional hand hole under hot and humid conditions.

Hot-conventional hand hole		
	Peak force	Deflection
Sample #1	445.5	0.24
Sample #2	312.6	0.13
Sample #3	433.2	0.21
Sample #4	417.8	0.18
Sample #5	420.8	0.21

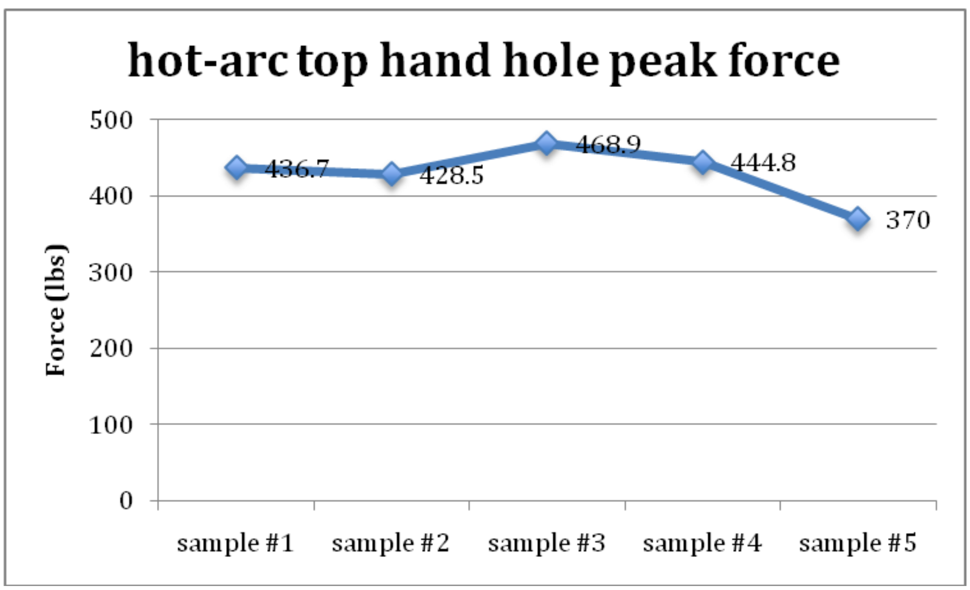
(Graph A- 3) Compression strength of samples having the conventional hand hole under hot and humid conditions.



(Table A- 4) BCT data of samples having the arc-top hand hole under hot and humid conditions.

Hot-arc top hand hole		
	Peak force	Deflection
Sample #1	436.7	0.23
Sample #2	428.5	0.24
Sample #3	468.9	0.22
Sample #4	444.8	0.22
Sample #5	370	0.19

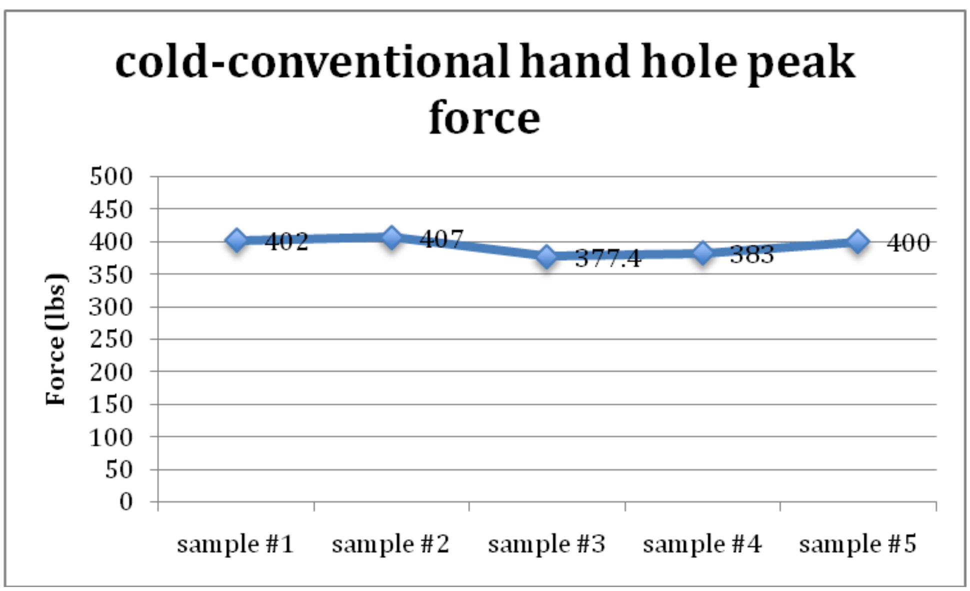
(Graph A- 4) Compression strength of samples having the arc-top hand hole under hot and humid conditions.



(Table A- 5) BCT data of samples having the conventional hand hole under cold and humid conditions.

cold-conventional hand hole		
	peak force	Deflection
sample #1	402	0.21
sample #2	407	0.21
sample #3	377.4	0.21
sample #4	383	0.2
sample #5	400	0.22

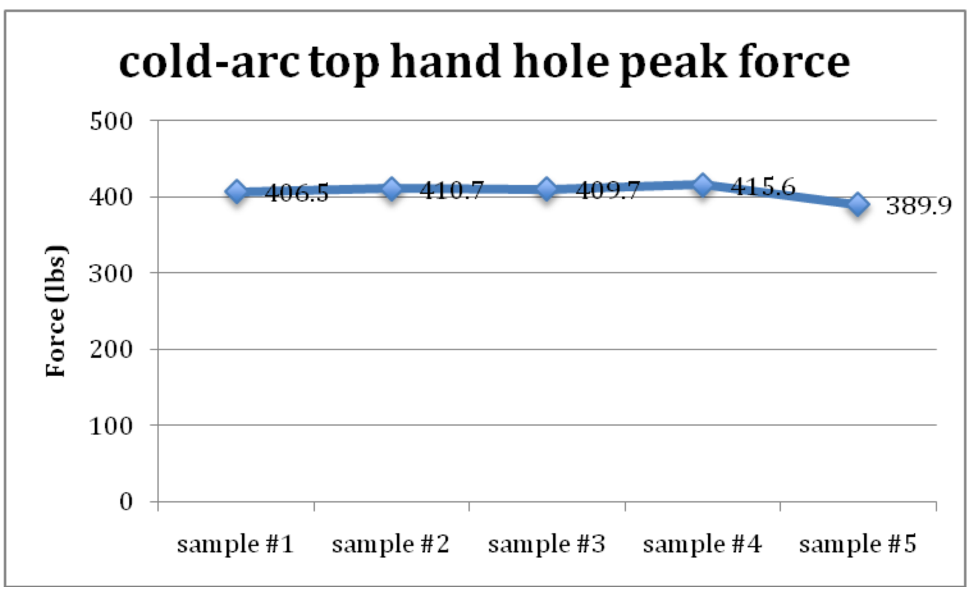
(Graph A- 5) Compression strength of samples having the conventional hand hole under cold and humid conditions.



(Table A- 6) BCT data of samples having the arc-top hand hole under cold and humid conditions.

cold-arc top hand hole		
	peak force	Deflection
sample #1	406.5	0.22
sample #2	410.7	0.21
sample #3	409.7	0.23
sample #4	415.6	0.23
sample #5	389.9	0.21

(Graph A- 6) Compression strength of samples having the arc-top hand hole under cold and humid conditions.



8.0 Appendix B

(Figure B- 1) Conditioning table <ISTA 2A 2008 - Page 6>.

2A

Packaged-Product Weight and Size Measurement

Before You Begin Atmospheric Conditioning

BEFORE YOU BEGIN PROCEDURE 2A

You shall know the packaged-product's:
- gross weight in pounds (kg), **and**
- outside dimensions of Length, Width and Height (L x W x H) in inches (mm or m)

Required Preconditioning:
The packaged-product should be stored prior to climate conditioning at laboratory ambient temperature and humidity for six (6) hours.

Required Conditioning (to be performed after the required preconditioning):
To permit an adequate determination of packaged-product performance at anticipated atmospheric limits and where it is known that the atmospheric extremes are detrimental to the product, ISTA:
- **Requires** the highest temperature and humidity limits of the product be used, **but**
- **Recommends** that both the highest and lowest atmospheric conditions be used.

Condition packaged-products according to one or more of the conditions listed in the table below.
- Remaining test requirements should be performed as soon as possible after removing the packaged-product from environmental conditioning apparatus.
- If more than one conditioning sequence is selected, a new and complete test should be performed following each sequence.

Anticipated Conditions	Time in Hours	Temperature in °C ±2°C (°F ±4°F)	Humidity in %
Extreme Cold, Uncontrolled RH	72	-29°C (-20°F)	uncontrolled RH
Cold, Humid	72	5°C (40°F)	85% RH ±5%
Controlled Conditions	72	23°C (73°F)	50% RH ±5%
Hot, Humid	72	38°C (100°F)	85% RH ±5%
Hot, Humid then Extreme Heat, Moderate RH:	72 then 6	38°C (100°F) then 60°C (140°F)	85% RH ±5% then 30% RH ±5%
Elevated Temperature, Uncontrolled RH	72	50°C (120°F)	uncontrolled RH
Extreme Heat, Dry	72	60°C (140°F)	15% RH +/- 5%
Severe Cold, Uncontrolled RH	72	-18°C (0°F)	uncontrolled RH
User Defined High Limit	72	Based upon known conditions	Known conditions
User Defined Low Limit	72	Based upon known conditions	Known conditions
User Defined Cycle	72	Based upon known conditions	Known conditions

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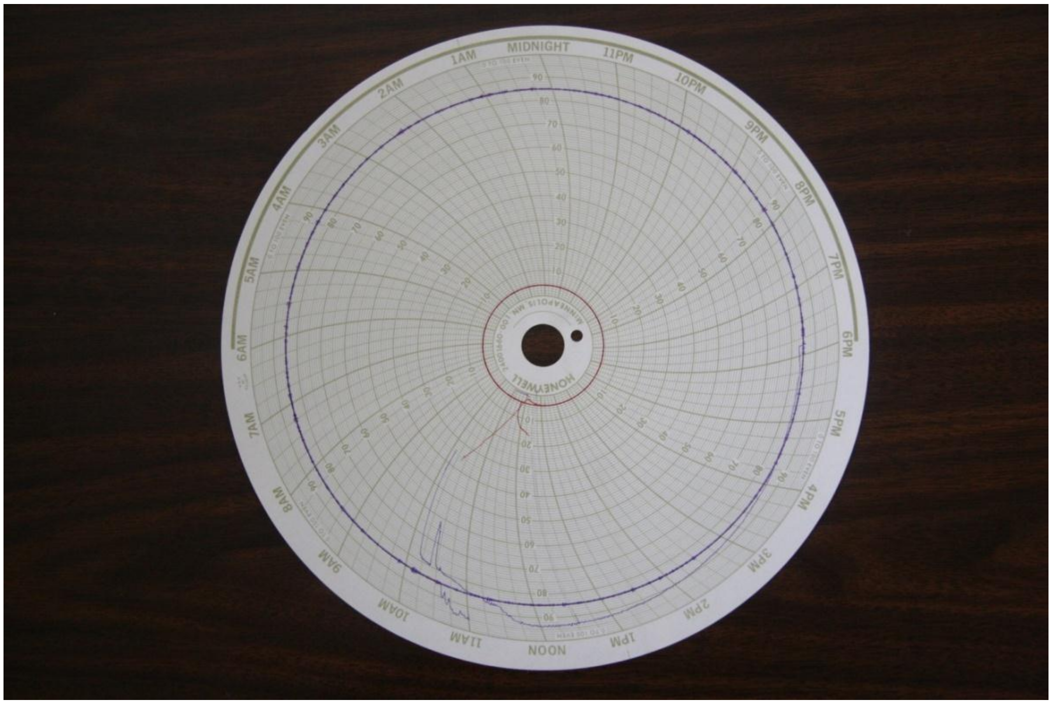
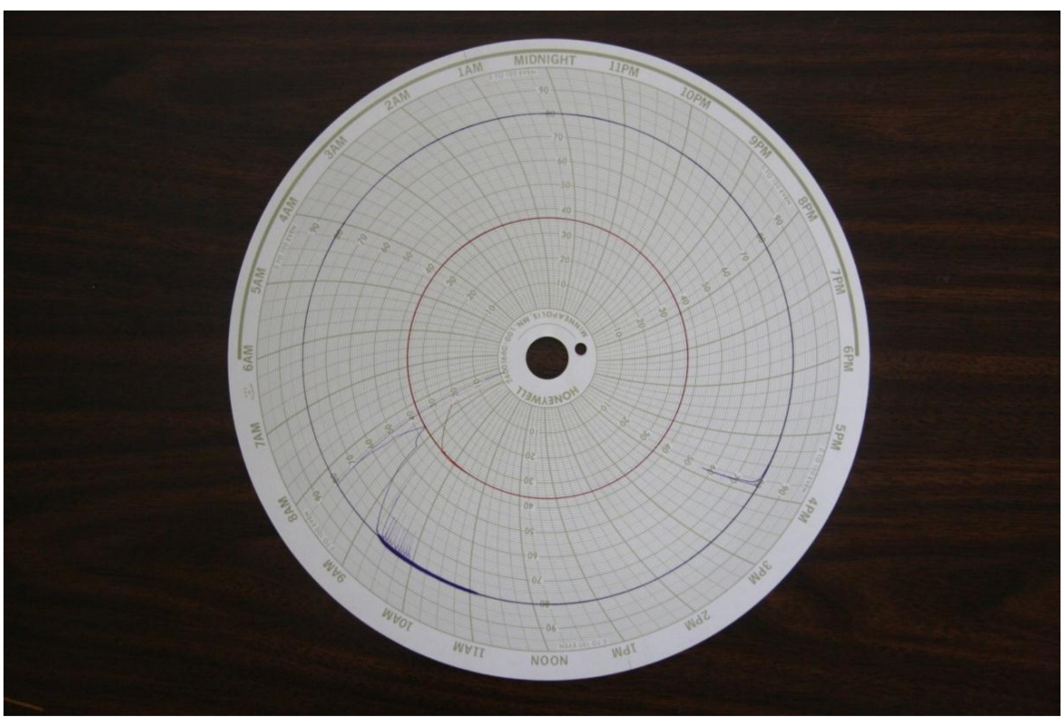
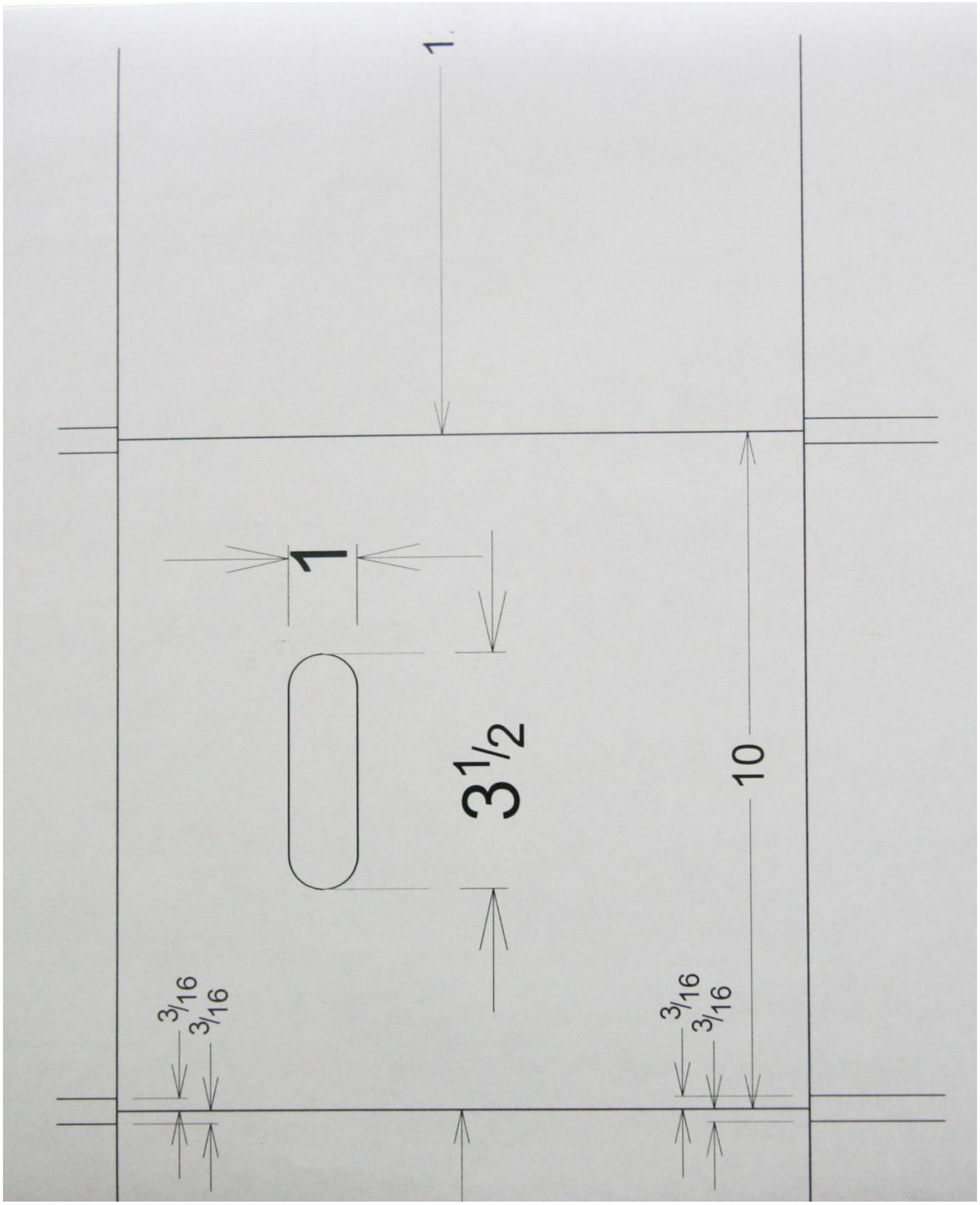
(Figure B- 2) 72hours graph for cold and humid conditioning.



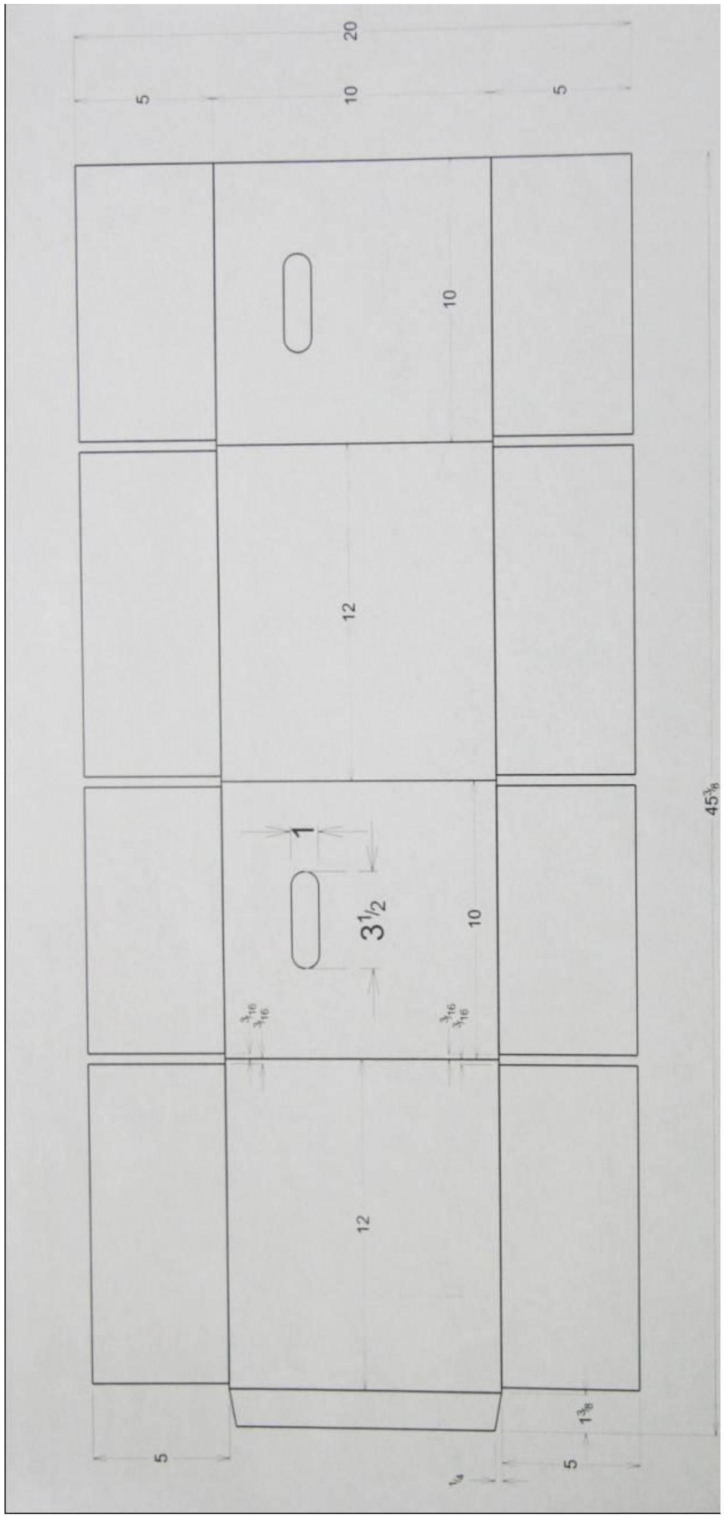
(Figure B- 3) 72hours graph for hot and humid conditioning.



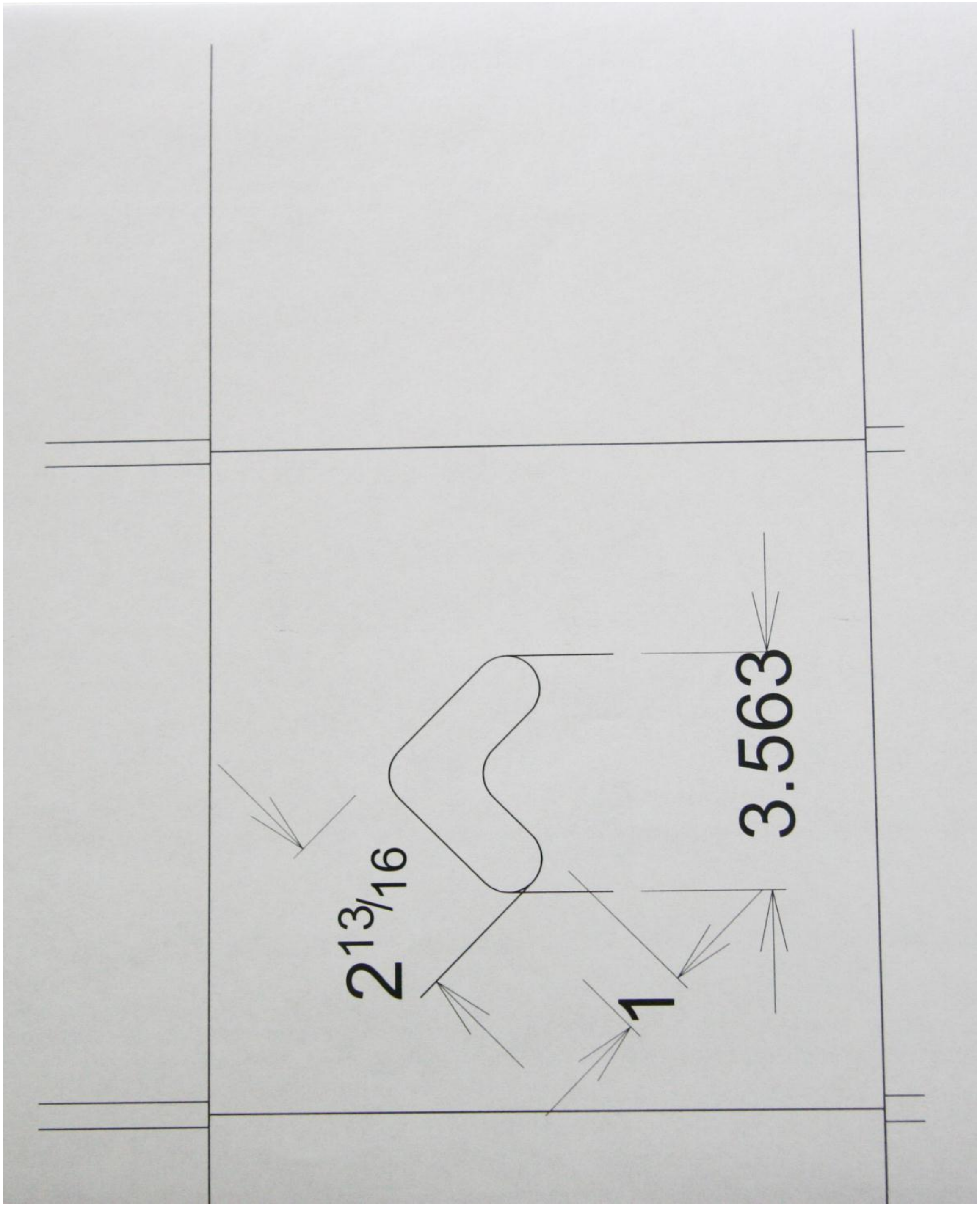
(Figure B- 4) Conventional purpose hand hole sample design.



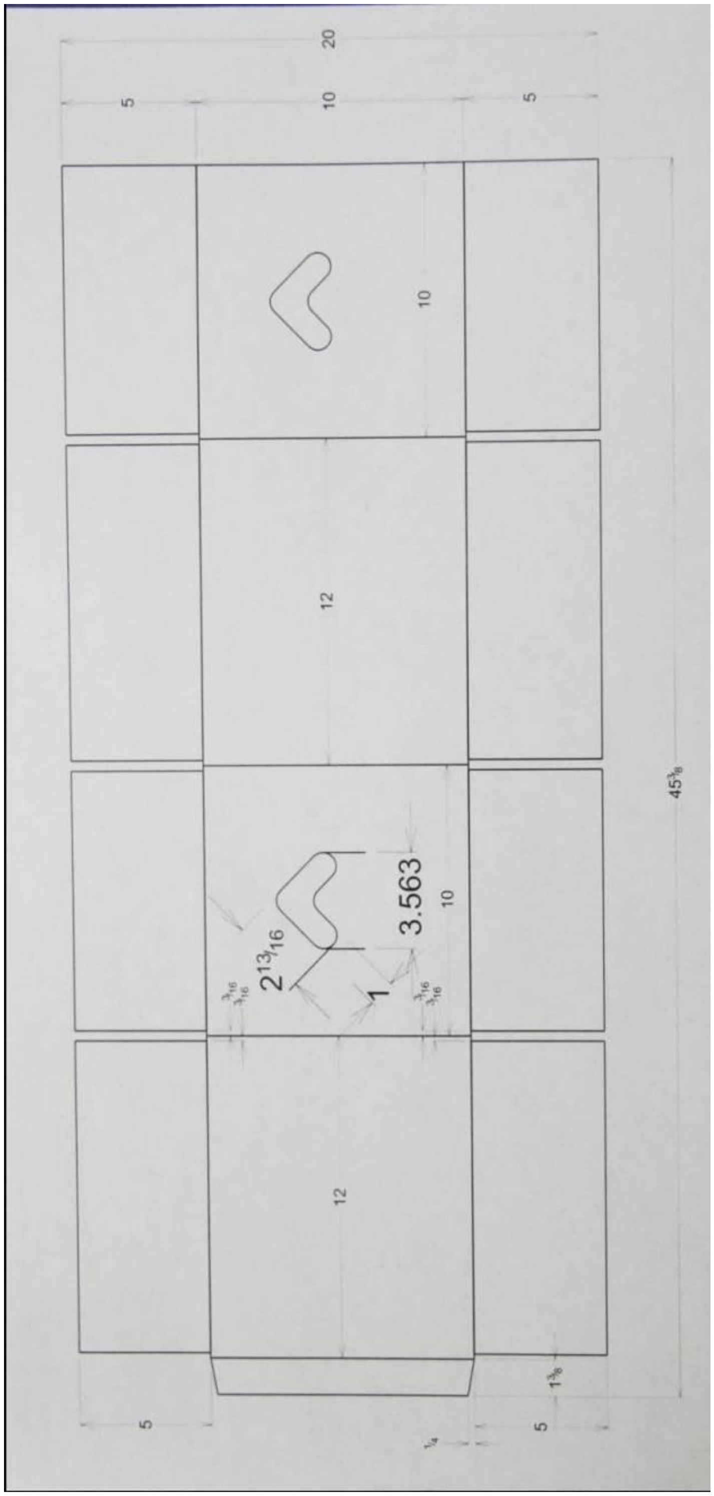
(Figure B- 5) Box sample design having Conventional purpose hand hole.



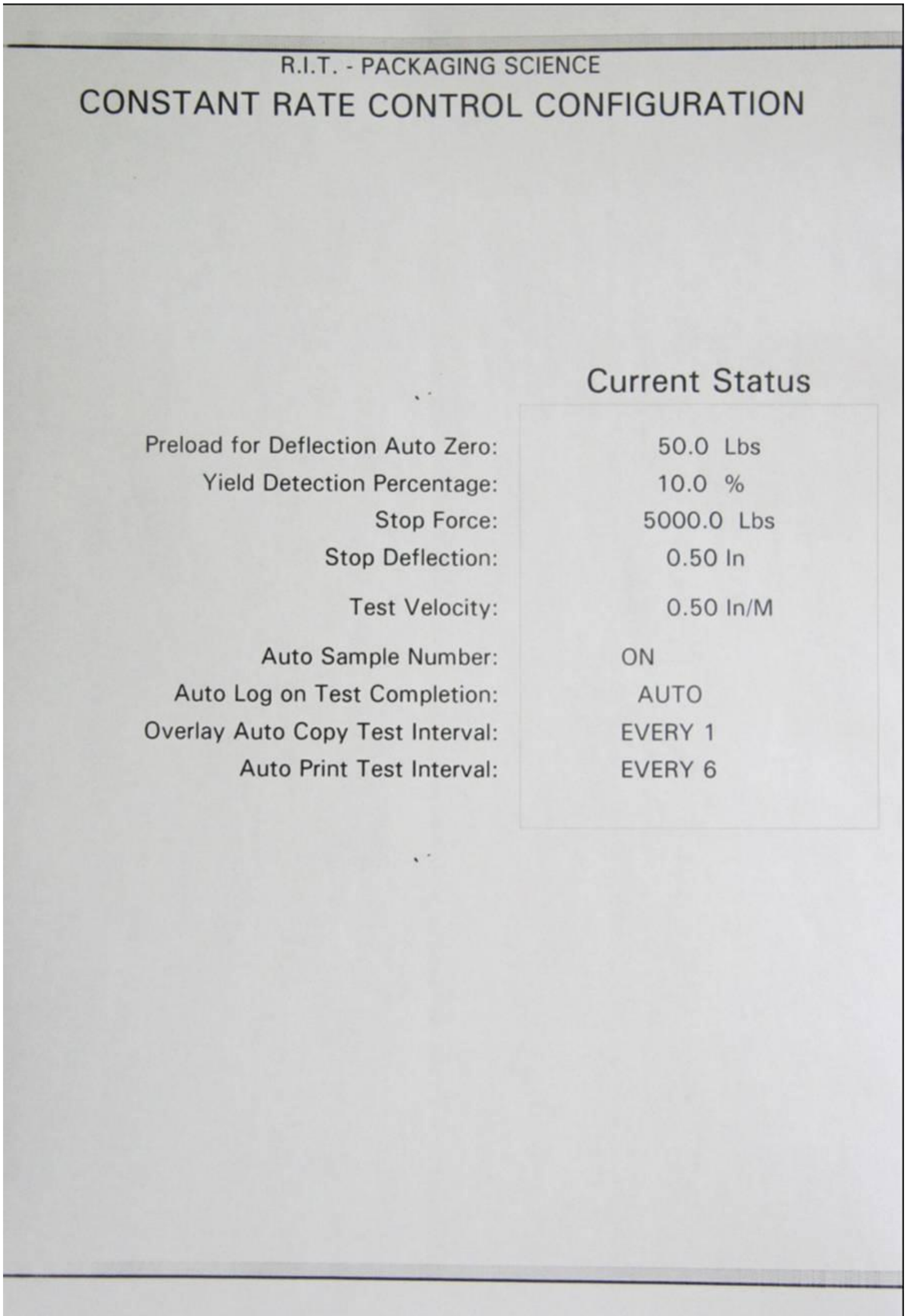
(Figure B- 6) Arc-top hand hole sample design.



(Figure B- 7) Box sample design having arc-top hand hole



(Figure B- 8) Constant rate control configuration.



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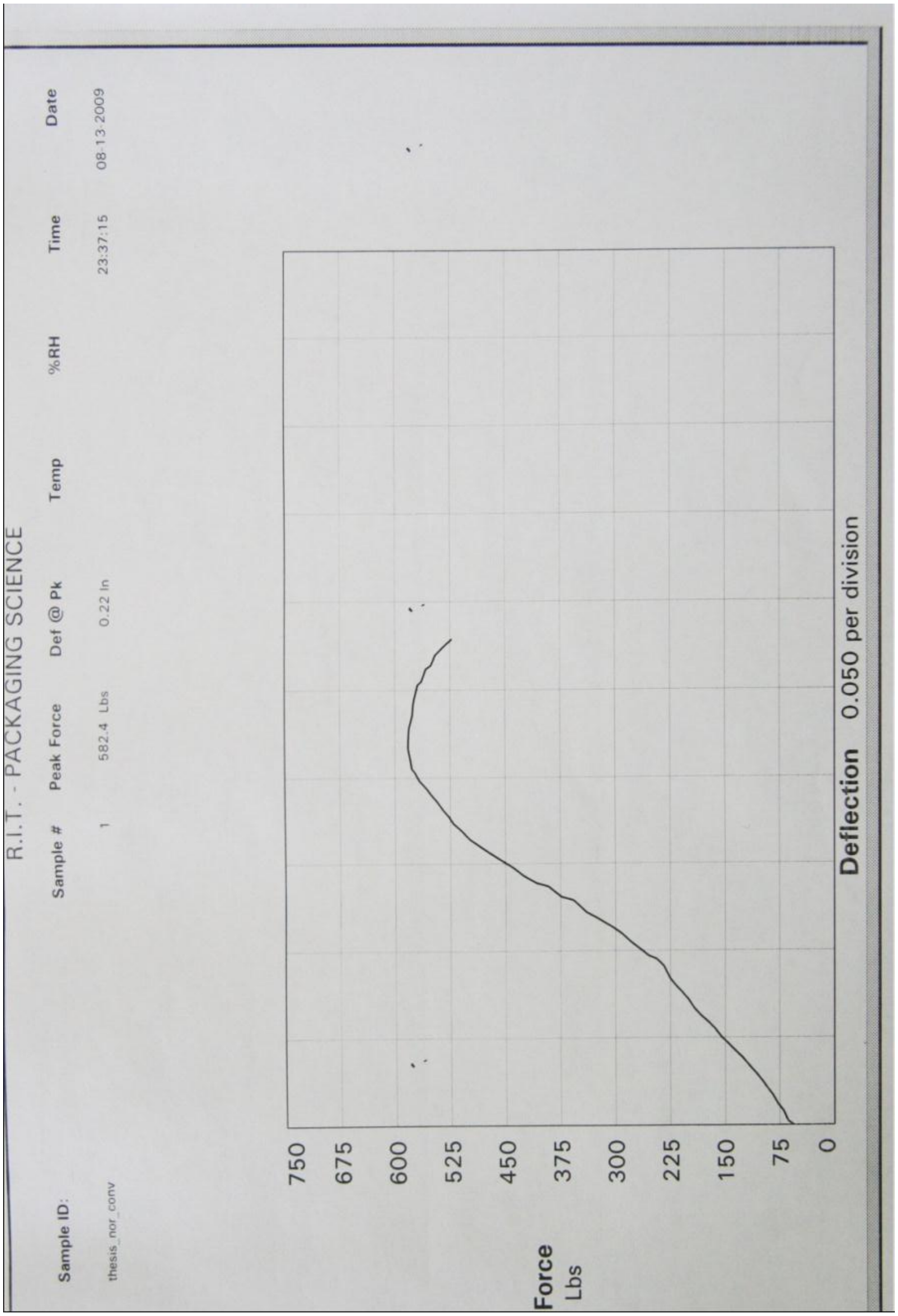
CONSTANT RATE CONTROL CONFIGURATION

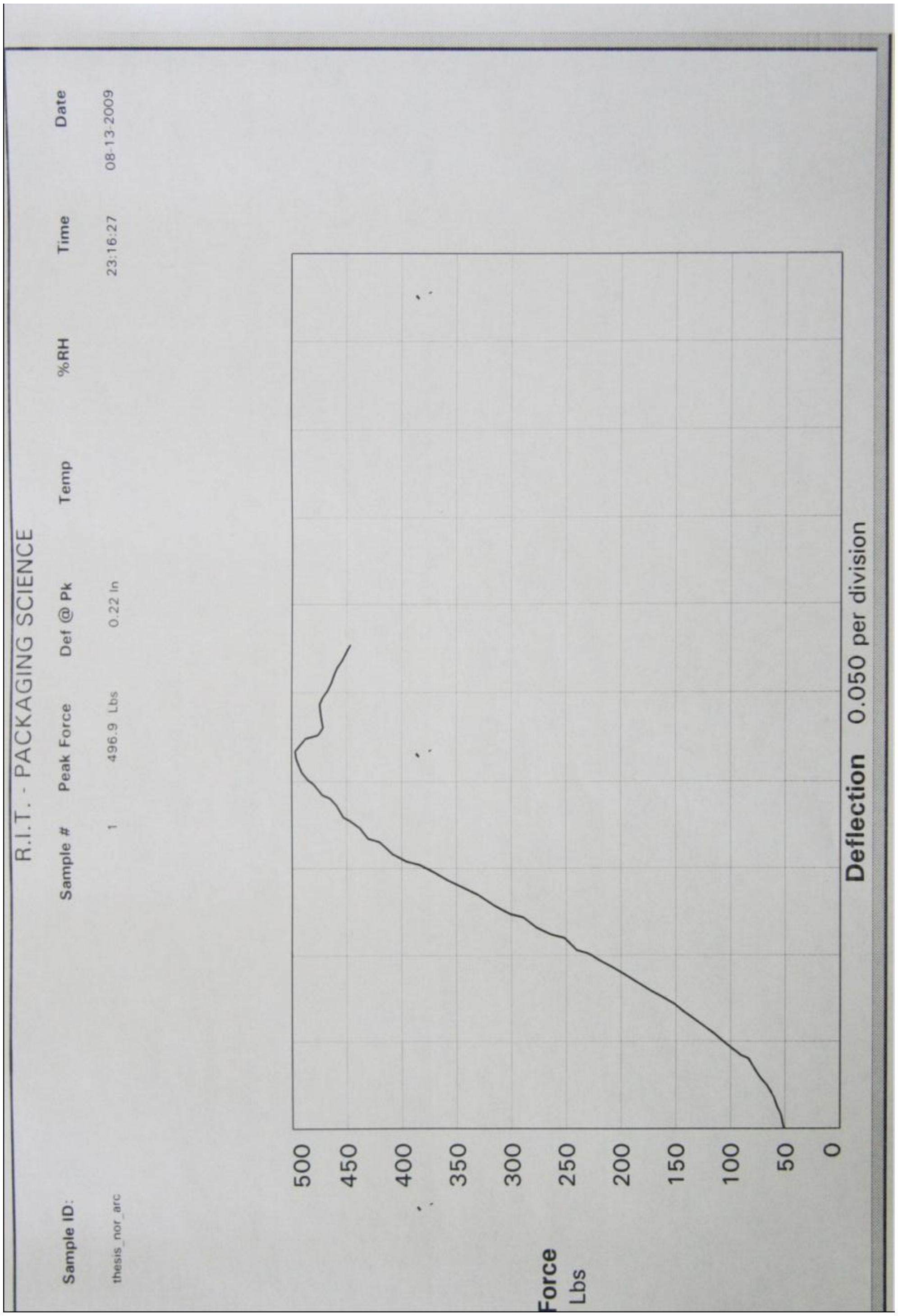
	Current Status
Preload for Deflection Auto Zero:	50.0 Lbs
Yield Detection Percentage:	10.0 %
Stop Force:	5000.0 Lbs
Stop Deflection:	0.50 In
Test Velocity:	0.50 In/M
Auto Sample Number:	ON
Auto Log on Test Completion:	AUTO
Overlay Auto Copy Test Interval:	EVERY 1
Auto Print Test Interval:	EVERY 6

9.0 Appendix C (Samples of BCT test result)

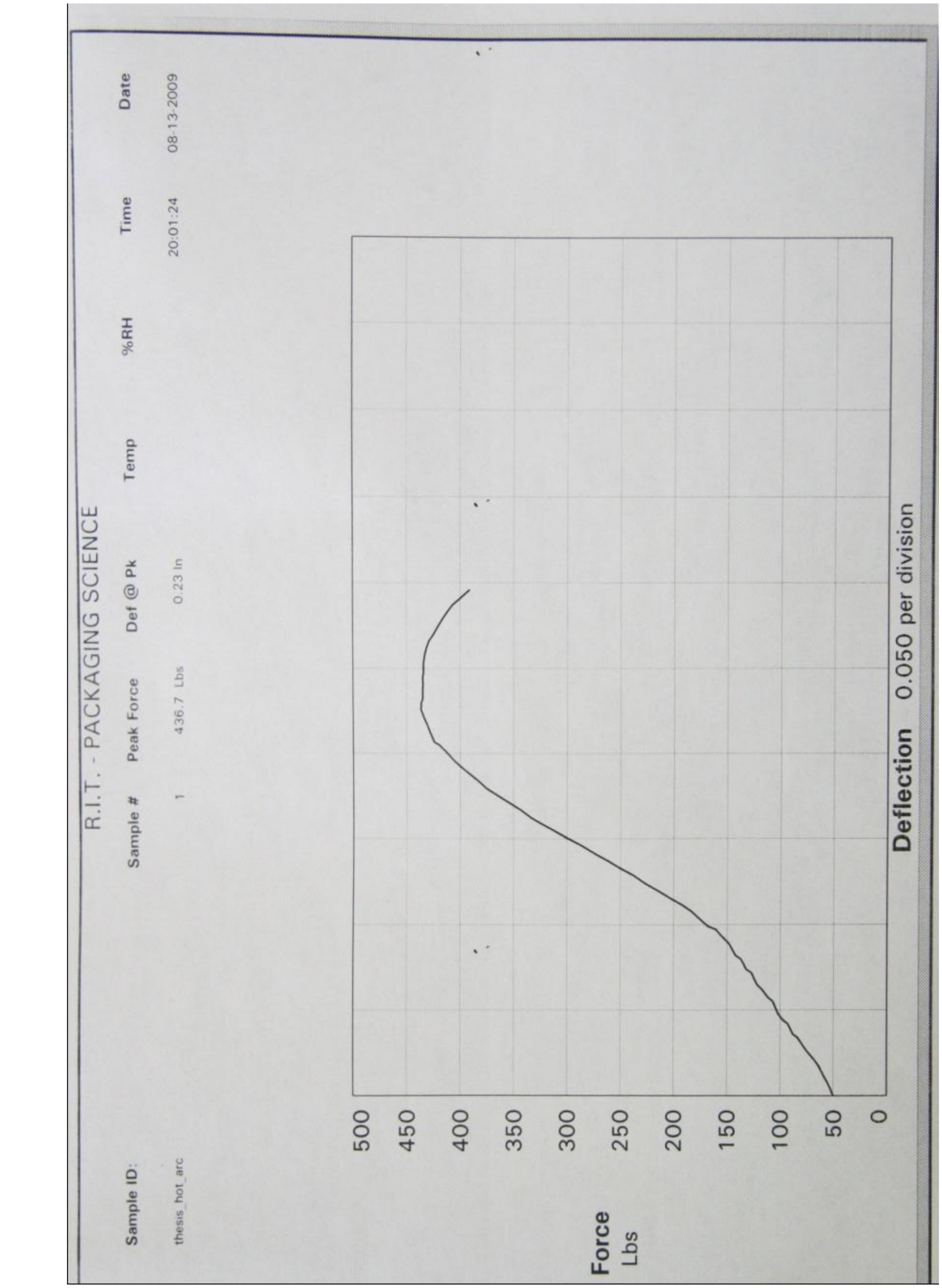
(Graph C- 1) BCT data of sample having conventional hand-hole under room conditions <Sample Graph 1>



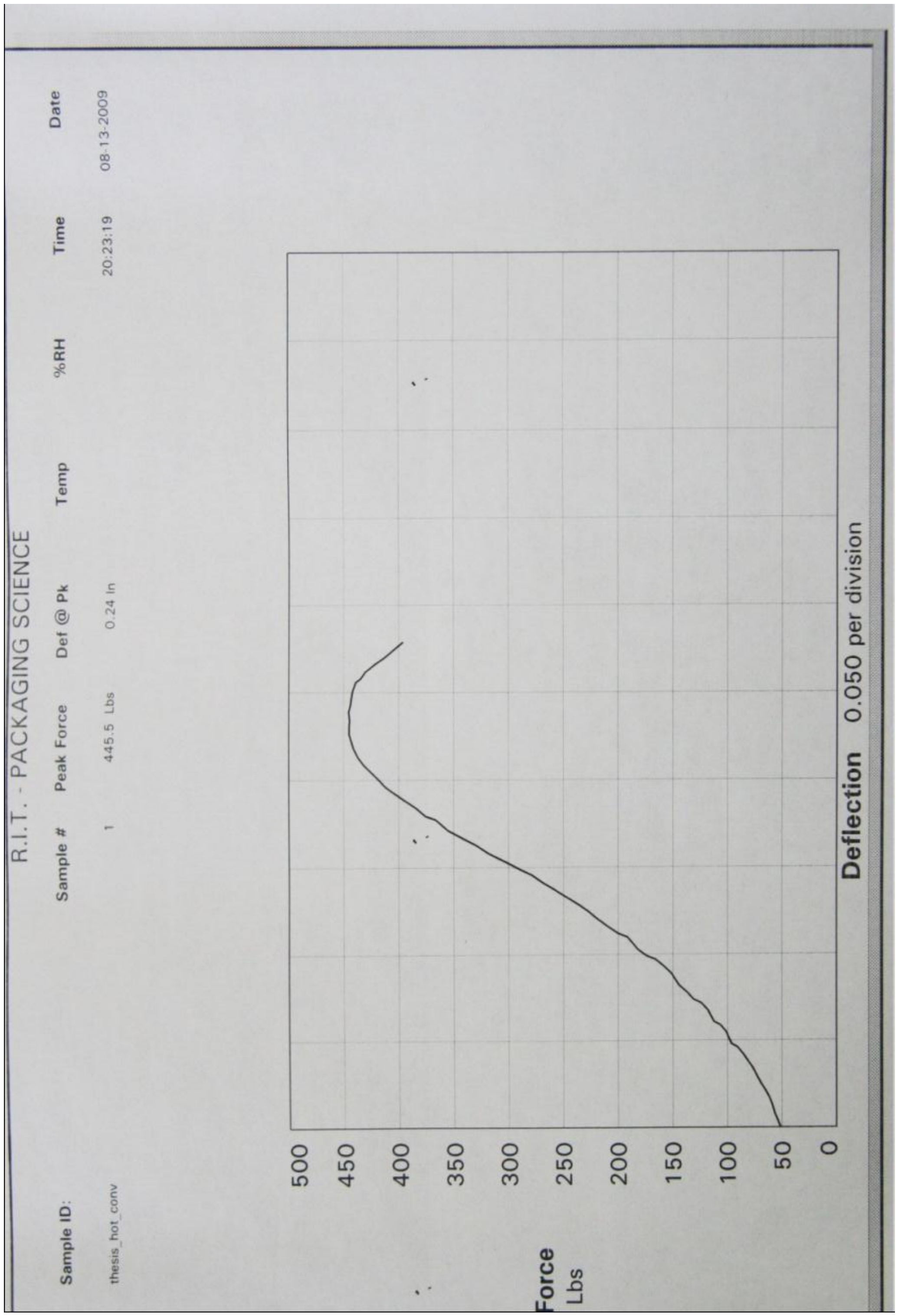
(Graph C- 2) BCT data of sample having arc top hand-hole under room conditions <Sample Graph 2>



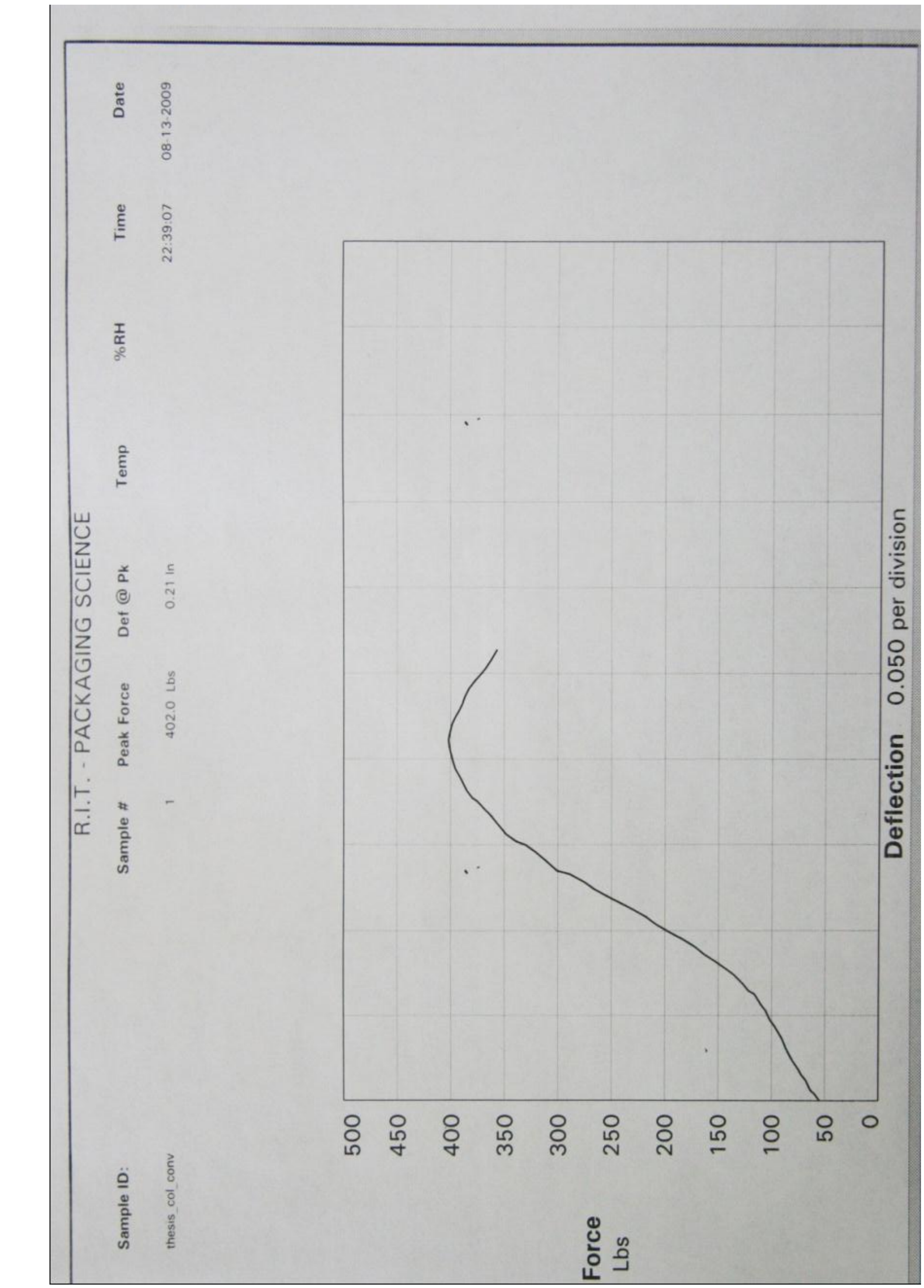
(Graph C- 3) BCT data of sample having arc top hand-hole under hot and humid conditions <Sample Graph 3>



(Graph C- 4) BCT data of sample having conventional hand-hole under hot and humid conditions <Sample Graph 4>



(Graph C- 5) BCT data of sample having conventional hand-hole under cold and humid conditions <Sample Graph 5>



(Graph C- 6) BCT data of sample having arc top hand-hole under cold and humid conditions <Sample Graph 6>

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