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COMPARISON STUDY OF CORRUGATED FIBERBOARD AND PAPERBOARD PARTITIONS TOWARDS DAMAGE OF GLASSWARE

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COMPARISON STUDY OF CORRUGATED FIBERBOARD AND PAPERBOARD PARTITIONS TOWARDS DAMAGE OF GLASSWARE

By

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ABSTRACT

COMPARISON STUDY OF CORRUGATED FIBERBOARD ANDPAPERBOARD PARTITIONSTOWARDS DAMAGE OF GLASSWARE

By

Sreekumar Ramasubramanian

This study compared the protective ability of inner packing partitions made from Corrugated material (currently used by Libbey Glass Company) with paperboard material for four different kinds of glass containers. The four types of glass containers that were used in this study were selected based on their differences in size, shape and fragility. The glass containers were coded in the following manner: 10 oz. Zombie as Item 94 / 6029, 14.5 oz. Hi-Ball as Item 170 / 4063, 11 oz Cocktail Tumbler as Item 64 / 3720 and 12 oz. Hour glass as Item 181 / 3142.

The Phase 1 test protocol used for testing palletized shipment distribution following ASTM D 4169 Assurance Level 2 test method resulted in least amount of damages to glassware packed in corrugated fiberboard partitions. Subsequently the Phase 2 test protocol for distribution in small parcel environment by parcel delivery carriers like Fed Ex & UPS following ISTA 3C test method resulted in no significant difference in damage to glassware packed using corrugated fiberboard and paperboard partitions. Overall it can be concluded that corrugated fiberboard partitions are better suited for palletized shipment and paperboard partitions can be used in the small parcel environment.

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1.0 INTRODUCTION

The definition of corrugated fiberboard (as described in Fiber Box Handbook) is the structure formed on a corrugator by gluing one or more sheets of fluted containerboard called medium to one or more layers of containerboard called as linerboard. The boxes made from such materials are called corrugated boxes. The corrugated board is valued as an inexpensive, recyclable and readily available engineering material that can be tailored to a variety of end uses. The versatility of the corrugated containers has led to wide acceptance of its use as a secondary / tertiary packaging for shipping different products. The corrugated boards are the subject of many interesting scientific studies with special importance been given to the performance of the corrugated containers under different transportation, handling and storage environment.

A lot of studies related to the different kind of materials used in making corrugated board, the improvement and the advancement made in the box designing process, and understanding the issues of strength properties relative to different transportation and climatic environments has given us insights on corrugated containers performance.

The purpose of this project was to evaluate the performance of the inner packing partitions made from corrugated material visavis with paperboard material. This study compared the protective performance of the inner packing partitions of two different materials namely the corrugated material and paperboard material.

It is well known that transportation of glass products without partitions would result in substantial damage in the distribution chain and attempts to reduce the damage can be achieved by using inner packing materials like partitions. The partitions created in the box would not only reduce the amount of mechanical abrasion between two glass products which are adjacent to each other by offering protection but also offer a cushioning effect.

The corrugated fiberboard is widely used as a shipping material and its use as inner partitions is based on the cushioning effects. More and more recycled materials are used in packaging today due to depletion of natural resources. This has forced companies to try secondary/recycled materials and one such material is called paperboard or chipboard. Paper board is made up of 70% recycled material and 30% old corrugated material according to Innerpac (a leading manufacturer of paperboard).

The paperboard partitions offer several advantages over corrugated partitions as a highly recycled material and the cost of paperboard partitions is much lower compared to that of corrugated partitions. The paperboards are dust free in nature and can offer better product protection. It can be made in many styles with lot of optional features and can be used in automated operations. The dimensional accuracy during the formation is much better than corrugated partitions and is easy to use in automated systems.

Currently Libbey Glass Company is packing all its glass products with inner packing partitions made from single wall corrugated board. The change over to paperboard partitions would be more economical from the material cost aspect as well as its ability to occupy much less space in the warehouse and a potential for automation. The performance of the boards (corrugated board versus paperboard) were tested for four different glass products manufactured by Libbey Glass Company. The four glass products were selected based on their differences in size, shape and fragility.

The four different type of glassware that were used in this study are shown in Figure 1.

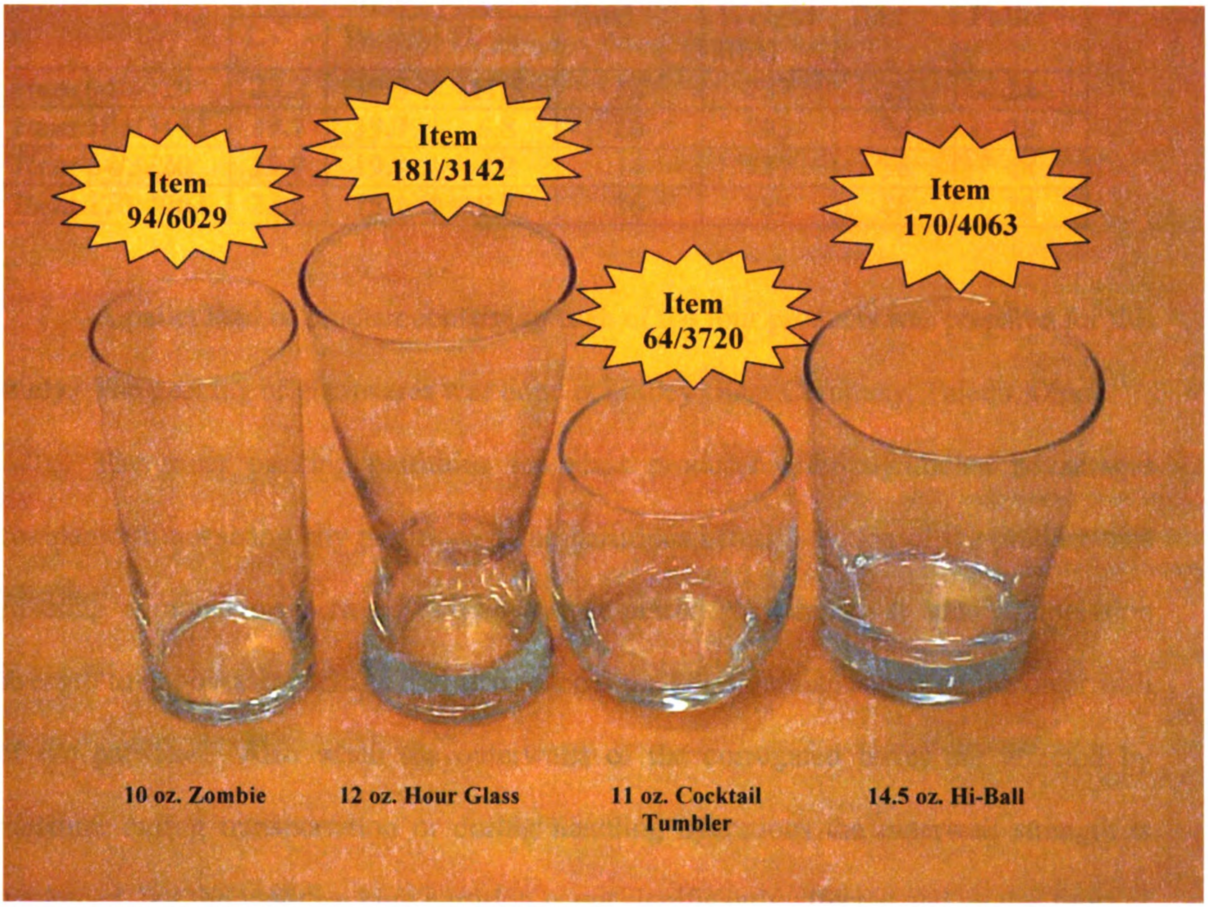

Figure 1 - Picture Showing Four Different kind of Glasswares with their Item Codes

The four different glassware products were packaged using both corrugated and paperboard partitions. The package configurations for the four different kind of glasswares are listed below in Table 1 and the pictures of the individual packages containing the four different glasswares are provided in APPENDIX C.

TABLE 1 - Package Specifications of Four Glassware Items

Package No.	Package Size (Inches) Outside Dimensions			Package Weight (lbs)	Pallet Load Weight (lbs)	Items per Box	Boxes per Pallet
	L	W	H				
Item 94/6029	23.2	10.5	11.5	28	737	72	24
Item 181/3142	19.7	19.7	6.8	26	793	36	28
Item 64/3720	19.9	19.9	4.2	14	737	36	48
Item 170/4063	22.5	15.1	9.7	36	785	48	20

A pallet load of product containing each of the four products was prepared for this study. The packing of glasswares was done at Libbey Glass Company, Toledo, Ohio.

The inner packing partitions for glass products offer significant advantages compared to not using any partitions. The partitions offers isolation of the product thus ensuring no abrasions between two adjacently placed glasswares. It adds compression strength to the overall package and also reduces the pressure/load acting on the outer wall of the package. Also when the outerwalls of the corrugated boxes are affected by moisture during transportation or during handling operations the outerwall strength is weakened, but the inner packing partition is not significantly affected and retains most of its strength. The partitions help in long-term storage of the boxes in the warehouses under high humidity conditions. They also help in reducing the pressure on the product, as the load will act directly on the partitions instead of the glass product. This greatly reduces the chances of breakage in glass products. The performance of the inner packing partition becomes a vital factor in the determination of the amount of glass breakages and any changes made to the inner packing partitions such as change over from one material type to another has to be tested extensively before its usage. The distribution environment is very complex as the packages in the pallet are being shipped through truck, rail, LTL (Less than Truck Load) and TOFC (Trailer on Flat Car). The packages undergo multiple handling during the distribution process and the pallets with glassware are stacked four high in the warehouse for a period of one year.

Currently all the packages are manually erected with inner packing partitions placed into the erected boxes manually and also the glass being manually placed inside the individual pockets formed by the partitions. The usage of paperboard partitions will facilitate automatic operations. The performance of the inner packing partition formed in the automated machines needs to be studied along with the selection of the right material type for partitions. This study would help to determine the type of partitions suited for packing glass products manufactured by Libbey Glass Company when exposed to Libbeys distribution environment.

The objectives of this study is to compare the performance of the inner packing partitions made of corrugated and paperboard material towards protection against the damage to four different kinds of glass products manufactured by Libbey Glass Company for palletized distribution and single parcel environment under simulated laboratory conditions following ASTM D 4169, Assurance level II (American Society for Testing and Materials) and ISTA 3C (International Safe Transit Association) test methods.

2.0 LITERATURE REVIEW

Corrugated fiberboard containers are used to ship a majority of products and its popularity is due to its low cost to strength and weight ratio, provides a smooth, non abrasive surface, good cushioning characteristics, excellent printability, easy to set up and collapsible for storage and finally it is reusable and recyclable material.

Corrugated fiberboard for fabrication of shipping containers is converted from paperboard. A paperboard is nothing but paper with a caliper or thickness greater than 0.20mm. Paperboard is manufactured from natural cellulose fiber found in trees. The trunk of the trees is used for fiber extraction and the remaining part of the tree such as bark and branches are removed. The debarked logs are then mechanically ground into small chips. These are mixed with several chemicals for the purpose of separating the organic binding material that holds the cellulose fiber strands together. This process of pulping process is called chemical as opposed to semichemical which involves mechanical tearing apart of fibers and final separation by chemicals. The semichemical paper has short fibers than that made by pure chemical pulping. Short weak fibers produce low quality paperboard, especially when recycled.

The most common papermaking process using a fiber pulp prepared by chemical or semichemical pulping is known as Fourdrinier. Slurry is a diluted suspension of about 1% fiber and 99% water, is applied over an endless woven conveyor belt. Paperboard used for fabricating corrugated fiberboard is manufactured by the Kraft process on a slightly modified Fourdrinier machine. Instead of depositing one fiber layer on the woven conveyor belt, two different layers are applied. The primary layer consists of coarse but strong fibers from which a minimum amount of organic fiber binding material had been removed during the pulping process. The secondary layer is composed of regular treated fine fibers. This smooth layer provides the outside appearance and printing surface, while the primary inside layers gives the Kraft paper its exceptional strength, required for fabricating shipping container quality corrugated fiberboard

Cylinder papermaking process is also quite frequently used for manufacturing paperboard for corrugated fiberboard fabrication. In the cylinder machine, a number of wire mesh vacuum drums rotate in a series of vats, providing individual plies of fiber. These are then matted together to form a multilayered paperboard. Once the plies are formed and pressed together, the remainder of the process is similar to Fourdrinier machine.

In both the process, various chemical additives may be mixed in with the pulp slurry to provide special paper properties most notably moisture resistance. The most common moisture resistant materials used are starch and natural or a synthetic resinous material mixed with aluminum sulfate.

The grade of the paperboard is measured by the basis weight in grams per square meter or pounds per 1000 ft^2 of sheet. Together with the caliper, basis weight defines the paperboard quality.

The components of corrugated fiberboard consists of two linerboards and a corrugating medium. The corrugated medium is called as unlined corrugated fiberboard may be manufactured from chemical, semichemical or recycled fiber. It is mostly used for internal packaging or cushioning. The double line or double-faced corrugated (single wall) board typically consists of outer and inner liner. The inner liner is usually made of kraft paperboard or referred to as kraftliner. The outer liner may be same as inner or may be bleached on one side to enhance printability and decoration. Corrugating medium is usually made of paperboard with a caliper between 0.2 to 0.3 mm and basis weight between 122 to 137 g/m^2. Liners are made from paperboard of caliper 0.2 to 0.7 mm and 175 to 235 g/m^2 basis weight. The liner together with the corrugated medium determine the total thickness and is summarized below as:

Flute Type	Total Board Thickness Range (mm)
A	4.9 -5.5
B	2.9 – 3.5
C	3.9 – 4.5

A, B, and C flutes have approximately 36, 50 and 42 flutes per linear foot. The reason C flute is between A and B flute is related to the history of the corrugated fiberboard manufacturing development. First A and B flute were standardized, while the need for an intermediate board, C flute was discovered later. Nowadays B and C flutes are most commonly used for fabricating shipping containers. The heaviest of three, A flute is used less frequently.

For heavy duty shipping containers required withstanding higher stacking load, double and triple wall corrugated fiberboards are available on the market.

The process of converting fabrication of double and triple wall is similar to that of single wallboard. This process begins by pre heating both the liners and corrugating medium by steamrollers. The corrugating medium is further processed by steam showers before passage through corrugating rollers. After the flutes are formed, adhesive is applied by a glue roller to the tip of the flutes, where upon the first liner joins it to form single-face board. The single face board is passed over a second glue application roller, which coats the flute tips with adhesive. The second web of liner joins the flute tips of the single face board. Weight rollers facilitate uniform and continuous glue line formation, critical to the strength properties of the board and the shipping container. These sheets are die cut and scored into preliminary blanks.

There are different styles of corrugated containers available in the market and the most common and widely used shipping container is RSC (regular slotted container). Also there are half telescopic containers (HTC), fully telescopic containers (FTC) and other specialty type containers.

Corrugated containers are used to ship a majority of products and therefore their design becomes an important task for any packaging engineer. Each and every product has its own requirements and the design for one particular product may not be suited for another product. This complexity in the packaging design makes it quite unique. Paper based materials are affected by many factors namely storage time, stacking pattern, exposure to humidity, transportation, and therefore require packaging engineer to evaluate the overall package performance.

The strength of a corrugated box is affected by various factors including the storage time, humidity levels, stacking pattern and by vibration. The primary measure of corrugated board strength was decided based on its bursting strength for many years and with lot of studies and experiments conducted over the years resulted in the finding that burst is not a true measure of stacking performance of boxes. Edge Crush Test (ECT) replaced the Burst test as the primary measure of the corrugated board strength. The change from Mullen or Burst test to ECT was decided because the corrugated medium offers significant strength to the board structure. The corrugated medium offering strength to the board structure makes the strength prediction complicated as the board strength has to be evaluated from the basic paper manufacturing process namely the length of the individual fibers, the combining process, and the strength of the adhesive bond formed on the corrugator. With this level of variability in the manufacturing of corrugated board and limited control over the properties, the ECT values may vary resulting in giving different compression strength values as the ECT and compression strength are related. This empirical relationship was established by McKee for measuring the top to bottom box compression strength. With increased use of recycled materials, the board the strength becomes weaker when compared to boards using virgin materials.

Compression strength is an indicator of box performance. In order to design corrugated boxes for long term storage, the strength required for the box has to be determined along with its influence under different humidity conditions. Kellicut found that corrugated board has greater compression strength when it has low moisture content. The increase in moisture content results a decrease in compression strength. The effect of temperature on the compression strength was not as significant compared to that of humidity.

The compression strength is a key property in the design for board structures and the desire to predict the performance of corrugated containers and understanding their mode of failure. It has therefore prompted a great deal of theoretical and experimental work. The compressive strength of a box can also be increased by increasing the strength of the linerboard.

The failure of corrugated container under compressive load has been of special interest as the container shape is thought to change progressively as compression loading increases, thus altering the loading and the restraint conditions acting on the vertical panels. Buckling phenomenon occur when applied load acting on the corrugated box is progressively increased. Buckling is when the vertical side panels deflect laterally inwards or outwards. The largest deflection can be found at the center of the panel with edges and corners of the panel remain vertical because of the support of the adjacent panels. The compression failures for shorter boxes having smaller height is because of the crushing along the top and bottom horizontal score lines whereas the box failure for boxes with taller height results from the combination of crushing of top and bottom horizontal score lines along with buckling.

The strength of the box plays a major role in the protection of the product and the role of inner partitions contribute to the compression strength of the packaging system. Compression strength is mostly a function of the wall perimeter with the greatest contribution coming from the four corners. By incorporating partitions, the strength of the container is increased and thereby reduces the ability to get crushed the corrugated boxes become difficult. This strength varies from material to material and also from one kind of board to another kind of board. With the use of recycled materials the strength of the partitions needs to be validated.

Preshipment Testing Procedures such as ASTM D 4169 and ISTA 3C test methods have been used to simulate the real transportation. An ASTM D 4169 test procedure is sequential test method that is used to evaluate new shipping container. The ASTM D 4169 test method has certain predesigned sequences for the various distribution cycles. Understanding Libbey's distribution environment, the distribution cycle can be selected according to the various assurance levels or the severity of handling the packages. ISTA 3C test method is a more realistic testing method and is very useful test method for overnight shipping environment. The vibration PSD profiles for the ASTM D 4169 and ISTA 3C test methods are different. Depending upon how expensive the product, good understanding about the distribution route/environment or the duration of the journey, the vibration levels can be selected which is again based on the assurance levels. ISTA 3C test method is considered more severe test method in comparison to ASTM D 4169 test method of Assurance Level 2 is because of a higher psd levels. The preshipment test procedure help us to simulate some of the important hazards encountered in the real time distribution journey and is a very valuable tool to test new product/package performance and provide us to resolve some of the issues related to movement of packages from one destination to another destination.

The major packaging material utilized for shipping container is corrugated paperboard. The predominantly used shipping container is RSC (regular slotted containers). The quantitative estimation of protective function, which shipping containers and unit load must provide when subjected to mechanical inputs of the distribution system can be understood by container strength prediction models. The computation of the static and the dynamic strength of the empty container need to be understood.

Static Strength of Corrugated Shipping Containers:

The static or dead weight loading of shipping containers originates from top to bottom stacking forces when containers or whole unit loads are stored or stacked on top of each other. This stacking is desirable for maximum utilization of storage and space in the warehouse as well as during transportation. The other source of static loading is due to strapping forces in unit loads or lashings in transport vehicles. Internal or outward static compression is also exerted by the product inside the container created by excessive bulging of overfilled containers. There are two basic approaches possible in constructing mathematical prediction model on container stacking strength and they are:

1. The properties of material such as paperboard facings and corrugating medium to the stacking strength of the fabricated container.
2. The container can be viewed as a single degree of freedom system with inherent viscoelastic properties.

Both these models have its own advantages and limitations as regards to the accuracy of predicting real life conditions. The former is the traditional approach taken by many researchers such as Mckee and others at Institute of Paper Chemistry in Appleton, WI, and Forest Laboratories in Madison, WI. Godshall (1968, 1971) and Urbanik (1978) at the Forest Laboratory, Madison, WI tried the latter approach. Peleg (1969-1981) also tried the latter approach at School of Packaging, Michigan State University.

McKee's Formula:

McKee adapted a well-known semiempirical formula commonly used in prediction of failure in shell-type structures, made of isotropic and non isotropic plates, for prediction of maximal top to bottom strength of corrugated shipping containers. The final simplified version of this formula relates the ultimate compressive strength of a RSC container to the board caliper, container perimeter and edgewise-compressive strength of the corrugated paperboard.

The observation of side panel failure in quasi-static compression test of RSC type corrugated containers. It was observed that as the applied load is progressively increased, a level is reached where the initially vertical side panels become unstable (buckle) and deflect laterally inwards or outwards. The largest lateral deflection appears at the central region of the panel, while the regions near the corners and edges of each panel are constrained to remain essentially vertical because of the mutual support of the adjacent panels. Thus the board near the vertical edges may continue to accept additional loading even after buckling in the center of the panel began. McKee found that the maximal compressive strength of the container P is ultimately reached when the board fails near a corner of the panel. Thus, the failure crease is triggered at and progresses from one of the corners to the center section of the panel. Just before failure the deflected region of the panel carries the relatively small portion of the load, primarily by bending, while the board at the corners and edges remain vertically flat, and carries the bulk of the load, by edgewise compression. For this reason, the edge wise compression strength (ECT) of the corrugated board is closely correlated to the maximal compressive strength of the container.

McKee et al (1963) conducted extensive tests of various corrugated paperboard and RSC containers to arrive at the below formula

$P = 5.87\ P_m\ (h\ Z)^{1/2}$

P denote maximal top to bottom compressive force of an RSC container

Pm denote the edgewise compression strength of the board

h denote the Board caliper

Z denote container perimeter

The assumptions and simplifications made to the formula by McKee had reported an accuracy within 6% for container with the perimeter range of 762-3429 mm and d/Z greater than equal to 1/7. (Reference Kalman Peleg - Produce Handling Packaging and Distribution, Pg 393)

The attractive feature of the formula is the correlation of the board properties in terms of edgewise-compressive strength with the ultimate strength of the container. The edgewise-compressive strength is determined by the properties of the paper used in fabricating the board such as facings, corrugating medium and the quality of glue.

Everything being equal, when we compare the edgewise-compressive strength based on the amount of material in the board, the decrease in the edgewise compressive strength is in the following order: A, C, B flute.

Some of the predicted values of edgewise compression strength of corrugated fiberboard is as below

Type of Corrugated paperboard	Edgewise compression strength Pm kg/cm
A flute	6.8-7.6
B flute	5.2-7.3
C flute	5.4-7.5

Moody (1965) reported contrary to the above data. He said that B flute edgewise compression strength is found to be higher than that of A and C flute. This discrepancy is because of B flutes buckling coefficient is slightly higher than that of C flutes, which in turn is somewhat higher than the A flutes. This discrepancy can be due to possible errors introduced from variables such as board caliper, basis weight, and recycled fiber vs. virgin fiber.

The product cannot carry significant stacking loads without some damage and thus one have to resort to either using a stronger FTC (full telescope containers) or internal partitions in RSC containers.

The ultimate strength of the container can be predicted by formula for an empty FTC container assuming it to be made up of two RSC containers. The ultimate strength of the outer part is added on to that of the inner part. Additional research is needed to account for RSC containers with internal partitions.

Many attempts have been made to modify the form of Mckee's formula for RSC containers in an effort to improve its accuracy {Wolf (1972, 1974) and Jeselius (1974)}. Unfortunately, better than 6% accuracy reported by McKee himself does not seem to be possible.

Inspite of the importance of edgewise compression strength many companies still specify corrugated containers in terms of board bursting strength. The burst strength has a poor correlation to the container strength.

A 250lb mullen test board may not necessarily perform significantly better than a 200lb test container, under high humidity and low temperature conditions. The reason for mullen test is retained is because it supposedly measures the bending stresses imposed on the side panels by internal loading, when overfilled containers bulge thus enhancing failure of the container in compression.

If compression-testing results in the form of compressive force vs. container deflection curves were recorded, this would help us assess the container performance. From the curve we can identify the critical deflection at which unacceptable product damage occurs and the maximal yield compressive force causing the container to collapse can be identified. Peleg (1981) was instrumental in having typical force deflection curves of corrugated containers. The conclusions made from the curves suggest that yield force signifies resistance to collapse of the container in the stack while the compression force at critical deflection indicates performance at normal stacking loads without unacceptable damage to the product.

Containers with internal dividers do not exhibit a distinct critical deflection and again depends on the product type, the actual shipping container used as well as the environment in which the containers are handled and stored.

Peleg (1981) studied the effect of internal dividers and its performance on some of the shipping containers. He had used four different type of shipping containers namely containers with vertical dividers, containers with T shaped dividers, tray pack, and bushel box type containers and calculated the yield deflection and the yield force under standard conditions (22.8°C, 50 % RH) and cold storage conditions (3.3°C, 92% RH). The average force deflection curves constructed from individual graphs obtained in compression tests for the different container style tested shows that vertical divider provides greater strength than the T shaped dividers both at normal and humid conditions when compared to no dividers.

The effect of contents in the container play a crucial role in determining the yield force as noted in the studies conducted by Peleg. The yield force of full container is markedly greater than that of the empty container.

The effect of handholes in the container significantly reduces the stacking strength. Studies conducted by Peleg demonstrated that there is at least 15-20% reduction in the strength properties and the benefits of having a hand-hole must be weighed in before having one in the shipping containers.

Kellicut (1963) demonstrated the effect of stacking patterns on the strength of the containers: that in a perfectly aligned three-high column stack the ultimate compressive strength of RSC containers was reduced by about 23% compared to the single container tested. However, in a unitized containers (strapped or over wrapped), there is an increase in stacking strength, because the neighbor containers surrounding each other provide stabilizing support for the side panels and reduce bulging and premature collapse. An optimal stacking pattern should permit column stacking of the first two layers and interlocking patterns of the upper container layers thus adding both strength and stability to the pallet.

Kellicut and Landt (1951) investigated the effect of moisture on container strength and its influence on ultimate top to bottom compressive strength of a typical RSC container. They derived an experimental formula based on compression test on various containers made of different boards and conditioned at different relative humidities and temperatures.

$$P_2 / P_1 = 10^{3.01\,M_1} / 10^{3.01\,M_2}$$

P_1 and P_2 are ultimate compressive strengths of containers having moisture contents M_1 and M_2.

Kellicut and Landt (1951), Moody and Skidmore (1966), and more recently Koning and Stern (1977) investigated the time effect or creep effect on RSC containers when top loaded by a dead weight for prolonged periods.

Moody and Skidmore (1966) study shows that there are three distinctive creep regions for RSC type containers and they are

1. Primary Creep region, characterized by rapid container deflection immediately following application of load.
2. Secondary Creep region or long duration region where the creep rate is fairly constant
3. Tertiary Creep region, where the creep rate increases rapidly and failure follows soon.

The total time, from load application to failure at a given relative humidity depends on the dead weight load applied.

Koning and Stern (1977) established an empirical relationship linking the duration to failure of dead load RSC containers in terms of creep rate as running experiments for a particular container and storage condition is time consuming process. The equation is listed below

$$\tau = 4988 / C_r^{1.038}$$

where τ (duration of failure) is in hours while the creep rate C_r is measured in strain units per hour times 10^6.

The commercial paperboard grades used for manufacturing corrugated fiberboard have some percentage of recycled fibers. The effect of recycled fibers on container strength properties upon repeated recycling up to three times (Koning and Godshall – 1975) indicate that there is a drop of 25% in top to bottom compression strength in containers. Therefore recycling will eventually lead to usage of heavier paperboard for manufacturing corrugated containers for given strength properties.

Dynamic Strength of Corrugated Shipping Containers:

Typically the dynamic load characteristics on shipping containers will be accounted as dynamic safety or ignorance factor. But to understand the dynamic characteristics, there have been a number of successful simulation models of shipping containers for field performance prediction that actually simulates to actual handling, transit and storage conditions. Consider several layers of shipping containers stacked in a pallet is moving on railroad cars and trucks, the bottom container of a stack must sustain a combination of static pressure, random vibration and shock spectra. The bottom container will experience a dead weight force along with the flexural strapping forces for keeping the container in the pallet together. The other kind of forces acting on the bottom container would be the spring force or the restoring force while the dissipative forces are the viscous forces and columb frictional forces.

The spring like behavior of the container is mainly due to the flexibility of the buckling side panels and flexibility of the product in the container. Viscous damping is present because the air trapped in the container and inside the flutes of the corrugated board is compressed and decompressed rapidly due to the pumping action of the flexing side panels. The columb frictional forces are due to the side panels of the closest neighbor containers in the stack flex too, thus damping the flexing panels of the neighbors container. These damping forces are frictional forces between the containers and between the floors and the containers. The contents inside the container also provide considerable damping.

The dynamic strength of corrugated container is based on approximate solution of a non-linear differential equation of motion, modeling a container in the bottom tier of a pallet load in terms of a single degree of freedom system including nonlinear elasticity and combined viscous and frictional damping.

The vibration and shock response of this container model can be evaluated with advanced mathematical equations to better understand the mechanical model for simulating dynamic loading of shipping containers in unit loads.

There have been limited studies performed on the shipping containers with different types of interior packaging. The study conducted by S. Paul Singh, Gary Burgess, and Ming Xu (Packaging Technology and Science, 1992, vol 5, pg 145-150) is bruising of apples in four different packages using simulated truck vibration. The four different interior packaging that were used are: foam tray, the paper pulp tray, and two different paperboard partition/box combinations. The results of the study showed that foam tray was the best type of interior packaging followed by paperboard partitions in having the least amount of bruises on apples during vibration testing. The paper pulp tray produced the highest level of damage. Also the air-cushion truck suspension showed larger damage levels than that of leaf-spring suspension for all the four package types.

There is very limited published data available on the effects of transportation and handling on packaged glassware. A recent study conducted by Jay Singh (Evaluating performance of internal packaging for damage to glassware, 1998) investigated the effect of shock and vibration on packaged glass stemware. Stemware is glassware mounted on a stem with a broad base such as wine glass. The results of the study indicate that a two-piece stemware is found to be more fragile compared to a single piece stemware when packaged in shipping container with different flute types of internal corrugated board partitions.

3.0 EXPERIMENTAL DESIGN

The purpose of this project was to evaluate the protective capabilities of the inner packing partition materials for Libbey Glass. Specifically the study was suited to compare the protective performance of the corrugated partitions currently being used to the paperboard partitions for four different glassware products. Paperboard partitions are significantly cheaper and offer automation in erecting as compared to corrugated board. Corrugated board is more popular due to its air cushion effect and potentially offers more impact protection. The following test materials and test methods are used for each experiment discussed in this chapter.

3.1 TEST PROTOCOL (Phase 1)

Each type of product was packaged using both corrugated and paperboard partitions. A pallet load of product using each type of internal partition was prepared by Libbey Glass for the four different glassware products and delivered to School of Packaging for evaluation.

The pallet loads were subjected to climatic conditioning, vibration and mechanical handling as described below. The tests will be conducted in accordance with ASTM D 4169, based on Assurance Level II. Assurance Level II was selected because some level of damage was acceptable to Libbey Glass based on the volume of the product. The selected packages undergo ISTA 3C test procedures. Both the methods were compared and evaluated. A total of fifteen box samples were tested for each type of glassware and internal packing combination.

3.1.1 PRE-CONDITIONING

All pallet samples were conditioned at 73°F and 50% RH for at least 24 hours prior to any test in accordance with ASTM D-4332. After pre-conditioning, the pallet load containing boxes were subjected to the test sequence that occur during transportation and handling according to ASTM D 4169 Assurance Level II.

3.1.2 VIBRATION TESTING *(According to Schedule E in ASTM D 4169 test method)*

The pallet load was subjected to a random vibration test in accordance with ASTM D 4728. A composite truck vibration spectrum was used. The test was conducted for 180 minutes.

3.1.3 PALLET MECHANICAL HANDLING *(According to Schedule A, 10.3.1.1 in ASTM D 4169 test method)*

The pallet loads were subjected to four leading edge drops from 6 inches. The drops was performed in sequence on the two leading edges and two corners. After completion of the test, fifteen boxes were removed from each pallet and was subjected to a climatic conditioning as described below.

3.1.4 CLIMATIC CONDITIONING

The sample boxes were subjected to 72 hours of tropical storage conditions in accordance with ASTM D 4332. The storage conditions will be 104°F and 90% RH. After conditioning the sample boxes were subjected to the following test.

3.1.5 DROP TESTING *(Schedule A - Manual Handling in accordance with ASTM D 4169 test method)*

The conditioned boxes was subjected to a six drop sequence based on

ASTM D 4169 Assurance Level II. The following Item/Code numbers provided by Libbey Glass Company namely 6029, 4063 and 3142 was drop tested from 13 inches and Item/Code number 3720 was drop tested from 15 inches. The difference in the drop height is based on the weight of boxes as box number 3720 weigh less than other three box numbers mentioned above. The drop sequence is as mentioned in the table 2 below

TABLE 2 - First Sequence of Drop Testing for Test Protocol (Phase1)

Drop No.	Drop Details
1	One Drop on Bottom Surface
2	Two Drops Adjacent Bottom Edges
3	Two Drops Diagonally Opposite Bottom Corners
4	One Drop on Top Surface

After the boxes were drop tested, they were subjected to compression testing explained in detail as below.

3.1.6 COMPRESSION TESTING *(Schedule B – Warehouse Stacking in accordance with ASTM D 4169 test method)*

The boxes were subjected to compression testing in accordance with ASTM D 642 test method. The compression load was based on a four high palletized load stack environment and a safety factor of 4.5. The individual test loads was determined based on package weight of each type of product. Following compression testing the boxes were subjected to second sequence of drop testing as mentioned below.

3.1.7 DROP TESTING *(Schedule A – Manual Handling in accordance with ASTM D 4169 test method)*

The box samples was subjected to second sequence of drop testing. The second sequence involves six drops with the last drop being performed from twice the drop height from the first sequence of drop.

TABLE 3 - Second Sequence of Drop Testing for Test Protocol (Phase 1)

Drop No.	Drop Details
1	One Drop on Vertical Edge
2	Two Drops on Adjacent Side Faces
3	Two Drops, One Drop on Top Corner and One Drop on Adjacent Edge
4	One Drop on the largest face at twice the height

The boxes were inspected after these tests. The location and type of the damage from each box was recorded.

3.2 TEST PROTOCOL (Phase 2)

Based on the results of the tests in Phase 1, an additional set of three boxes for the selected category of box number 3142 and 3720 were tested using the following test protocol. The preliminary test result from Phase 1 for the above two-glassware type did not lead to any conclusion as far as the performance of the internal packing partition. Therefore a more realistic test method such as ISTA 3C test method was used in order to evaluate the performance of the internal packing partitions.

3.2.1 CONDITIONING

All the three box samples for each type of internal packing partition and glassware type was numbered and all the faces were numbered according to the ISTA 3C standards. The boxes were placed in a condition chamber at 100°F and 90% RH for at least 72 hours prior to any tests in accordance with ASTM D 4332 test method. After conditioning the boxes were subjected to the following test sequence.

3.2.2 DROP TESTING

All the sample boxes of the same type of internal partition packing with same glassware type was numbered and drop tested in a sequence of 7 drops as mentioned below in table 4. Hazard is made of hardwood or steel. The hazard that was used for the testing was hardwood. The hazard shall be 2 inches in height x 6 inches in width (51mm x 152mm) and 8 inches (203mm) longer than the length of the package. The longest edges of the hazard shall be rounded to a radius of 0.25 inch ± 0.0625 inch (6.35 mm ± 0.02mm).

TABLE 4 - First Sequence of Drop Testing for Test Protocol (Phase 2)

Drop Number	Drop Height	Box Sample 1	Box Sample 2	Box Sample 3
1	15 inches	Face 3	Face 4	Face 6
2	15 inches	Face 3	Face 4	Face 6
3	15 inches	Face 3	Face 4	Face 6
4	15 inches	Corner 3-4-6	Corner 2-3-6	Corner 1-4-6
5	15 inches	Edge 3-6	Edge 4-5	Edge 1-6
6	30 inches	Face 3	Face 4	Face 6
7	15 inches	Face 3 on Hazard	Face 4 on Hazard	Face 6 on Hazard

3.2.3 COMPRESSION TESTING

All the box samples undergo compression testing in a compression tester. The boxes were subjected to compression load determined based on the formula listed below as per the ISTA 3C test method.

TL = 0.007 x (54 –H) x L x W x 5, where

TL: Calculated Test Load

H: Height of shipping unit

L: Length of shipping unit

W: Width of shipping unit

3.2.4 VIBRATION TESTING

Following compression testing, the boxes were subjected to a vibration test. The boxes were subjected to a random vibration of 90 minutes in the following steps. The box samples are stacked one upon the other with box number 1 at the bottom of the stack and box number 3 on the top of the stack. The boxes are stacked in such a way that Face 3 is in down orientation. The boxes were vibrated for a period of 60 minutes and stopped. The orientation of the boxes was changed so that Face 4 is in down direction without disturbing the stack order. The boxes were randomly vibrated for a period of 15 minutes and then stopped. The stack order being the same the boxes orientation is changed to a new orientation with Face 3 now in the down direction for all the boxes. The boxes were again vibrated for a period of 15 minutes and then stopped. The vibration testing was now complete.

3.2.5 DROP TESTING

Following the vibration testing, the boxes were subjected to final sequence of drop testing. The boxes were dropped for the final set of 8 drops according to the below table.

TABLE 5 - Second Sequence of Drop Testing for Test Protocol (Phase 2)

Drop Number	Drop Height	Box Sample 1	Box Sample 2	Box Sample 3
1	15 inches	Face 3	Face 4	Face 6
2	15 inches	Face 3	Face 4	Face 6
3	15 inches	Face 3	Face 4	Face 6

4	15 inches	Corner 2-3-5	Corner 3-4-6	Corner 1-2-5
5	15 inches	Edge 2-3	Edge 3-5	Edge 3-4
6	15 inches	Edge 2-5	Edge 4-5	Edge 4-6
7	15 inches	Face 1	Face 2	Face 5
8	15 inches	Face 1	Face 2	Face 5

The testing is now complete and the boxes were inspected for any kind of damage. The location and type of damage in each of the box was recorded.

4.0 DATA AND RESULTS

The Protocol (Phase 1) and Protocol (Phase 2) was executed and the data collected and the results of the experiment are discussed in this section. The sample boxes that underwent the protocols were inspected after completion of each phase of testing.

4.1 RESULTS OF PHASE 1

The sample boxes containing four different kind of glasswares with two different kind of internal partition packing namely the corrugated partitions and the paperboard partitions had the following damages as mentioned below in the Table 6.

TABLE 6 - Summary of Damage of Glasswares and Cases

SAMPLE	ITEM 181/3142		ITEM 64/3720		ITEM 170/4063		ITEM 94/6029	
	CORR	P/B	CORR	P/B	CORR	P/B	CORR	P/B
GLASSWARES	74	48	12	27	38	83	8	26
CASES	14	15	8	10	11	14	6	13

The data in the Table 1 shows that for Item 64/3720, Item 170/4063, Item 94/6029 the internal partition packing of corrugated pattern had seen less damage compared to paperboard pattern. However for Item 181/3142, the paperboard partition pattern had seen less damage compared to corrugated pattern. A more realistic test method namely ISTA 3C method was used in the Phase 2 of the protocol to compare the internal partition packing performance for Item 181/3142 and Item 64/3720 respectively.

Also listed below in Table 2 is the damage detail of all the fifteen boxes tested using four different kind of glassware with two different kind of partitions.

TABLE 7 – Damage Details of all the Sample Boxes (Phase 1 Testing)

SAMPLE	ITEM 181/3142		ITEM 64/3720		ITEM 170/4063				ITEM 94/6029			
	CORR	P/B	CORR	P/B	CORR		P/B		CORR		P/B	
					T	B	T	B	T	B	T	B
BOX 1	4	2	1	1	1	0	4	2	1	1	2	0
BOX 2	5	4	1	2	0	1	3	2	1	0	1	1
BOX 3	6	2	3	1	1	2	5	3	1	0	2	1
BOX 4	6	5	1	2	2	1	5	3	0	1	1	0
BOX 5	5	3	1	3	2	3	4	6	1	0	1	0
BOX 6	5	4	1	5	0	2	6	0	1	0	1	1
BOX 7	3	4	2	2	5	0	2	2	0	1	1	0
BOX 8	8	7	2	5	5	3	5	0	0	0	1	0
BOX 9	3	3	0	3	1	0	1	0	0	0	2	0
BOX 10	7	1	0	3	2	2	5	0	0	0	6	0
BOX 11	4	4	0	0	5	0	5	1	0	0	1	0
BOX 12	8	2	0	0	0	0	7	4	0	0	2	0
BOX 13	6	2	0	0	0	0	1	1	0	0	2	0
BOX 14	0	4	0	0	0	0	3	3	0	0	0	0
BOX 15	4	1	0	0	0	0	0	0	0	0	0	0
					24	**14**	**56**	**27**	**5**	**3**	**23**	**3**
TOTAL	**74**	**48**	**12**	**27**	**38**		**83**		**8**		**26**	

4.2 RESULTS OF PHASE 2

The sample boxes containing two different glasswares namely Item 181/3142 and Item 64/3720 with two different internal packing partitions was inspected for damages and is summarized below in Table 8.

TABLE 8 - Damage Details of all the Sample Boxes (Phase 2 Testing)

SAMPLE	ITEM 181/3142		ITEM 64/3720	
	CORR	P/B	CORR	P/B
GLASSWARES	18	17	18	16
CASES	2	2	2	2

The sample boxes that were tested under the Protocol (Phase 2) for the performance of two different kind of partition namely the corrugated board partition and the paperboard partition had performed similarly with similar number of glassware damages. The Item 181/3142 of paperboard partition which had seen less damage in the Protocol (Phase 1) when subjected to a more realistic test method in Phase 2 had not performed significantly better than Item 181/3142 of corrugated partition.

The data collected from Phase 1 and Phase 2 gives a good comparison on the performance of the two different kind of internal partitions namely the corrugated and the paperboard.

5.0 CONCLUSIONS

- Item 181/3142 is the most fragile of the four different kinds of glasswares that were tested. The least fragile glassware was Item 94/6029.
- The glasswares that had shown the maximum damage during Phase 1 testing when using a corrugated internal partition is in the following decreasing order

  Item 181/3142, Item 170/4063, Item 64/3720 and Item 94/6029

  and the glasswares that had shown the maximum damage when using a paperboard partition is in the following decreasing order as below

  Item 170/4063, Item 181/3142, Item 64/3720 and Item 94/6029
- The Item 181/3142 glassware packaged using a paperboard partition had performed better than corrugated partition. A more realistic Phase 2 testing indicated that there is no major significant difference in the number of glasswares damaged. This leads to the conclusion that paperboard partition was not able to protect the glasswares Item 181/3142 better than the corrugated partitions.
- The paperboard partition package containing four different kind of glasswares had seen the most number of damages compared to corrugated partition package. The paperboard partition package did not perform well when the glasswares were double stacked in comparison to corrugated partitions package.
- The most number of glassware breakages occurred in the perimeter cell location followed by middle location inside the package and the least amount of breakages occurred in the inner cell location inside the package. The corrugated partitions package provided better protection in comparison to paperboard partition packages for the four different kind of glasswares tested.

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APPENDIX A

RAW DATA AND ANALYSIS OF DAMAGE LOCATION CHARTS OF PHASE 1 TESTING

					X
					X
					X
				X	

Figure A 1 - Damage Location for Test Protocol (Phase 1), Box 1, Item 181/3142 CORR

X	X			X	X
X					

Figure A 2 - Damage Location for Test Protocol (Phase 1), Box 2, Item 181/3142 CORR

				X	
		X			
	X				
X					
	X				X

Figure A 3 - Damage Location for Test Protocol (Phase 1), Box 3, Item 181/3142 CORR

	X				
			X		
					X
		X	X	X	

Figure A 4 - Damage Location for Test Protocol (Phase 1), Box 4, Item 181/3142 CORR

X					
X					
	X				
X					
				X	

Figure A 5 - Damage Location for Test Protocol (Phase 1), Box 5, Item 181/3142 CORR

X		X			
		X			
		X			
	X				

Figure A 6 - Damage Location for Test Protocol (Phase 1), Box 6, Item 181/3142 CORR

X					
	X				
X					

Figure A 7 - Damage Location for Test Protocol (Phase 1), Box 7, Item 181/3142 CORR

X	X				
					X
				X	
X	X				
X		X			

Figure A 8 - Damage Location for Test Protocol (Phase 1), Box 8, Item 181/3142 CORR

X				X	X

Figure A 9 - Damage Location for Test Protocol (Phase 1), Box 9, Item 181/3142 CORR

X					
X	X				
	X				
		X			
X					
X					

Figure A 10 - Damage Locations for Test Protocol (Phase 1), Box 10, Item 181/3142 CORR

		X			
					X
X			X		

Figure A 11 - Damage Locations for Test Protocol (Phase 1), Box 11, Item 181/3142 CORR

X					X
X				X	
X					
		X			X
X					

Figure A 12 - Damage Locations for Test Protocol (Phase 1), Box 12, Item 181/3142 CORR

X		X			
X					
X					
X					
X					

Figure A 13 - Damage Locations for Test Protocol (Phase 1), Box 13, Item 181/3142 CORR

Figure A 14 - Damage Locations for Test Protocol (Phase 1), Box 14, Item 181/3142 CORR

X					
		X			
			X		
X					

Figure A 15 - Damage Locations for Test Protocol (Phase 1), Box 15, Item 181/3142 CORR

					X
			X		

Figure B 1 - Damage Locations for Test Protocol (Phase 1), Box 1, Item 181/3142 P/B

		X			
X	X				
X					

Figure B 2 - Damage Locations for Test Protocol (Phase 1), Box 2, Item 181/3142 P/B

X					
X					

Figure B 3 - Damage Locations for Test Protocol (Phase 1), Box 3, Item 181/3142 P/B

					X
	X	X		X	
				X	

Figure B 4 - Damage Locations for Test Protocol (Phase 1), Box 4, Item 181/3142 P/B

		X		X	X

Figure B 5 - Damage Locations for Test Protocol (Phase 1), Box 5, Item 181/3142 P/B

		X			
			X		
				X	X

Figure B 6 - Damage Locations for Test Protocol (Phase 1), Box 6, Item 181/3142 P/B

X					
X					
			X		X

Figure B 7 - Damage Locations for Test Protocol (Phase 1), Box 7, Item 181/3142 P/B

X					X
	X		X		
		X			
	X				
		X			

Figure B 8 - Damage Locations for Test Protocol (Phase 1), Box 8, Item 181/3142 P/B

					X
	X			X	

Figure B 9 - Damage Locations for Test Protocol (Phase 1), Box 9, Item 181/3142 P/B

				X	

Figure B 10 - Damage Locations for Test Protocol (Phase 1), Box 10, Item 181/3142 P/B

X			X		X
		X			

Figure B 11 - Damage Locations for Test Protocol (Phase 1), Box 11, Item 181/3142 P/B

X					
					X

Figure B 12 - Damage Locations for Test Protocol (Phase 1), Box 12, Item 181/3142 P/B

X				X	

Figure B 13 - Damage Locations for Test Protocol (Phase 1), Box 13, Item 181/3142 P/B

					X
				X	
				X	X

Figure B 14 - Damage Locations for Test Protocol (Phase 1), Box 14, Item 181/3142 P/B

			X		

Figure B 15 - Damage Locations for Test Protocol (Phase 1), Box 15, Item 181/3142 P/B

TOP LAYER

	X				

BOTTOM LAYER

Figure C 1 - Damage Locations for Test Protocol (Phase 1), Box 1, Item 170/4063 CORR

TOP LAYER

BOTTOM LAYER

					X

Figure C 2 - Damage Locations for Test Protocol (Phase 1), Box 1, Item 170/4063 CORR

TOP LAYER

			X		

BOTTOM LAYER

X					
					X

Figure C 3 - Damage Locations for Test Protocol (Phase 1), Box 3, Item 170/4063 CORR

TOP LAYER

					X
			X		

BOTTOM LAYER

X					

Figure C 4 - Damage Locations for Test Protocol (Phase 1), Box 4, Item 170/4063 CORR

TOP LAYER

X					
	X				

BOTTOM LAYER

X	X				
X					

Figure C 5 - Damage Locations for Test Protocol (Phase 1), Box 5, Item 170/4063 CORR

TOP LAYER

BOTTOM LAYER

			X		
			X		

Figure C 6 - Damage Locations for Test Protocol (Phase 1), Box 6, Item 170/4063 CORR

TOP LAYER

X		X	X		X
			X		

BOTTOM LAYER

Figure C 7 - Damage Locations for Test Protocol (Phase 1), Box 7, Item 170/4063 CORR

TOP LAYER

	X	X	X		
					X
				X	

BOTTOM LAYER

					X
		X	X		

Figure C 8 - Damage Locations for Test Protocol (Phase 1), Box 8, Item 170/4063 CORR

TOP LAYER

	X				

BOTTOM LAYER

Figure C 9- Damage Locations for Test Protocol (Phase 1), Box 9 Item 170/4063 CORR

TOP LAYER

				X	X

BOTTOM LAYER

					X
					X

Figure C 10 - Damage Locations for Test Protocol (Phase 1), Box 9, Item 170/4063 CORR

TOP LAYER

					X
	X		X	X	X

BOTTOM LAYER

Figure C 11 - Damage Locations for Test Protocol (Phase 1), Box 11, Item 170/4063 CORR

TOP LAYER

BOTTOM LAYER

Figure C 12 - Damage Locations for Test Protocol (Phase 1), Box 12, Item 170/4063 CORR

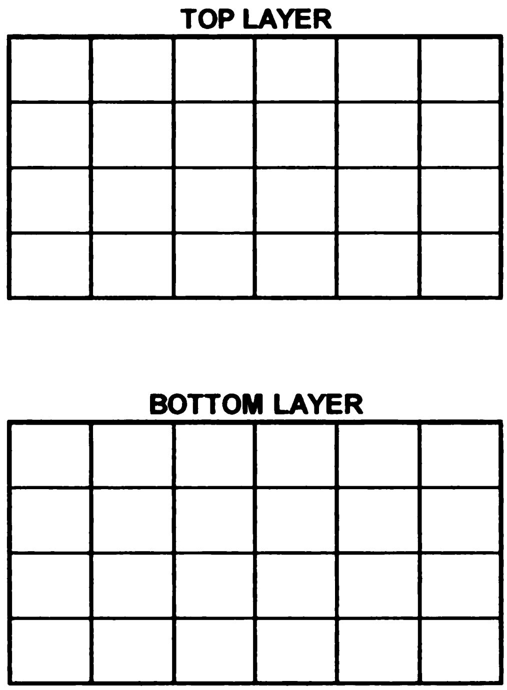

Figure C 13 - Damage Locations for Test Protocol (Phase 1), Box 13, Item 170/4063 CORR

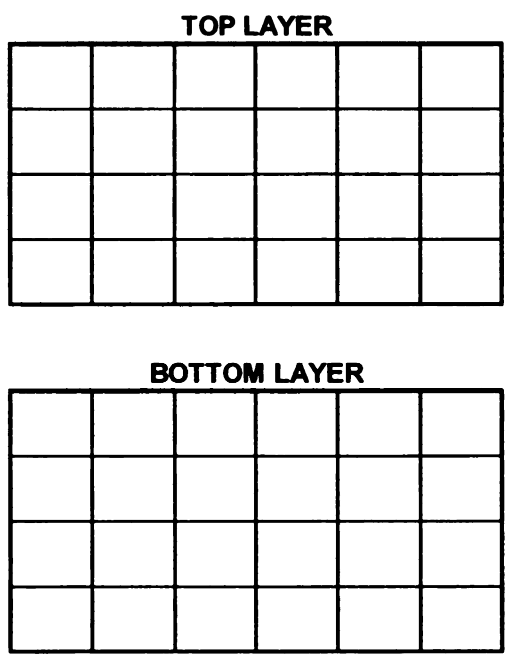

Figure C 14 - Damage Locations for Test Protocol (Phase 1), Box 14, Item 170/4063 CORR

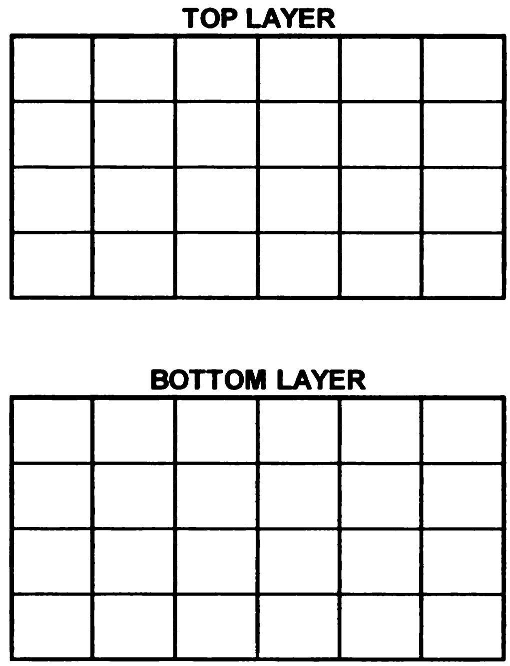

Figure C 15 - Damage Locations for Test Protocol (Phase 1), Box 15, Item 170/4063 CORR

TOP LAYER

X	X			X	
				X	

BOTTOM LAYER

X					
			X		

Figure D 1 - Damage Locations for Test Protocol (Phase 1), Box 1, Item 170/4063 P/B

TOP LAYER

		X	X		X

BOTTOM LAYER

				X	
	X				

Figure D 2 - Damage Locations for Test Protocol (Phase 1), Box 2, Item 170/4063 P/B

TOP LAYER

		X			
		X			
		X			
X		X			

BOTTOM LAYER

				X	
X					
X					

Figure D 3 - Damage Locations for Test Protocol (Phase 1), Box 3, Item 170/4063 P/B

TOP LAYER

			X	X	X
			X		

BOTTOM LAYER

		X	X		
		X		X	X
X					

Figure D 4 - Damage Locations for Test Protocol (Phase 1), Box 4, Item 170/4063 P/B

TOP LAYER

					X
					X
					X
			X		

BOTTOM LAYER

X					X
X					
					X

Figure D 5 - Damage Locations for Test Protocol (Phase 1), Box 5, Item 170/4063 P/B

TOP LAYER

X	X	X		X	
		X	X		

BOTTOM LAYER

Figure D 6- Damage Locations for Test Protocol (Phase 1), Box 6, Item 170/4063 P/B

TOP LAYER

					X
X					

BOTTOM LAYER

			X	X	

Figure D 7 - Damage Locations for Test Protocol (Phase 1), Box 7, Item 170/4063 P/B

TOP LAYER

		X			
X					
X	X				X

BOTTOM LAYER

Figure D 8 - Damage Locations for Test Protocol (Phase 1), Box 8, Item 170/4063 P/B

TOP LAYER

				X	

BOTTOM LAYER

Figure D 9 - Damage Locations for Test Protocol (Phase 1), Box 9, Item 170/4063 P/B

TOP LAYER

					X
		X			
					X
X		X			

BOTTOM LAYER

Figure D 10 - Damage Locations for Test Protocol (Phase 1), Box 10, Item 170/4063 P/B

TOP LAYER

X					
			X		
	X	X	X		

BOTTOM LAYER

X					

Figure D 11 - Damage Locations for Test Protocol (Phase 1), Box 11, Item 170/4063 P/B

TOP LAYER

X	X			X	X
					X
			X	X	

BOTTOM LAYER

		X		X	X
X					

Figure D 12 - Damage Locations for Test Protocol (Phase 1), Box 12, Item 170/4063 P/B

TOP LAYER

					X

BOTTOM LAYER

					X

Figure D 13 - Damage Locations for Test Protocol (Phase 1), Box 13, Item 170/4063 P/B

TOP LAYER

	X		X		
			X		

BOTTOM LAYER

		X		X	
					X

Figure D 14 - Damage Locations for Test Protocol (Phase 1), Box 14, Item 170/4063 P/B

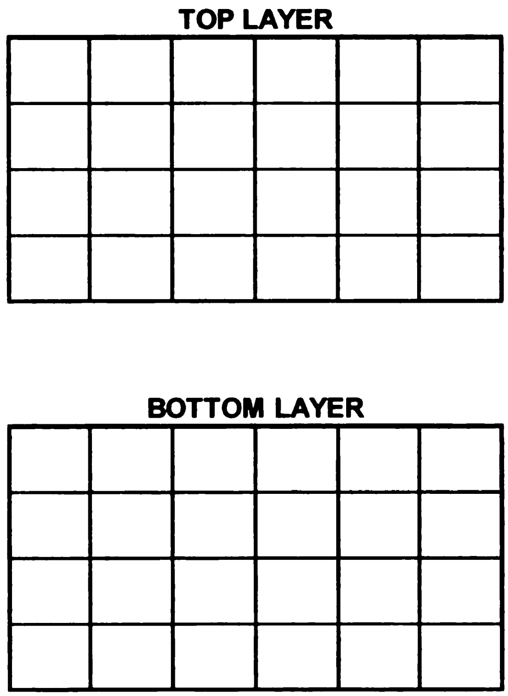

Figure D 15 - Damage Locations for Test Protocol (Phase 1), Box 15, Item 170/4063 P/B

TOP LAYER

								X

BOTTOM LAYER

								X

Figure E 1 - Damage Locations for Test Protocol (Phase 1), Box 1, Item 94/6029 CORR

TOP LAYER

								X

BOTTOM LAYER

Figure E 2 - Damage Locations for Test Protocol (Phase 1), Box 2, Item 94/6029 CORR

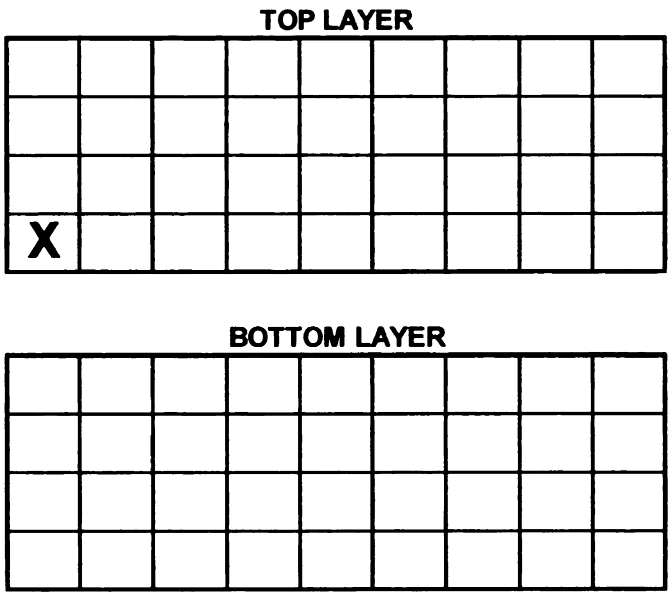

Figure E 3 - Damage Locations for Test Protocol (Phase 1), Box 3, Item 94/6029 CORR

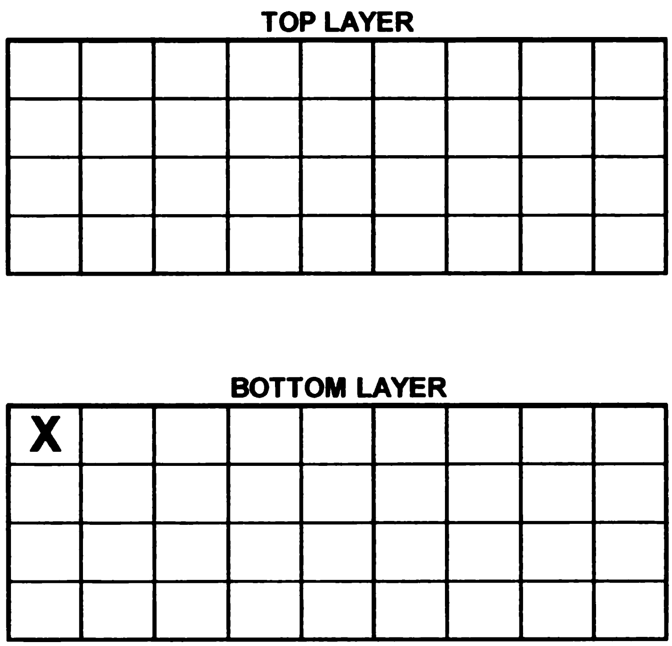

Figure E 4 - Damage Locations for Test Protocol (Phase 1), Box 4, Item 94/6029 CORR

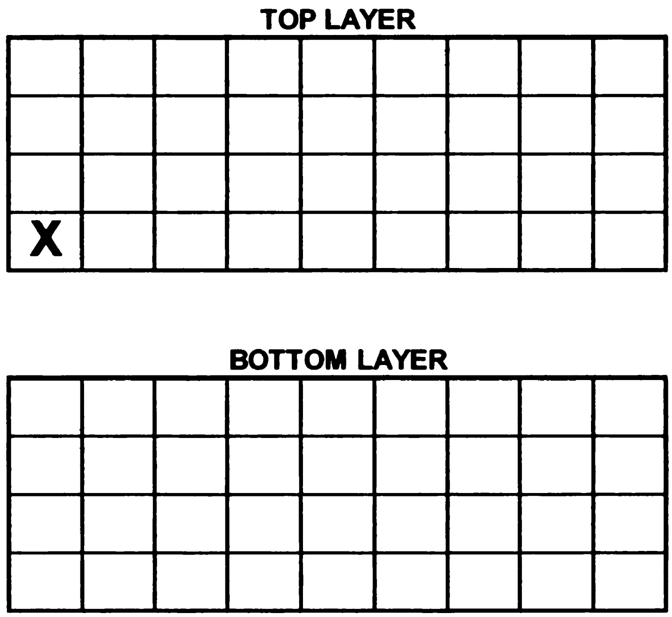

Figure E 5 - Damage Locations for Test Protocol (Phase 1), Box 5, Item 94/6029 CORR

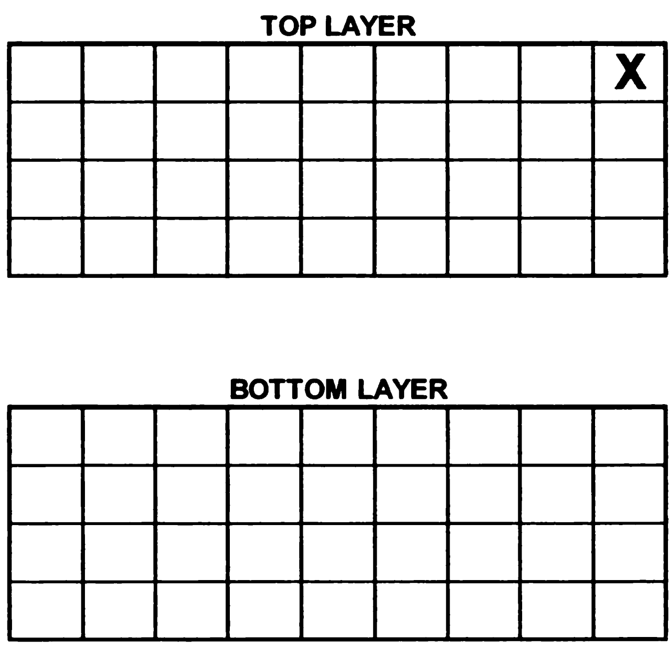

Figure E 6 - Damage Locations for Test Protocol (Phase 1), Box 6, Item 94/6029 CORR

TOP LAYER

BOTTOM LAYER

X								

Figure E 7 - Damage Locations for Test Protocol (Phase 1), Box 7, Item 94/6029 CORR

TOP LAYER

BOTTOM LAYER

Figure E 8 - Damage Locations for Test Protocol (Phase 1), Box 8, Item 94/6029 CORR

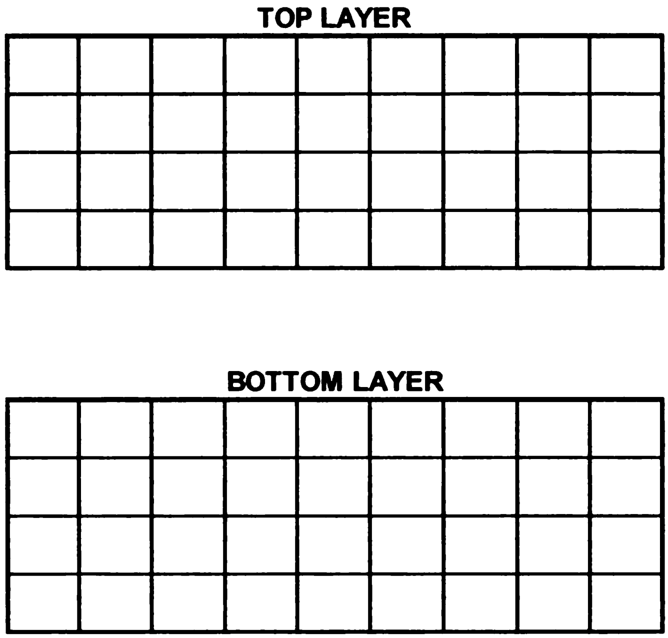

Figure E 9 - Damage Locations for Test Protocol (Phase 1), Box 9, Item 94/6029 CORR

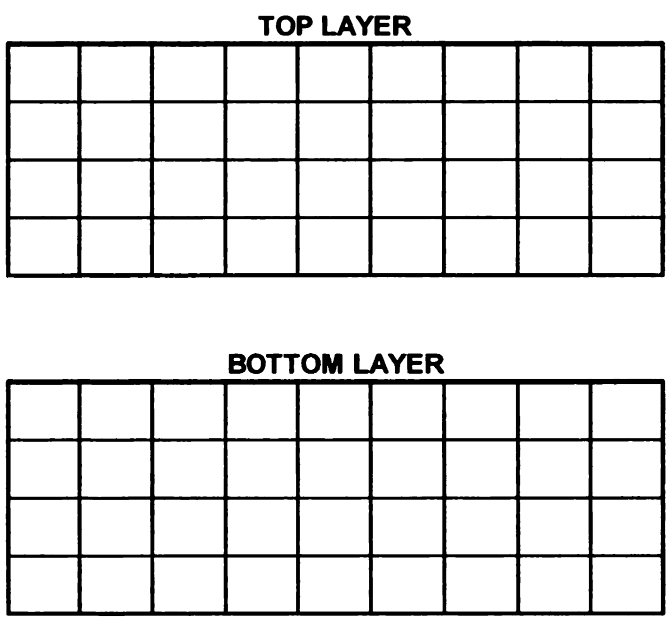

Figure E 10 - Damage Locations for Test Protocol (Phase 1), Box 10, Item 94/6029 CORR

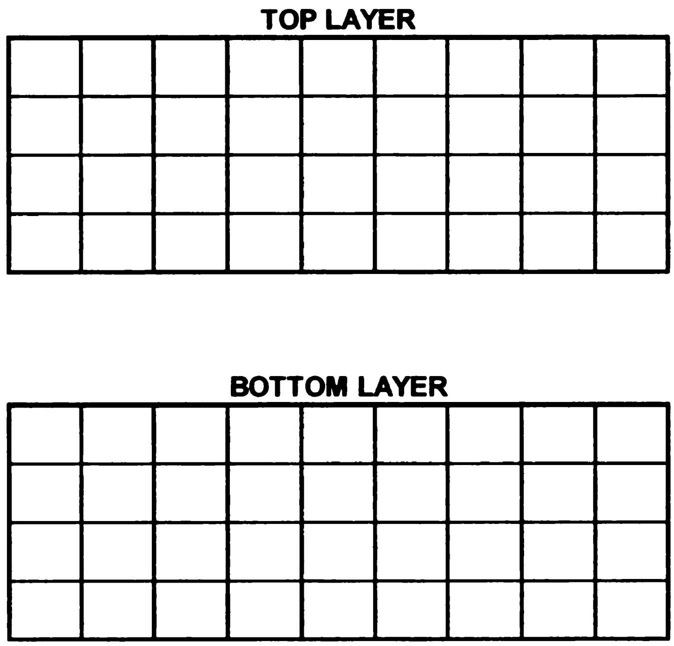

Figure E 11 - Damage Locations for Test Protocol (Phase 1), Box 11, Item 94/6029 CORR

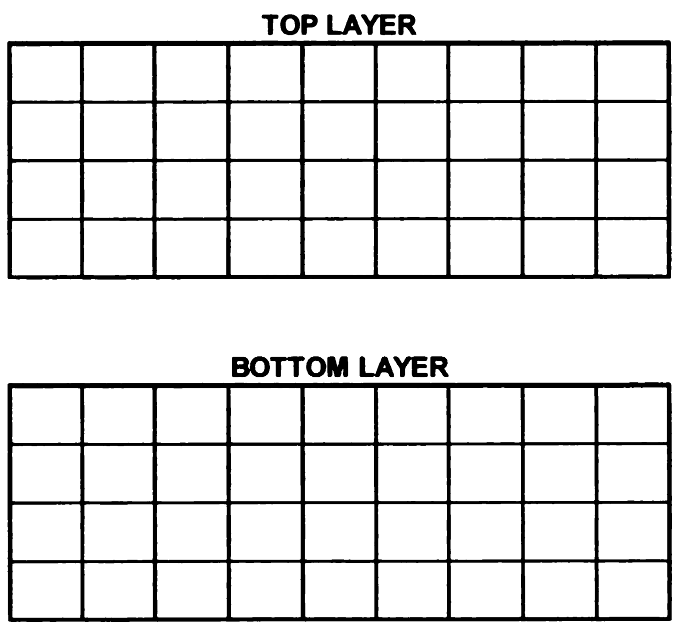

Figure E 12 - Damage Locations for Test Protocol (Phase 1), Box 12, Item 94/6029 CORR

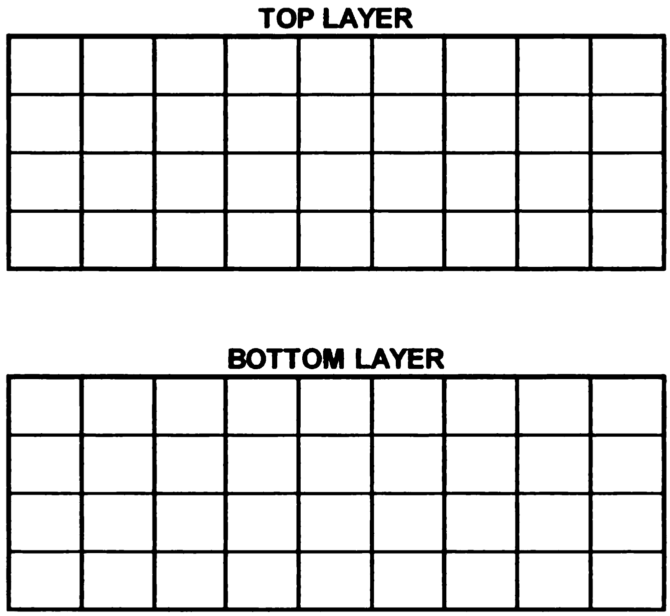

Figure E 13 - Damage Locations for Test Protocol (Phase 1), Box 13, Item 94/6029 CORR

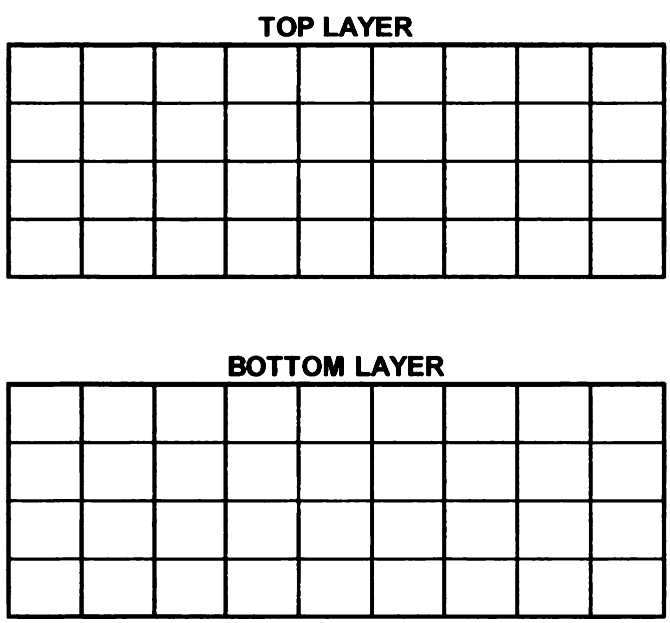

Figure E 14 - Damage Locations for Test Protocol (Phase 1), Box 14, Item 94/6029 CORR

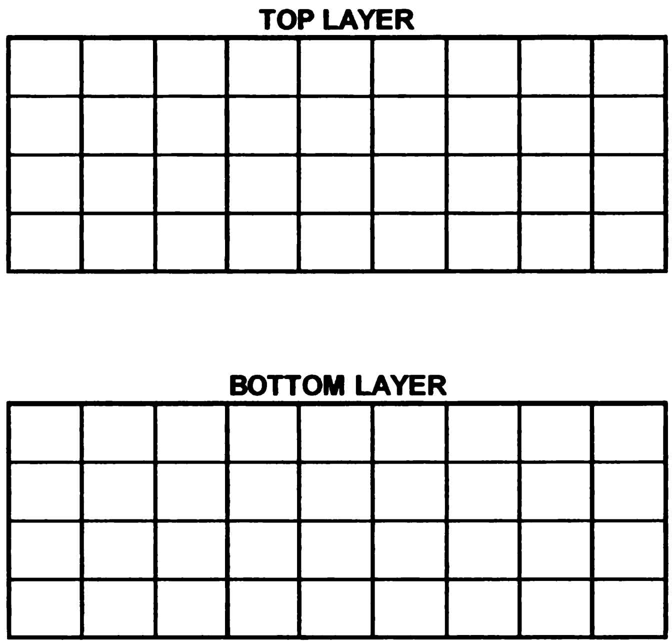

Figure E 15 - Damage Locations for Test Protocol (Phase 1), Box 15, Item 94/6029 CORR

TOP LAYER

						X		
					X			

BOTTOM LAYER

Figure F 1 - Damage Locations for Test Protocol (Phase 1), Box 1, Item 94/6029 P/B

TOP LAYER

	X							

BOTTOM LAYER

						X		

Figure F 2 - Damage Locations for Test Protocol (Phase 1), Box 2, Item 94/6029 P/B

TOP LAYER

X	X							

BOTTOM LAYER

								X

Figure F 3 - Damage Locations for Test Protocol (Phase 1), Box 3, Item 94/6029 P/B

TOP LAYER

		X						

BOTTOM LAYER

Figure F 4 - Damage Locations for Test Protocol (Phase 1), Box 4, Item 94/6029 P/B

TOP LAYER

X								

BOTTOM LAYER

Figure F 5 - Damage Locations for Test Protocol (Phase 1), Box 5, Item 94/6029 P/B

TOP LAYER

								X

BOTTOM LAYER

	X							

Figure F 6 - Damage Locations for Test Protocol (Phase 1), Box 6, Item 94/6029 P/B

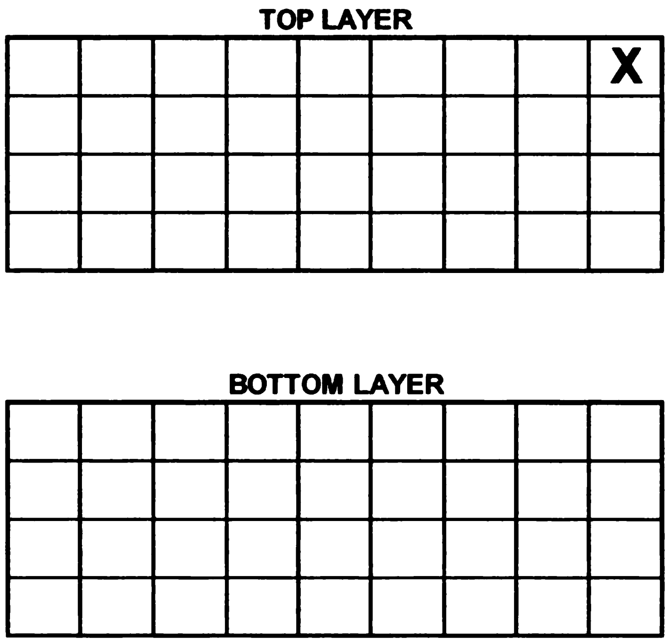

Figure F 7 - Damage Locations for Test Protocol (Phase 1), Box 7, Item 94/6029 P/B

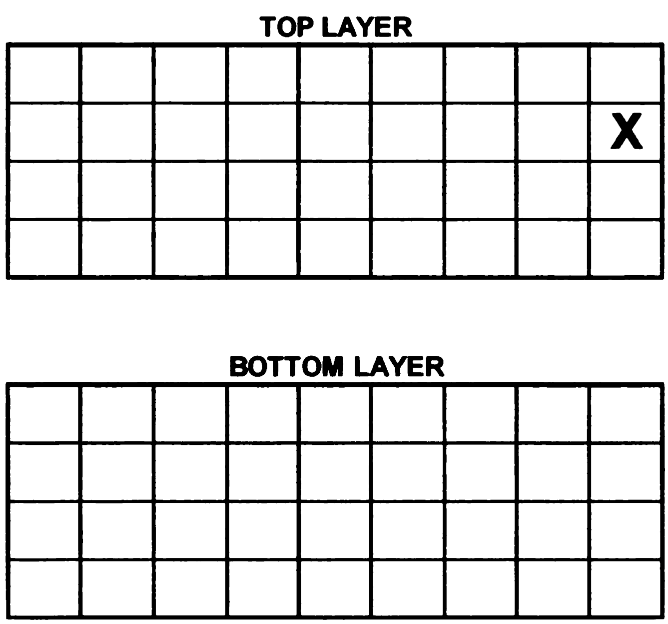

Figure F 8 - Damage Locations for Test Protocol (Phase 1), Box 8, Item 94/6029 P/B

TOP LAYER

		X						
								X

BOTTOM LAYER

Figure F 9 - Damage Locations for Test Protocol (Phase 1), Box 9, Item 94/6029 P/B

TOP LAYER

X		X						
	X	X		X				X

BOTTOM LAYER

Figure F 10 - Damage Locations for Test Protocol (Phase 1), Box 10, Item 94/6029 P/B

TOP LAYER

X								

BOTTOM LAYER

Figure F 11 - Damage Locations for Test Protocol (Phase 1), Box 11, Item 94/6029 P/B

TOP LAYER

X			X					

BOTTOM LAYER

Figure F 12 - Damage Locations for Test Protocol (Phase 1), Box 12, Item 94/6029 P/B

TOP LAYER

	X							
X								

BOTTOM LAYER

Figure F 13 - Damage Locations for Test Protocol (Phase 1), Box 13, Item 94/6029 P/B

TOP LAYER

BOTTOM LAYER

Figure F 14 - Damage Locations for Test Protocol (Phase 1), Box 14, Item 94/6029 P/B

TOP LAYER

BOTTOM LAYER

Figure F 15 - Damage Locations for Test Protocol (Phase 1), Box 15, Item 94/6029 P/B

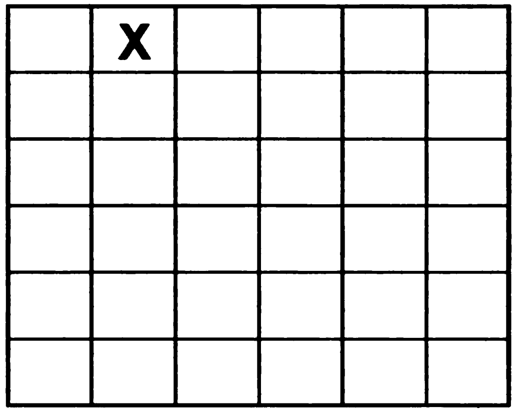

Figure G 1 - Damage Locations for Test Protocol (Phase 1), Box 1, Item 64/3720 CORR

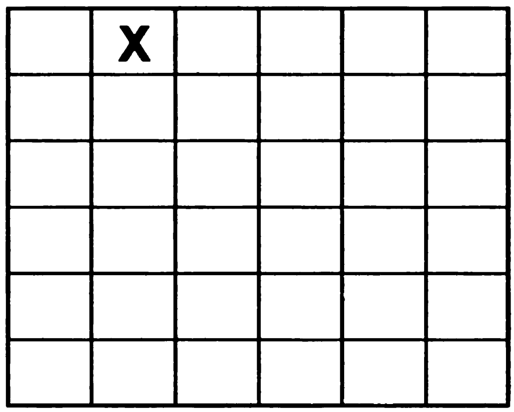

Figure G 2 - Damage Locations for Test Protocol (Phase 1), Box 2, Item 64/3720 CORR

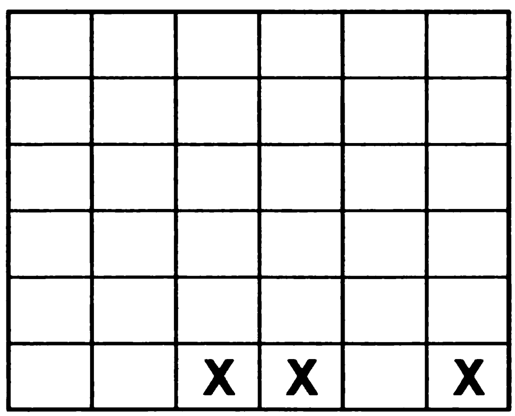

Figure G 3 - Damage Locations for Test Protocol (Phase 1), Box 3, Item 64/3720 CORR

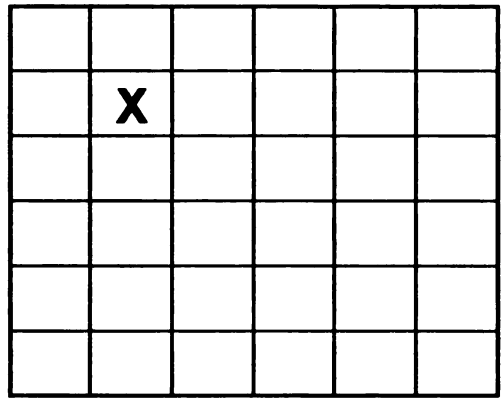

Figure G 4 - Damage Locations for Test Protocol (Phase 1), Box 4, Item 64/3720 CORR

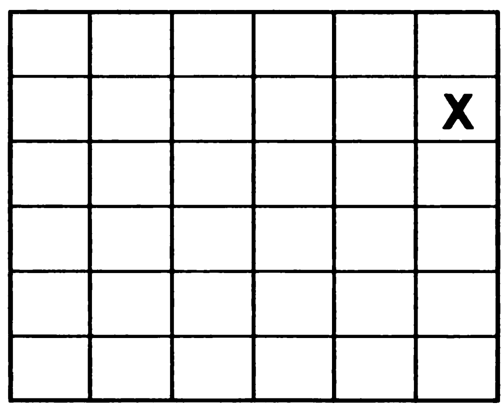

Figure G 5 - Damage Locations for Test Protocol (Phase 1), Box 5, Item 64/3720 CORR

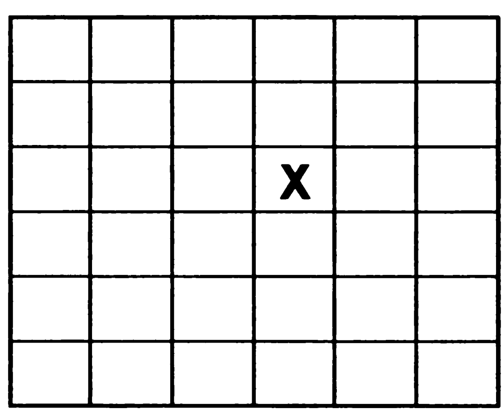

Figure G 6 - Damage Locations for Test Protocol (Phase 1), Box 6, Item 64/3720 CORR

					X
				X	

Figure G 7 - Damage Locations for Test Protocol (Phase 1), Box 7, Item 64/3720 CORR

X					
					X

Figure G 8 - Damage Locations for Test Protocol (Phase 1), Box 8, Item 64/3720 CORR

Figure G 9 - Damage Locations for Test Protocol (Phase 1), Box 9, Item 64/3720 CORR

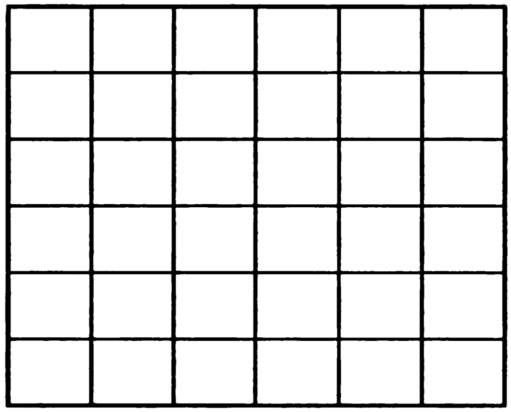

Figure G 10 - Damage Locations for Test Protocol (Phase 1), Box 10, Item 64/3720 CORR

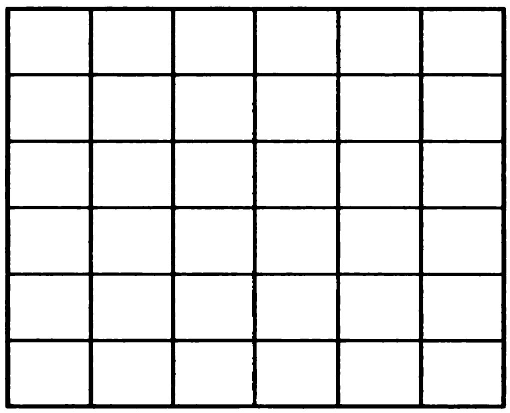

Figure G 11 - Damage Locations for Test Protocol (Phase 1), Box 11, Item 64/3720 CORR

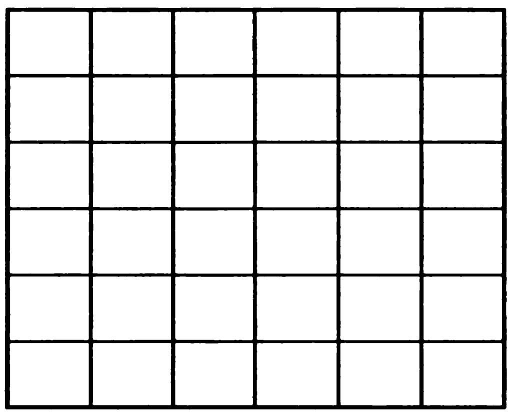

Figure G 12 - Damage Locations for Test Protocol (Phase 1), Box 12, Item 64/3720 CORR

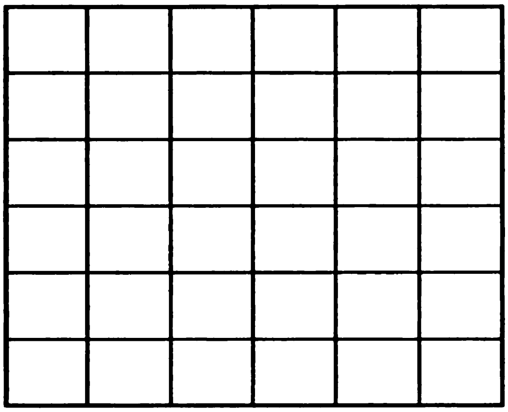

Figure G 13 - Damage Locations for Test Protocol (Phase 1), Box 13, Item 64/3720 CORR

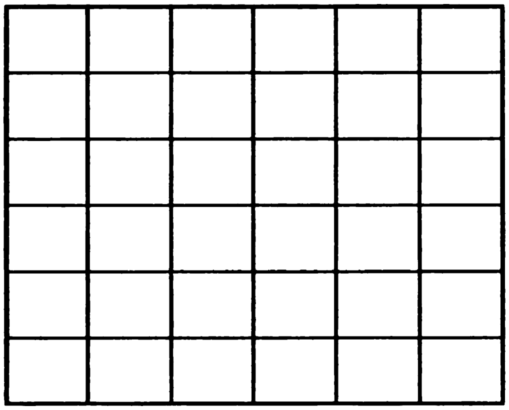

Figure G 14 - Damage Locations for Test Protocol (Phase 1), Box 14, Item 64/3720 CORR

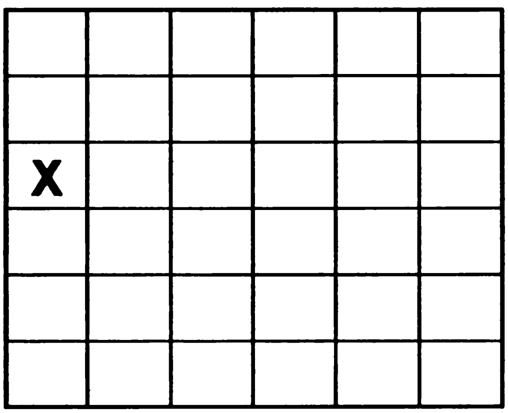

Figure G 15 - Damage Locations for Test Protocol (Phase 1), Box 15, Item 64/3720 CORR

X					

Figure H 1 - Damage Locations for Test Protocol (Phase 1), Box 1, Item 64/3720 P/B

			X		
			X		

Figure H 2 - Damage Locations for Test Protocol (Phase 1), Box 2, Item 64/3720 P/B

X					

Figure H 3 - Damage Locations for Test Protocol (Phase 1), Box 3, Item 64/3720 P/B

			X		
X					

Figure H 4 - Damage Locations for Test Protocol (Phase 1), Box 4, Item 64/3720 P/B

			X		
X					
X					

Figure H 5- Damage Locations for Test Protocol (Phase 1), Box 5, Item 64/3720 P/B

	X				
				X	
			X		X
			X		

Figure H 6 - Damage Locations for Test Protocol (Phase 1), Box 6, Item 64/3720 P/B

					X
X					

Figure H 7 - Damage Locations for Test Protocol (Phase 1), Box 7, Item 64/3720 P/B

X					
				X	
				X	
				X	
				X	

Figure H 8 - Damage Locations for Test Protocol (Phase 1), Box 8, Item 64/3720 P/B

				X	
				X	
	X				

Figure H 9 - Damage Locations for Test Protocol (Phase 1), Box 9, Item 64/3720 P/B

X				X	
					X

Figure H 10 - Damage Locations for Test Protocol (Phase 1), Box 10, Item 64/3720 P/B

Figure H 11 - Damage Locations for Test Protocol (Phase 1), Box 11, Item 64/3720 P/B

Figure H 12 - Damage Locations for Test Protocol (Phase 1), Box 12, Item 64/3720 P/B

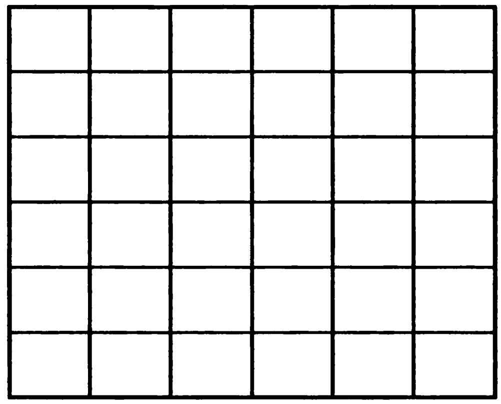

Figure H 13 - Damage Locations for Test Protocol (Phase 1), Box 13, Item 64/3720 P/B

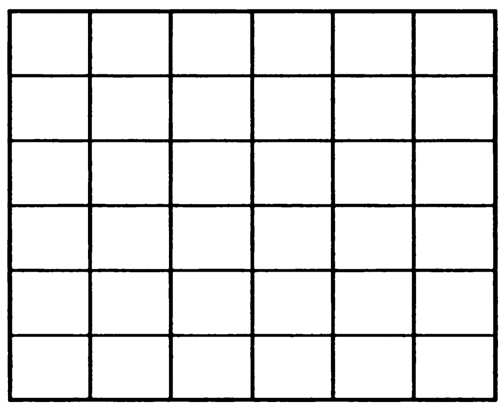

Figure H 14 - Damage Locations for Test Protocol (Phase 1), Box 14, Item 64/3720 P/B

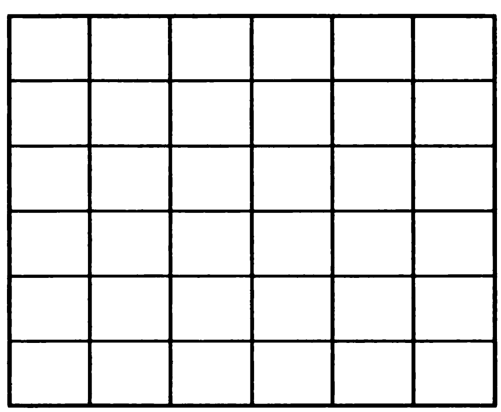

Figure H 15 - Damage Locations for Test Protocol (Phase 1), Box 15, Item 64/3720 P/B

INTERPRETATION OF THE DAMAGE LOCATION CHARTS

P	P	P	P	P	P
P	M	M	M	M	P
P	M	I	I	M	P
P	M	I	I	M	P
P	M	M	M	M	P
P	P	P	P	P	P

The damage location chart can be divided into three zones for the interpretation of the data. The three zones in the chart are categorized into Perimeter zone denoted as P in the chart, Middle zone denoted as M in the chart and Inner zone denoted as I in the chart . The X in the damage location area indicates the damage of a glassware during Phase 1 testing and depending upon where the X is located within the matrix, the damage location area can be categorized into P, M or I region of the chart.

The damage location chart for all the four different kind of glasswares using two different kind of partitions namely the corrugated partition and paperboard partitions are shown below.

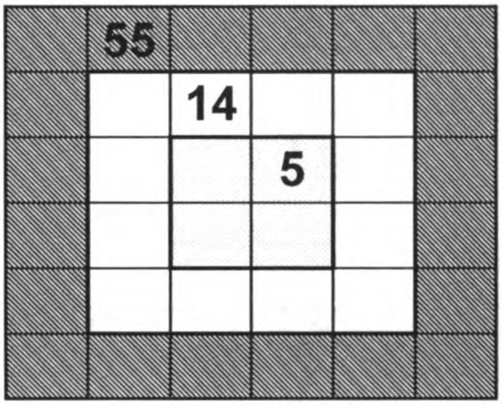

Figure A 16 - Damage Location Chart for Test Protocol (Phase 1), Item 181/3142 CORR

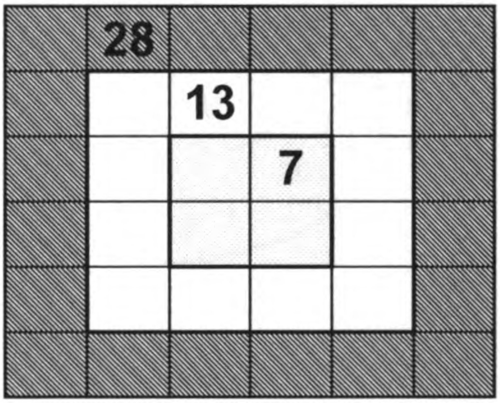

Figure B 16 - Damage Location Chart for Test Protocol (Phase 1), Item 181/3142 P/B

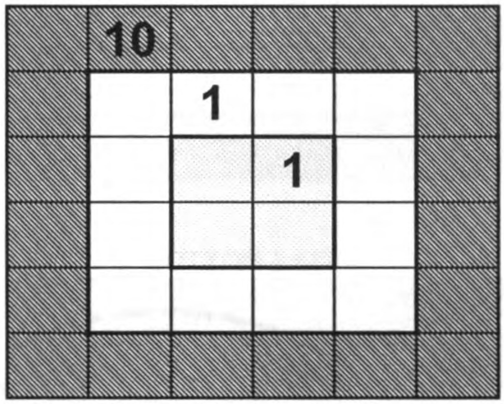

Figure C 16 - Damage Location Chart for Test Protocol (Phase 1), Item 64/3720 CORR

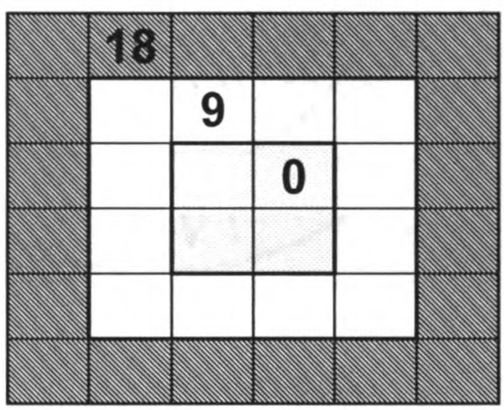

Figure D 16 - Damage Location Chart for Test Protocol (Phase 1), Item 64/3720 P/B

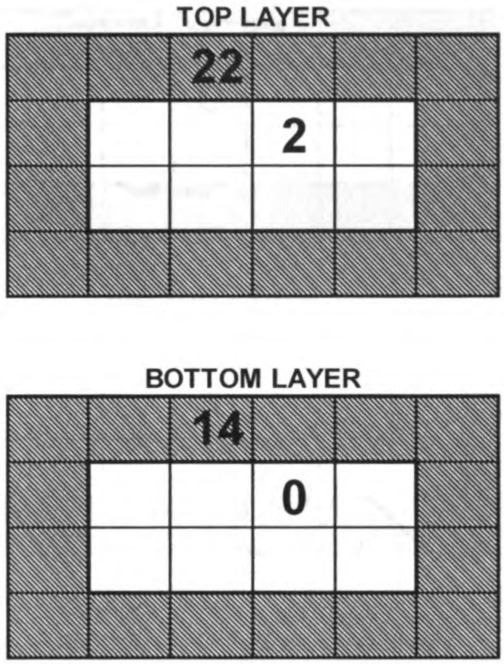

Figure E 16 - Damage Location Chart for Test Protocol (Phase 1), Item 170/4063 CORR

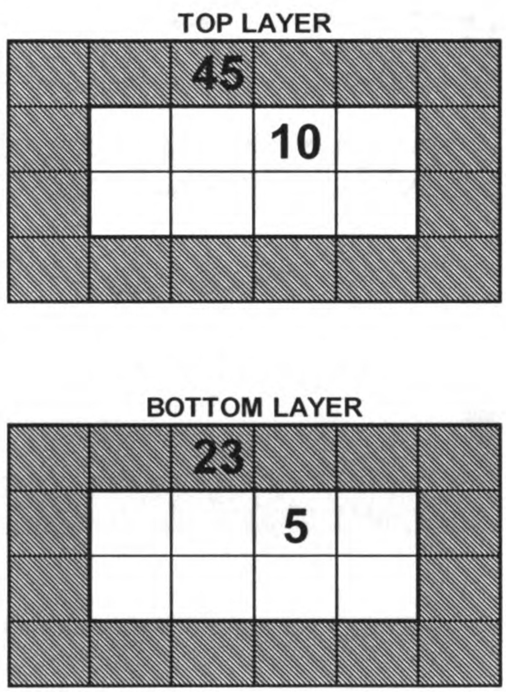

Figure F 16 - Damage Location Chart for Test Protocol (Phase 1), Item 170/4063 P/B

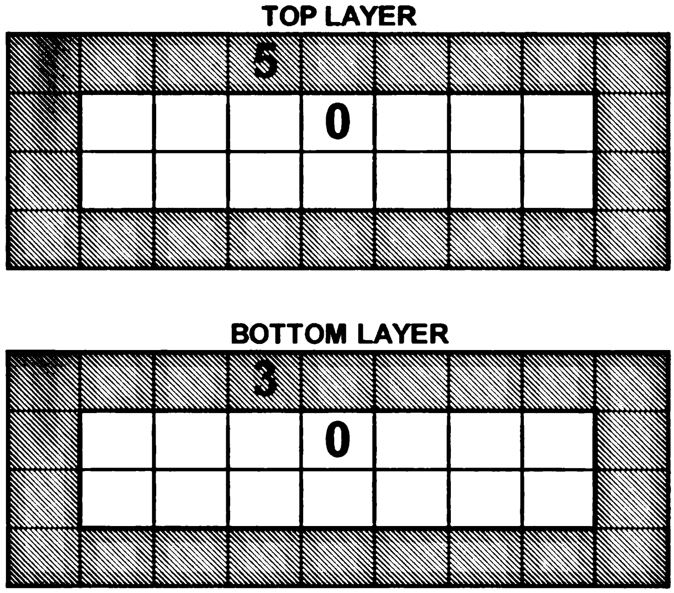

Figure G 16 - Damage Location Chart for Test Protocol (Phase 1), Item 94/6029 CORR

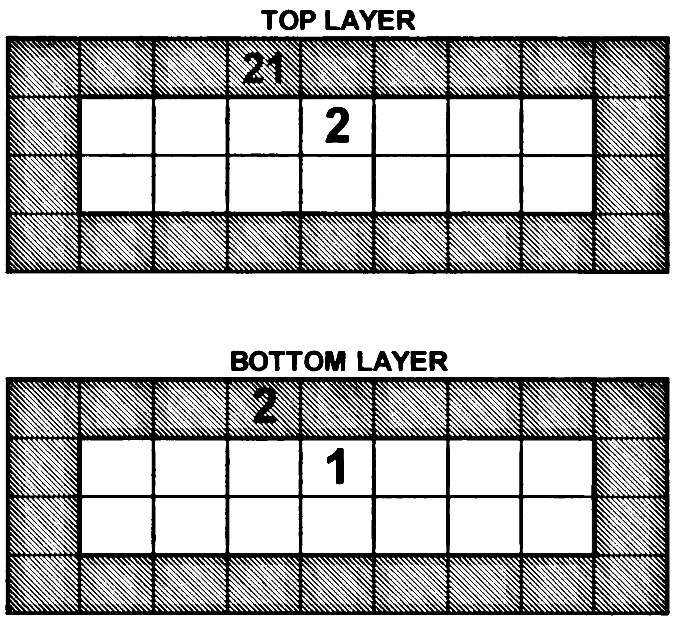

Figure H 16 - Damage Location Chart for Test Protocol (Phase 1), Item 94/6029 P/B

The zonal analysis for the four different kind of glasswares with two different internal partitions packing for Phase 1 testing is presented in the below table.

TABLE 9 - Zonal Analysis with Reference to Glasswares (Phase 1 Testing)

Sample	No. of Cases Tested	Zone			Total Damage
		P*	M**	I***	
Item 181,3142 Corr. Ptn.	15	55	14	5	74
Item 181, 3142 P/B. Ptn.	15	28	13	7	48
Item 64, 3720 Corr. Ptn.	15	10	1	1	12
Item 64, 3720 P/B Ptn.	15	18	9	0	27
Item 94, 6029 Corr. Ptn.	15	8	-	0	8
Item 94, 6029 P/B Ptn.	15	23	-	3	26
Item 170, 4063 Corr. Ptn.	15	36	-	2	38
Item 170, 4063 P/B Ptn.	15	68	-	15	83

According to the table, the maximum damage was caused in the Perimeter zone followed by Middle zone and the least damage was observed in the Inner zone.

APPENDIX B

RAW DATA AND ANALYSIS OF DAMAGE LOCATION CHARTS OF PHASE 2 TESTING

Figure I 1 - Damage Locations for Test Protocol (Phase 2), Box 1, Item 181/3142 CORR

X	X				
X		X			
X					
X					
X					
		X			

Figure I 2 - Damage Locations for Test Protocol (Phase 2), Box 2 Item 181/3142 CORR

	X	X	X	X	X
X		X	X		
	X				
					X

Figure I 3 - Damage Locations for Test Protocol (Phase 2), Box 2 Item 181/3142 CORR

Figure J 1 - Damage Locations for Test Protocol (Phase 2), Box 1 Item 181/3142 P/B

X					
	X				
	X				
		X		X	
	X				
X					

Figure J 2 - Damage Locations for Test Protocol (Phase 2), Box 2, Item 181/3142 P/B

X	X				
X	X				
X	X				
X	X				
X					
X					

Figure J 3 - Damage Locations for Test Protocol (Phase 2), Box 3, Item 181/3142 P/B

Figure K 1 - Damage Locations for Test Protocol (Phase 2), Box 1, Item 64/3720 CORR

				X	X
X	X	X	X	X	X

Figure K 2 - Damage Locations for Test Protocol (Phase 2), Box 2, Item 64/3720 CORR

X					
	X				
X	X	X			
X	X	X			
X	X				

Figure K 3 - Damage Locations for Test Protocol (Phase 2), Box 3, Item 64/3720 CORR

Figure L 1 - Damage Locations for Test Protocol (Phase 2), Box 1, Item 64/3720 P/B

	X				
	X				
X					
	X				
X				X	

Figure L 2 - Damage Locations for Test Protocol (Phase 2), Box 2, Item 64/3720 P/B

X	X				
			X	X	X
		X			
	X				
	X	X			X

Figure L 3 - Damage Locations for Test Protocol (Phase 2), Box 3, Item 64/3720 P/B

INTERPRETATION OF THE DAMAGE LOCATION CHARTS

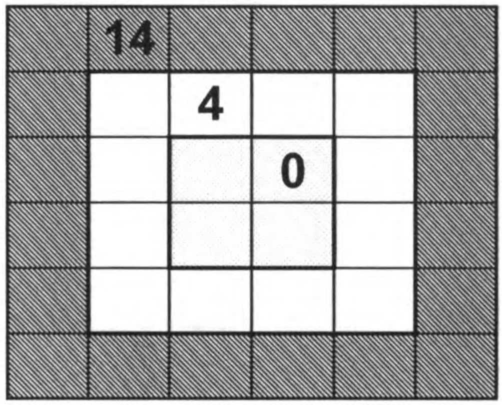

Figure I 4 - Damage Location Chart for Test Protocol (Phase 2), Item 181/3142 CORR

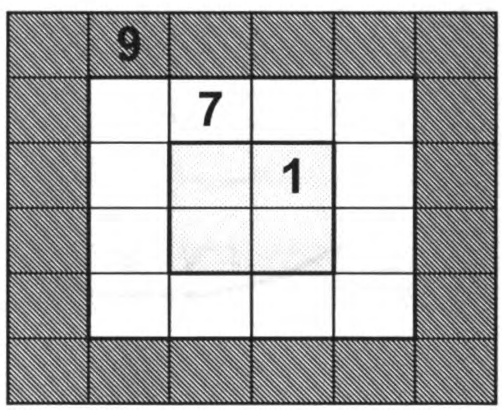

Figure J 4 - Damage Location Chart for Test Protocol (Phase 2), Item 181/3142 P/B

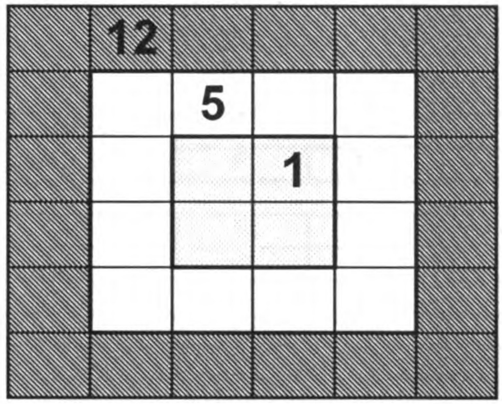

Figure K 4 - Damage Location Chart for Test Protocol (Phase 2), Item 64/3720 CORR

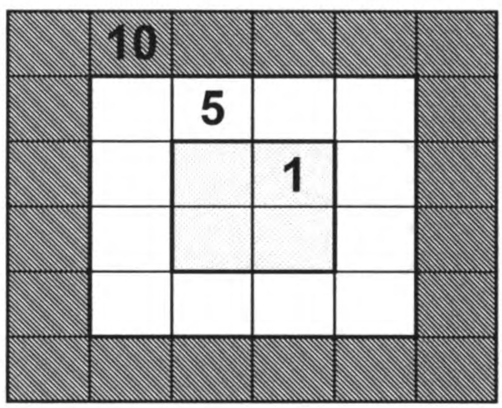

Figure L 4 - Damage Location Chart for Test Protocol (Phase 2), Item 64/3720 P/B

TABLE 10 - Zonal Analysis with Reference to Glasswares (Phase 2 Testing)

Sample	No. of Cases Tested	Zone			Total Damage
		P*	M**	I***	
Item 181,3142 Corr. Ptn.	3	14	4	0	18
Item 181, 3142 P/B. Ptn.	3	9	7	1	17
Item 64, 3720 Corr. Ptn.	3	12	5	1	18
Item 64, 3720 P/B Ptn.	3	10	5	1	16

APPENDI X C

PICTURES OF GLASSWARE TAKEN BEFORE AND AFTER PHASE 1 TESTING

Figure 2 - Package containing Undamaged Item 181/3142 with Corrugated Partitions

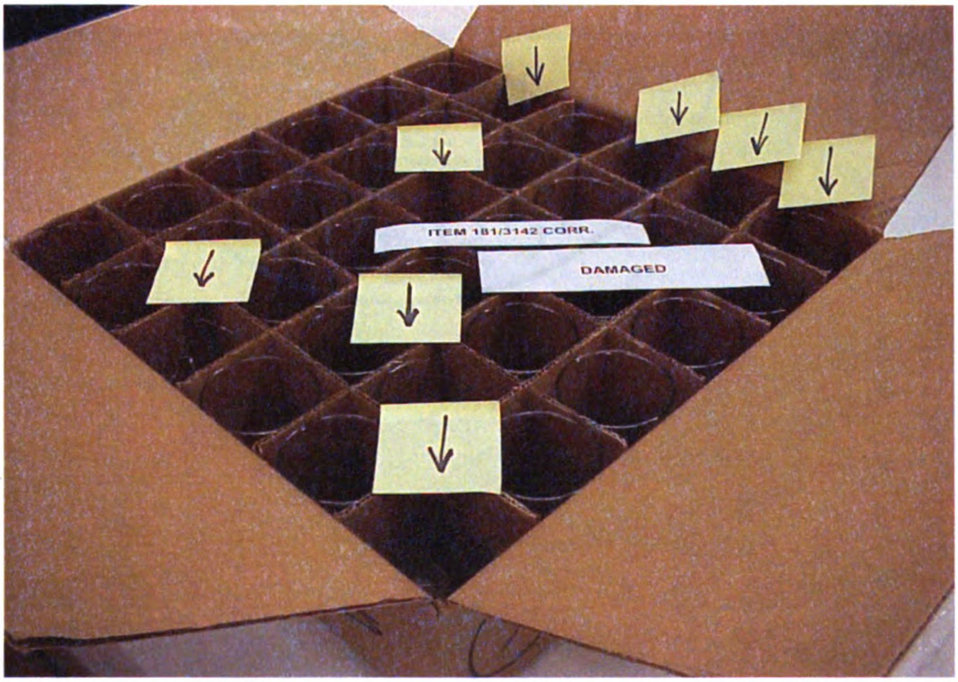

Figure 3 - Package containing Damaged Item 181/3142 with Corrugated Partitions

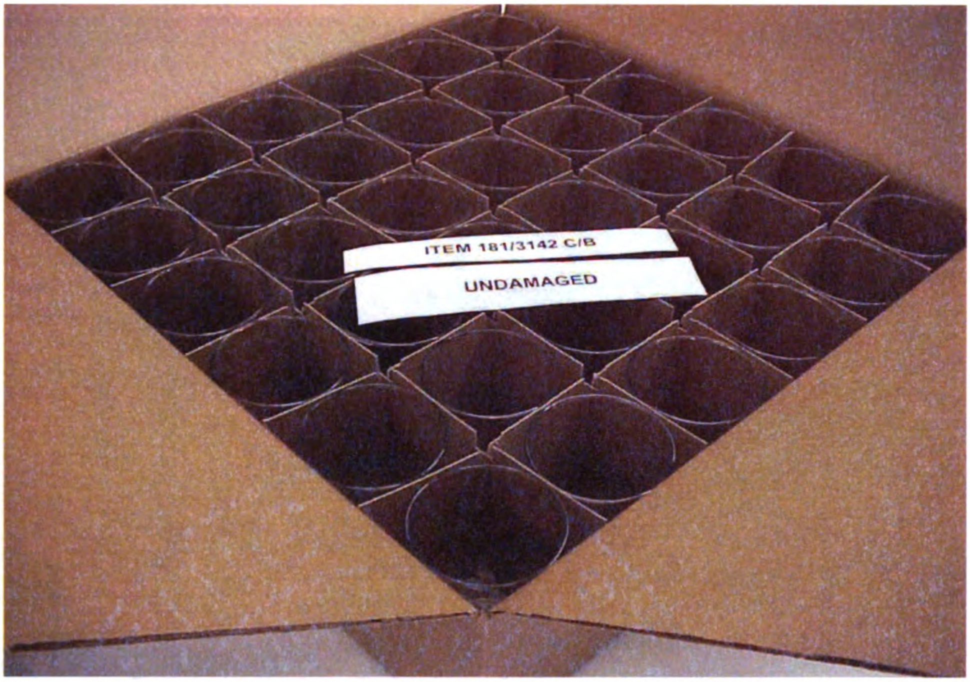

Figure 4 - Package containing Undamaged Item 181/3142 with Paperboard Partitions

Figure 5 - Package containing Damaged Item 181/3142 with Paperboard Partitions

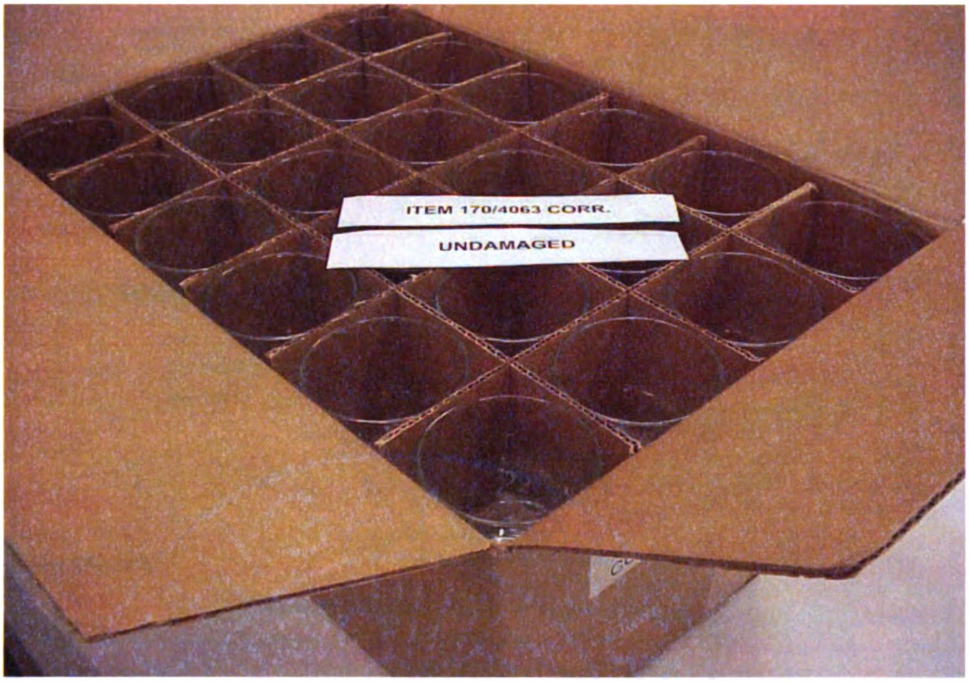

Figure 6 - Package containing Undamaged Item 170/4063 with Corrugated Partitions

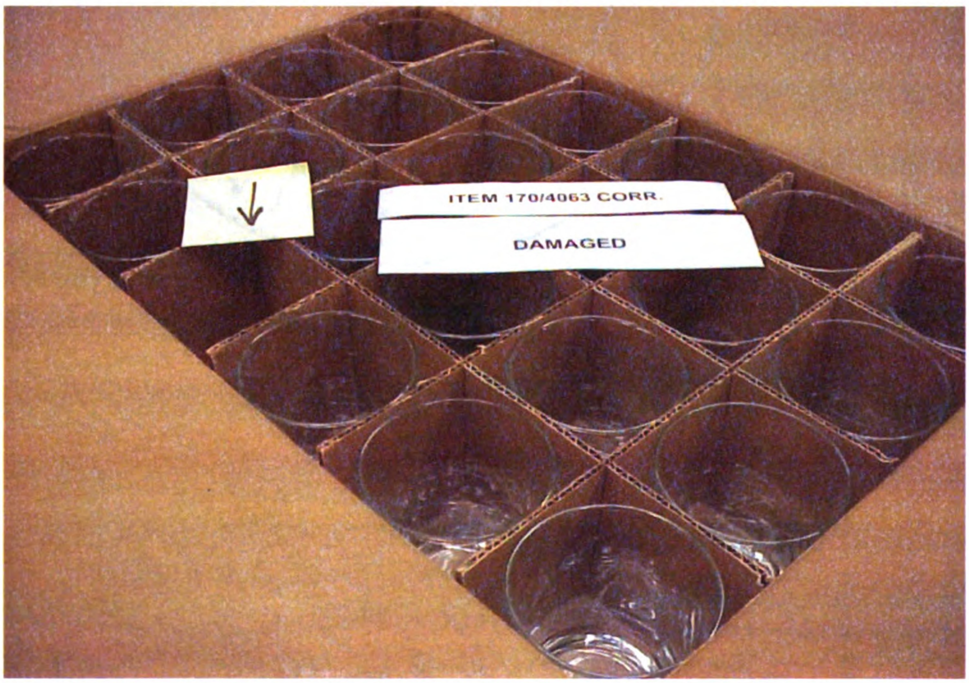

Figure 7 - Package containing Damaged Item 170/4063 with Corrugated Partitions

Figure 8 - Package containing Undamaged Item 170/4063 with Paperboard Partitions

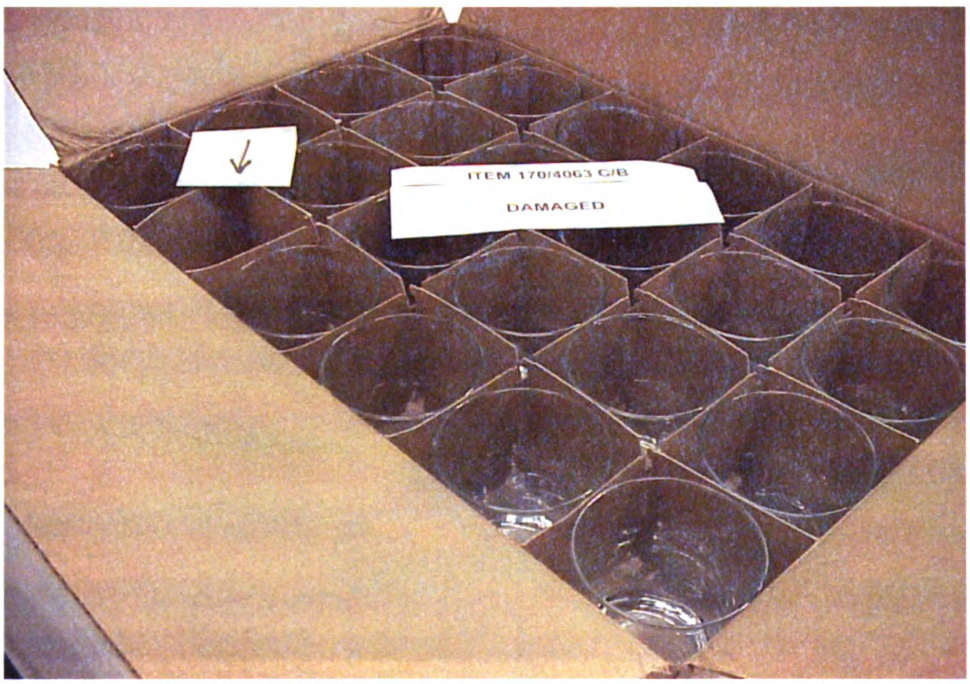

Figure 9 - Package containing Damaged Item 170/4063 with Paperboard Partitions

Figure 10 - Package containing Undamaged Item 94/6029 with Corrugated Partitions

Figure 11 - Package containing Damaged Item 94/6029 with Corrugated Partitions

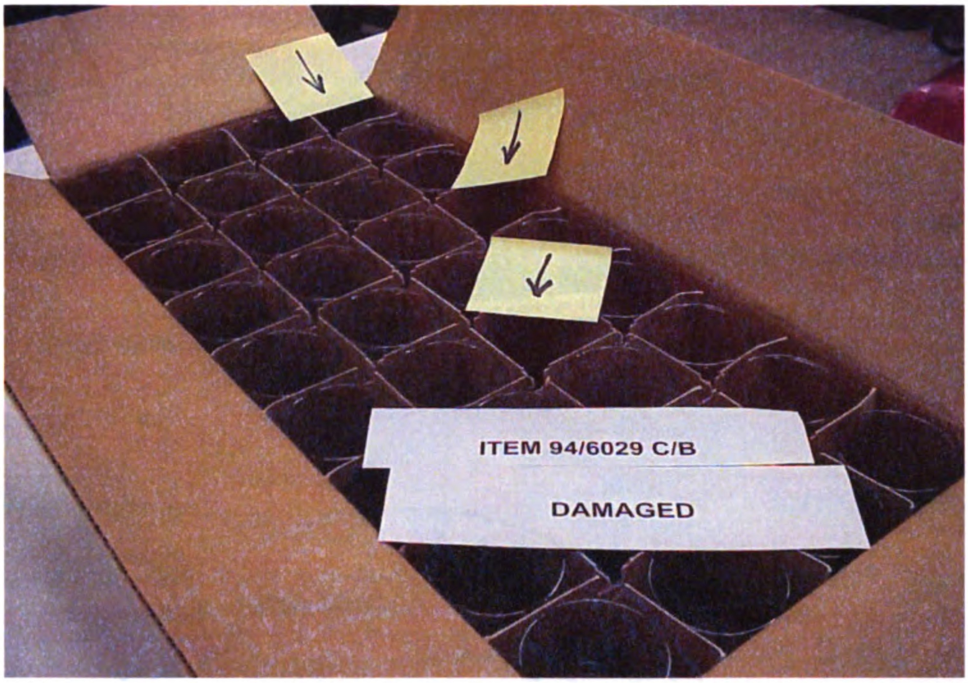

Figure 12 - Package containing Undamaged Item 94/6029 with Paperboard Partitions

Figure 13 - Package containing Damaged Item 94/6029 with Paperboard Partitions

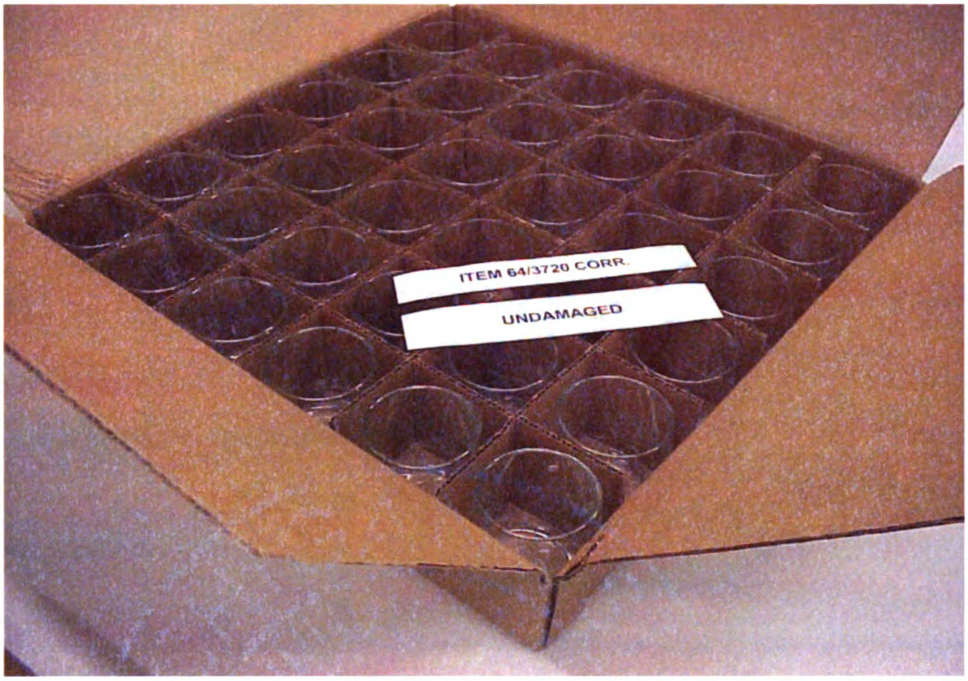

Figure 14 - Package containing Undamaged Item 64/3720 with Corrugated Partitions

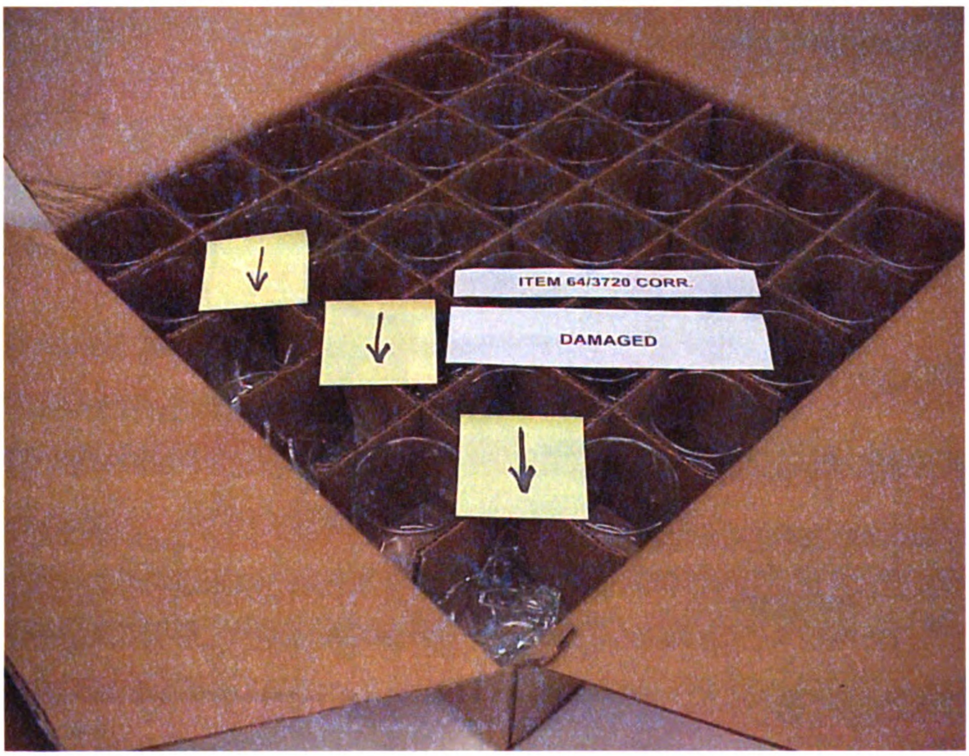

Figure 15 - Package containing Damaged Item 64/3720 with Corrugated Partitions

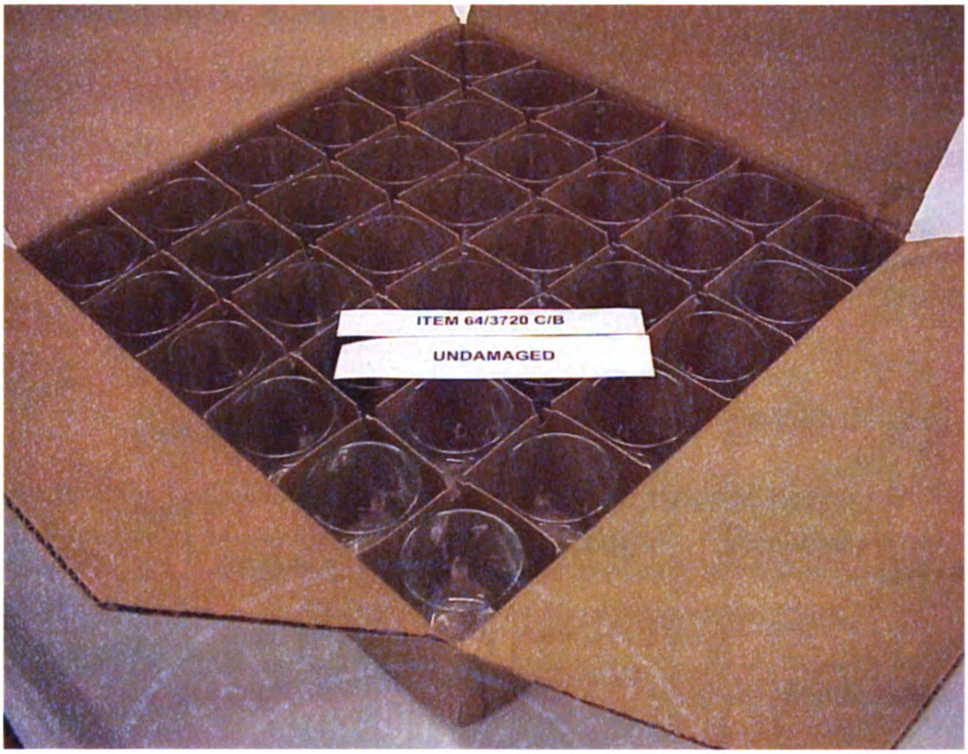

Figure 16 - Package containing Undamaged Item 64/3720 with Paperboard Partitions

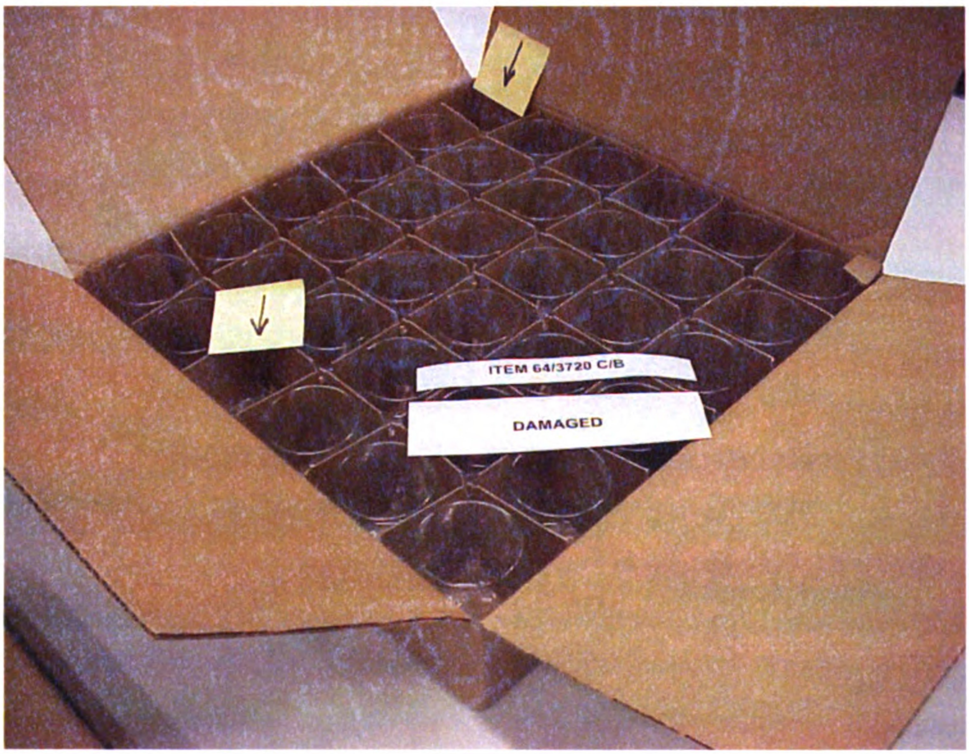

Figure 17 - Package containing Damaged Item 64/3720 with Paperboard Partitions